Biodiversity

10 Must Knows from Biodiversity Science 2024

The majority of people in Germany believe that social change towards sustainability and compatibility with nature is necessary, and many would actively support it[1].

We are living beyond our means. We would need three Earths if all of humanity lived like Europeans do[2].

We are deeply interfering with the networks of life and are already breaking *planetary boundaries* – this also affects biodiversity in particular[3].

We can change this.

The *Kunming-Montreal Global Biodiversity Framework (GBF)* of December 2022, which is binding under international law, sets out 23 clear targets for the protection of biodiversity. These are to be achieved by 2030. For the first time, the 196 parties to the United Nations *Convention on Biological Diversity (CBD)* have agreed on specific ways to achieve these targets, monitor compliance and finance the necessary processes. It is crucial for the conservation of biodiversity – the basis of human life[4,5] – to realise these goals over the next six years.

This requires increased cooperation at international, national and regional level – between different policy areas, civil society and business, and also between different knowledge cultures[4]. This cooperation must be geared towards the goal of preserving the health of the planet and its living beings and enabling all people to live a good life[6,7].

The authors of the *10 Must-Knows from Biodiversity Science* 2024 (*10MustKnows24*) want to contribute to the goal of an ecologically and socially just transformation. Building on the scientific findings of the *10MustKnows22*, they have updated the texts and added new relevant findings from the ten key areas. The findings and the recommendations derived from them are intended to promote the implementation of the 23 global goals of the GBF in Germany's *National Biodiversity Strategy 2030 (NBS2030)* and support the goals of the *EU Biodiversity Strategy 2030* and the global *Sustainable Development Goals (SDGs)*.

There are no scientifically justified obstacles to protecting biodiversity in all its beauty and diversity. Resistance is of a cultural, social, structural and political nature. By acting together, we can overcome such obstacles over the next six years – we need to take action now. It is high time.

Five years ago (2019), the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES) estimated in its scientific report that around one million of a total of eight million species worldwide are threatened with extinction[4]. A recent study based on data from the *IUCN Red List* suggests that twice as many species (two million) could be threatened[8]. In Europe, a fifth of the species studied could be threatened with extinction, with plants (27 percent) and invertebrates (24 percent) being more affected than vertebrates (18 percent)[8].

Climate change and the biodiversity crisis affect us all. However, from a global perspective, the poor, children and women are hit harder by the consequences. According to *UN Women*, child marriage, for example, is more common in arid areas and in regions with frequent droughts – a way for families to cope with declining agricultural yields and higher food prices[9]. In Germany, too, ecological, cultural and social crises hit the weakest members of society the hardest.

In order to prevent these crises, a transformative reorientation is needed both globally and nationally, which must be ecologically sustainable and socially just. This is confirmed by numerous scientific publications[10]. For example, the *German Biodiversity Assessment* 2024 by the *BMBF Research Initiative for the Conservation of Biodiversity* (FEdA) – scientific cooperation partner of the *10MustKnows24* – emphasises the need for ecological reorientation through a comprehensive inventory of biodiversity and its change in Germany. According to the latest *nature awareness study*, the majority of people in Germany

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(86 percent) believe that social change is necessary and many would actively support it[1]. Current sociological findings indicate that, while some sections of society are tired of change, there is no evidence of a divided society when it comes to existential issues such as climate change[11].

Socio-ecological change requires intensive debates between multipliers and committed individuals from politics, science, business, the media and civil society in order to explore joint solutions and, by working together, seize the opportunity for change and realise it for the benefit of all. The necessary change requires a vibrant democracy in which there is broad discussion and the common goals are driven forward in an alliance for progress.

The authors contribute to this discourse with the *10MustKnow24*. They are all looking forward to being invited to solution-orientated discussions – please challenge us!

There are no scientifically justified obstacles to protecting biodiversity in all its beauty and diversity. Only six years are left to achieve the biodiversity targets by 2030. We must work together now to get there in time.

1 Achieving climate and biodiversity protection together

1 On the path to effectively tackling the twin crises of biodiversity loss and climate change, trade-offs between reversing biodiversity loss and protecting climate can be minimised when biodiversity conservation action is taken as the starting point.

2 Among terrestrial ecosystems, *peatlands* are exceptionally well suited to combine biodiversity conservation and climate protection. Many of Germany's currently drained peatlands used by agriculture can be rewetted and still allow sustainable agriculture (*paludiculture*). While CO_2 emissions decrease with rewetting and peatlands sequester CO_2 in the long term, natural methane emissions return. Still, recovery of peatland biodiversity may take several decades and requires continued but sustainable land use.

3 *Marine protected areas* (MPAs) are essential for biodiversity conservation and carbon storage, yet allow too much use of the sea. Instead, excluding destructive uses such as bottom trawling will increase MPAs' effectiveness. In seagrass transplantations, a *habitat* restoration action, biodiversity recovers faster than carbon storage if combined with protection and conservation.

4 Non-food crop and forest biomass should be prioritised for long-living materials rather than as a source for energy, e. g. in *BECCS*, in view of more efficient renewable energy sources such as solar and wind. The EU goal on bioenergy production, if implemented, risks further land-use conflicts and externalises biodiversity losses (>*MustKnows6, 7, 10*).

5 *Biodiversity offsets* are only effective with good governance, monitoring and enforcement that ensure biodiversity is effectively safeguarded elsewhere. Where authorisation procedures are to be accelerated, as in the current acceleration legislation in Germany (>*MustKnow7*), it is crucial to maintain the basic principles of the intervention regulation: priority is given to compensation or replacement; payment should only be considered for unavoidable and non-compensable impairments.

Many actions that conserve biodiversity also have positive effects on climate change mitigation and adaptation, while far fewer actions that protect climate help biodiversity.

While in *MustKnow1* in 2022 we explored the reasons causing the twin biodiversity-climate crises, we now focus on considering solutions from the biodiversity-action viewpoint.

Biodiverse land- and seascapes often maintain or enhance ecosystem carbon storage while increasing ecosystem resilience and offering natural protection against climate risks (e. g. droughts, floods). Protecting natural and diverse forests from destruction and degradation is a win-win situation: 0.4 to 5.8 Gt *CO_2e* can be mitigated per year globally while safeguarding biodiversity in vegetation and soils[1]. Restoring forests where they once occurred mitigates another 1.5 to 10.1 Gt *CO_2e* per year globally (>*MustKnow5*)[1]. By contrast, focusing solely on carbon-only actions, such as growth of bioenergy crops in large areas or afforestation through monocultures,

3 *Seagrass recovery takes one growing season (3 months), its **faunal community** is restored after 15 months (two growing seasons) in the Baltic Sea[11].*

-400 Mill. *The EU's carbon trade deficit is about 400 million tonnes of CO_2e per year. If every EU citizen consumes 17% less meat and milk, up to 30% of cropland could be used for biodiversity and climate protection (>MustKnow10)[15].*

30 ha *By reducing newly sealed areas for transport and settlements to < 30 ha per day, land fragmentation can be substantially reduced in the EU.*

can adversely impact biodiversity and should be avoided[1]. Technological renewable energy measures (e. g. hydropower, solar photovoltaic) should be designed to avoid biodiversity loss (*GBF targets 8, 11 ; SDG 7*)[1].

While we should protect and restore healthy peatlands globally to protect the climate and water cycling, we are still destroying them at an alarming rate (500,000 ha annually[2]). Conversely, peatland restoration would protect and enhance carbon uptake of 0.15-0.81 Gt CO_2e per year globally until 2050 (GBF target 2)[1]. Whereas CO_2 emissions drop immediately back to natural levels in temperate Europe after rewetting, biodiversity recovery lasts decades, perhaps never reaching its natural analogue[3]. With restoration, natural methane emissions are restored, but this effect is outweighed by the avoided CO_2 emissions, enabling long-lasting, positive climate change mitigation effects[4]. Rewetting all of the drained peatlands, i. e. 7 percent of agricultural land in Germany, would reduce GHG emissions from agriculture by up to 40 percent[5-7]. Under paludiculture, wet peatlands retain water in the area to the benefit of biodiversity and regional climate.

Protection and restoration of marine "blue carbon pools" (seagrass beds, salt marshes, *kelp forests*, mangroves)[8], benefit marine biodiversity and food supplies. Undisturbed marine sediments represent the largest long-term organic carbon store[9] and are rich in biodiversity, but are endangered by bottom trawling[10], infrastructure projects in coastal areas and riverine substance inputs. Only with effective protective measures can marine habitat restoration be successful. In seagrass transplantations, biodiversity is restored locally much faster than belowground biomass[11]. The design and enforcement of marine protected areas (MPAs) is currently insufficient to achieve MPAs' conservation goals[12]. Even though MPAs cover 29 percent of EU territorial waters, the majority are heavily affected by industrial fishing pressure, which exceeds even that of non-protected areas[13]. Achieving *GBF targets 3, 8 and 10* for marine areas means making enormous progress in legislation and practical implementation in addition to finding compromises with all stakeholders using a whole-systems approach[14].

Importing goods from countries with biodiverse and carbon-rich ecosystems to the EU has created a biodiversity and carbon trade deficit. The EU's plan to devote 22 million hectares to bioenergy production externalises CO_2 emissions and biodiversity loss (*>MustKnow10*) and increases – instead of reducing – pressure on land and sea (*GBF target 10; >MustKnow6*)[15]. Since efficient alternative energy sources via wind and photovoltaic are available and biomass should rather be used for long-lived materials[1], a further expansion of bioenergy crops should be discouraged.

Land and sea areas are scarce resources, meaning new conversions should be restricted to the most important uses in the transformation process (*>MustKnow7; GBF target 1; SDG 11*) and quantifiable targets to reduce newly sealed areas for transport and settlements (e. g. < 30 ha per day and *net zero* by 2050[16]) are required. Biodiversity offsets are only effective with good governance, monitoring and controlling[17] and with binding regulation from national

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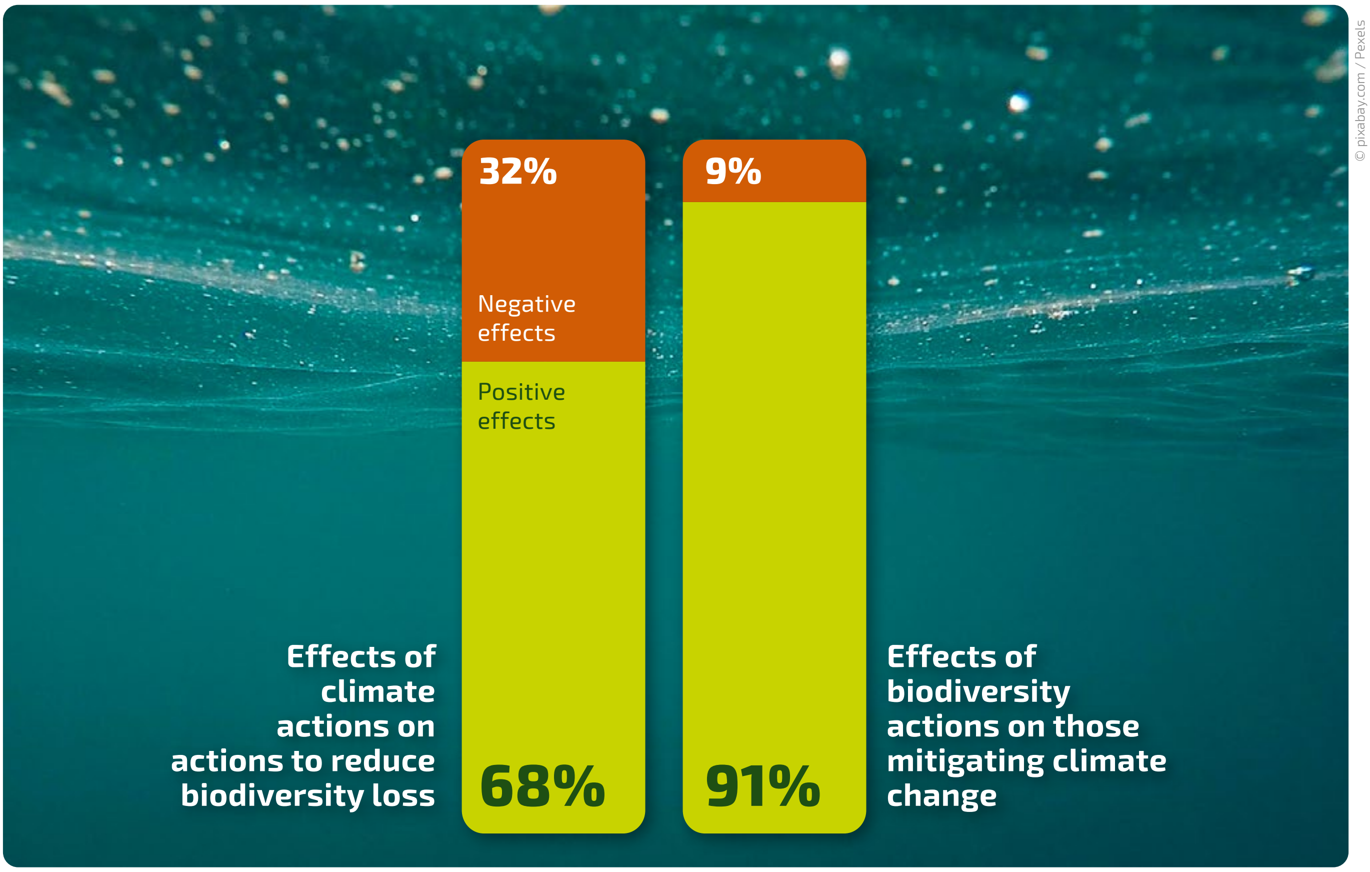
legislation and national biodiversity strategies. Gains in one area of action (climate or biodiversity) cannot substitute losses elsewhere, and unintended substitutions (e. g., compensating sea uses on land)[14,18] must be avoided[1,19].

Background to the key findings

Afforestation, a carbon-only action, on areas that have not been forested for millennia, imposes the risk of biodiversity loss. Instead, natural grassland or extensively used grasslands in cultural landscapes are diverse ecosystems with a large carbon storage in grassland soils[1]. If all formerly drained peatlands could be rewetted immediately, the biophysical warming effect of methane, CO_2 and N_2O emissions would peak mid-century and stabilise at low levels for the remaining 21st century given continued climate change[4]. Rewetting later in the century or only half of the drained peatlands means warming effects persist longer and CO_2 emissions from decomposing drained peatlands continue[4].

Increasing effectiveness of MPAs is critical given that pollution from terrestrial sources continues, oceans warm because they absorb the heat from the warming atmosphere, resulting in ocean heatwaves and oxygen depletion[20], while taking up 29 percent of the CO_2 emitted from anthropogenic sources[21]. Marine *nature-based solutions*, such as seagrass replanting, represent a means towards solving the twin crises that are just, equitable and sustainable[22].

Reducing pressure on land ecosystems is also achieved by solar-power generation on existing building rooftops, or combined in *agriphotovoltaic* systems and include a grasing option[1] to the benefit of *SDGs 2, 7 and 12*. Where land- and sea-area loss cannot be avoided, biodiversity offsets should be closely monitored and controlled[6] to ensure biodiversity increases over time and linked to clear conservation outcomes in order to avoid further losses[23]. The offset should have similar ecological and biodiversity value[24] to effectively contribute to *GBF target 19 (d)*.



Proportion of actions having negative (orange) or positive (green) effects when taking climate action as the starting point, or biodiversity action. Many climate actions have negative effects on biodiversity, i. e. a focus on optimising carbon uptake and storage would not reduce biodiversity loss (left bar). A great majority of biodiversity actions help climate change mitigation, reducing the number of trade-offs to a small margin (right bar, redrawn from reference 1).

Land and sea areas are scarce resources, meaning new conversions should be restricted to the most important uses in the transformation process and quantifiable targets to reduce newly sealed areas for transport and settlements are required.

Recommendations for political decision-makers

1. Because the window of opportunity to address the twin crises is narrow and available resources are limited, defining areas and ecosystems (especially seagrass meadows, wetlands and forests) that serve as refuges and carbon sinks and, thanks to their high biodiversity, remain rather stable under climate change, is key. Therefore, we recommend prioritising the implementation of nature-based actions in these areas, via policy programmes such as the German *Action Plan on Nature-based Solutions for Climate and Biodiversity (ANK)* and the *EU Nature Restoration Law*, and ensuring continued funding.
2. Rewetting peatlands has clear advantages for climate, water cycling and biodiversity, and avoiding continued CO_2 emission. Facilitating change by setting clear rewetting targets in the EU Nature Restoration Law, substantiated by adequate funding and incentivising new value chains from wet peatlands while co-designing implementation with all actors involved in the transition process is recommended.
3. Ensure via binding regulation with accompanied monitoring and controlling that marine protected areas can achieve their protection goals for marine biodiversity and function as blue carbon sinks. Further specify quantifiable targets in respective fields of action in national biodiversity strategies (*NBS2030*) as well as programmes such as the German ANK.

Recommendations for society

1. Biodiversity conservation supports ecosystem resilience and adaptation, thus climate protection. Raise awareness and address concerns in the transformation for protecting, restoring and sustainably using wetlands, land- and seascapes by involving all societal actors (*>MustKnow8*). Involve existing information channels such as the *UN Decade on Ecosystem Restoration* (*www.decadeonrestoration.org*).
2. Enhance energy efficiency and continue societal dialogue to achieve targets for biodiversity-friendly expansion of solar power generation and wind energy to alleviate pressure on land ecosystems and its biodiversity (*>MustKnow7*).
3. Raise awareness that land and marine areas are scarce resources. Landscape fragmentation and newly sealed areas for transport and settlements need to be reduced.

2 Enabling a healthy life on a healthy planet

1 There is an urgent need for multi-lateral, multi-sectoral cooperation on biodiversity and health, which is increasingly important and linked with climate change and social well-being[1,2]. Human health and wellbeing is reflected in numerous *Global Biodiversity Framework (GBF)* targets, which can be seen as an instrument of nature-based health policy. Its full implementation requires engagement with the health sector and other related sectors (>*MustKnow1*).

2 The role of biodiversity e. g. in understanding and potentially mitigating *vector-borne disease* dynamics is still largely neglected in the public and political discourse, due to siloed thinking and limited public awareness of the connections between biodiversity and zoonotic diseases[3]. This results in little political interest, disincentives towards development of integrated policies, short-term budgeting and reporting cycles, a lack of guidance for decision-makers on how to recognise and address linkages, and a lack of appropriate structures to facilitate cross-sector collaboration (>*MustKnows3-5, 7*).

