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Review

Measuring the Impact of Conservation: The Growing Importance of Monitoring Fauna, Flora and Funga

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Abstract: Many stakeholders, from governments to civil society to businesses, lack the data they need to make informed decisions on biodiversity, jeopardising efforts to conserve, restore and sustainably manage nature. Here we review the importance of enhancing biodiversity monitoring, assess the challenges involved and identify potential solutions. Capacity for biodiversity monitoring needs to be enhanced urgently, especially in poorer, high-biodiversity countries where data gaps are disproportionately high. Modern tools and technologies, including remote sensing, bioacoustics and environmental DNA, should be used at larger scales to fill taxonomic and geographic data gaps, especially in the tropics, in marine and freshwater biomes, and for plants, fungi and invertebrates. Stakeholders need to follow best monitoring practices, adopting appropriate indicators and using counterfactual approaches to measure and attribute outcomes and impacts. Data should be made openly and freely available. Companies need to invest in collecting the data required to enhance sustainability in their operations and supply chains. With governments soon to commit to the post-2020 global biodiversity framework, the time is right to make a concerted push on monitoring. However, action at scale is needed now if we are to enhance results-based management adequately to conserve the biodiversity and ecosystem services we all depend on.

Keywords: aquatic species; biodiversity; business; data; fauna; flora; funga; marine species; monitoring; results-based management; terrestrial species

1. Introduction

Effective action is needed to monitor biodiversity and to improve the conservation, restoration and sustainable management of nature [1–3]. However, many stakeholders, from governments to civil society to businesses, lack the data they need to make informed decisions on planning and management, jeopardising the success of conservation interventions.

Blockages to data access are numerous, and can relate to a lack of data, inadequate monitoring and data collection, inadequate sharing of existing data, and the sharing of data that are of poor quality or in the wrong formats [4–7]. Lack of high quality, standardised data blocks our ability to compare trends over time and space. Existing data on species and their habitats have taxonomic and geographic biases, with more data on certain vertebrates and trees and less data on other plants, invertebrates and fungi, more data in wealthy nations and less in poorer high-biodiversity nations, and generally less data for marine and aquatic species [8–12]. Many of the taxa for which data are lacking tend to be the rarest or less charismatic taxa, with many critical for ecosystem functioning. Information biases jeopardise our ability to monitor, detect and influence ecosystem change over time. Furthermore, the costs of decision-making in the absence of data are tremendous and can lead to irreversible environmental change. Shifting baselines occur where the absence of historical data means we are unable to understand the scale of ecosystem change that has already occurred and consequently implement effective management [13].

The lack of suitable data manifests itself in poor reporting. For instance, Australia's 2021 State of the Environment report found that "reporting on the current state and recent trends of Australia's marine environment is highly variable and often inadequate for robust assessment" [14]. Many governments fail to report accurately on their delivery of commitments under the Convention on Biological Diversity (CBD) and other multilateral environmental agreements (MEAs) [15,16] and there is very little biodiversity reporting by businesses [17].

The corporate sector is a key driver of biodiversity loss through habitat conversion, overexploitation of natural resources and pollution, and as a vector of spreading invasive alien species [18]. The estimated annual loss of ecosystem services resulting from land use change was between USD 4 and 20 trillion between 1997 and 2011 [19]. At the same time many companies are dependent on biodiversity to provide natural resources for their operations and products. Biodiversity also presents significant commercial opportunities through options such as drug discovery [20]. Nature-based tourism contributes USD 120 billion to global GDP and supports around 22 million jobs worldwide [21]. Biodiversity loss, therefore, represents a major financial risk [22] and highlights the urgent need for the corporate sector to monitor and sustainably manage natural resources, to consider both risks and opportunities, as well as contribute to global biodiversity goals.

With the post-2020 global biodiversity framework being finalised by Parties to the CBD [23,24], it will be vital for countries to have the data they need for informed decision-making and reporting. It will also be more important than ever for governments, businesses and conservation organisations to measure their impact, and apply results-based, adaptive management, not only nationally but at regional, transboundary and global levels. Long-term monitoring that effectively detects systems change is required to ensure successful adaptive management.

This paper, therefore, reviews the biodiversity data needs of actors across sectors, assesses the challenges involved in monitoring to better understand why data are often inadequate to meet user needs, and identifies potential practical solutions to enhance data availability. In doing so we also challenge some of the common myths and excuses surrounding biodiversity monitoring.

2. Biodiversity Data, Data Users and Data Use

Data are used by numerous stakeholders for numerous reasons. Figure 1 summaries data types and data users, and Box 1 provides some examples.

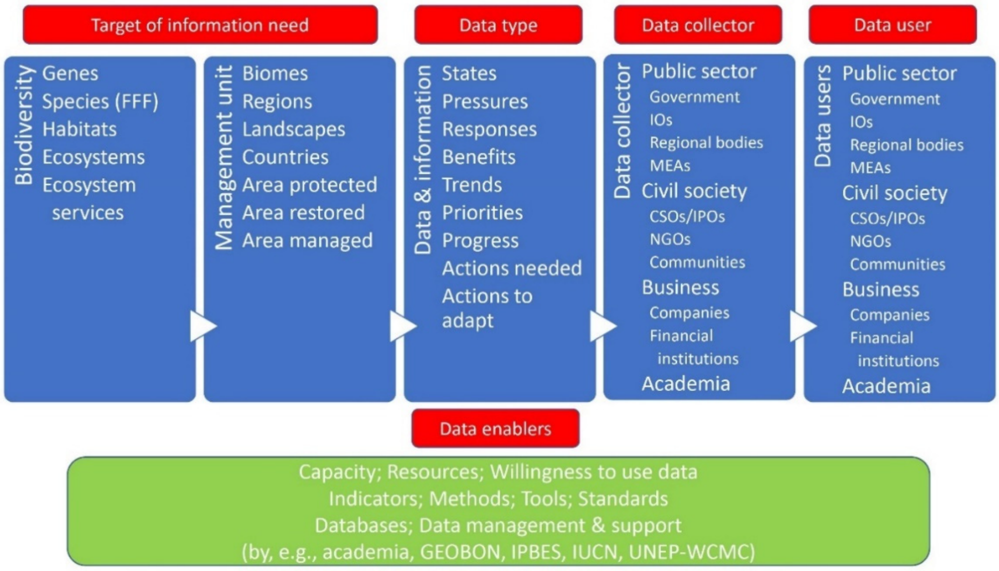

Figure 1. A summary of the types of biodiversity data users and their data needs, and the enabling factors (data enablers) that facilitate data flow. MEA = multilateral environment agreements; IO = international organisation; CSO = civil society organisation. IPO = indigenous peoples organisation.