3 When considered from a One Health lens, the protection of biodiversity can play an important role in reducing the risk of zoonotic diseases and disease emergence at the source and ultimately pandemic prevention[3-5]. Opportunities in this area across research, policy and implementation, e. g. as outlined by the *Quadripartite One Health Alliance*'s Joint Plan of Action and corresponding Implementation Guide must be prioritised, including for their cost-effectiveness and synergies (>*MustKnows1, 3-5, 7, 10*)[6,7].

4 *Nature-based solutions* to health challenges especially in urban settings – e. g. as piloted in Canada – could play an important role in preventive public health strategies and should be explored. Environmental settings in urban areas should allow for equitable access to green and blue spaces to allow for everyone to gain their regular dose of nature, while minimising and avoiding creating disease risks in their design (>*MustKnows1, 4*)[8-10].

5 Intensive agriculture practices – including overproduction and -consumption of animals and industrial-scale harvesting of marine products for food and manufacturing – can have negative health impacts via pollution, climate impacts, and the loss of biodiversity and *ecosystem services*, while also threatening soil and ocean health and contributing to further transgression of several *planetary boundaries* (compare debates on the *EU Nature Restoration Law*; >*MustKnows6, 7*)[11-15].

Biodiversity loss and climate change are one indivisible crisis now so severe as to be a global health emergency – the loss of biodiversity threatens the full range of life-supporting services provided by ecosystems. This has multiple direct and indirect implications for the health of life on Earth, and exacerbates existing health inequities worldwide.

500 *Around 100 trillion intestinal bacteria from more than 500 species keep us healthy[34].*

4% *People have had a drastic effect on mammals: Since the rise of humans, wildlife biomass is estimated to have declined by 85%. Livestock now make up 62% of biomass, humans 34%, but wild mammals only 4%[33]. This reduces the resilience function of biodiversity and increases the chances of zoonoses.*

20 *Spending 20 minutes in the forest is good for you. It can reduce stress and increase positive emotions[36].*

In *MustKnow2* from 2022 we addressed the links between biodiversity and health more generally and focused on selected examples such as mental health and emerging infectious diseases. With this update, we address examples with particular relevance to current policy processes (e. g. EU Nature Restoration Law) or recent developments (due to climate change or war). *MustKnow2* does not cover the full range of biodiversity-health linkages.

Health depends on a well-functioning natural environment as highlighted by several recent reports[16,17]. The *Budapest Declaration*[18], adopted by countries in the WHO European Region in July 2023, prioritises urgent and far-reaching action to address the health challenges posed by climate change, biodiversity loss, land degradation and pollution. Threats to biodiversity and health – and the need to address them in an integrated manner – are also highlighted in the *Global Framework on Chemicals – For a Planet Free of Harm from Chemicals and Waste* and by the *Intergovernmental Negotiating Committee* (INC) crafting an international legally binding instrument on plastic pollution, including in the marine environment, before the end of 2024. The timeliness is exemplified by the first disease caused by ingested plastic described in seabirds[19]. Anthropogenic disturbances and the subsequent loss of biodiversity are altering species communities and abundances. Since species vary in their *pathogen* competence, spatio-temporal changes in host assemblages may lead to changes in disease dynamics (for example, coronaviruses). Integrated biodiversity-health governance is needed to address hidden costs of biodiversity loss and help maximise health outcomes[20,21]. Biodiversity, when integrated into public health strategies and vice versa – through a *One Health approach* – has the potential to preventatively address important health threats, offering cost-effective solutions for the simultaneous protection of human, animal, plant and environmental health.

Vector-borne diseases are emerging or re-emerging in Europe due to global environmental changes and anthropogenic factors (e. g., travel and trade). Some trends are associated with climate change; ecological factors, however, such as host density, the role of predators, *invasive species*, and *dilution and amplification effects* are understudied for most vector-borne diseases and ecosystems[22]. For example, in Germany, higher forest management intensity decreased *vector* abundance for certain bird parasites, but the parasite infections in the *vectors* increased[23]. The role of ecological factors needs to be further explored to increase the benefits of synergistic nature and health protection, while the *One Health approach* can help address unintended consequences such as potentially increased disease risk through specific biodiversity measures (e. g. rewetting of wetlands).

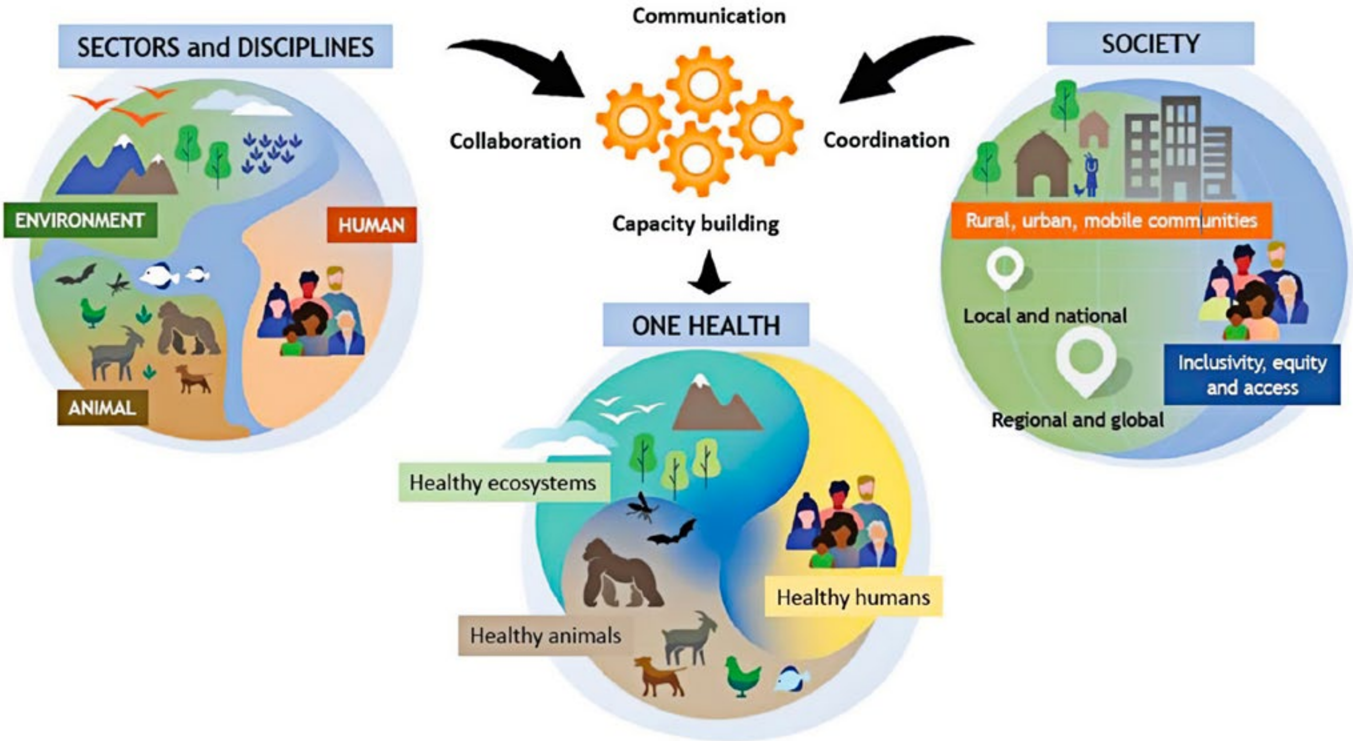
The upcoming *World Health Organisation* (WHO) pandemic instrument, treaty, agreement or other (to be adopted by member states in May 2024) could be a useful instrument for mainstreaming One Health concepts into national and global health strategies and interventions[5]. For it to be successful, the drivers of *spillover* and disease emergence must be addressed, including the potential for preserving pathogen-regulating ecosystem functions. The regulation of pathogens within ecosystems is influenced and altered by changing environmental factors, often accompanied by changing socio-economic dynamics that can increase spillover risk and vulnerability to impacts[4]. Even though predictions for specific pathogen shifts and their consequences are only possible to a limited extent, the precautionary principle demands that these effects be taken into account in view of dramatic changes in ecosystems and the loss of *habitats*[24]. Furthermore, a joint definition as suggested by the One Health High Level Expert Panel and consistent use of the term "prevention" is crucial in order to avoid confusion[25].

National One Health strategies – as outlined by the Quadripartite One Health Alliance[7] – are essential to ensure important impulses towards a nature-positive, climate-friendly and socially just civilisation. Health systems in Europe should therefore focus more on preventive public health measures and incorporate cost-effective nature-based solutions to health challenges that also address the increase in non-communicable diseases (e. g. cardiovascular disease, mental health)[26]. Nature-based health solutions and social prescription programmes (e. g., prescribed activities in green or blue spaces) are a promising intervention that can reduce both health expenditures and – as part of a suite of approaches – prescriptions at the community level while simultaneously contributing to biodiversity conservation[9,10]. Nature-based solutions, such as health walks or gardening, are promising in terms of stress reduction, lowering blood pressure, depression and anxiety levels[8]. Such programmes can be oriented to also address issues of urban environmental and social justice, and the growing problem of health inequalities in EU cities.

Some agricultural systems, especially intensive animal production, are major drivers of is one of the major drivers of biodiversity loss[12,14]. Replacing, reducing and refining (*3R*)[27] the intensive and harmful overproduction and -consumption of animal-source foods, particularly in industrialised countries, along with biosecurity enhancements, are therefore important levers to ensure food security, protecting human health from harmful direct and indirect effects of agriculture and harmful diets, and creating a food system that remains within planetary boundaries[11,13,24]. Integrated biodiversity and health policy can help address issues of nutrition security and hidden hunger in Europe[28].

Background

The GBF, adopted in 2022, acknowledges the human right to a clean, healthy and sustainable environment and the interlinkages between biodiversity and health[2]. It states that the GBF needs to be implemented with consideration of the One Health approach, which recognises the intrinsic connection between human health, animal health and healthy resilient nature. This is necessary to mobilise multiple sectors, disciplines and communities to work together to sustainably balance and optimse the health of



In order to realise the One Health approach, communication, coordination and cooperation between all sectors, disciplines and areas of society(ies) mentioned in the diagram are required at local, regional, national and global level (figure: OHHLEP One Health definition, source: WHO, FAO, OIE, UNEP).

people, animals, plants and ecosystems. Our findings are particularly reflected in *GBF targets 5-7, 9-12 and 14-16*.

An additional example of the multiple linkages between biodiversity and health that only recently received more attention is the broad range of microorganisms that underpins our health: a wealth of recent studies have demonstrated that microbial symbionts and commensals, i. e. benign microorganisms constituting the gut *microbiome*, and the overall microbial diversity (>*MustKnow3*) are cornerstones of health[29,30]. Environmental perturbations and global change drive microbiome composition change, with severe implications for host resilience to external stressors and adaptability to modified environmental conditions, pathogen susceptibility and fitness/health[31,32]. This is important, because limiting the focus on infectious disease and mental health in policy dialogues obstructs broader co-operation on health and biodiversity which results in missed opportunities for better policy alignment.

Similarly, the *EU Biodiversity Strategy 2030* states that the EU will enhance its support of global efforts to apply the One Health approach.

For Germany's *National Biodiversity Strategy 2030 (NBS2030)*, our findings support especially the fields of action 12 and 18 in the discussion points.

Recommendations for political decision-makers

1. Develop incentives to strengthen and harness the public health potential of biodiversity through linking biodiversity and health policy across sectors.
2. Work toward an EU coalition on One Health principles in support of the Quadripartite, the GBF and the *Sustainable Development Goals (SDGs)*, strengthening and restoring nature-based solutions to health, including supporting the collaboration between the CBD and the WHO regarding a new *Global Action Plan on Biodiversity and Health* (>*MustKnows4, 8*).
3. Support communities in developing local initiatives for the conservation and management of biodiversity and ecosystems, for improved health and social well-being, working with local businesses, schools and civil society organisations, linking with the EU Nature Restoration Law (>*MustKnow7*).

Recommendations for society

1. Support development of local sustainable enterprises through education, community outreach and engagement (>*MustKnow8*).
2. Encourage individuals and communities to engage in exploring exciting, fun, flavourful, healthy and sustainable food options, such as more plant-based diets, and to decrease of commercial meat products (>*MustKnows6, 10*).
3. Engage as local communities in opportunities and mechanisms for biodiversity restoration and conservation including the design and development of urban green and blue infrastructure, with multiple benefits for health and social well-being (>*MustKnows 3, 7, 8*).

3 Considering undiscovered biodiversity

1 The amount of hidden biodiversity is much larger than estimated. Ignoring hidden diversity means neglecting more than half of the species-level diversity and hence is incompatible with the goals of the German *National Biodiversity Strategy 2030 (NBS2030)*.

2 Functions of hidden biodiversity are underestimated. The estimated decline of hidden biodiversity likely contributes to ecosystem instability and thus may cause, among other things, losses of economic benefits for society at large.

3 The awareness and understanding of hidden biodiversity by decision-makers and citizens can help to strengthen the protection of *ecosystem services* and associated *nature-based solutions*, like for example the resilience of ecosystems.

4 Current assessments of biodiversity are severely biased in the assessment of species as well as spatial and temporal spaces. For example, knowledge gaps in the transformative potential of urban nature-based solutions and sustainable city land-use practices and management need to be closed.

5 Monitoring and knowledge are key. Modern monitoring tools, assisted by artificial intelligence (AI), can support action to mitigate the bias, if data is following the principles to be *FAIR*.

We must be aware of the complexity of hidden biodiversity, which includes organisms either very small, or living in *habitats*, areas, and temporal spaces less accessible to us. Ecosystem-based habitat management rather than single-species and habitat-focused practices, standardised monitoring, and *FAIR* data principles can accommodate the gaps in knowledge.

In 2022, *MustKnow3* highlighted how *taxonomic* knowledge gaps bear the risk of underestimating the vulnerability or resilience of biodiversity and ecosystems, making outbreaks of emerging diseases and spread of alien species less predictable. Here, we show that the number of understudied taxonomic groups is even larger than expected and offer solutions for better monitoring.

Humans tend to consider and have empathy with charismatic, macroscopic species. However, there is hidden biodiversity in neglected spatial and temporal contexts, including organisms invisible to the naked eye, beneath the surface in soil, freshwater, or marine environments, or invertebrates active at night. The decline of this hidden biodiversity is probably significant but often the existing data is lacking or unavailable. In particular, many “hidden *taxa*” in megadiverse groups contribute to the huge biodiversity of insects, but still are undiscovered due to *entomological* knowledge gaps[1-3].

Recent estimates of overall global biodiversity range from the low millions to the trillions. Insects make up roughly half of currently

12% *Canada possesses one of the largest renewable supplies of freshwater in the world. 12% of its freshwater species are known to be endangered, threatened, or at risk. About 40% lack sufficient data to enable their status to be assessed*[7].

50% *of the flying insect diversity belongs to only 20 families regardless of continent, climatic region, and habitat type. The same families contain many "hidden taxa" in that they suffer from increasing taxonomic knowledge gaps*[2].

59% *A recent review of the biodiversity literature indicates that soil harbours approximately 59% of all species on Earth, with organisms ranging from microbes to mammals. This is about double the previously estimated amount*[5].

described species with their *microbiome* harbouring even more undetected species of microorganisms[4] (Figure 1). Soil is the most biodiverse single *habitat* on Earth[5], but only a small fraction of the species in soils and sediments (freshwater and marine) are known[6]. In freshwater, much of the biodiversity is hardly accessible[7]. Assessing the status and trends of biodiversity therefore is highly complex but needed when estimating (changes in) ecosystem functions provided by biodiversity in these habitats (>*MustKnows1, 2, 5-10; GBF targets 2-4, 12*)[2,8].

As a a great part of biodiversity is known to be hidden, conservation measures must shift to focusing on ecosytem functioning, thereby accounting for the multidimensionality of biodiversity and ecosystem services[9,10]. Factors to be considered are: species composition and abundance, *symbiosis*[11] and *functional traits* (the *phenological* or *morphological adaption* of organisms to the environment[12]), understanding the role of habitat, the connectivity and ecotones, where different communities meet and integrate between different habitats[13,14] as well as interactions with stressors[15,16]. We need an integrative perspective and focus on ecosystem-based habitat management rather than single-species and habitat-focused practices (*GBF targets 2, 11, 14*)[14].

Monitoring must estimate threats to hidden biodiversity and ecosystem resilience (e. g., the persistence of pesticides in soil and recovery of *biomes*[1,17-19]) and include compliance with existing regulations (e. g., *Fertilizer Ordinance* and the *Nitrates Directive*)[20]. In conservation, knowledge on interactions of organisms with each other and their environment is required[9,11], as well the establishment of valid indicator systems[21,22]. For example, it is no longer sufficient to focus only on water quality as the indicator in freshwater, but management actions are needed to revive the recovery of sites at greater risk of biodiversity decline, while protecting the least impacted systems as biodiversity refuges[23]. It should be noted that increasing urbanisation[24] is an important driver of habitat and biodiversity loss, but less well studied than agriculture and forestry (>*MustKnows 5-7*). Further, interventions to protect biodiversity are often daytime biased[25], neglecting the impact of noise[26,27] and light pollution that critically affect nature conservation areas[28], freshwater bodies[29], and their hidden and exposed biodiversity (>*MustKnows2, 7, 8*). A stronger focus is needed for the development of biodiversity refuges in urban areas[30] and standardised monitoring of stressors like artificial light at night[31] and noise (*GBF targets 2-4, 7, 12*).

Standardised monitoring, incorporating cost-effective, *high-throughput DNA sequencing* and AI identification tools can be a game changer for observing hidden biodiversity. They can reduce the cost of biomonitoring, thereby enabling large monitoring campaigns, and involve stakeholders (e. g. citizens) who are currently often unable to contribute. *FAIR* data management is essential, because "hidden biodiversity" can also be monitored species for which data is inaccessible (>*MustKnow9, GBF target 21*).

Background

The National Strategy on Biological Diversity (NBS) is useful even today for hidden biodiversity, but the lack of FAIR monitoring data in Germany can be a great barrier to implementing it. Furthermore, the NBS includes indicators that are too habitat- and subject-specific, but lacks indices for hidden biodiversity, such as sediment-bound, soil-bound, freshwater organisms, and other "hidden" biomes[9,21]. For soil, these could be

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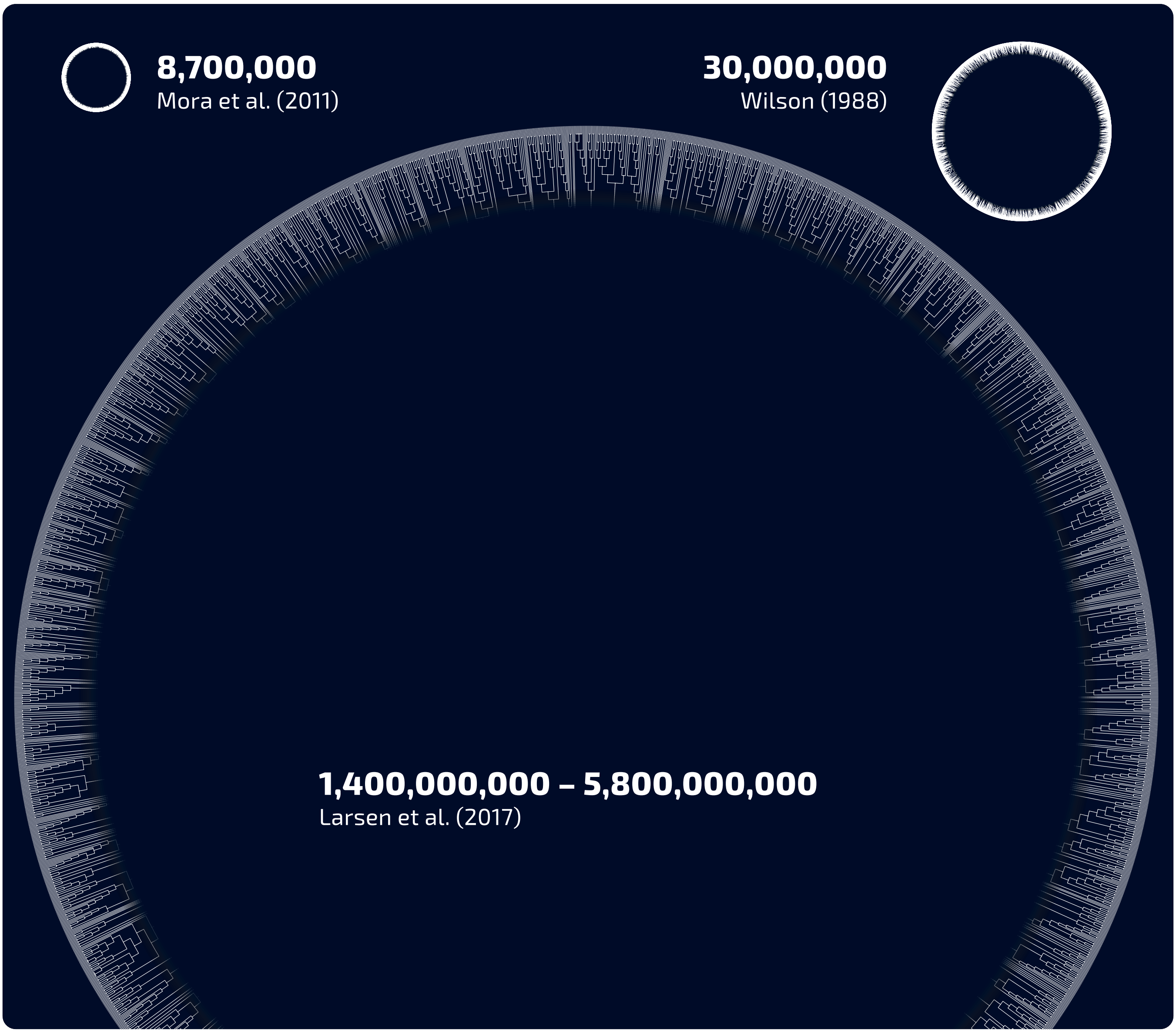
based on the European Land Use and Coverage Area frame Survey (LUCAS), which now includes soil biodiversity[32] and pesticides[33], or the new EU soil monitoring law (*GBF targets 2, 3, 7, 11*).

Soils and inland waters have a particularly close exchange relationship and direct impact on the climate. Thus, the proposed federal funding for inter- and transdisciplinary scientific coordination on biodiversity and natural climate protection is essential in order to develop indicators for the good ecological status of interacting biomes (>*MustKnows1, 7*)[34, 35]. Further, indicators for protection against light emissions and noise need to be developed, existing indicators enforced, and urban areas need to be included into area protection targets (*GBF targets 6-11, 14, 20*).

For detecting hidden biodiversity, high-throughput DNA sequencing, the expansion of idea development and implementation by the "Artificial Intelligence and Big Data Application Laboratory" and the "Competence Centre Satellite Remote Sensing" can provide solutions, as the improved practical use of AI techniques can help to include more stakeholders in



Following the quote "the black hole of taxonomy" (Edward O. Wilson), we illustrate various estimates of the number of species on Earth, which vary between 8.7 million and 5.8 billion[36–38]. The differences result from species demarcation and the assumed occurrence of very small, undiscovered insect and microorganism species. The white borders symbolise the number of species identified to date (approx. 1.7 million) compared to the amount as yet undescribed species (approx. 90%).

the monitoring of biodiversity. But regulations need to be followed to ensure that data collected, whether by private or public stakeholders, is accessible and reusable (>*MustKnow9; GBF targets 14, 20, 21*).

In conclusion, acknowledging that we only understand a small part of biodiversity is a first critical step to improve conservation measures. Research and better monitoring are needed to discover hidden biodiversity, support conservation measurements, and review the compliance to existing legislation (such as the habitats directives). Monitoring programmes must include all spaces and temporal niches, and should integrate pollution sources such as noise and light. To detect changes in ecosystem resilience and conserve sustainable land use, a much stronger monitoring must be established using the most advanced tools, such as AI identification for remote sensing, phenological or genetic data analysis. A prerequisite for all the efforts to bend the curve of biodiversity decline is that the data need to be FAIR.

Recommendations for political decision-makers

1. The fact that we know only a small fraction of total biodiversity should be acknowledged in future political decisions. The focus should be put on ecosystem-based habitat management rather than single-species and habitat-focused practices, in order to acknowledge the great hidden part of organisms and their contribution to nature-based solutions for people (*GBF targets 3, 11*).
2. The monitoring needs improvement. Thus, the implementation of a nationwide standardised monitoring of biodiversity (e. g. *Darwin Core Standard*) is necessary, using FAIR principles in order to find and reuse data when new insights into hidden biodiversity are discovered (*GBF targets 14, 20, 21*).
3. Inter- and transdisciplinary research needs to be supported and results applied. For area protection, indicators need to include urban spaces and stressors, including noise and light at night. The integration of DNA sequencing and AI identification tools will be necessary to detect today's hidden biodiversity (*GBF targets 7, 14, 20, 21*).

Recommendations for society

1. Get involved and request the data. Everyone can help to protect biodiversity and assist in the monitoring. Engaging in monitoring and other *citizen science* activities can help to discover species of understudied taxa and to implement large campaigns at multiple sites. Help to ensure that the data is not only collected but comparable and accessible (GBF targets 14, 20, 21).
2. Allow wilderness. Nature left in part to its own strategies can best promote hidden biodiversity. Increase your awareness for conservation of hidden biodiversity on your property and in areas you are part of, such as the design of open public spaces or your employer's commercial space (GBF targets 9, 11, 12, 16).
3. Don't wait for regulations. Reducing stressors, for example pesticides, noise, and light at night, are useful measures to protect organisms we normally do not perceive. If these decisions are made without political pressure, the solutions can act as *bottom-up best-practice* examples for changing societal behaviour (*GBF target 7*).

4 Linking linguistic, cultural and biological diversity

1 *Indigenous peoples and local communities (IPLCs)* play a critical role in the sustainable use and conservation of biodiversity and ecosystems. Ensuring the rights of IPLCs to their territories and resources remains crucial for the maintenance of *biocultural diversity*[1].

2 Most Indigenous and local languages, as well as much of the *Indigenous and local knowledge (ILK)* encoded in them, are critically endangered. Any loss of language leads to the erosion of *ecoliteracy*. Ultimately, it also means the loss of knowledge and values about the ecosystems and the environment, the surrounding nature, which reciprocally sustain biodiversity and nature's contributions to people around the globe.

3 Language resuscitation is important and should be done in time and respond to actual demands of the Indigenous peoples and local communities. It fosters a positive attitude towards endangered cultural heritage. Community members themselves should receive training for documentation and revitalisation initiatives. Free, prior and informed consent (FPIC) is paramount to establish participation and consultation of IPLCs prior to the beginning of any projects that affect them.

4 We need to better understand and value the coupling and decoupling of biodiversity and the linguistic and sociocultural diversity, and disentangle our understanding of the underlying processes that drive this mutual relationship.

5 There still persists a knowledge and policy gap in coordinating efforts to articulate linguistic studies and language revitalisation efforts into biodiversity studies, inventories, and management plans[2,3].

Of the utmost importance to the conservation of *Indigenous and local knowledge* are language maintenance and revitalisation programmes which support *Indigenous and local communities*, as well as the documentation and analysis of Indigenous and local languages as the primary carriers of such knowledge that links to and sustains biodiversity.

Within the framework of the *International Decade of Indigenous Languages 2022-32*[4], *MustKnow4* of 2022 highlighted the concept of biocultural diversity, which considers the diversity of life in its human-environment dimensions. This includes biological, sociocultural, and linguistic diversity, which are interconnected and have developed over time through mutual adaptation and possibly co-evolution as socio-ecological systems[5,6]. This aspect is deepened in the present version of *MustKnow4*.

There is a strong co-occurrence of these diversities in IPLCs' lands containing most of Earth's remaining species[2,7,8]. The Indigenous peoples and local communities play a critical role in the sustainable use and

6 *Inari Sámi, a language spoken in Finland, has six different words for whitefish (Coregonus lavaretus). Oral stories and knowledge provide baselines for the (ecological) knowledge on management and restoration of natural pastures.*

50 *Germany has comparatively few native languages, eight from a single language family (the Germanic languages German, Danish, North and Saterland Frisian, the Slavic languages Upper and Lower Sorbian, the Indo-Aryan language Romani) and the German Sign Language. Some of them are highly regionally diversified in dialects. In comparison, the Southwest Amazon is about the same size but has over 50 languages representing seven language families and harbours ten* isolates*.*

7,000 *There are about 7,000 known languages. If we do not intervene, we could lose 1,500 by the end of this century. That would amount to at least one language per month.*

conservation of biodiversity and ecosystems. The Kunming-Montreal Global Biodiversity Framework (GBF) highlights their role as custodians of nature and partners in conservation efforts, particularly section C which recognises the roles, rights and contributions of IPLCs, and includes eight targets that contain specific mentions of IPLCs (*GBF targets 1, 3, 5, 9, 13, 19, 21, 22*).

These diversities are threatened by the same drivers. Of the approximately 7,000 known languages worldwide[9], nearly half are considered endangered. Without intervention, language loss could triple in 40 years, equivalent to one language lost per month for the rest of this century[10].

Closely intertwined with language loss and the associated Indigenous and local knowledge is the erosion of ecoliteracy, as people are increasingly distanced from nature, and biodiversity is being lost at unprecedented rates[11]. Fundamental changes in lifestyles are triggered by processes that result in sedentarisation (settling down) and urbanisation. They can take place in less than two generations when there is a lack of economic incentives due to drastically reduced employment in agriculture, forestry, fisheries and other natural resource–based economic activities, and tend to lead to *habitat* loss and societal change[12,13]. They involve loss of livelihoods and the displacement of Indigenous and local languages and cultures through substitution by national ones and widespread homogenisation, eroding the conditions for a meaningful usage of IPLCs' languages and cultures[14,15]. These erosion processes take a heavy toll on the intergenerational transmission and formation of nature-related values, attitudes and actions, facilitating further destruction of *biocultural diversity* altogether[2,16-18].

Preserving and revitalising languages is also relevant in regions with few languages, but manifold dialects, such as Germany and the *Global North* in general. In efforts to recuperate original landscapes and biodiversity from cultural landscapes (rewilding), traditional knowledge, as embedded in local dialects, is needed, whereas leaving cultural landscape to its fate (cultural severance) with the intention of returning it to its wild state has a comparatively detrimental effect on

Closely intertwined with language loss and the associated *Indigenous and local knowledge* is the erosion of *ecoliteracy*, as people are increasingly distanced from nature, and biodiversity is being lost at unprecedented rates[11].

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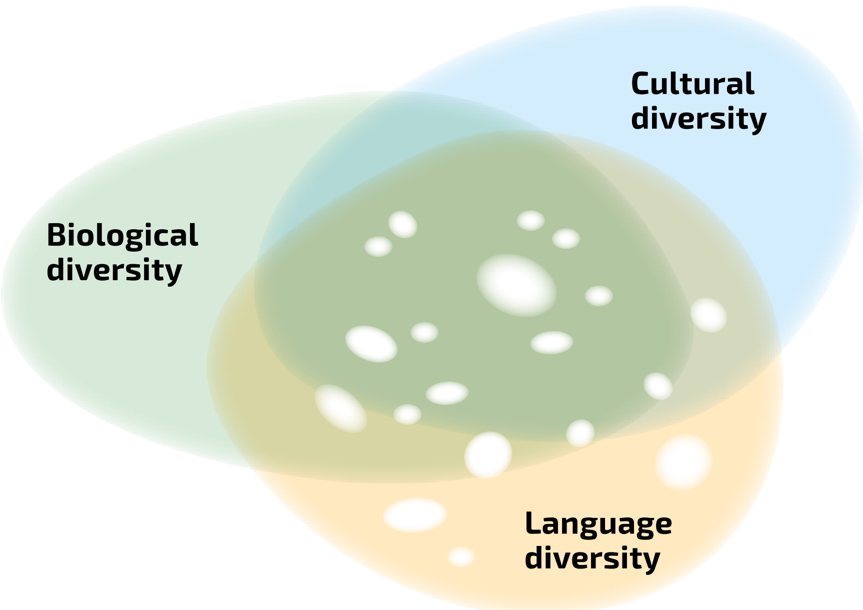
biodiversity and overall ecological richness[19]. Traditional local knowledge is endangered at present and should be documented to prevent its disappearance, preferably by community members, who should receive training for documentation initiatives.

Although there is scientific knowledge and awareness about



With the loss of linguistic diversity, the knowledge about biodiversity and cultural practices inscribed in it is also irrevocably lost, which is symbolised by white spots in this graphic.

biocultural diversity[2], this knowledge has yet to be applied to concrete policies that effectively support the preservation of biocultural diversity[3,20]. By recognising the connections between people and other parts of nature and directly incorporating them into decision-making, we hope the biocultural framework enables more effective action to reach the 2050 *Convention on Biological Diversity (CBD)* goal of *living in harmony with nature*[21].

Background

The issue of ecoliteracy should be high on the biodiversity research agenda[22-24]. Much of what we know about the natural world lies outside of academic knowledge and mostly resides in unwritten language in people's concepts and memories[14,15]. Evidence from the literature shows how ILK and ecoliteracy are being eroded among both IPLCs and the broader society through the loss of cultural values[3,25,26]. Natural phenomena cannot be understood apart from the languages that encode them, and vice versa. Thus, language diversity is critical to safeguarding biodiversity and a balanced human relationship with nature. An example from Vanuatu explains how the interplay of several factors is important to achieve a high retention rate of traditional languages: tolerated multilingualism, limited urban drift, and government recognition of traditional land rights[27].

Biocultural diversity also manifests itself in crises, negatively affecting all components. Land conflicts mainly emerge due to unequal access to knowledge and power structures. Such conflicts become more acute due to the aggravating effects of land-use sectors such as agriculture and forestry[28] when further measures towards changes in human diets or transition to deforestation-free product chains in Europe do not accompany them (EU regulation 2023/1115; >*MustKnows5–7, 10*). Land rights for IPLCs are a precondition to ensure the transition is just and equal (*GBF targets 18, 22; SDG 10*)[29,30]. Indigenous and traditional livelihoods and production systems should be maintained, as they have in general a positive effect on the conservation and restoration of nature and sustainable development (>*MustKnows 7, 8, 10*)[31].

Recommendations for political decision-makers

1. Campaign for the *Indigenous and Tribal Peoples Convention* (ILO 169)[32] to be ratified and applied by as many countries as possible. It is the only convention in the world that legally protects the rights and cultures of indigenous peoples and thus biocultural diversity.
2. Advocate that all nature restoration and protection measures affecting Indigenous lands and traditional territories should be planned and executed in collaboration with IPLCs in a participative approach that respects and integrates their perspectives and invaluable and irreplaceable knowledge. These measures should also focus on areas that are critical for conserving biocultural diversity, i. e. biodiversity, language, cultural and knowledge systems. This should explicitly be reflected in the ongoing revisions of national biodiversity strategies and action plans.
3. Policies seeking to value nature or conserve biodiversity should be reinforced by better integration with knowledge, culture and language-oriented research and policies, including intercultural and multilingual language education and revitalisation.

Recommendations for society

1. Philosophies of good living (*buen vivir*) of Indigenous peoples and local communities usually contrast with conventional economic indicators of a good quality of life, because they are not primarily conceived at a materialistic or individual level. It is therefore necessary to consider the community and its relationship with nature as a socio-ecological system, requiring new platforms for thinking, practicing, and experiencing alternative futures based on biocultural ethics.
2. Language revitalisation is a community effort, involving all stakeholder groups, and measures must be taken to allow that all voices are heard. Professional researchers should be involved in linguistic documentation of languages, but in consultation and agreement with the speakers' community. Monitoring efforts and practicing the language actively should be a community-led effort.
3. Nation states often try to impose monolingualism. However, multilingualism is the usual situation in human societies[33,34]. Supporting multilingualism is one of the main strategies to preserve Indigenous and local languages and opens avenues for discovering new descriptions and views of nature, historic story-telling, shared experiences and traditional practices, thereby supporting ecoliteracy.

5 Harmonising the diverse use of forest ecosystems and biodiversity conservation

1 Past forest management often did not reproduce *natural forest dynamics* and created forest structures and compositions that made forests more susceptible to climate change-induced disturbances and consequent economic damages. Yet recent disturbance events also provide a window of opportunity for promoting (tree) species-rich and structurally diverse forests.

2 Various policy sectors and levels often pose competing demands on forests that may ultimately cause unintentional prioritisation of single *ecosystem services*, which can result in trade-offs between policy objectives on provisioning of forest resources, climate change mitigation, biodiversity conservation and other services.

3 A combination of several management intensities and approaches at different spatial scales (including no management) may be able to reconcile competing policy objectives.

4 Sustainable forest management practices that focus on enhancing structural and compositional diversity from *stand* to landscape level, often have synergistic benefits for biodiversity, climate change mitigation, and the resilience to a changing climate and shifting *disturbance regimes*.