2.1. Types of Data

Numerous different types of data are required to provide the information needed for the effective conservation and management of biodiversity and natural resources [7,25]. The main data categories are:

1. The state of biodiversity, such as trends in species presence and distribution, species abundance and population density, species conservation status, habitat extent and quality. Essential biodiversity variables or EBVs [26] have also been proposed in the following categories: genetic composition, species populations, species traits, community composition, ecosystem functioning, and ecosystem structure.
2. The values of nature and its contribution to people, including biophysical, monetary and socio-cultural types of data, are needed to assess human livelihoods and wellbeing, and to measure nature's instrumental, intrinsic or relational values [27].

3. The threats and pressures on biodiversity and the drivers behind them, including anthropogenic impacts, especially industrial and agricultural activity, institutional and governance systems that drive pressures [28], and the effects of climate change and land-use change on habitats and species [29,30].
4. The level and success of actions, policies, strategies and responses to address threats and pressures, especially those relating to the protection, restoration, management and sustainable use of biodiversity, including relevant data on business efforts to mitigate the impacts of their operations and supply chains.

These types of data are often classified as states, benefits, pressures and responses, and form the basis of many biodiversity indicator frameworks [31–34].

The data are needed for different types of species, such as those targeted for conservation action in terrestrial, marine and freshwater biomes, as well as for species that might represent threats, such as invasive alien species, pests or disease vectors. Most conservation data users will require data primarily on animals, plants, and fungi. However, data on species in other kingdoms of micro-organisms (sensu Ruggiero et al. [35]) may sometimes be required, such as the prokaryotic kingdoms Archaea (Archaebacteria) and Bacteria (Eubacteria), and the eukaryotic kingdoms Protozoa and Chromista, which collectively may account for 70 to 90% of all species on Earth but of which less than 1% have been formally described [36].

2.2. Types of Data Users and Their Uses for Data

A diverse array of stakeholders need biodiversity data for a diverse array of reasons [6,7,32,33,37]. In the public sector, governments (national and subnational structures in a diversity of ministries and departments) need data for the development, implementation, and monitoring of environmental resource policies and legislation, and for planning and budgeting (including landscape and seascape planning) for resource management across sectors (e.g., protected areas, forestry, fisheries, agriculture, infrastructure, mining, water management). Governments need data to guide planning and to report on progress towards their global MEA commitments, such as the CBD, the United Nations Convention to Combat Desertification (UNCCD), the Ramsar Convention, the Convention on Migratory Species (CMS), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), as well as the environment-related Sustainable Development Goals (SDGs). Data are also needed to help plan and coordinate conservation efforts relating to shared or transboundary populations and habitats. Data help governments make informed decisions about access and benefit sharing and the control and licensing of resource use (mining, hunting, fishing, etc.). They also inform decisions on the mitigation of resource-related conflicts and human-wildlife conflict, and the impact of environmental mitigation measures and recovery programmes, ranging from forest restoration to bans on wild meat exploitation to climate change mitigation actions. Understanding human and wildlife health-related issues and the attribution of zoonotic disease outbreaks to human-wildlife interactions is increasingly important, as has been seen with recent outbreaks of Avian Influenza [38], Ebola, COVID-19, and Monkeypox.

Protected areas remain a key government strategy for conservation. Data are needed to plan protected areas networks and to ensure they are large enough and connected enough to conserve threatened species [39]. Effective management of protected areas is dependent on information on the legal and illegal use of the protected habitat by people, the ecological and behavioural needs of key species, and trends in resource availability and ecological processes [40], as well as species diversity, abundance and body size. Monitoring therefore provides a means to determine if a protected area is working. For example, ecological monitoring and law enforcement monitoring provide protected area managers with information that prompts appropriate responses to ecosystem threats [41–44]. The International Union for Conservation of Nature (IUCN) Green List of Protected Areas [45] requires the monitoring of assets within protected areas to demonstrate effective management.

Conservation NGOs (non-governmental organisations) and other civil society organisations require data for monitoring the status of species and habitats and the impacts and outcomes of their projects, as well as tracking existing and emerging threats to help with planning. Conservation project responses that need monitoring are diverse but include actions for land and water management, law enforcement and prosecution, conservation designation and planning, livelihood incentives, legal and policy frameworks, research and monitoring, education and training, and institutional development [46]. In turn, conservation donors and funders need to monitor their return on investment and the performance of funded projects. Academic institutions base their research and teaching on biodiversity statistics, and an abundance of academic research into various ecological and environmental disciplines requires long-term data.

Local communities, including community groups and indigenous people, require information on the location and status of their resources to manage their natural capital either individually or collectively [47,48]. For example, in marine biomes, local communities need data to manage Locally Managed Marine Areas [49] and local fisheries [50].

Private and public companies from a range of business sectors, especially infrastructure, energy and extractives, require or are legally obliged to collect data on the state of biodiversity for environmental impact assessments (EIAs) and for the ongoing planning and monitoring of the biodiversity affected by their operations and supply chains. Monitoring may also include actions undertaken to conserve or restore biodiversity by companies on-site or to compensate off-site for biodiversity loss, a concept referred to as offsets [51]. In many cases, monitoring and data use is a requirement for certification processes associated with the sustainable production of timber, fisheries and crops, such as cotton and palm oil [34,52–54].

Data are therefore used by companies for biodiversity management and performance (at the site, landscape, business unit, corporate and product levels), communications and external disclosure of biodiversity management and performance, and for third-party biodiversity performance assessments and ratings [25]. Financial institutions, investors and insurance companies use environmental data to assess the impact of their operations on biodiversity and ecosystems and the risk and exposure of their investments [55,56]. Among the different financial mechanisms being developed [57], countries that sell and buy biodiversity credits, for example, require data on biodiversity over a long time period.