5 Growing demand for wood products has the potential to increase harvest pressure and negative side-effects on biodiversity in domestic and foreign forests. Domestic demand for wood products, wood supply as well as wood imports and exports need to be considered in an integrated way to avoid biodiversity losses through decreasing harvests in one place while increasing them in another.

Intensifying climate change impacts and trade-offs between competing forest-related policy objectives require management practices and spatial planning that safeguard forest biodiversity and secure *ecosystem service* provisioning.

MustKnow5 of 2022 highlighted sustainable forest management and impacts by climate-related disturbances in forests. This edition picks up these considerations and presents solutions that benefit biodiversity by resolving trade-offs between competing policy objectives.

In Germany, natural forest dynamics have been suppressed to optimise timber production, and processes triggered by natural disturbances, such as regeneration, are replaced by management. Yet, management effects are not identical to those of natural disturbances in terms of forest structure, microclimate and *habitat*[1]. Forest management has created forests that are more susceptible to climate-related large-scale disturbances, e. g. spruce in monospecific, even-aged forests outside their natural growing area. Large-scale disturbances alter the structure and functioning of forests, which benefits some species while others

62% *In the last 5 years (2018-22), 62% of the on average 75.1 million m^3 annually harvested wood in Germany resulted from salvage logging related to disturbances[33].*

>< *The average lifetime of different wood products varies greatly from around a year or less for wood used for energy, up to a decade for wood used for paper, to several decades or more for wood used in construction[35-37].*

47 *distinct types of tree-related microhabitats such as cavities, tree injuries or crown deadwood provide valuable benefits for biodiversity, and a subset of them is systematically assessed in the German national forest inventory[14,34].*

suffer[2]. Small-scale disturbances often have positive effects on biodiversity, while large-scale disturbances leading to widespread forest dieback can be detrimental. However, recent large-scale disturbances provide an opportunity to change tree species and forest management and so improve conditions for biodiversity (*GBF target 2*).

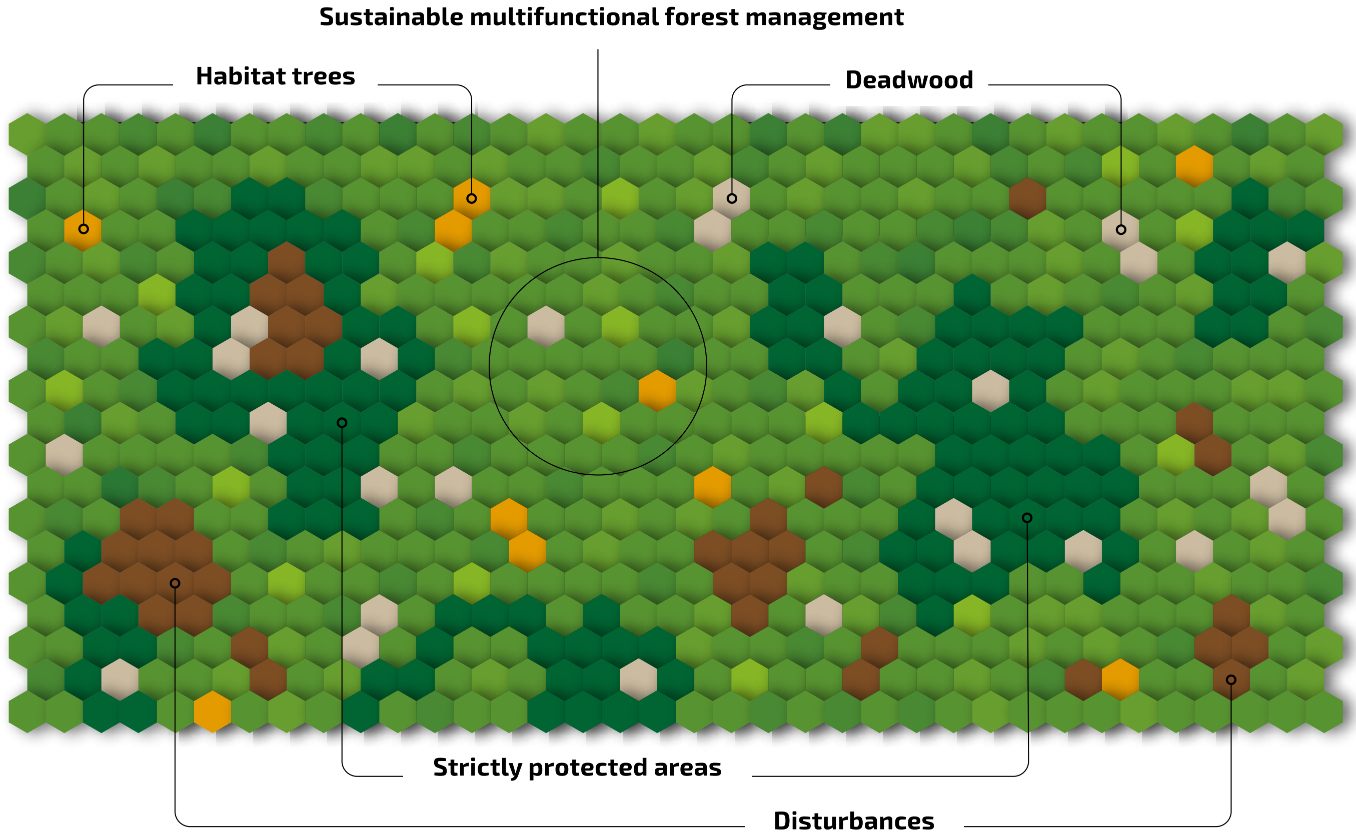
European forests provide a range of timber and non-timber ecosystem services to society[3]. Various policy sectors and levels pose sometimes competing demands on management and ecosystem service provisioning, which result in trade-offs between policy objectives such as climate change mitigation and adaptation (*>MustKnow1, GBF target 8*), biomass production and biodiversity conservation[4]. If those trade-offs are not balanced, prioritisation of single ecosystem services can result in adverse effects on multiple other ecosystem services and biodiversity[5]. Thus, multifunctional management for multiple ecosystem services, participatory decision-making in public forests and incentives for private forest owners are needed[6,7] and require cross-sectoral coordination of policies (*GBF target 14*).

Primary forests are *biodiversity hotspots* and need protection from large-scale timber extraction and land-cover change (*>MustKnow7, GBF targets 1, 3, 4*). Managed *secondary forests* usually host less biodiversity. In regions with no primary forests left, a mixture of management intensities and approaches produces diverse habitats[8]. Therefore, spatial integration of several management approaches may help balancing the supply of timber with provisioning of other ecosystem services and the promotion of biodiversity[9]. Studies from Canada and Northern Europe suggest that landscapes composed of areas with no management (*>MustKnow7*), and a matrix of different management approaches, may be able to reconcile competing policy objectives[10,11]. Adapting this concept to central Europe should consider the diverse ownership structure facilitating a diversity of management intensities and approaches (*GBF target 22*)[12].

In managed forests, sustainable management practices that focus on structural and compositional diversity from *stand* to landscape scale[13] and the promotion of *tree-related microhabitats*[14] often have multiple benefits for biodiversity, climate change mitigation, and the resilience to climate change (*>MustKnow1, GBF target 8*)[15-18]. Retention of forest elements such as deadwood and old *habitat trees* secure the continuity of structural and compositional diversity, and thereby preserve habitats for a variety of species (*GBF target 10*)[19,20].

Increasing demand for wood products and the need to decarbonise fossil-fuel-intensive sectors might increase harvests and negative effects on biodiversity in domestic and foreign forests. At present, German wood imports are not exclusively from sustainable forestry[21,22]. Recently, Germany has been exporting timber from recent large-scale disturbances that have been addressed by clear-cuts, with negative effects on biodiversity[23]. Therefore, it is key to consider present and projected domestic wood supply as well as wood imports and exports to prevent the German demand for wood from leading to increasing harvest pressure domestically as well as deforestation and forest degradation elsewhere (*GBF targets 1, 5*)[24]. The Supply Chain Act[25] and similar policies can help to ensure that only

Primary forests are *biodiversity hotspots* and need protection from large-scale timber extraction and land-cover change.



Model forest landscape including crucial elements to align ecosystem service provisioning with biodiversity conservation. Small and large protected areas (dark green), such as Natura2000 and national parks, are embedded in a matrix of sustainable, multifunctionally managed forest with various management intensities and approaches (various green shadings). Deadwood (grey), habitat trees (orange) and other tree-related microhabitats play important roles in managed forests by providing habitat for diverse species. Small and large disturbed areas (brown) resulting from natural forest dynamics and climate-related impacts, such as drought, bark beetle outbreaks and storms, provide opportunities to shift species and management approaches in managed forest but also affect protected areas where they are part of the natural processes that should be protected (adapted from reference 38).

sustainably harvested wood enters domestic value chains. Prioritising long-lived wood products, fostering innovation to increase the longevity and recycling of wood products as well as reducing the consumption of goods and services that use wood only in the short or medium term can help avert biodiversity loss from harvest increases (*GBF target 16*).

Background

At the EU level, current management practices are projected to further decrease the forest carbon sink in the future[26], indicating a need for shifting management practices. Those changes need to consider the role of forests for biodiversity conservation and capitalise on existing co-benefits of increasing forest carbon storage by decreasing harvest[27]. However, it is key to also consider that more forests might turn into a carbon source during the 21st century under projected climate and disturbance regime shifts[28].

Discussing how to manage and cope with disturbance impacts in forests, especially those of large-scale events that have affected German forests since 2018, has become an emotional debate[29]. Leaving dead trees and uncleared patches in large-scale disturbed areas has benefits for biodiversity, regeneration and microclimate, but may adversely affect the local population's sense of place without appropriate information campaigns on the benefits of such action. At the same time, large-scale disturbances in ill-adapted forest stands can be seen as an opportunity for accelerated forest conversion to climate-adapted and biodiversity-rich communities.

Forest regeneration – natural, assisted or human-made – is a crucial process contributing to forest resilience. However, *browsing* of young trees by large populations of naturally occurring ungulate species, such as roe and red deer, can have strong impacts on the next

In managed forests, sustainable management practices that focus on structural and compositional diversity from *stand* to landscape scale[13] and the promotion of *tree-related microhabitats*[14] often have multiple benefits for biodiversity, climate change mitigation, and the resilience to climate change[15-18].

generation of forests[30]. Especially due to selective browsing, tree species diversity can be reduced[31] if no protective measures are taken. Additionally, natural predators have been extirpated and hunting by humans is insufficient. A study from Poland suggests that the presence of large carnivores such as wolves can have a strong impact on natural regeneration by modulating the use of forest areas with young trees by deer[32].

Moreover, active restoration of areas affected by large-scale disturbances such as large monospecific conifer forests is needed. Restoration efforts that combine natural dynamics, such as *succession*, with complimentary planting of diverse tree species mixtures adapted to projected environmental conditions from appropriate genetic sources can have both positive ecological and economic effects.

Recommendations for political decision-makers

1. Coordinate forest, climate, biodiversity, bioeconomy and other policies to foster policy integration and coherence on different spatial scales to align forest ecosystem service provisioning, disturbance risk management and biodiversity conservation.
2. Participatory decision-making in public forests (*>MustKnow8*) and incentives for private forest owners boost the integration of biodiversity-enhancing measures into forestry practice.
3. Domestic demand for wood products, wood supply as well as wood imports and exports need to be balanced to avoid biodiversity losses by increased harvests either domestically or internationally.

Recommendations for society

1. Raise acceptance and awareness through, e. g., information campaigns, that temporary treeless forests, dead trees and uncleared patches in areas of large-scale disturbances are part of natural forest dynamics and crucial for many species' life cycles.
2. Raise awareness that retention of different forest elements, such as deadwood habitat and old habitat trees, during management interventions secures and enhances structural and compositional diversity, and thereby a continuity of habitats for a variety of species on a landscape scale.
3. Promote the prioritisation of long-lived wood products, recycling of wood products and a decrease in the consumption of other goods and services that use wood only in the short or medium term to help avert biodiversity loss from harvest increases.

6 Transforming agricultural and food systems

1 Biodiversity and its *ecosystem services* are crucial prerequisites and production factors for all agricultural and food systems.

2 Agricultural practices should be more closely orientated towards the mechanisms of natural ecosystems and integrate regenerative practices.

3 Agriculture can promote biodiversity, create additional spaces for nature and species conservation and strengthen *ecosystem services* by contributing to improved soil quality, sustainable water management and the preservation of *habitats* for animals and plants.

4 Transparency regarding the true economic effects of biodiversity in overarching systems promotes changes in society's behaviour and economic activity (>*MustKnow10*).

5 Farmers are vital actors in the protecion of biodiversity and climate.

Sustainable agricultural systems contribute to the conservation and promotion of biodiversity, strengthening the resilience of corresponding cultivation systems and improving food security.

MustKnow6 from 2022 focused on the transformation of agriculture, emphasised biodiversity as an essential production factor and highlighted farmers as crucial actors in biodiversity conservation. This basic idea is being developed into a joint consideration of agricultural and food systems and aims to promote comprehensive social change.

The preservation of biodiversity is not only a question of environmental protection but also a decisive factor for the functionality and productivity of agroecosystems[1-3]. Natural ecosystems have developed over long periods of time. Knowledge of the complex interactions in biological systems forms the basis for agricultural practices that support sustainable and resilient agroecosystems[4,5], which respond optimally to challenges such as climate change or the continued growth of the world's population[6,7]. Higher genetic diversity leads to more stable yields in the long-term, reduces pest and disease pressure and benefits soil life, which indirectly increases soil health and the capacity of soils to store carbon and water (>*MustKnows2, 3*)[8,9]. Biodiversity can thus make a critical contribution to reducing the use of agrochemicals. As a natural resource, biodiversity is also an essential building block for securing various ecosystem services and must therefore become an indispensable production factor in agricultural systems[10,11]. This includes, for example, knowledge about the interaction of different types of organisms and the genetic diversity within a species. Shifting to more sustainable agricultural practices promotes productivity and long-term economic viability and helps maintain or restore habitats for various organisms[12,13]. Diversity stabilises agroecosystems and reduces production costs[14]. Promoting mixed cropping, as an example of agro-ecological intensification, can create space for nature conservation locally and globally. These contribute to the preservation of global biodiversity[11]. Irrespective of the controversially discussed possibilities of new production approaches – for example, *vertical* or *cellular agriculture* – a combined approach of a more plant-based diet (>*MustKnow10*), closing yield gaps in and halving losses

€ *Prices must represent true costs and reflect the reality.*

40% *A combination of a more plant-centred diet, closing yield gaps and halving losses in/after the field could reduce land requirements for agriculture by at least 40% by 2050.*

2/3 *Global agricultural subsidies for producers currently amount to almost USD 540 billion annually. More than 2/3 of these subsidies are considered price-distorting and highly damaging to the environment.*

after the field could reduce the land required for agriculture by at least 40 percent by 2050[14-16]. Therefore, the ecological transformation of agricultural and food systems can create additional space for nature and species conservation. In particular, this supports targets 1-3, 7, 8, 10, 12 and 16 of the *Kunming-Montreal Global Biodiversity Framework (GBF)*.

The science-based registration and inclusion of previously outsourced costs in pricing create the necessary transparency for decisions and control consumption in a market economy via the price. For example, costs arising from water pollution, *soil degradation* or greenhouse gas emissions have not yet been internalised in product costs. If these previously socialised costs are made transparent and included in pricing, the true value of sustainably produced food becomes visible and the motivation for more environmentally friendly practices increases[17,18]. Farmers thus play a vital role in the fight against climate change and become part of the solution to protect biodiversity in agricultural systems. A further shift in land use and the conversion of natural habitats in other countries can be prevented through the holistic approach of biodiversity-friendly agriculture (>*MustKnow10*)[19].

This requires a master plan that gives farmers a perspective and initiates a consistent agricultural turnaround. The transformation of agriculture can only be achieved through improved institutional cooperation between environmental and agricultural policy and as part of a fundamental social (value) change. In addition, there is currently a lack of comprehensive interdisciplinary and participatory research and transfer of expertise into practice to test the diversity of solutions, accelerate the integration of sustainable cultivation concepts and support transformation processes.

Background

Learning from natural ecosystems: The combination of agricultural practices and fundamental principles of natural ecosystems such as diversity, circularity and site-adaptability can help to develop more sustainable agricultural production. Biodiversity is becoming a driver for the *socio-ecological transformation* of production and thus a driver for innovation – a central element of sustainable, resilient farming systems. Digitalisation, artificial intelligence and automation can support the management of biodiverse systems and help to identify and better utilise the benefits of biodiversity (>*MustKnows8, 9*)[20-23]. Agricultural practices should be rethought and reorganised, considering these aspects to enable more future-proof and sustainable agriculture and food production[24].

Diversified agricultural and food systems: A wide range of crop species and varieties, cultivation methods and products increase the resilience of farming systems to external influences. It also increases farmers' productivity and income. An integrated approach to health and environment (>*MustKnow2*) is essential and enables the integration of systemic principles. This requires collaboration across different disciplines and sectors.