All stakeholders need data to monitor the progress of their projects, programmes and policies and to apply adaptive management. This means that, in many cases, data users need the same information on species, their habitats and threats, whether they are a government department, a local community or a company.

Box 1. A selection of examples of biodiversity data use by different users. Note that these are a random selection of examples to highlight key issues, not an exhaustive list.

Monitoring wolves in Switzerland. One specific example that illustrates the data and user types highlighted in Figure 1 is the Swiss wolf programme [58]. The target for the information need is the protection and management of the grey wolf (*Canis lupus*) population in Switzerland. The data type is individual wolf presence. Data are collected by local government (cantonal) environment agencies, co-ordinated by the in-state foundation KORA [59]. The data user is the Swiss Federal Office for the Environment in the federal government. Data are in turn used by regional government environment bodies to make decisions on wolf conservation and management and the mitigation of human–wildlife conflict. Data are also used by academic and NGO partners to produce research and monitoring outputs. The data enablers for this system include non-invasive methods of data collection (genetic sampling and camera trapping), and the capacity and expertise of (1) a research lab in the University of Lausanne [60] which analyses samples using modern genetic techniques [61], (2) KORA for capacity building, co-ordination of data collection and data management, and (3) local government staff for sample collection. The federal government's willingness to provide financial resources for data collection and to use the data in decision-making are also key enablers.

Box 1. *Cont.*

Using Key Biodiversity Area (KBA) Data for business planning. Key Biodiversity Areas (KBAs) are sites contributing significantly to the global persistence of biodiversity [62]. A number of development banks, including the World Bank, the International Finance Corporation, the European Investment Bank and the European Bank for Reconstruction and Development, have incorporated KBAs into their environmental safeguard policies, performance standards and guidance. This means that the location of KBAs and the species for which they are identified are considered when deciding whether development projects should proceed, and with what design requirements, to minimise environmental risks. For example, the International Finance Corporation's Performance Standard 6 (PS6) requires projects in 'Critical Habitat' to achieve a net gain in biodiversity. Critical Habitat is identified according to five criteria similar to those used for identifying KBAs [63,64]. PS6 has become recognised as international best practice for biodiversity management and is increasingly used throughout the finance and private sector. Data are essential for the identification of KBAs and Critical Habitats.

Using arthropod data for island species conservation. The LIFE-BEETLES project [65] aims to improve the population size, distribution area and conservation status of three endemic beetle species in the Azores. As part of the project, an ongoing monitoring project aims to quantify an Index of Biodiversity Integrity or IBI [66]. This index, that is based on several community ecology indices, has to be delivered to a governmental stakeholder (Minister of Environment) on an annual basis to track progress and make appropriate management decisions. Arthropods are sampled using standardised techniques including pitfall [66], canopy tree beating [67] and SLAM traps [68]. Decisions made include where to tackle invasive alien plant species and where to protect and restore habitats.

Using mammal data to make protected areas management decisions. In the Udzungwa Mountains, an area in Tanzania of exceptional conservation importance, long-term monitoring of primates and other terrestrial mammals show how open-ended wildlife monitoring can serve to evaluate the impact on wildlife of various management efforts. Examples of data use include: assessing park management decisions such as banning firewood collection [69]; understanding how contrasting management regimes in similar habitats impacts wildlife [70]; assessing species recovery following an increase in ground patrols (F. Rovero, unpubl.). Such work is being replicated in Shai Hills in Ghana by the IUCN SSC Species Monitoring Specialist Group, the Centre for Biodiversity Conservation Research and the Wildlife Division [71]. The camera-trapping protocol for monitoring terrestrial mammals originates from the pan-tropical TEAM Network [72]. This is, in turn, part of Wildlife Insights, a global platform for sharing camera trapping for wildlife conservation [73].

Using citizen science bird data to identify suitable areas for wind farms. Identification of areas with migration flyways and high concentrations of endangered or endemic species is important for governments when approving large-scale infrastructure developments, such as wind farms in southern South America. Available data from citizen science platforms such as eBird [74] offer large-scale data at low cost. So far, migration pathways have been identified for a range of species (e.g., hooded grebe *Podiceps gallardoi* (Critically Endangered) and magellanic plover *Pluvianellus socialis* (Near Threatened)) and different types of important areas (e.g., national and provincial protected reserves), both by non-profit conservation institutions and by energy production companies. Furthermore, the Secretary of Environment of Santa Cruz Province in Austral Patagonia is now focusing its efforts on improving the results and developing more detailed maps by using multiple citizen science databases covering not only birds but other taxa.

Company use of data for sustainability reporting. Mining company BHP uses biodiversity data both to set targets and track and monitor the performance of biodiversity on and near its operational sites. In the sustainability section of their 2021 annual report [75], BHP sets five-year marine and terrestrial biodiversity targets, and highlights the value of water conservation, biodiversity and reforestation in its products and services. The company monitors its biodiversity risks in terms of freshwater withdrawals, operations near protected or high biodiversity value areas, the number of IUCN Red List species on or near its sites that are Critically Endangered, Endangered or Vulnerable, and migratory and endemic species. BHP uses these data to make investment decisions for environmental protection and restoration, and also for scientific publications and thought-leadership articles. The company also uses the information to capture the co-benefits of nature as climate change mitigation and carbon storage solutions, particularly in the context of wetland, coastal and marine ecosystems.

In conclusion, there is a growing demand for more evidence-based conservation and natural resource management, with data informing decisions and evaluating performance [2,76] for a variety of reasons for a variety of users (Figure 1). This is especially important for governments needing to report on progress towards global biodiversity goals [77], NGOs needing to demonstrate their conservation impacts and return on investment [34] and companies needing to enhance the measurement of their biodiversity performance [17]. However, while there is an increasing demand for data, that demand is not always being met.

3. Ongoing Challenges with Biodiversity Monitoring and Data Availability

We recognise three main challenges to biodiversity monitoring, with several underlying drivers. Examples of data blockages are presented in Box 2.

3.1. Biases and Gaps in Biodiversity Research and Data

A geographical bias persists in conservation science, with 40% of recent studies carried out in Australia, the UK, or the USA, compared with only 10% in Africa and 6% in southeast Asia [78]. Tropical regions housing the most biodiversity and the most threatened species are the least studied [79–81]. This mismatch and the poor alignment of research with biodiversity distribution and conservation priorities are reflected in monitoring and data biases. Moussy et al. [82] recently found more species population monitoring schemes in countries with higher per capita gross domestic products, especially in Europe. An analysis of the Global Biodiversity Information Facility (GBIF) database [83] found that the greatest gaps in digitally accessible information on terrestrial vertebrates were in Asia (48% of grid cells with no data), followed by Africa (35%) and South America (21%). Asia was also slightly weaker than South America and Africa in biodiversity research publications [84]. This underlines the general trend for greater capacity for data collection and use in Europe and North America, with a more detailed analysis of gaps in monitoring data and capacity required [85].

Temporal biases in biodiversity data can hinder the study of impacts caused by environmental changes. For example, global coverage of plant occurrence records experienced steep drops since the mid-1990s. Some regions have been affected more than others by poor temporal data coverage and ageing records, such as those in Canada, central Africa and Asia [86].

There is also a significant taxonomic bias in available data, with more data and data collection on vertebrates than invertebrates, more data on large vertebrates than smaller vertebrates, more data on animals than plants or fungi, and more data on terrestrial species than marine or aquatic species [9,82,87–90]. For example, fungi are a mega-diverse kingdom of importance for ecological functionality yet are rarely included in conservation monitoring. The IUCN Red List of Threatened Species [91] (hereafter "The IUCN Red List") includes only 633 out of 148,000 described fungal species, of which 36% are classified as least concern. The reason for the inadequate monitoring of fungi seems to be a lack of awareness compounded by the lack of teaching of mycology in academia, as well as the lack of mycologists in government conservation and management agencies and in research institutions [92].

Some of the data biases across taxa may be linked to practicalities and cost- effectiveness. Gathering data, especially on a continuous basis can be logistically difficult, time consuming and expensive, and it is often underfunded [93–95]. For example, species that are small, nocturnal, aquatic, marine, subterranean, rare or cryptic are generally harder to monitor [96–99]. Marine surveys tend to be focused on coastal areas, with pelagic and deep sea surveys more expensive, and often with high data uncertainty [100–103].

Urban biodiversity is important to urban residents' health and wellbeing [104] and creates opportunities for residents to access nature and understand the importance of protecting global biodiversity. Biodiversity data are also essential for environmentally sensitive urban planning [7]. Nevertheless, existing biodiversity monitoring networks frequently exclude urban areas. Lack of professionally collected species occurrence data is often the main hurdle to urban biodiversity assessments [105].

Data collection biases are likely to be influenced by the general tendency of conservation projects to focus on species perceived as more charismatic or appealing to donors. For example, across a European conservation grants programme, on average each arthropod species received 1000 times less funding for its conservation than each mammal species [8]. US federal government funding for endangered species is also influenced by the perceived charisma of species [106]. Troudet et al. [107] suggested that public opinion guides biodiversity data gathering, and it is noteworthy that many of the European and North American cultures that provide a high proportion of the resources for global databases usually perceive vertebrates such as large mammals to be the most charismatic species [108–110]. It may therefore not be surprising that vertebrates dominate those databases.

Funding focussed on protected areas rather than individual charismatic species may benefit entire ecosystems [111]. The implicit assumption is that the whole habitat or ecosystem, is conserved and that monitoring of larger species serves as a proxy for the trajectories of smaller species. However, the use of surrogates or proxy measures has its pitfalls [8,112] and may mean that taxa not monitored decline without us knowing. Consequently, several calls have been made to enhance the monitoring of neglected taxa such as invertebrates, plants, fungi and marine and aquatic species [8,99,113–115]. Ecosystems are dependent on the complex interactions between functional species to be healthy, dynamic and resilient [116]. A focus on sampling whole assemblages is therefore needed to understand the trajectories of all components of ecosystems, not just large vertebrates [117].

The types of data collected are also biased. Many conservation projects collect more response data than pressure or state data [2], and ecosystems and ecosystem services tend not to be monitored as much as species. For example, the IUCN Red List of Threatened Species [91] currently has far more data than the IUCN Red List of Ecosystems [118]. In the marine environment, there is a focus on documenting process versus outcomes. For instance, Marine Stewardship Council certification is highly skewed towards documenting management activities (e.g., collection of fisheries statistics, use of observers), with less attention paid to the degree to which targeted species are responding positively to management efforts [119].

Data from satellite-based remote sensing (SRS) systems, such as LIDAR or GEDI [120], have provided new opportunities to monitor the pressures, states and benefits of biodiversity, increasing the spatial and temporal coverage of data associated with habitat extent and condition [121] and also being harnessed to produce EBV's [122]. However, the use of SRS data has focused on forest ecosystems, with many challenges still remaining for its effective use, such as image interpretation, habitat definitions and in situ data integration, among others [123].

Changes in research capacity are also influencing data biases. Basic natural history fieldwork with a focus on faunistic, floristic, and fungal data has declined in recent decades [124]. The acquisition of much of the knowledge needed by decision makers lies with ecologists, taxonomists, and field naturalists (both professionals and citizen scientists) and requires more specialists with species knowledge [115]. In particular, the loss of taxonomic expertise (sometimes called the "taxonomic impediment") is still ongoing, despite decades of publicity on the problem [125,126]. More knowledge needs to be built from interdisciplinary research, including computational, biological and remote sensing science [127].

Another key gap is data on the absence of species. Citizen science programmes such as eBird [74], iNaturalist [128] and RedMap [129] are collecting data on species from birds to butterflies to fishes, yet most schemes collect only data on when a species is recorded. Absence data (failure to find a species at a given site) are not usually collected yet filling this gap would greatly enhance the value of such databases in monitoring species distributions. Furthermore, misinterpretation of absence data can have adverse consequences for threatened species and their conservation [130], so the current spatial bias needs to be resolved to help more accurately infer future extinctions. Another challenge with citizen science programmes is that they cannot identify certain taxa due either to a lack of expertise and taxonomic knowledge among the voluntary observers or the difficulty in identifying some species solely from photographs. Again, such observer biases tend to favour larger terrestrial and diurnal species of mammal and bird.