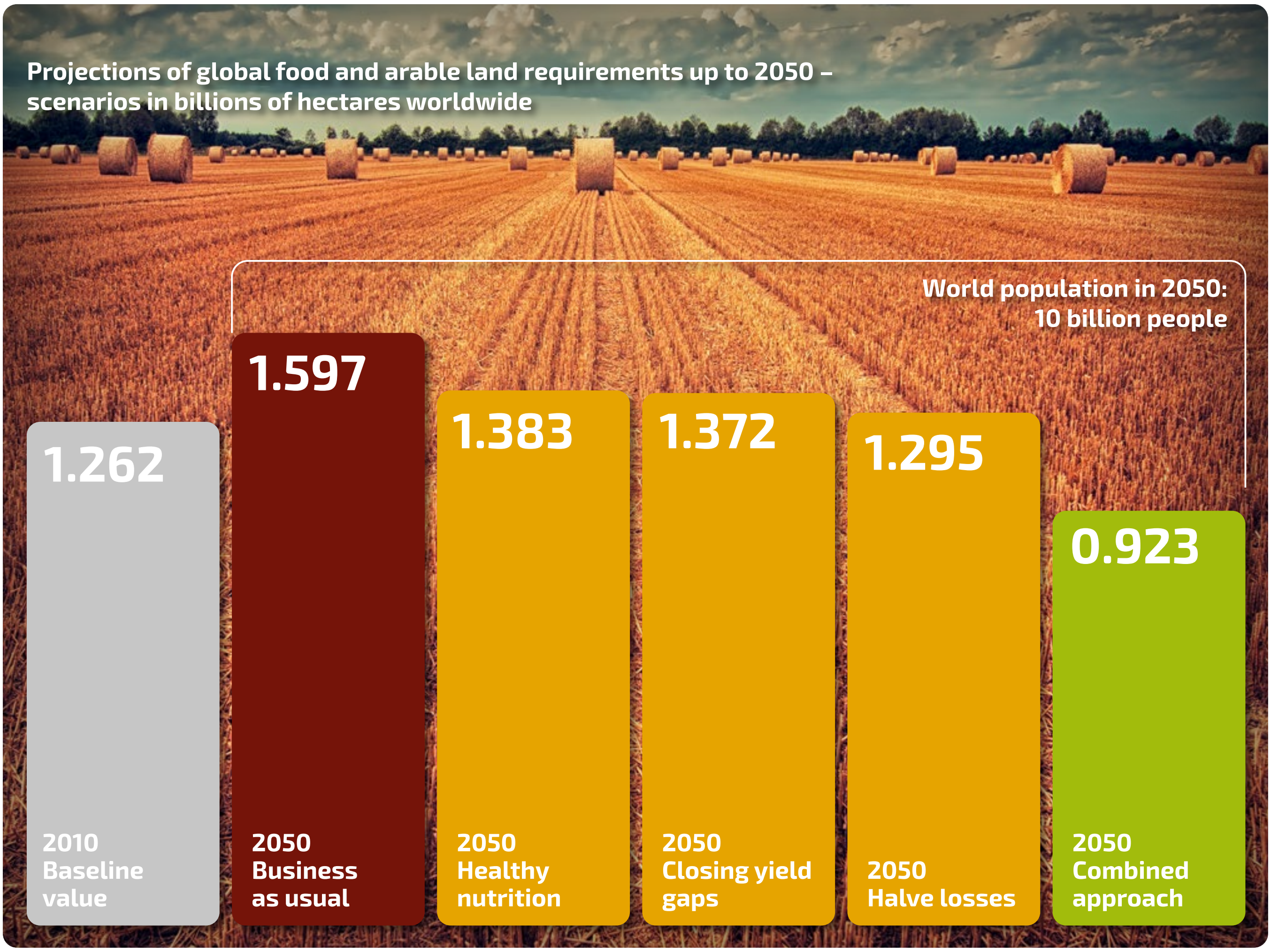
Societal change: Farmers have a high intrinsic motivation to protect

As a natural resource, biodiversity is an essential building block for securing various *ecosystem services* and must therefore become an indispensable production factor in agricultural systems[10,11].

Digitalisation, artificial intelligence and automation can support the management of biodiverse systems and help to identify and better utilise the benefits of biodiversity[20-23].

biodiversity[26]. The main difficulties in implementing measures to conserve biodiversity lie not in a lack of biodiversity awareness but in practical implementation aspects: a lack of flexibility in funding programmes, concerns about risks and a high measurement and documentation effort make it extremely difficult for farmers to realise this motivation. Public attention should focus less on attributing fault to agriculture and more on farmers' willingness to remove obstacles[22]. Innovative approaches and methods are required to adapt the agricultural sector to future tasks and requirements, as well as financial incentives through public funds and private sector incentives (>*MustKnow7*). Furthermore, a change in society's consumer behaviour is necessary (>*MustKnow10*), which can be promoted through tax incentives.

Ecosystem services that are strengthened by promoting biodiversity and improving soil, air and water



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If we continue with business as usual (pillar 2), there will be an additional need for arable land that cannot be covered, while the combined measures (pillar 6) of healthier nutrition, closing yield gaps and halving losses in and after the field or barn can even reduce the need for arable land. This frees up land that can be used for other measures in line with the GBF objectives (graphic based on reference 15).

Biodiversity is becoming a driver for the *socio-ecological transformation* of production and thus a driver for innovation – a central element of sustainable, resilient farming systems.

quality ultimately lead to more climate-resilient agriculture and thus also significantly contribute to society's well-being. These cross-system connections are already being communicated locally and with scientific support. Politics, business and society must recognise the importance of biodiversity in the agricultural landscape and food production and act accordingly. Exemplary farms, educational gardens and *living labs*, as well as training and further education, can have a supportive effect in this regard and actively drive innovation (>*MustKnow8*).

Recommendations for political decision-makers

1. Diverse agriculture with biodiversity-promoting measures is more resilient to global challenges and crises. It ensures that the functioning of agricultural ecosystems is maintained and thus provides sustainable productivity and greater food security.

2. The reorganisation of the agricultural and food sector must be accompanied by political and economic incentives such as adjusted tax rates and subsidies, but also an innovative regulatory framework. The price dictates of food corporations, large dairies and large slaughterhouses must be abolished. In addition, targeted education and training based on scientifically proven facts has a fundamental role to play.

3. It is not only necessary to increase biodiversity in agriculture, but it must also be integrated into the entire food system. Public funds must promote public services. The goal should not be the preservation but the transformation of agricultural and food systems, replacing established practices such as land premiums. Concepts such as *One Health* or One Planet (>*MustKnow2*) serve as orientation aids.

Recommendations for society

There is a large gap between perception and behaviour. This gap must be closed as sustainable action can also be associated with higher costs. Incentives for changes in behaviour and action are necessary, combined with social compensation measures that relieve the burden on people with lower incomes (>*MustKnow10*). This results in the following action premises for society:

1. Biodiversity conservation is a fundamental societal task and a better understanding of its diverse interactions is required. With the *10MustKnows24*, we want to strengthen this understanding.

2. The existing knowledge about the problematic situation of biodiversity in the agricultural landscape and its importance for society must be communicated more effectively using the current expertise to the public and politicians (>*MustKnow8*).

3. A fundamental understanding of the impact of one's consumption and lifestyle on biodiversity, climate, and health drives the transformation of the agricultural and food systems. Changed nutritional environments (>*MustKnow10*) support the change in individual behaviour.

7 Protecting land and resources

1. Biodiversity and the protection, restoration and development of natural resources should be reflected in all land-use discussions, decisions and spatial planning processes at all levels, starting with international and national conservation area planning, including their interconnections (biotope networks), and down to regional and local spatial planning.

2. The restoration of degraded areas should begin immediately and must be accelerated.

3. Protected areas and their interconnections are the backbone of biodiversity conservation. The weakening of EU species protection standards and landscape-protected areas from other uses, such as photovoltaic systems, must be prevented. New protected area implementation should be enforced, and existing and new areas must be effectively managed.

4. Integrative cross-sectoral biodiversity management should also be enforced beyond protected areas, e. g., in agricultural landscapes and forests (>*MustKnows5, 6*).

5. Societal discourses should be initiated and intensified, existing policy and governance instruments strengthened and supplemented by new ones in a targeted manner. Stakeholders should be enabled to recognise the consequences of their actions, so that they avoid negative impacts and make effective contributions to biodiversity conservation (>*MustKnow8*). This is a central prerequisite for *socio-ecological transformation*.

Since 2022, the social debate on transformation has intensified once again, and policymakers and planners are faced with increasing and often conflicting courses of action. The conservation of biodiversity and natural resources must have top priority in land use and spatial planning decisions.

To implement the GBF targets, spatially designated and cross-sectorally integrated targets are required, particularly at local and regional levels.

Biodiversity protection must be integrated into land-use decisions across sectors and substantiated and made binding in spatial planning. Avoiding adverse impacts on biodiversity have to be given priority over other interests. Current accelerated legislative timetables that weaken species protection laws in the transport, industrial, and renewable energy and building sectors and that limit impact regulation to actual compensation or compensation payments are heading in the wrong direction (cf. results of the government coalition committee of March 2023). Instead, exploring sustainable development synergies should have priority. To this end, it is vital to monitor whether GBF targets are being achieved. Every project and associated land consumption should be assessed for its compatibility with the conservation of nature and landscape, biodiversity and land-use targets.

The *EU Nature Restoration Law* constitutes an important basis for the restoration of nature, covering all ecosystems. One of its provisions is the restoration of degraded

3x *A 3-fold internal development is necessary. This triple development is to develop mobility, green and open spaces and building together in a qualified approach*[17]*.*

268,721 *Global management effectiveness of protected areas: 268,721 protected areas exist worldwide: 16% of the terrestrial and inland waters are under protected area coverage*[15]*. Only 59 sites are listed (as of October 2023) in the IUCN Green List of protected or conserved areas that are certified and recognised as achieving ongoing results for people and nature in a fair and effective way.*

50% *Less than 50% of water bodies in the EU exhibit good ecological status. In Germany, more than 95% of original peatlands have been drained. Thus, it is not surprising that biodiversity is most threatened in aquatic ecosystems*[16]*.*

wetlands and *peatlands*, which is also called for in Germany's Action Plan on Nature-based Solutions for Climate and Biodiversity (ANK). On 27 February 2024, the European Parliament passed the EU Nature Restoration Act. This law must now be implemented with ambitious national standards. Potential areas for the restoration of ecosystems must be identified, saved and developed. It is furthermore vital to regularly monitor whether GBF targets are being achieved.

Target 3 of the Kunming-Montreal Global Biodiversity Framework (GBF), which calls for the effective conservation and management of 30% of terrestrial and inland waters, and of marine and coastal areas, requires an effective protection status for protected areas (>*MustKnow1*); it is not sufficient to merely sum up existing protected areas. Besides achieving the quantitative target, it is also indispensable to foster effective qualitative protection[1].

A green infrastructure concept[2] and a nationwide biotope network should go beyond the existing protected area landscape, linking protected areas and *biodiversity hotspots* on a large scale in a legally binding manner. This network could be implemented by a new *Naturflächengesetz* (Act on the Required Extent of Natural Areas). The protection of biodiversity, water, soil and climate should be interlinked to ensure consistent and comprehensive resource protection. *Nature-based solutions* are the first choice both in the urban and rural context, as they form a basis for water retention, the protection of open and green spaces, the restoration of groundwater reserves and climate mitigation, but also due to recreational benefits[3,4].

Societal discourse and consensus on the question "How do we want to live in the future?" are important prerequisites for a socio-ecological transformation. It includes the development of new *narratives* and the forming of novel alliances[5]. Farmers and foresters play a central role. In particular, the farmer or forester should become a "nurturer of biodiversity" (>*MustKnow6*)[6]. One approach is to ensure adequate financial compensation within the agricultural and forestry sectors for the development of *ecosystem services* and biodiversity[7]. Subsidies harmful to biodiversity should be abolished, and the *GBF target 18* needs to be nationally

The protection of land and natural resources is an indispensable, essential part for sustainable transformation processes in society, politics, economy and planning. Clashes of interests in the valuation and use of natural resources should be resolved through integrated approaches for climate change mitigation and biodiversity protection.

implemented. Until the overall goal of *net zero* land use is reached, municipalities whose leeway may be restricted by new protected areas or restored ecosystems should receive financial compensation. Nature conservation authorities and decision-making authorities must be accorded sufficient capacity to effectively carry out their work. It is furthermore essential to take into account *biodiversity offsets*, as an internationally recognised principle. However, mitigation hierarchy should be given priority[8] in order to achieve a net gain in spatial planning[9,10].

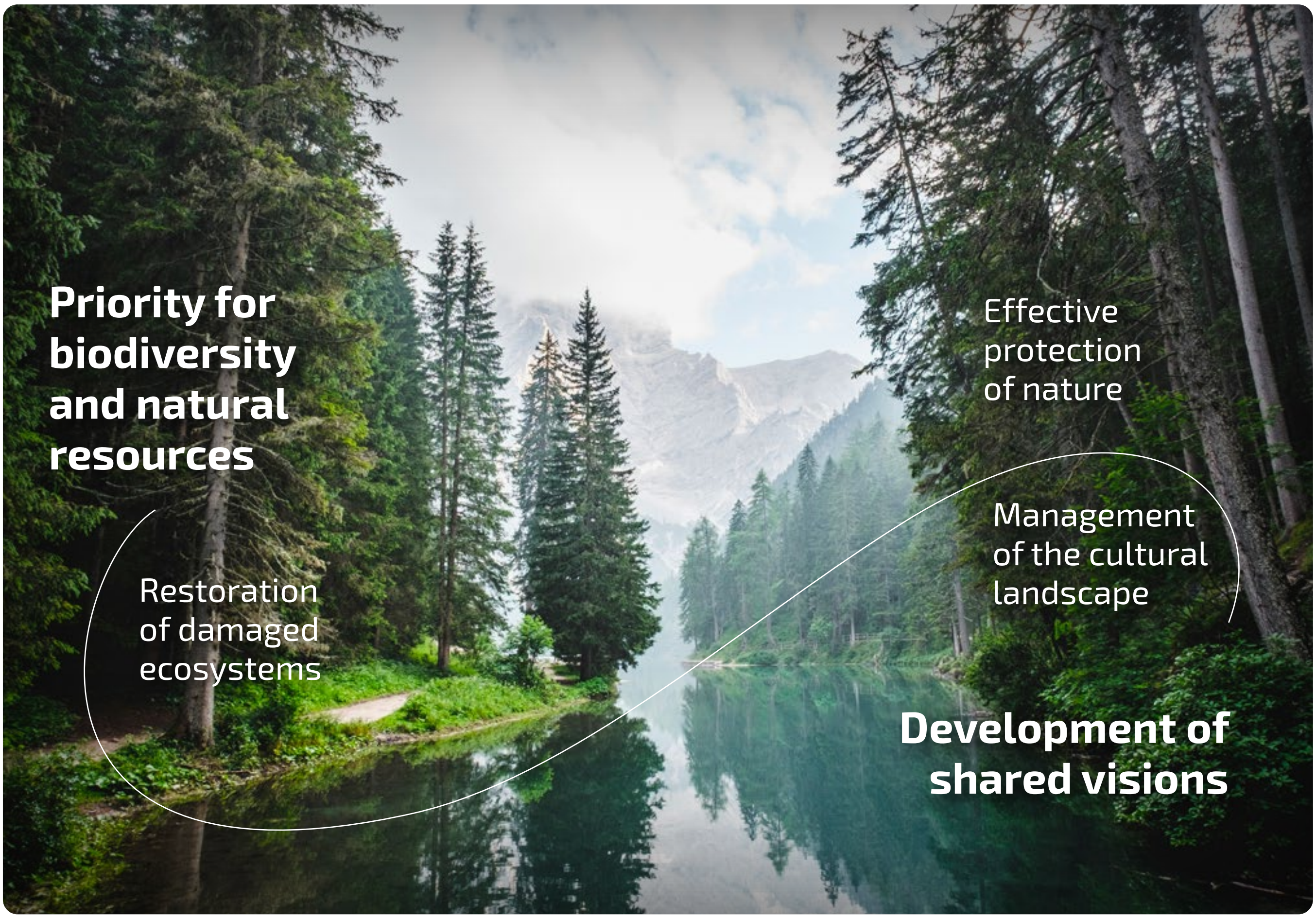
Background

Every day, about 60 hectares (ha) of new settlement and transport areas are designated in Germany, so the federal government's land consumption target of consuming 30 ha per day or *net zero* is a long way off. Soils can no longer provide basic functions (e. g. water and carbon storage), their ecosystem services are lost and *habitats* disappear[11].

The restoration of ecosystems is a laborious and costly process that is subject to competition for land. Thus, it is vital to avoid negative impacts on ecosystems. Wetlands, water bodies and peatlands, in particular, are crucial for regulating water quantity and quality and recharging groundwater to ensure a healthy agriculture sector and protect climate and biodiversity[12]. Yet they are facing increasing pressure from climate change and agricultural use[13]. Their restoration must be given high priority (*>MustKnow1*).

Many protected areas in Germany are not achieving the intended conservation aims[14]. They are too small and isolated, poorly managed or not managed at all and subject to the impacts of climate change. The target of 30 percent land- and marine area protection must therefore account for the extent, connectivity and quality of such sites (*>MustKnow1*). In addition, efforts must be undertaken to prevent an ever more intensive utilisation of land in the remaining areas.

The protection of land and natural resources is an indispensable, essential part of sustainable transformation processes in society, politics, economy and planning. Clashes of interests in the valuation and use of natural resources should be resolved through integrated



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Biodiversity must be given a more prominent role in decisions on planning and land use.

Biodiversity protection must be integrated into land-use decisions across sectors and substantiated and made binding in spatial planning.

approaches for climate change mitigation and biodiversity protection.

Political actors should strive to create shared visions and processes for more biodiversity protection by means of appropriate narratives and dialogue processes such as those accompanying the implementation of the German *National Biodiversity Strategy (NBS2030)*. Regulatory law in combination with economic incentives like taxes and subsidies should also be exploited. Concrete positive examples should address not only the institutional level (e. g. *Zukunftskommission Landwirtschaft*) but also civil society as a whole in addition to professional representatives and associations.

Recommendations for political decision-makers

1. Call for action: It is insufficient to aim for the lowest common denominator. Rather, relevant actors must assume political responsibility for decisions taken to ensure the consistent protection of biodiversity and land-water ecosystems as a form of biodiversity responsibility. Integrative, cross-sectoral strategies are available as part of the National Biodiversity Strategy, the *European Green Deal*, the potential *Naturflächengesetz*, and various laws and draft laws. These strategies should be consistently applied, i. e. the required legal, personnel, financial and technical resources should be provided and clear responsibilities and level-related objectives need to be defined.

2. Synergistic action: Resource protection works best when and if there is a long-lasting majority regarding the protection of biodiversity-creating synergies with other sustainable development aspects. A goal-oriented, well-founded debate on the protection of natural life-support systems is not possible if contrary political goals are played off against each other, e. g. within the debate on biodiversity and resource protection like the use of wood (*>MustKnow5*). It is therefore important that political goals, plans and programmes address potential conflicts and resolve them already in advance.

3. *Biodiversity mainstreaming* in all sectors: The protection of natural resources (land, water, soils, air, biodiversity and landscapes) as a cross-sectional task must be primarily reflected in all decision-making processes – the balance in considerations must be shifted in favour of biodiversity and ecosystem services – and prioritised for sustainable development across all sectors.

Recommendations for society

1. We all benefit from the conservation of natural resources and biodiversity – building on nature can become a synergistic driver for innovation and new jobs.

2. We can all contribute to objectifying the debate; we are all responsible and we all can do something to save land, preserve natural resources and protect and develop biodiversity.

3. We can all work together to preserve our natural resources. We need positive narratives where people can find their own needs and hopes reflected. Society must overcome existing narratives, e. g. the false dichotomy of nature conservation versus agriculture. We have to develop fresh visions of a shared and healthy future as a prerequisite for new alliances.