In the corporate sector, there is an industry bias in business management research on biodiversity. Businesses tend to take a more anthropocentric approach to the use of nature data, focusing on what benefits can be derived from biodiversity and on maintaining the functioning of healthy ecosystems [131]. As a result, business research on biodiversity has a limited focus on a few industries, such as agriculture, forestry, fisheries, urban development, mining, and other sectors linked to land use change [51].

3.2. Inadequate Data Availability, Sharing, Quality and Usability

Blockages to biodiversity monitoring include a lack of access to existing data sets [6,7], exacerbated by many organisations acting independently to develop their own databases and data platforms [132].

Most existing monitoring programmes have been designed at localised scales and produce information that is disaggregated, heterogeneous, and non-standardised when considered at national or regional scales [133]. A lot of environmental data collection efforts are part of one-off studies or projects which limits their usefulness [134]. Existing data are housed in a range of different institutions and government departments, and these records are rarely available electronically. Data are often not shared because of political tensions and poor institutional connections, the poor links between science and biodiversity policies, and the limited interaction between the data gatherers (such as academic institutions and NGOs) and the data users, such as those within government ministries [6,7] (Box 2). There are frequently poor communications between scientists and conservation practitioners [135]; bridging the gap between science and policy has often been called for, but there is no consensus on how to achieve this goal [136,137].

Good quality data remain hard to compare and aggregate when standardised methods and protocols are not used for data collection and management, yet many institutions fail to follow data curation and management best practices [138]. Metadata and methodologies are usually poorly annotated and common systems like DARWIN Core data fields are often not explicitly matched up, making it difficult to combine data. There are also frequently time lags between the data being collected and the production of summary indicators needed by stakeholders. Consequently, national and global data sets are often inadequate or not accessible to decision makers [139]. Furthermore, the accuracy of global datasets may vary considerably and not be locally validated or calibrated. Many data collection tools such as satellite-based remote sensing need to be ground-truthed to be useful.

Data accessibility can also be blocked by a lack of capacity to identify, collate, and use the data (see below), as well as a lack of clear national policies and legislation on data sharing. Where data accessibility is not a barrier, data are frequently scattered, fragmented, of poor quality, and rarely available in the right format at the right time [4–6,113,139,140]. In some cases, such as with protected areas management in Kenya [7], data may be used for planning new reserves but less so in their management, where preventing poaching becomes a higher priority than biodiversity monitoring. Fundamentally, insufficient resources are invested in data management.

Companies struggle to access or collect biodiversity data, with a confusing array of business-focused metrics being developed but no common approach [17]. Many companies tend to use a materiality matrix to define what data they should collect, or a standard set of indicators such as the Global Reporting Initiative biodiversity indicators [141] or Product Biodiversity Footprint [142]. While available indicator frameworks for business are generally rigorous, replicable and consistent, covering most parts of the value chain, none of them cover all types of business applications in all types of biomes, and rely heavily on out-of-date or inaccurate secondary data [37]. Companies are therefore having to manage with inadequate data, even though such incomplete measures can lead to flawed biodiversity conservation approaches [143]. Corporate biodiversity measurement also regularly fails to consider key concepts around resilience that are important for identifying thresholds and changes [131]. Monitoring required for certification in the sustainable production of commodities is often inadequate, especially in tropical countries [144,145].

3.3. Technical and Financial Capacity Gaps for Data Collection, Analysis and Use, Especially in New Technologies and Key Disciplines

There are ongoing challenges with biological research and monitoring capacity in high-biodiversity tropical countries [146–148]. For example, in a review of national reports submitted to CBD by African governments [6], inadequate technical and financial capacity were highlighted as key obstacles to implementing National Biodiversity Strategy and Action Plans (NBSAPs). This reflects a broader lack of funding and capacity for conservation monitoring [149]. Many monitoring tools are expensive and poorly adapted to local needs [150]. As a result, many systems are unable to detect change over time, or determine conservation impacts. New technologies are often tested first in wealthier low-biodiversity countries and, as a result, modern monitoring tools are more commonly used in wealthier countries than in high biodiversity regions [151–153]. Environmental DNA (eDNA) [154] highlights this issue very well. For example: eDNA studies are uncommon in areas of high reptile species richness [155]; most eDNA freshwater and marine fish studies were conducted in Europe, Asia and North America [156]; more studies identifying vertebrate DNA from water have been done in temperate areas than in the tropics [157]; in eDNA research in freshwater ecosystems, there is geographic inequality in study numbers and goals biased towards the global North [158]; and, overall, eDNA research conducted in the tropics so far comprises only a small proportion of the cumulative eDNA literature [159].

As well as suitable capacity to apply new technologies, we need more capacity to monitor biodiversity at scale. For example, with plans to protect 30% of our oceans by 2030 [160], and the increase in large-scale marine protected areas required, the need to monitor biodiversity effectively at scale is becoming even more acute. Monitoring large ocean areas including pelagic zones can be relatively costly [161] and requires more research [162], more capacity for strategic, cost-effective monitoring [163] and repeatable methods such as video-based sampling [102]. Because of its nearly global coverage and regular acquisition schedule, as well as ongoing advances in sensor technology, satellite-based remote sensing has the potential to help monitor biodiversity at scale [123,127,164]. However, numerous gaps in capacity exist in many countries and organisations, compounded by challenges with the cost of data acquisition, the need for data processing and derived products, and lack of harmonisation of methods [164,165].

Significant challenges exist in sharing data [139,166,167], with problems most apparent in high-biodiversity regions. For example, across Africa, the problems of data sharing and use are often compounded not only by more limited resources to pay for data access, raw images and data processing, but also by limited internet capacity [168]. Many assessments of African biodiversity data are conducted by scientists who are predominantly based outside Africa [169]. For example, of the 3,942 publications produced on Madagascan biodiversity from 1960 to 2015, only 8.9% had a lead author based at a Malagasy institution [170]. Overall, geographic publication bias relating to biodiversity and conservation is most apparent in sub-Saharan and Central Africa, the most remote regions of South America, Central Asia and many countries of the former Soviet Union [171].

Similar trends and issues emerge in other high-biodiversity tropical countries. As a result, during the United Nations negotiations for the CBD, Parties requested capacity building and development to support least developed countries in the implementation of the monitoring framework [24].

These trends reflect the fact that, while there are regional hubs in countries like South Africa and Colombia, most of the global data sets, and most of the scientists with access and capacity to analyse them, are housed in Europe or North America [139], as are many of the museum collections that often present the best available taxonomic data and serve as historic references for biodiversity. As a result, many poorer countries without adequate museums or specimen storage facilities ship their specimens out of the country for identification, the specimens often then remaining abroad.

Many local communities use indigenous knowledge to measure a range of variables, including biological indicators, for local decisions on resource use and farming [47,48]. However, this capacity is rarely tapped for more formal decision-making, despite the complementarity between indigenous and scientific knowledge systems which can enhance collective understanding of ecosystems [172,173].

The capacity for biodiversity monitoring is lacking across the corporate sector [17]. Many companies rely on consultants for EIAs and ongoing monitoring. The slow adoption of GIS techniques by businesses is in part due to a lack of exposure and opportunity to learn to use GIS in business schools, as well as a lack of education on biodiversity or environmental science and its connection to business [174,175]. Thus, the workforce of companies lags in developing the necessary skillset in contrast to governments or NGOs [176]. Decision makers in companies have difficulty in assessing the quality of data and determining the relevance of available spatial data to address business challenges [177]. The necessary capacity to plan and monitor biodiversity, whether internally or through partners, is clearly a key prerequisite for companies to improve the monitoring of their operations and supply chains [37].

3.4. Root Causes and Interlinkages between Challenges

The challenges with data collection and use have a number of linkages and root causes. Many conservation programmes have inadequate monitoring and evaluation systems [178], which are often compounded by the lack of measurable goals to provide the basis for monitoring [179,180]. Improving monitoring methods and indicators is a priority topic for research [181], yet it is still not a priority for many donors or academic bodies [182,183]. This may be a factor in the general lack of funding and capacity for conservation monitoring [149]. Global biodiversity indicator sets are incomplete [33,184]. Interlinkages between indicators are poorly understood [31] and many global assessments [32–34] were not able to analyse any interrelationships between indicators.

While monitoring is standard best practice in conservation project cycle management, and while NGOs, governments and companies have numerous reporting obligations to investors, partners, stakeholders and shareholders, the current blockages to data access and use suggest there is still no adequate understanding of the importance of monitoring. There is an urgent need to make and sell the case for monitoring and a results-based management culture that relies on data for informed decision-making and adaptive management.

Competition for resources is another underlying factor, especially given the often low importance of biodiversity when compared to other public or private sector priorities. Furthermore, monitoring is not seen as important compared with other natural resource management actions. As a result, funding, and the capacity to fund research and monitoring, is an underlying cause of weak monitoring. Most of the conservation projects developed by governmental organisations or NGOs allocate the vast majority of their budgets to implementation. As a result, an inadequate proportion of conservation budgets is set aside for monitoring project performance and impact [2]. There is a significant relationship between resource availability and the duration of monitoring, with government funding for species monitoring lower in low-income countries [82].

Data collection and sharing is complicated further by a lack of consensus about what to monitor, with different organisations and projects adopting diverse measurements and different indicators [26]. Actors within and between different public and private sector agencies have different priorities and information needs. The lack of inter-ministerial collaboration and the disconnections within and between government ministries are major barriers to the willingness to use biodiversity information [6]. NGOs also tend to have their own, rather than shared, monitoring systems.

There is circumstantial evidence that some government, NGO, and business leaders may not always be keen to use data if those data do not show the trends they want or reflect badly on their management decisions [6,7]. Political interests may therefore drive managers to disregard biodiversity information. The reluctance to use biodiversity data may be compounded by the low level of importance given to environmental issues. In conservation bodies, there is often a reluctance to share bad news or project failures, presumably to avoid putting off donors, which has led to the suggestion there is limited space to fail [2,185], despite the importance of sharing experience and learning from failure [186].

In the corporate sector, monitoring is often by receptor (i.e., the species or habitat impacted by company operations). For a given project, however, it is not uncommon for different receptors to be monitored by different actors. For example, separate consultants might be monitoring marine birds and marine mammals around an offshore wind farm. The absence of an integrated, multi-species monitoring programme reduces efficiency and cost-effectiveness and is also likely to reduce the comparability of data sets [187].

Many data users, especially in the corporate sector, are not sure which indicators are most relevant for them and which methods and tools to use to collect data. This is not helped by the wide range of metrics and tools developed specifically for business and by competition between developers to promote their products. Companies do not always understand biodiversity, its complexity, and how it can be measured. The focus among corporate sustainability agendas has been on climate change, while the link between climate change and biodiversity is not always made. Even when companies do address biodiversity, they may only make surface level changes to comply with stakeholder pressures without proactively engaging with the issues and making fundamental changes to business operations [188,189]. Companies also tend to focus on mitigation and adaptation approaches (for both climate change and biodiversity) rather than resilience, which supports underlying ecosystems and can lead to nature-positive solutions that solve both problems. Resilience will often come from conserving existing ecosystems so companies need to shift from worrying only about restoration to conserving natural habitats and protecting what is already there.

Box 2. Examples of data blockages and challenges. Note that these are a random selection of examples to highlight key issues, not an exhaustive list.

Reporting to the Convention on Biological Diversity. Many countries fail to use data to report on their contributions to CBD reports. For example, a widespread paucity of data is a recurring theme in African national reports to the CBD [6]. Many African countries conduct regular wildlife surveys, yet the resultant data are rarely analysed and presented in a form that could be used by decision makers [190]. Only 36% of Fourth National CBD Reports contained data [15]. A review of a representative sample of 21 of the Fifth National CBD Reports found 11 with inadequate data, compounded by the fact some countries had no defined national indicators [16].

Red Listing of poorly known species Lack of data means the conservation status cannot be determined for many species. In the latest IUCN Red List [91], 20,469 of the 147,517 species assessed (13.9%) were Data Deficient. Even for many species not considered Data Deficient (such as many African small mammals), the information needed for Red List assessments is often incomplete [7]. There are an estimated 11,846 species of fungi in Australia [191] yet only 39 species have been assessed for the IUCN Red List [91]; no fungi have been listed at a federal level and less than a hundred listed at state levels.

Reporting to the FAO on fisheries. Countries provide data on industrial fisheries landings to the FAO. However, these records underestimate catch as they exclude bycatch, recreational and subsistence fishing and fail to estimate illegal, unreported and unregulated catches [192]. These partial data mask the actual scale of fisheries declines and hinder effective management to halt and reverse these trends.