8 Releasing transformative change through international collaboration and Education for Sustainable Development

1 Although actions to protect biodiversity have been increasing over the last decades, more holistic approaches are needed that recognise differential responsibilities of actors and also address inequalities and injustice[1,2].

2 Capacity building, technology transfer and scientific cooperation, particularly between high-, middle-, and low-income countries, are needed to identify and close indicator gaps, as well as gaps in monitoring data supporting the indicators. This includes the integration of *Indigenous and local knowledge (ILK)*.

3 *Education for Sustainable Development (ESD)* is key for galvanising translational collaboration and transformative action and, first and foremost, the behaviour change needed to achieve the goals of the *Kunming-Montreal Global Biodiversity Framework (GBF)* as well as the *Sustainable Development Goals (SDGs)*. Use of innovative and attractive digital tools or collaborations between arts and science help to engage a broad range of people and increase awareness at all levels of society of the importance of biodiversity for mankind and the impact our actions and activities have on the conservation and preservation of biodiversity.

4 *Citizen science* has the potential to promote and deepen the understanding of the importance of biodiversity and the loss of biodiversity in the broader public or society. At the same time, these projects contribute to a vibrant democracy.

5 Large investment companies have the power to (de)stabilise the Earth system[3]. Business, industry, and finance institutions need to track their impacts on biodiversity along value chains and in investments as requested by the recently adopted *Corporate Sustainability Reporting Directive (CSRD)*. This directive has the potential to create positive actions for biodiversity, potentially provides transparency and information on the actual impact of economic activities and may reduce negative impacts.

Given global interdependencies, biodiversity loss can only be mitigated by international and transnational collaborations and infrastructures. Due to the complex nature of biodiversity loss, stopping it requires connecting science, politics, economy and society and enhancing education of different formats for sustainable development across all age and social groups.

1/3 *Of 97 citizen science projects in Germany, more than 1/3 deal with biodiversity science[41].*

7% *Species occurrence records are available for less than 7% of the Earth's surface (11% for terrestrial and 4% for oceans)[33].*

€ 3.8 bill. *Pollination by insects has an economic value of € 3.8 billion in Germany and 1% of the global gross domestic product worldwide.*

In 2022, *MustKnow8* explored how linkages and connections between countries impact biodiversity, and how citizen science contributes to improving our knowledge on biodiversity. In this edition, we pick up on these considerations, presenting opportunities and options for how international collaborations could be shaped to increase the protection of biodiversity, and explore the transformative power of Education for Sustainable Development.

Human activities negatively impact biodiversity, with widespread consequences for human well-being[4]. Although impacts on biodiversity are local in nature, drivers of biodiversity change are linked globally. Telecoupling means that Germany's *biodiversity footprint* is much bigger outside its borders than within (>*MustKnow10*)[5,6]. Many German and EU trade regulations and offset measures place the responsibility to conserve biodiversity on low- and middle-income countries (LMIC) that not only harbour the most biodiverse regions of the planet (>*MustKnow4*)[7,8] but are also disproportionally affected by climate change and biodiversity loss. Protecting biodiversity increases resilience and safeguards human and planetary health[9,10].

Actions to protect biodiversity have increased over the last decades, but more holistic approaches that recognise differential responsibilities of actors and address inequalities and injustice[1,2] are essential. Increased financial contributions and developmental aid from high income to lower income countries can offset costs for biodiversity protection and restoration and compensate for biodiversity loss and damage to the environment (*GBF target 19*).

Indirect drivers such as investment in production, trade and financial flows[3], but also consumption patterns[6] contribute to biodiversity loss and climate change[11,12]. *GBF targets 14–16 and 18* propose measures to address these drivers. Independent, translational partnerships between science and business enable the development of science-based indicators and help avoid the pitfalls of market-based measures in *biodiversity offsetting* and credit trades. A start has been made at the European level with the Corporate Sustainability Reporting Directive (CSRD).

Decision-makers require access to the best available data, information, and knowledge (>*MustKnow9; GBF target 21*). However, gaps in indicators and in reliable monitoring data supporting these indicators exist. Historic inequities also contribute to a bias in the availability, collection, and monitoring of biodiversity data on a global scale (>*MustKnow4*)[13,14]. The integration of Indigenous and local knowledge (respecting *FAIR*[1] and *CARE*[2] data principles[15] (>*MustKnow4*) contribute to filling these gaps and facilitate equitable decision-making[16,17]. A mechanism that ensures that benefits arising from the use of genetic resources in the form of *Digital Sequence Information (DSI)* are shared in a fair and equitable manner also contributes to addressing inequalities.

Capacity building, technology transfer and scientific cooperation (*GBF target 20*) are key in filling knowledge gaps and contributing to an equitable knowledge transfer. *NFDI4Biodiversity*[3] offers access to services and tools for handling and management of biodiversity and environmental data across research, government as well as citizen and community science (>*MustKnow9*)[18]. A *Global Biodiversity Observation System* (GBiOS)[19] combining technology, data, and knowledge from around the world could foster collaboration and data sharing. It could provide the data needed to comprehensively monitor biodiversity (change), identify drivers of change, and measure effectiveness of targeted actions (>*MustKnow9*)[20].

The education sector is a primary change agent, building the capacity underpinning the whole-of-society approach core to the GBF[21],

Although impacts on biodiversity are local in nature, drivers of biodiversity change are linked globally.

A *Global Biodiversity Observation System* (GBiOS)[19] combining technology, data, and knowledge from around the world fosters collaboration and data sharing.

raising awareness of biodiversity and co-producing knowledge on the biodiversity status through novel partnerships[22,23]. Innovative and co-creative approaches serve to sensitise the public to threats to biodiversity and consequences of its loss and offer opportunities to take action[24–26]. Citizen and community science projects encourage the public to explore biodiversity in their surroundings, increasing engagement with nature, contributing data, and filling knowledge gaps[25]. Creating incentives for the public to participate in citizen science projects can raise society's awareness of the importance of biodiversity, and the consequences of ongoing biodiversity loss (>*MustKnow9*)[25].

Background

Since the CBD entered into force in 1993, countries are under legal obligation to halt and reverse biodiversity loss[27], yet biodiversity continues to decline[28]. Following the *2010 Biodiversity Target* and the *2020 Aichi Targets*, countries adopted the *Kunming-Montreal Global Biodiversity Framework (GBF)*[4] in December 2022. The GBF takes a comprehensive approach to conservation, restoration, and sustainable use of biodiversity, relying on countries' commitments as well as contributions of all sectors of society[29]. Transnational collaboration is crucial to achieving the framework's goals; several targets address global imbalances and inequities[1,2], requiring a change in international cooperation, and new governance approaches and instruments[30].

Tracking progress (and correcting course) towards the 23 Action Targets of the GBF are vital to reversing biodiversity decline[31]. Gaps exist in the availability of suitable indicators[32] as well as supporting data, in particular in regions with high biodiversity[33]. Even in Europe, access to available data is often restricted, limiting our capability to e. g. compare impacts on biodiversity across regions, or track changes over time[34,35].

ESD is a key enabler of the whole-of-society approach, and to galvanise the transformative action needed to achieve the SDGs[36,37].

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Wordcloud of the most relevant terms from MustKnow8, weighting by relevance.

**Terms explained in the glossary or the infobox.*

The education sector is a primary change agent, building the capacity underpinning the whole-of-society approach core to the GBF[21], raising awareness of biodiversity and co-producing knowledge on the biodiversity status through novel partnerships[22,23].

Education targets all segments of society and increases awareness of the importance of biodiversity. Novel and innovative methods involving a wide variety of stakeholders can trigger the behavioural change needed for mainstreaming biodiversity. Citizen science has a positive impact on the attitudes of participants towards biodiversity and conservation actions[38,39], and can have transformative impact on science, society and policy[25]. However, even if knowledge and access to knowledge is sufficient, (lasting) behavioural change is dependent on a multitude of factors[40].

Recommendations for political decision-makers

1. The German *National Biodiversity Strategy 2030 (NBS2030)* and funding instruments such as the *Action Plan on Nature-based Solutions for Climate and Biodiversity (ANK)* need to include guidance for business and finance to internalise currently external costs to biodiversity. To support implementation, regulations are required.
2. Strong international collaborations including scientific cooperation and technology transfer are the foundation to understand the drivers of biodiversity change, and track the effectiveness of targeted actions to conserve biodiversity, for example in the control of *invasive species*.
3. Education for Sustainable Development and especially biodiversity conservation requires transformative learning approaches across all age and social groups, using various formats to attract all members of society.

Recommendations for society

1. Education for Sustainable Development is an approach that should be implemented across all levels of education, from primary to tertiary/higher level educations, as it raises awareness of the importance of biodiversity and intact ecosystems for human wellbeing and can galvanise behavioural change through action with illustrative examples.
2. Citizen and community science is not only a powerful method to collect a bigger set of monitoring data, but also to build stronger connections between citizens and scientists, and to integrate new sources of information and knowledge (including new methods) in biodiversity research. Examples are the use of apps and social media to harness information on species occurrences. Both are an important part of ESD development by increasing the understanding of the importance of biodiversity and biodiversity research.
3. Indirect drivers such as investment in production, trade and financial flows, but also consumption patterns contribute to biodiversity loss and climate change. It is vital that business, industry, and finance institutions track their impacts on biodiversity along value chains and in investments.

9 Ensuring free access and open use of biodiversity-related data

1 Freely accessible, openly usable and scientifically sound data on biodiversity and its functions are essential for *Open Science*, knowledge-based political decision-making, the social valorisation of biodiversity and the effective conservation and sustainable use of biodiversity.

2 The application of internationally recognised *data standards* and interfaces for data exchange is the key to efficiently link, integrate and use biodiversity-related data at regional and global levels.

3 Innovative technologies, artificial intelligence (AI) and new algorithms and analysis methods can significantly improve data collection and analysis in biodiversity research and open up new ways of increasing and communicating knowledge. However, their use also brings new challenges.

4 Open access and free use of *digital sequence information (DSI)* is a prerequisite for achieving the goals of the *Kunming-Montreal Global Biodiversity Framework (GBF)*. International benefit-sharing mechanisms must not interfere with this. They should be implemented *multilaterally* and decoupled from data access, and be applicable to all forms of DSI in order to establish a system that is as simple, harmonised and standardised as possible.

5 Investments in the development, networking and long-term utilisation of information infrastructures and the comprehensive digitalisation and provision of biodiversity-related data that was previously not openly available are urgently required for the sustainable and open use of data from research and other sources.

Open access, free exchange and the long-term provision of biodiversity-related data are crucial prerequisites for preserving and better utilising biodiversity – at scientific, political and societal levels.

In 2022, *MustKnow9* focused on open and free access to *primary data* for biodiversity research, in particular in view of the *UN Biodiversity Conference* (CBD COP15). The updated version broadens this scope, including also *metadata*, data integration and derived data products, and considers the importance, challenges and potential of open access and free provision of biodiversity-related data.

GBF target 21 on data availability explicitly emphasises the importance of the open availability of scientifically sound data and information on biodiversity for the successful implementation of the GBF. Reliable data is a prerequisite for (new) indicators in order to assess whether the objectives of the GBF are being achieved.

There are still challenges on at least three levels:

1. The (digital) data situation on biodiversity remains inadequate, particularly with regard to spatial resolution at the regional level and understudied areas of biodiversity (soils, wetlands; *arthropods*, microorganisms; *>MustKnow3*)[1].
2. Many of the (digitally) available data are not freely accessible for various reasons or can only be used to a very limited extent[2,3].

90%

About 2 million species are currently described, while about 90% of the species are still waiting to be discovered.

3.3 Bn

individual sequence data entries and 28.3 million data sets (53.3 petabytes of data) from high-throughput sequencing are made available globally via the databases of the International Sequence Database Collaboration (INSDC).

463,000

The citizen science platform iNaturalist (www.inaturalist.org/observations, last accessed on: 26.2.2024) contains 173 million observations of approx. 463,000 species contributed by over 3 million people worldwide.

3. Despite the COP15 decision on DSI, which provides for *Open Data* access and a multilateral approach to benefit-sharing (*GBF target 13*), some countries insist on bilateral mechanisms[4].

Affected are primary data on the occurrence, structure, function and status of individual organisms and ecosystems, as well as associated data on the environment and derived data on the use or social perception of biodiversity and the assessment of *ecosystem services*.

In special circumstances (e. g. to protect extremely endangered species and *habitats* or personal data), it may make sense to restrict free access to certain primary data, whereby the *metadata* documenting the existence of the primary data must remain accessible[5]. Likewise, the general obligation of free availability in the sense of Open Science, Open Data[6,7] and the *FAIR* principles[8] (at least for publicly funded data) must not be restricted either. This is essential for reproducible and reliable (scientific) findings and to open up new fields of research for a better understanding and protection of the biosphere.

In this context, it is essential to agree on a political framework in international negotiations[1-4] that guarantees open access to DSI globally and at the same time enables fair benefit-sharing (>*MustKnow8*). Such a system should be implemented multilaterally and decouple data access from benefit-sharing[9-11] in order to ensure the free availability of DSI as a common good, while also considering the *CARE* principles (>*MustKnow4*)[12].

Efficient and, above all, integrative use of biodiversity-related data also requires that the data is comparable and machine-readable in the sense of modern technology. This is ensured by data standards, *ontologies* and *taxonomies*, which are well developed for the field of biodiversity at the international level (see *Biodiversity Information Standards*: www.tdwg.org). These should also be observed and increasingly utilised at local level. The use of international data standards is fundamental to the functioning and success of distributed data and information infrastructures in particular, such as the *Global Biodiversity Information Facility (GBIF)* with currently over 2.5 billion available datasets that drive biodiversity research worldwide[13]. Data standards also enable the integration and networking of different data types and levels: from remote sensing data to gene sequences. Their use further ensures that digitally published data can be meaningfully (re-)used by third parties and thus become part of a collective body of knowledge.

The rapid development of new technologies (e. g. *eDNA*, bioacoustic monitoring, *imaging spectroscopy*) and AI-supported algorithms are enabling enormous progress in the collection and analysis of biodiversity-related data (>*MustKnow3*), especially for predicting changes in biodiversity[14]. With the appropriate data volume and availability, it is now possible to predict in detail, both regionally and locally, how communities or *ecosystem services* will change in the context of specific scenarios. As far as can be seen, challenges in the use of modern AI applications mostly relate to the misuse of user data and incorrect data interpretation.

For the computationally intensive use of biodiversity-related

In this context, it is essential to agree on a political framework in international neagotiations[1-4] that guarantees open access to *DSI* globally and at the same time enables fair benefit-sharing.

The numerous data collected through participatory initiatives and *citizen science*, often in the local environment, make an essential contribution to mapping biodiversity[15].

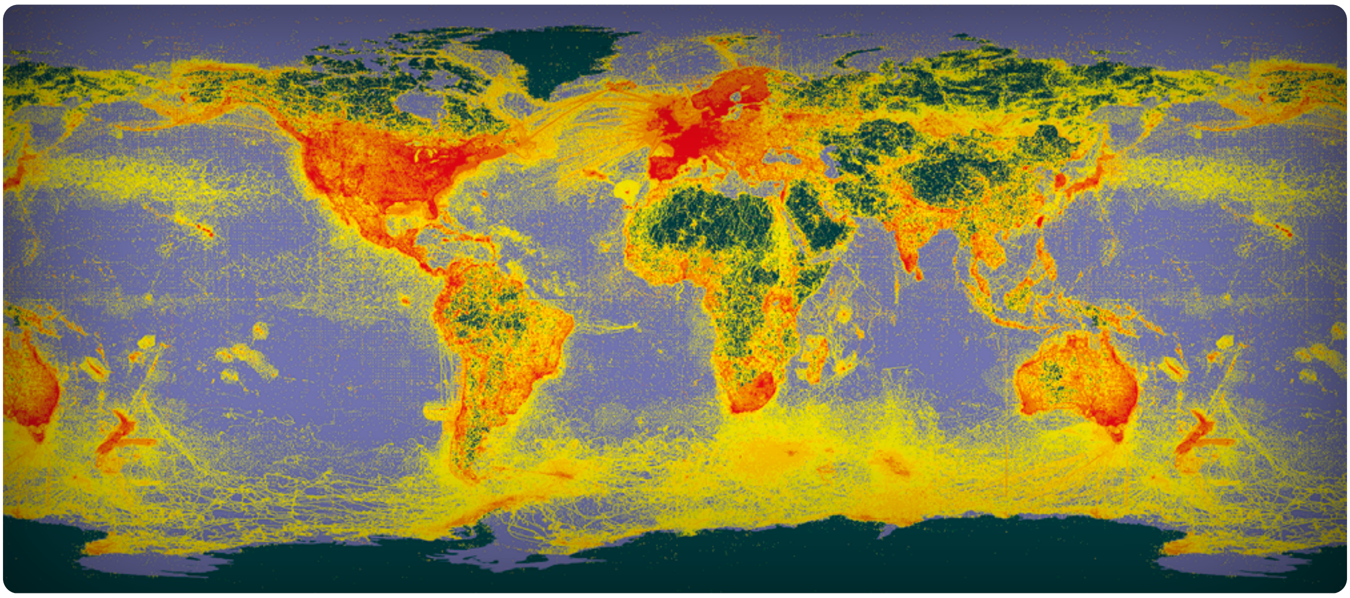
data, continuous investment in expanding and improving the performance of data and IT infrastructures (including long-term storage and sustainable data provision) at research and educational institutions is essential. This will also allow us to effectively close the considerable data and knowledge gaps in the field of biodiversity research and to meet future challenges and crises in the environmental sector with foresight (>*MustKnows1, 4, 5, 7, 8*). At the international level, data infrastructures in the countries of the *Global South* should be expanded, since such resources are currently concentrated in the *Global North*.

The numerous data collected through participatory initiatives and *citizen science*, often in the local environment, make an essential contribution to mapping biodiversity (>*MustKnow3*)[15]. Publicly accessible data infrastructures must ensure the free and sustainable availability of this data. The networking and long-term safeguarding of these often very detailed and therefore particularly valuable biodiversity-related data is a growing challenge for research institutions as well as for authorities and decision-makers (>*MustKnow8*).

Background

In order to implement the GBF, an effective synthesis of biodiversity-related data is of crucial importance[16]. However, open access and the integrative use of biodiversity-related data is often limited due to political frameworks (>*MustKnow8*) or unfulfilled practical and technical requirements. The programmes and systems for monitoring biodiversity, for which the federal states are responsible in Germany, should be harmonised. Long-term strategies must be developed for the synthesis and integration of biodiversity-related data[17].