Box 2. *Cont.*

National data management–Indonesia. In Indonesia, as with many high-biodiversity countries, there is no clear centralised and standardised biodiversity database, as different government agencies are assigned to manage different biodiversity data [193,194]. For example: the Ministry of Environment and Forestry manages the database of terrestrial wildlife, forest, and mangroves; the Ministry of Marine Affairs and Fisheries manages the database of marine wildlife and economically important fish species; the national research agency manages the database of coral reefs and seagrass. This makes it difficult to carry out large-scale monitoring of coastal ecosystems that may have all these components, as the different agencies may use different units of measurement and different monitoring methods, and some agencies may be more reluctant to share data than others. The government in Indonesia is implementing a one map policy to address some of these issues [195], but data quality and standardisation is still a challenge. At the moment there is a budding initiative led by the Indonesian Biodiversity Consortium (KOBI) that is made up of academics, NGOs, and civil society groups aimed at establishing a national biodiversity index for Indonesia to help compile these data and work on standardising them, and bridging communication between the different stakeholders. However, this initiative is still in its infancy [196].

Business disclosures on biodiversity. As summarised by Stephenson & Walls [17], accurate, reliable and timely data are essential for corporate biodiversity governance. Nevertheless, companies face challenges accessing existing data or collecting new data, especially spatial (geo-referenced) data that links activities to specific sites, supply chains, species and habitats. This may be the main reason that only 3-12% of European and US companies report anything on biodiversity [197,198]. Even where companies do report on nature in some way, the information is often not specific, measurable, or time-bound, making it difficult to determine business impacts [199]. This is compounded by the fact many business-specific biodiversity indicators rely on secondary data and modelling rather than direct measurement, using assumptions that may not be accurate [37].

4. Solutions Needed

Based on this review, we propose nine main solutions to enhance the collection and use of data on fauna, flora and funga for conservation work across sectors. Figures 2 and 3 present the relationship between identified challenges, root causes and solutions.

4.1. Build Capacity Where It Is Most Needed

Capacity for monitoring fauna, flora and funga (and priority microorganisms, where necessary) needs to be enhanced urgently in poorer, high-biodiversity countries. Shortfalls in required resources should be made up with support from wealthier developed countries and large conservation organisations, whose financial and technical capacity could help realise data collection needs and make existing data more available, as well as support local capacity development. Ultimately, we need more people from high-biodiversity countries monitoring their own species.

Enhanced capacity is needed specifically for using new monitoring methods and technologies, and to focus on long-neglected taxa: invertebrates, such as molluscs, arthropods and worms; fungi; non-tree plants; and, where necessary, protozoa, prokaryotes and chromistans. Existing capacity building programmes need to be learned from and replicated (Box 3). For example, several space agencies provide regular, virtual training sessions on a variety of different topics often geared towards SRS users in developing countries [200,201]. Capacity for urban monitoring needs to be enhanced through the roll out of improved methodologies [202] to build on and scale up long-term biodiversity monitoring efforts found in some US cities [203].

Development of capacity to monitor all taxa needs to be at multiple levels, to help enhance national, regional and global efforts [204]. Capacity development is also needed for scientific disciplines on the decline, such as taxonomy. To that end, "taxonomy needs to be rebranded to the scientific community as a modern, active and important discipline" [126].

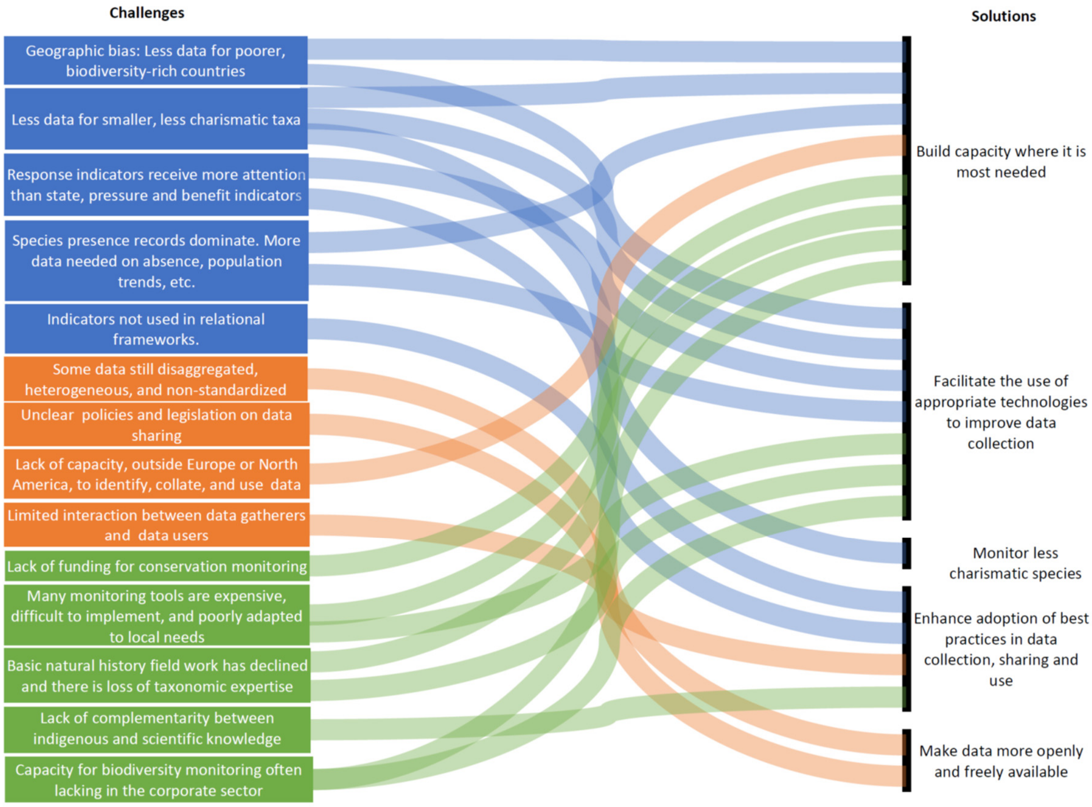

Figure 2. Relationship between challenges to biodiversity monitoring and data use and the solutions to address them. In blue, challenges related to data and research bias; in orange, challenges related to inadequate data availability, sharing, quality and usability; in green, challenges related to technical and financial capacity gaps for data collection, analysis and use, especially in new technologies and key disciplines.