Analysing DSI (especially eDNA) is an essential part of biodiversity research. Although the amount of digital sequence information is increasing exponentially[18], it is currently not possible to use the majority of this data for biodiversity assessment due to insufficient metadata[19,20]. The *interoperability* and (re)usability of these data must be improved according to the FAIR principles[8] so that they can be integrated into biodiversity portals such as GBIF using adequate *metadata standards*[21,22]. The potential of DSI for biodiversity monitoring



Global distribution and density of digital biodiversity data provided through GBIF (www.gbif.org) on the occurrence of individual organisms worldwide (last accessed on: 12.1.2024).

can only be realised if free access to sequence data continues to be guaranteed in the long term and harmonised at a global level[23].

New, often AI-powered systems in biodiversity research improve data collection, analysis and interpretation as well as the development of implementation strategies, enabling more effective biodiversity conservation[24,25]. In species detection and monitoring, AI systems are used to identify species from images or acoustic recordings (e. g. bird calls, images from camera traps or underwater recordings[26]). In *habitat* analysis and mapping, satellite images and drone data are used to quantify biodiversity and monitor changes[27], while in the prediction of species distributions, AI models are used to understand how species occurrences will change in space and time due to climate change or agricultural use, for example[28]. AI also analyses environmental data (e. g. trends in air or water quality) to identify how they may affect biodiversity[29]. The occurrence and spread of *invasive species* and *pathogens* such as viruses, bacteria, fungi or species that transmit pathogens to humans, animals and plants can also be monitored and predicted in this way (>*MustKnow2*)[30].

The amount of biodiversity-related data from citizen science projects is constantly increasing. However, many of these projects and the data generated or modified by them often lack long-term strategies and structures for validation and analysis[31]. Here too, AI can help to efficiently process and analyse the collected data and thus improve public participation in the protection of biodiversity[32,33].

Recommendations for political decision-makers

1. As an investment in the future, institutions and structures that collect, maintain and provide openly available biodiversity-related data must be specifically supported, developed and expanded as strategic infrastructures. This includes directly investing in existing infrastructure, promoting capacities in data expertise, and creating long-term development plans and strategies, both nationally and globally.

2. Internationally, the principles of open availability and free use of biodiversity-related data in the sense of Open Science and the FAIR principles must be defended and further strengthened as the foundations of an open, democratic, global knowledge society. This also includes the mandatory use of internationally established data standards and domain-specific conventions to facilitate efficient data integration and networking at regional, national and global levels.

3. The establishment of an international benefit-sharing mechanism for the use of DSI data must remain true to the above principles and must be multilateral. Bilateral approaches to benefit-sharing or linking access to DSI data to direct remuneration will significantly harm science and biodiversity conservation.

Recommendations for society

1. The collection and dissemination of biodiversity-related data should be supported and promoted by the public at all levels.

2. Public and private institutions that collect biodiversity-related data and make it openly available should be more closely involved in the discussions and in *Education for Sustainable Development (ESD*; >*MustKnow8*) to increase the appreciation of living nature.

3. Biodiversity-related data should be used to a greater extent regionally and locally for all landscape and habitat management projects to strengthen the *One Health approach* and support the *socio-ecological transformation* (>*MustKnows2, 4-8, 10*).

10 Reducing biodiversity impacts from food consumption

1. Resource-intensive food consumption is responsible for substantial biodiversity losses in Germany and abroad, including in biodiversity-rich areas of the *Global South*.
2. The consumption of animal products accounts for three quarters of the global *biodiversity footprint* of German food consumption.
3. Shifting toward more plant-based diets and reducing food loss and food waste lowers pressure on land use and related biodiversity threats, both domestically and abroad.
4. Supply-side interventions, such as incentives for biodiversity-friendly and sustainable production strategies or taxes on biodiversity-harming production, can help steer land use toward more sustainable practices.
5. Policy measures at national and EU levels increasingly require strong sustainability reporting, which includes accounting for biodiversity loss embedded in food production.

Regulatory measures and monetary incentives can support sustainable consumption and production that reduce impacts on biodiversity along the value chain.

MustKnow10 of 2022 emphasised that policies that direct market and investment behaviour toward biodiversity conservation and restoration are urgently needed to solve the current biodiversity crisis. This updated version of *MustKnow10* focusses on the biodiversity impacts of food consumption and emphasises the importance of regulatory measures and monetary incentives to reduce biodiversity impacts through more sustainable consumption and production of food products.

Current diets, particularly the high share of animal proteins, have substantial environmental impacts and contribute to the transgression of several *planetary boundaries*[1]. The linkage of distant places through global trade means that production practices and consumption decisions in one place have implications elsewhere. More than one third of tropical deforestation has been linked to internationally traded agricultural commodities[2], especially the production of soybean, palm oil, coffee, and cocoa, which are predominantly destined for export markets[3].

Food consumption in Germany alone occupies a total of 166,000 km^2 of land in Germany and abroad. While animal products account for one third of the weight and 30 percent of the kilocalories of the food consumed, they are responsible for 69 percent of greenhouse gas (GHG) emissions, 75 percent of the land area used, and 77 percent of the loss of biodiversity[4,5]. The food system is also responsible for additional environmental pressures, in particular excessive nitrogen pollution[6], overuse and pollution of freshwater resources, *ecotoxicity* due to pesticide application, as well as *soil degradation* and erosion, and threats to the livelihoods of Indigenous populations, including in the *Global South* (>*MustKnow4*).

Half of the *land-use footprint* of German food consumption occurs in Germany, 9 percent in the United States, and 8 percent in Brazil. The largest share of land used for German food consumption is for wheat (15 percent), followed by soybeans (14 percent) and maize (11 percent). However, the highest impacts on biodiversity are caused by soybeans (30 percent), followed by wheat (15 percent). 20 percent of the biodiversity footprint of German food consumption occurs in Brazil due to

166,000 *Food consumption in Germany alone occupies 166,000 km² of land worldwide.*

46% *A flexitarian planetary health diet can reduce the **biodiversity footprint** by 18%, a vegetarian diet by 46%, and a vegan diet can halve the footprint.*

75% *Consumption of animal products is responsible for 75% of the land area used and for 77% of the impacts on biodiversity.*

imports of soybeans that are grown in the Amazon and *Cerrado* areas[4,5].

A dietary shift towards more plant-based diets, which require less land and fewer biodiversity-harming production practices, constitutes a contribution to the global biodiversity crisis (*GBF targets 1, 2, 3, 10, 11, 14, 16*). For example, a flexitarian diet with a maximum consumption of 100 grammes red meat per week, as recommended for healthy diets by the *EAT-Lancet Commission*[7], could reduce the land-use footprint by 20 percent and the biodiversity impacts by 18 percent; a vegetarian diet without meat and fish could lower the land-use footprint by 45 percent and biodiversity impacts by 46 percent; a vegan diet without animal products can nearly halve land use and biodiversity impacts (*GBF targets 1, 3*)[4]. Furthermore, a higher share of plant-based diets can generate co-benefits for farming practices, such as freeing land for less intensive production practices and integrating biodiversity-friendly landscape elements (*>MustKnows5, 6; GBF target 10*).

Against this background, we call for compulsory biodiversity reporting for companies, which implies making biodiversity impacts of consumption transparent to consumers (*GBF target 16*). However, to substantially reduce negative impacts on biodiversity, additional measures must be implemented, such as product labels or targeted procurements, positive monetary incentives for biodiversity-friendly products, and regulations or increased taxes for biodiversity-harming production (*GBF target 18*).

Background

More sustainable food systems, including less adverse impacts of food production on biodiversity, are crucial to achieve the *Sustainable Development Goals (SDGs)*, in particular *SDGs 2, 12, 14, and 15*. Dietary changes, especially a reduced intake of animal-based foods in affluent countries, have been shown to be most effective in achieving progress toward these SDGs from the perspective of emissions, health and biodiversity (*>MustKnows1, 2, 5, 6*)[8].

Food consumption in Germany has substantial impacts on biodiversity not only domestically but also abroad. Biodiversity footprinting can assess and quantify the impacts of food commodities on biological diversity. Biodiversity footprinting methods, such as *life-cycle impact assessments*[9], are already operational and can link the consumption footprint with biodiversity impacts (*GBF target 14*). The approaches used for footprint accounting focus on processes that consume terrestrial and marine resources, including the production of food, feed, and fibre, animal husbandry, and the

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Change of diet to:

... flexible:

-20% on land use footprint and
-18% on biodiversity impacts

... vegetarian:

-45% on land use footprint and
-46% on biodiversity impacts

... vegan:

around **-50%** on land use footprint and biodiversity impacts

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A dietary shift towards more plant-based diets, which require fewer biodiversity-harming production practices, constitutes a contribution to the global biodiversity crisis.

extraction of ores, minerals, and fossil energy resources. Footprint accounting is particularly relevant if the commodities were produced in places that are rich in biodiversity.

To measure the biodiversity footprint of consumption, biodiversity loss due to land use and land-use changes must be linked with consumer demand. New data sources, such as supply chain data and better computing options, enable better documentation of global interconnections between producing regions with trading companies and import markets. These advances permit a more solid understanding of the deforestation and associated biodiversity loss caused by food consumption.

Biodiversity footprints can inform policy-makers towards evidence-based regulations that can encourage more sustainable production and trade, provide information to food producers and processing companies on how to reduce productive activities that harm biodiversity, and can enable consumers to make more responsible consumption choices (e. g., with biodiversity labelling; *GBF targets 16, 21*). The increasing importance of sustainability for politics, businesses, and financial institutions will facilitate the growing interest in including biodiversity-friendly and nature-positive pathways in their decision-making. We urge governments, civil society, and the private sector to assume their responsibility in incentivising more sustainable

Food consumption in Germany has substantial impacts on biodiversity domestically and abroad. *Biodiversity footprinting* can assess and quantify the impacts of food commodities on biological diversity.

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value chains, including a strong focus on reducing biodiversity loss inherent in food consumption and production.

In conclusion, dietary changes towards less meat consumption can play a vital role in mitigating biodiversity loss domestically and abroad by decreasing land use pressure. These changes promote sustainable food systems that support healthy ecosystems and foster biodiversity conservation for current and future generations.

Recommendations for political decision-makers

1. Facilitate improvement of methods, indicators, and data quality to allow better tracking of the footprint of products along the value chain and, therefore, better product labelling. Use the already available methods for policies of value chain interventions, such as the implementation of mandatory due diligence, to ensure that imports into the EU are associated with a less inherent loss of biodiversity.
2. Accounting for the biodiversity footprint of food consumption should be operationalised with concrete action plans as soon as possible and should be included in the *German National Nutrition Strategy 2050* (*Ernährungsstrategie 2050*)[10]; the same applies to the footprints of food consumption on greenhouse gas emissions, water, and reductions in soil fertility.
3. Monetary incentives and disincentives, such as subsidies for biodiversity-positive practices or taxes for biodiversity-negative production, should be enacted to steer consumption toward more sustainable and healthy patterns; resulting tax income should be redistributed to consumers in the form of biodiversity payments, similar to the planned climate payments (*Klimageld*). Decision-makers should not shy away from monetary disincentives that make extremely biodiversity-harming products prohibitively expensive.

Recommendations for society

1. Consumer-side measures, such as product labelling, taxation, and public procurement, that incentivise more biodiversity-friendly consumption patterns must be stepped up to facilitate the reduction of the consumption footprint.
2. The level of biodiversity literacy (e. g., the knowledge about cause-effect relationships) must be improved to make society aware of the importance of food consumption decisions for local and global biodiversity.
3. A planetary health diet benefits human health and the environment simultaneously; facilitating these dietary changes, such as with higher meat taxes, can lead to lower costs in the health sector and lower environmental costs in the medium and long term.

Acknowledgements and outlook

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We would also like to draw your attention to FEdA's *German Biodiversity Assessment* (*Faktencheck Artenvielfalt*), which will be published this summer. It is the complementary standard work to the *10MustKnows24*. While the *10MustKnows24* briefly and concisely summarise the latest scientific findings and the recommendations derived from them for the protection, conservation and sustainable use of global biodiversity, the *German Biodiversity Assessment* provides a comprehensive inventory of biodiversity and its changes in Germany. The three-year assessment was compiled as a joint task by more than 150 authors from a wide range of scientific and practical disciplines and supported by many other experts.

The *German Biodiversity Assessment* summarises the current state of knowledge on the status of and changes to biodiversity in German *habitats* and describes the reasons for and consequences of these changes for *ecosystem services*. It also analyses efforts to protect and promote biodiversity and underlines the need for a *socio-ecological transformation*. To this end, the *German Biodiversity Assessment* has analysed more than 6,000 publications and other data sets on long-term trends in biodiversity, which make it possible to comprehensively present the current state of knowledge on biodiversity in Germany and also to identify options for action for its conservation and sustainable use.

The Kunming-Montreal Global Biodiversity Framework (GBF) consists of a "2050 vision of a world living in harmony with nature" (four goals) as well as a "2030 mission to take urgent action to halt and reverse biodiversity loss" (23 targets). The 23 action-oriented global GBF targets to be achieved by 2030 should reduce threats to biodiversity, meet people's needs through sustainable use and benefit-sharing, and include tools and solutions for implementation and mainstreaming: www.cbd.int/gbf/targets (last accessed on: 28.2.2024). The graphic on the right matches the 23 GBF goals with each of the 10MustKnows24 with regard to their content and relevance.

The GBF 2030 targets in the *10MustKnows24*

The 23 targets of the Kunming-Montreal Global Biodiversity Framework (GBF)	1	2	3	4	5	6	7	8	9	10	
1 Plan & manage all areas to reduce biodiversity loss	very important	important	touches	very important	important	important	important	very important		important	Reducing threats to biodiversity
2 Restore 30% of all degraded ecosystems	very important	important	important		important	important	important				
3 Conserve 30% of land, waters & seas	important	important	important	important	important	important	important		important	important	
4 Halt species extinction, protect genetic diversity, manage human-wildlife conflicts	important	important	important	very important	important	important	important		important	important	
5 Ensure sustainable, safe, legal harvesting & trade of wild species		important		important	important				important	important	
6 Reduce introduction of invasive alien species (-50%), minimise their impact		touches	important						important		
7 Reduce pollution to levels not harmful to biodiversity		important	important			important	important				
8 Minimise impacts of climate change on biodiversity & build resilience	very important	important	important	important	important	important	important				
9 Manage wild species sustainably to benefit people		important	important	touches							Meeting people's needs through sustainable use and benefit-sharing
10 Enhance biodiversity & sustainability in agriculture, aquaculture, fisheries & forestry	very important	important	important	important	very important	very important	important			important	
11 Restore, maintain, enhance nature's contributions to people	very important	important	very important	important	important	important	important		touches	important	
12 Enhance green spaces & urban planning for human well-being & biodiversity		important	important			important	important		important		
13 Increase benefit sharing from genetic resources, DSI & traditional knowledge		important	touches	very important				touches	very important		
14 Integrate biodiversity in decision-making at every level	very important	important	important	important	important		very important	very important	important	important	Tools and solutions for implementation and mainstreaming
15 Businesses assess, disclose & reduce biodiversity-related risks & negative impacts								very important	important	very important	
16 Enable sustainable consumption choices to reduce waste & overconsumption		important	important		important	important		touches		very important	
17 Strengthen biosafety, distribute the benefits of biotechnology			touches								
18 Reduce harmful incentives (≥ $500 Billion p. a.), scale up positive incentives for biodiversity			touches	touches		important	important	touches	touches	important	
19 Mobilise $200 billion p. a. for biodiversity (incl. $30 billion through international finance)	important			touches				important			
20 Strengthen capacity-building, tech transfer, scientific & technical cooperation for biodiversity		touches	important	important		important		very important	important	important	
21 Ensure knowledge is available & accessible to guide biodiversity action			important	very important			touches	important	very important	important	
22 Ensure participation in decision-making, access to justice & biodiversity-related information for all		touches		very important	important			touches			
23 Ensure gender equality & a gender-responsive approach for biodiversity action								important			

GBF target very important in MustKnow — GBF target important in MustKnow — GBF target touches MustKnow

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From science and politics	**Prof. Dr. Klaus Müller**, Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg and Humboldt University of Berlin

MustKnow8

From science	**Dr. Giles Sioen**, Future Earth Global Secretariat Hub Japan and National Institute for Environmental Studies, Tsukuba, Japan
From politics and society	**Dr. Eva Spehn**, Swiss Biodiversity Forum, Bern, Switzerland **Friedrich Wulf**, Pro Natura, Basel, Switzerland

MustKnow9

From science	**Dr. Sebastian Bosse**, Fraunhofer Heinrich Hertz Institute, Berlin **Prof. Dr. Konrad Förstner**, ZB MED Information Centre for Life Sciences and TH Köln – University of Applied Sciences, Cologne **Dr. Aidin Niamir**, Senckenberg Society for Nature Research (SGN), Frankfurt am Main
From politics and administration	**Dr. Carsten Loose**, German Advisory Council on Global Change (WBGU), retired

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From science	**Prof. Dr. Manfred Lenzen**, University of Sydney, Australia **Prof. Dr. Martin Quaas**, German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig and Leipzig University
From politics and administration	**Vincent Colomb**, The French Agency for Ecological Transition (ADEME), Paris, France
From society	**Elisa Kollenda**, WWF Germany, Berlin **Johann Rathke**, Nature and Biodiversity Conservation Union (NABU), Berlin

Participating institutions

Leibniz Biodiversity

Leibniz Research Network Biodiversity

PIK – Potsdam Institute for Climate Impact Research

ARL – Academy for Territorial Development in the Leibniz Association

IPK Leibniz Institute

DPZ – Deutsches Primatenzentrum, Leibniz-Institut für Primatenforschung

zalf – Leibniz Centre for Agricultural Landscape Research (ZALF)

LIB – Leibniz Institute for the Analysis of Biodiversity Change

Leibniz Institute of Ecological Urban and Regional Development

IGZ

IOW – Leibniz Institute for Baltic Sea Research Warnemünde

Leibniz Institute for Zoo and Wildlife Research, in the Forschungsverbund Berlin e.V.

SENCKENBERG world of biodiversity

DSMZ – Leibniz Institute DSMZ-German Collection of Microorganisms and Cell Cultures GmbH

IGB – Leibniz Institute of Freshwater Ecology and Inland Fisheries

Museum für Naturkunde Berlin

ZAS

ATB

IAMO – Leibniz Institute of Agricultural Development in Transition Economies

Other institutions

Greifswald Mire Centre

Universität Leipzig

Universität Augsburg University

Institute for Social-Ecological Research

DLG

iDiv – German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig

KIT – Karlsruhe Institute of Technology

future earth

MPEG – Museu Goeldi

Charité – Universitätsmedizin Berlin

Eberswalde University for Sustainable Development

universität ulm

CPHP – Centre for Planetary Health Policy

Technische Universität Dresden

UFZ – Helmholtz Centre for Environmental Research

University of Zurich UZH

Philipps Universität Marburg

VU University Amsterdam

universität Witten/Herdecke

Hochschule Geisenheim University

HIFMB Oldenburg

EFI

cohabinitiative

rijksuniversiteit groningen

Glossary

Where possible, the explanations of the *Intergovernmental Panel on Climate Change* (IPCC), the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES), the *Convention on Biological Diversity (CBD)*, the *International Union for Conservation of Nature* (IUCN) and other official bodies such as the *German Federal Agency for Nature Conservation* (BfN), the *German Federal Environmental Agency* (UBA) etc. have been used for the following terms.

Agrivoltaics
Refers to the process of utilising land for the cultivation of plants (agriculture) and at the same time for the production of electricity using the sun's energy.

Arthropods
A phylum of the animal kingdom that includes insects and arachnids, among others.

BECCS (Bioenergy with Carbon Capture and Storage)
Refers to an industrial process in which biomass (e. g. sugar cane, maize or wood waste) is burnt to generate "green" electricity and the resulting carbon dioxide is captured and stored underground.

Biocultural diversity
The diversity exhibited by interacting natural and cultural systems. The concept is based on three propositions: firstly, the diversity of life includes human cultures and languages; secondly, there are links between biodiversity and human cultural diversity; and thirdly, these links have evolved over time through mutual adaptation and possibly co-evolution between humans, plants and animals.

Biodiversity hotspots
Regions with a particularly high density and diversity of characteristic species, populations and *habitats*.

Biodiversity mainstreaming
The sufficient consideration of biodiversity and the services it provides in laws, policies and practices.

Biodiversity offsets
Measurable actions for the restoration of nature, which are generally regarded as compensation for negative and unavoidable interventions in nature. Efficient biodiversity compensation (offsets) should guarantee that construction projects result in a gain, or at least no net loss, of biodiversity. Only when all avoidance and minimisation options have been exhausted should planners consider biodiversity offsets.

Biome
Biomes comprise large *habitats* with all the plants, animals, etc. potentially living in them. They are a generic term for the totality of all biotopes occurring in them. Examples of biomes are tundra, coral reefs or savannahs.

Bottom-up best practice
Bottom-up strategies start at the grassroots level and gradually bring the discussion about goals and solutions into more complex social contexts. Best practice represents methods, measures, procedures, etc. that have already been successfully tested.

Buen vivir
An idea developed by *IPLCs* of communities living in harmony with nature. It stands for peace, diversity, solidarity, the right to education, health, safe food, water and energy as well as prosperity and justice for all.

CARE
The CARE Principles for Indigenous Data Governance are people- and purpose-centred and reflect the critical role of data in promoting innovation and self-determination of indigenous peoples. These principles complement the existing *FAIR* principles. The CARE principles are **C**ollective benefit, **A**uthority to Control, **R**esponsibility and **E**thics.

Cerrado
The almost two million square kilometres of wet savannahs in inland south-eastern Brazil.

Citizen science
An approach in which scientific knowledge is gained by people who do not work in the relevant scientific field, with or without the involvement of full-time researchers.

CO_2e (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 (CO_2) are converted into CO_2 equivalents according to their global warming potential (CO_2=1) for better comparability.

Digital sequence information (DSI)
The digital result of the molecular biological decoding (sequencing) of genomes or proteins, i. e. information on the molecular composition of genetic resources.

Dilution and amplification effect
The theory of the dilution effect states that the diversity of an ecological community reduces the transmission of a *pathogen*. The amplification effect theory states that a loss of diversity in an ecological community increases the transmission of a pathogen.

Disturbance regime
Disturbances are temporally and spatially discrete events that lead to loss of living biomass and profoundly alter communities, e. g. by wind, fire, drought, insects or human land use. The sum of all disturbances affecting a landscape results in a disturbance regime characterised by typical rhythms and interactions.

Ecoliteracy
The combination of experiential and academic knowledge about the environment. Much of what we know about the natural world lies outside of books, libraries and databases: it is largely anchored in unwritten language in people's concepts and memories of their long-standing coexistence with mountains, rivers, forests, deserts and other ecosystems. The further development of this knowledge by the various actors involved is increasingly coming to the fore[35].

Ecosystem services
The benefits that people derive from ecosystems. This can be a monetary or non-monetary value for the individual or society.

Ecotoxicity
The effects that harmful substances have on living organisms in various ecosystems such as fresh water, salt water, air and soil.

eDNA (environmental DNA)
The entirety of the deoxyribonucleic acid (DNA) contained in an environmental sample. This can originate from different sources: free DNA, DNA from microorganisms, DNA from deposited cell material of higher organisms like mucus, scales, fur or cell remains.

Entomology
The study of insects.

FAIR
Guideline for digital data management with a focus on machine readability, which requires data and *metadata* to be **F**indable, **A**ccessible, **I**nteroperable and **R**eusable.

Faunal community
Animal species that occur together in a *habitat* (biotope). They can be related to each other.

Footprint
The (ecological) footprint is a complex sustainability indicator. It describes how much land a person uses to cover their need for resources (land-use footprint), how much biodiversity a person consumes (biodiversity footprint) or how much carbon dioxide is released per person (CO_2 footprint which e. g. becomes larger or smaller as a result of consumption decisions).

Functional traits
Any characteristic of an organism that is expressed in its external appearance (phenotype), is measurable at an individual level and is demonstrably related to the function of the organism. In animals, these include body size, litter size, age of sexual maturity, nesting site and activity time.

Global North and Global South
The two terms are intended to describe the situation of countries in the globalised world in a way that is as value- and hierarchy-free as possible. In this sense, a country of the Global South is a politically, economically or socially disadvantaged state. The countries of the Global North, on the other hand, are in a privileged position in terms of prosperity, political freedom and economic development. This is also intended to highlight inequality and the resulting relationships of dependency. The terms can only be understood geographically to a limited extent: While Australia and New Zealand, e. g., are assigned to the Global North, countries such as Afghanistan and Mongolia are counted as part of the Global South.

Habitat and habitat tree
The natural environment in which a particular animal or plant species lives. Habitat trees are living or standing dead trees that provide microhabitats for a variety of species.

High-throughput (DNA) sequencing
It enables the parallel sequencing of thousands to billions of DNA segments in a single run.

Imaging spectroscopy
Here, each pixel of an image captures many bands of light intensity data from the spectrum instead of just the three bands of the RGB colour model.

Indigenous and local knowledge (ILK)
IPLCs developed this knowledge by over centuries to the present day. It provides a unique and rich source of information about biodiversity and represents an important aspect of people's cultural and behavioural diversity ILK has an important role to play in environmental decision-making, management, policy, and assessments. Application of ILK into formal scientific processes increases the likelihood that these processes are informed by the best available information[40].

Indigenous peoples and local communities (IPLCs)
Indigenous peoples can be defined as ethnic groups that are descended from the original inhabitants of a particular region and identify with their culture[36]. Local communities can be defined as a heterogeneous group comprising traditional communities that possess collective knowledge and whose livelihoods are closely linked to local ecosystems and natural resources. The *United Nations Permanent Forum on Indigenous Issues*[38] and *Cultural Survival* advise against mixing the two categories as it "weakens the recognition of indigenous peoples' affirmed rights and identities and has been imposed without consultation with indigenous peoples"[39].

Interoperability
Property of standardised data and *metadata*, enabling the integration of datasets from different sources and the use of programs and automated workflows for processing, analysis and storage.

Invasive species
Species whose introduction by human activity outside their natural range affects biodiversity, food security, human health or well-being.

Isolates
Languages that cannot be assigned to any known language family according to the recognised methods of historical-comparative linguistics.

Kelp forests
Underwater ecosystems that develop in shallow water through the dense growth of various kelp species. Although they look very similar to plants, kelps are extremely large brown algae. Some species can reach a height of 45 metres (underwater), and under ideal physical conditions kelp can grow 45 cm in a single day.

Life cycle assessment
A method used to analyse the environmental impact of a particular product or action.

Living labs
Real-world laboratories for joint research between science and practice to solve real-world and socially relevant sustainability problems, such as reducing environmental and climate impacts in the area of land use. Through joint learning, they can lead to social and technical innovations as well as to a better scientific understanding of challenges and solutions.

Metadata
Background information on data collection that describes the context of a measured value, e. g. analysis method, location, measurement date, identification numbers. Comprehensive *metadata* is essential for the fulfilment of the *FAIR* principles.

(Meta)data standards
Definition of the structuring and formatting of data and *metadata* in order to ensure their long-term and sustainable *interoperability* across various data sources and thus increase data integration and reusability.

Microbiome
Entirety of all microorganisms (bacteria, fungi, viruses) in a certain environment.

Morphological adaptation
Physical changes of a living organism as an adaptation to changed living conditions.

Multilateral
Several partners (e. g. states) working together on an equal footing to achieve common goals or solve (cross-border) problems.

Narrative
Account that relates e. g. to global developments in different areas and is based on facts.

Natural forest dynamics
Forests are dynamic ecosystems and are subject to constant changes that shape and alter forest ecosystems. This naturally occurring change in forests includes disturbance and *succession*, including regeneration, growth and death of trees.

Nature-based solutions
Measures for the protection, sustainable management and restoration of natural or altered ecosystems that can effectively and adaptively address societal challenges while benefiting human well-being and biodiversity.

Net zero
In the context of the loss of natural areas through new construction measures (sealing), net zero means not allowing any more new sealing in total. This means that for every new sealing that nevertheless takes place, the same area must be unsealed so that no natural area is lost in the balance.

NFDI4Biodiversity
A consortium under the umbrella of the National Research Data Infrastructure (NFDI), which is dedicated to the joint use of biodiversity and environmental data.

One Health approach
An integrative and systemic approach to health based on the realisation that human, animal and ecosystem health are inextricably linked.

Ontology
Organised and carefully selected vocabulary to describe the relationships between the components of a system in a formal and machine-readable way. The use of ontologies can increase the *interoperability* of *metadata*.

Open Data
They are freely accessible to all people and can be (re)used freely (by science, business, administration and civil society) on the basis of open and non-discriminatory licences. Open Access also enables the reproducibility of research data in science.

Open Science
This term bundles strategies and procedures (e. g. digitisation) that aim to make all components of the scientific process openly accessible, reproducible and reusable via the Internet.

Paludiculture
The agricultural and forestry utilisation of wet raised bogs and fens, e. g. for the cultivation of thatch. Ideally, new peat is formed in the process.

Pathogens
Microorganisms such as bacteria, fungi or viruses that can cause harm to their host (humans, animals and plants).

Peatlands
Wetland ecosystems whose soils are dominated by peat. Peat is a type of soil typical of bogs that is formed from decomposed plants.

Petabyte
An extremely large unit of digital data. It consists of 1,000 terabytes.

Phenological adaptation
Reaction of a living organism to periodically (e. g. annually) recurring developmental phenomena in nature.

Planetary boundaries
The concept presents nine planetary boundaries within which humanity can continue to develop and thrive for generations to come. Crossing the boundaries increases the risk of large-scale, abrupt or irreversible environmental change. Drastic changes will not necessarily occur suddenly and unexpectedly, but overall the boundaries mark a critical threshold for increasing risks to humans and the ecosystems to which we belong.

Primary data
Often also called raw or original data, primary data is based on a survey, observation, measurement or other type of direct data collection and therefore enables direct reference to the object of investigation.

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

Secondary forest
Forest that forms after the destruction of the original *primary forest* and whose composition differs from the primary forest.

Socio-ecological transformation
The call for a fundamental rethink and action in the areas of economy, society, politics, culture and technology as well as a change in individual lifestyles in order to be able to comply with *planetary boundaries*.

Soil degradation
The decreasing ability of the soil to provide the desired *ecosystem services* and goods.

Spillover (effects)
The point in time at which a virus has overcome the many naturally occurring barriers and has been transferred from one species to another, i.e. has "jumped over".

Stand
A definable part of the forest that is similar in structure, age and/or tree species and differs from neighbouring stands.

Succession
Process of change in species composition after a disturbance has taken place.

Symbiosis
Coexistence of individuals of different species for mutual benefit.

Taxonomy and taxa
Naming, description and hierarchical classification of organisms into domains, phyla, classes, orders, families, genera and species, based on similar characteristics such as phylogenetic relationships and morphological (form-giving) differences. Taxon (plural: taxa) refers to the name of an organism at one of the levels mentioned.

Tree-related microhabitats
All distinct and clearly demarcated structures on living or dead trees that provide a particular and essential substrate or *habitat* for species or species communities to develop, feed, protect or reproduce for at least part of their life cycle, e. g. caves, tree injuries and dead crown wood.

Vector and vector-borne disease
A vector is a living organism that transmits *pathogens* to a human or another animal. Vectors are often *arthropods*, e. g. mosquitoes, ticks, flies, fleas and lice. This leads to vector-borne diseases.

Vertical or cellular agriculture
Vertical farming is an extreme form of agricultural intensification that is detached from the agroecological system and utilises indoor farming techniques, controlled environments and technology. Cellular agriculture utilises technologies to grow muscle tissue in cultures of animal stem cells to produce meat.

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

3-fold internal development
The aim of this approach is to develop mobility, green and open spaces and construction together in a qualified manner in order to achieve a high quality of life for all city dwellers.

3R
The central ethical principles of experimental scientific work with laboratory animals. The so-called 3R rule is intended to **R**eplace animal experiments with alternatives, **R**efine the number of laboratory animals and **R**educe the stress on the animals to an unavoidable level. This rule is to be applied analogously to animal husbandry.

Do you know already know the ***10 Must Knows from Biodiversity Science 2022*** and the ***10 Must Dos from Biodiversity Science 2022***?

2022
10 Must Dos from
Biodiversity Science

In the run-up to the *UN Biodiversity Conference* 2022 in which the 23 GBF targets were to be adopted, we put together the *10MustKnows22* to support an ambitious *Kunming-Montreal Global Biodiversity Framework* (GBF) for a good life on a healthy planet. In the *10MustDos22* we called for decision-makers in Germany, Europe and worldwide to take concrete next steps to strengthen biodiversity and presented solutions from the *10MustKnows22* to support them.

Both publications are still up-to-date and can be used complementary to the *10MustKnows24*.

Laws, directives, strategies, commissions, institutions

Action Plan on Nature-based Solutions for Climate and Biodiversity (ANK)
The aim of the ANK is to preserve, strengthen and restore ecosystems such as forests and oceans. This serves to protect the climate and biodiversity. The restoration and rewetting of moors is one of the key components.

Convention on Biological Diversity (CBD)
The CBD is a global, internationally binding agreement on the protection and sustainable use of living nature and refers to the diversity of animal and plant species as well as the diversity within species and the diversity of ecosystems. The CBD has 196 member states, including Germany and the European Union.

Corporate Sustainability Reporting Directive (CSRD)
Since the 2017 fiscal year, around 500 large, capital market-oriented companies as well as banks and insurance companies in Germany have been obliged to prepare a so-called "non-financial statement". In this declaration, they must set out the concepts, risks and performance indicators they pursue in relation to the environment, employee concerns, social concerns, human rights and corruption, if these are deemed to be material. The legal basis for this is the European CSRD.

EAT-Lancet Commission
The EAT-Lancet Commission is a cooperation between the non-governmental organisation EAT and The Lancet, a leading medical journal.

Education for Sustainable Development (ESD)
ESD equips learners of all ages with the knowledge, skills, values and competences to tackle interlinked global challenges such as climate change, biodiversity loss, unsustainable resource use and inequality. It enables learners to understand the impact of their own actions on the world and to make responsible and sustainable decisions.

EU Biodiversity Strategy 2030
A comprehensive, systemic and ambitious long-term plan to protect nature and reverse the degradation of ecosystems. It is a key pillar of the *European Green Deal* and the EU's leadership in international action on global public goods and *Sustainable Development Goals*. With the aim of ensuring that Europe's biodiversity recovers by 2030, the strategy identifies new ways to implement existing legislation more effectively, new commitments, measures, targets and governance mechanisms.

EU Nature Restoration Law
With this law, EU member states commit to developing national plans to achieve the binding targets agreed to by 2050.

European Green Deal
It aims to create a transition to a modern, resource-efficient and competitive economy that emits zero net greenhouse gases by 2050, decouples growth from resource use and leaves no one – people or region – behind.

Global Biodiversity Information Facility (GBIF)
An international network and data infrastructure funded by the world's governments that aims to provide open access to data on all forms of life on Earth to anyone, anywhere.

IUCN Green List
The *International Union for Conservation of Nature*'s Green List is a global campaign for successful nature conservation. It provides locally relevant technical guidance for achieving fair and effective conservation outcomes in protected areas.

IUCN Red List
It has been published since 1964 and is an important indicator of the state of biodiversity. It has developed into the world's most comprehensive source of information on the global conservation status of animal, fungal and plant species and is constantly being updated by experts from more than 160 countries, who analyse all relevant and accessible data on a scientific basis.

Kunming-Montreal Global Biodiversity Framework (GBF)
The framework sets out strategic goals by 2050 and action targets by 2030 aimed at realising the mission and vision of the *Convention on Biological Diversity (CBD)*.

National Biodiversity Strategy 2030 (NBS2030)
The NBS2030 is the German Federal Government's central nature conservation strategy and a key instrument for implementing international agreements on the protection of biodiversity in Germany. With the adoption of the *Kunming-Montreal Global Biodiversity Framework (GBF)* in December 2022, new global targets for the protection of biodiversity by 2030 were put in place. With a comprehensive further development of the NBS2030, the Federal Government wants to fulfil its responsibility in this area in Germany and worldwide and make an ambitious contribution to the implementation of the GBF and the *EU Biodiversity Strategy 2030*.

Quadripartite One Health Alliance
In this alliance, the *Food and Agriculture Organisation of the United Nations* (FAO), the *United Nations Environment Programme* (UNEP), the *World Health Organisation* (WHO) and the *World Organisation for Animal Health* (WOAH) work together to implement the *One Health concept*.

Sustainable Development Goals (SDGs)
17 goals and 169 targets agreed to by the United Nations that balance the social, economic and environmental dimensions of sustainability and aim to promote sustainable peace and prosperity and protect our planet.

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Preface

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