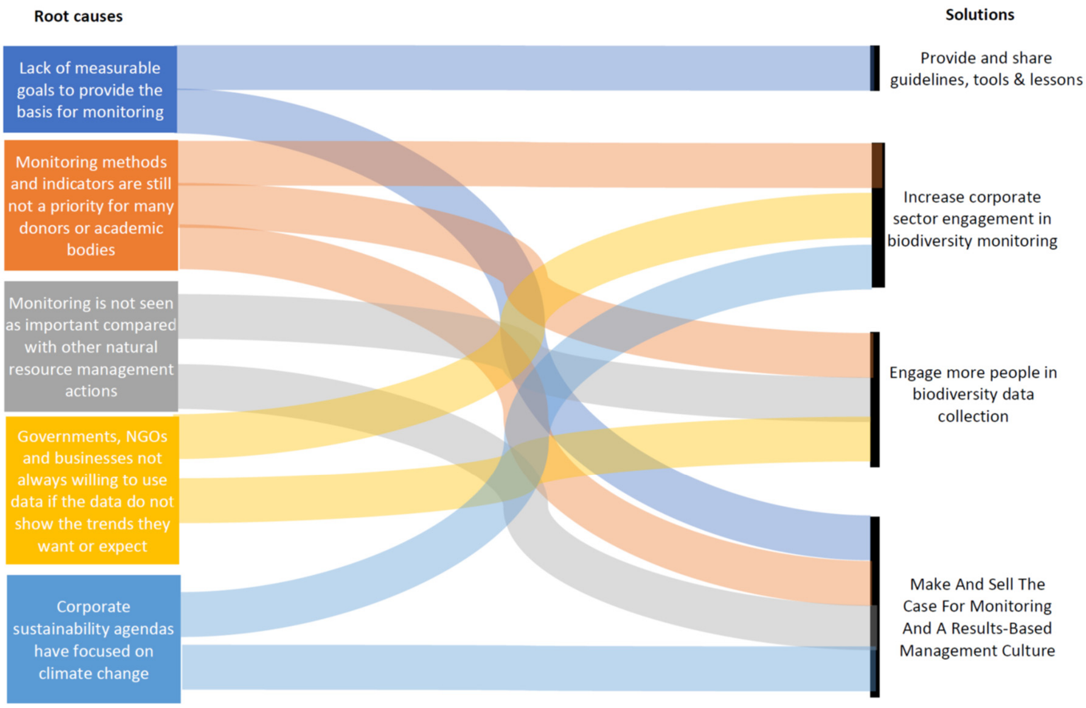

Figure 3. Relationship between the root causes of weak biodiversity monitoring and data use and the solutions to address them.

More integration of disciplines is required, not only to improve data collection but to better understand the interactions between species and the ecosystem service benefits they provide people (through, for example, clean air, water, natural resources like food, timber and other fibres). Businesses are increasingly building capacity for biodiversity, not only in mining and agricultural companies which traditionally had some in-house expertise, but also in consulting, investment, and insurance companies [205].

Across stakeholders, more training is needed in monitoring programme design, to ensure systems are statistically robust and can detect change. Regional capacity may be built more effectively through networks, such as regional or thematic biodiversity observation networks [206,207].

Box 3. Capacity building examples. Note that these are a random selection of examples to highlight key issues, not an exhaustive list. Other case studies are presented by Schmeller et al. [208].

NBSAP Forum and Global Biodiversity Information Facility. There is support from the NBSAP Forum [209] for countries developing and using indicators to measure delivery of their national goals and contribution to global goals. This support will need to be expanded when the indicator list is finalised for the post-2020 global biodiversity framework. Initiatives under the Global Biodiversity Information Facility-GBIF are helping countries build capacity to acquire data by creating networks of data holders and users and digitising and mobilising existing data from natural history collections and surveys [210]. This work has underlined the importance of increased technical capacity and information resources to assist data mobilisation [6].

Developing island monitoring systems. Two key examples of successful capacity building for a range of stakeholders at a regional scale is BIOTA CANARIES [211] and the AZORESBIOPORTAL [212]. Starting in 2006, both systems provide the detailed distribution of terrestrial and marine biotas of the Canary and Azores archipelagos, respectively. Both projects support research, but particularly local stakeholders (from governments to civil society to businesses), to enable them to make informed decisions on conservation planning and management. Training sessions on the use of these biodiversity portals and their associated tools allowed the enhancement of biodiversity data collection and monitoring by park rangers.

Establishing national bird monitoring schemes in Africa. The Royal Society for the Protection of Birds and BirdLife International worked with partners in Botswana, Kenya and Uganda to establish national bird population monitoring schemes. These were based on citizen science approaches used in Europe that are capable of monitoring population trends in common and widespread species. Challenges encountered included recruiting, training and retaining volunteer surveyors, and securing long-term funding [213]. However, with technical support and modest investment, meaningful biodiversity indicators can be generated and used in African countries. Sustained resourcing for the existing schemes, and replication elsewhere, would be a cost-effective way to improve our understanding of biodiversity trends and measure progress towards environmental goals.

Sino BON: China Biodiversity Observation and Research Network. The construction of Sino Bon by the Chinese Academy of Sciences started in 2013. The network focuses on monitoring the mid- and long-term population trends of key species in typical regions. Sino BON provides biodiversity data for supporting China to fulfil its commitment to the Convention on Biological Diversity. The network consists of ten sub-networks that are devoted to monitoring mammals, birds, amphibians, freshwater fishes, insects, soil animals, forest plants, grassland and desert plants, tree canopy and soil microorganism diversities. So far, the network covers 30 main sites and 60 affiliated sites all over China [214]. Optimising the monitoring network to cover more key biodiversity spots and facilitating the data sharing will be important to increase the programme's impact.

4.2. Monitor Less Charismatic Species

Efforts need to be made to integrate smaller, less well known, less charismatic species into monitoring schemes. For example: fungi could be included in broader ecological monitoring schemes [92]; small mammals could be added to monitoring schemes in protected areas targeted for larger mammals such as primates [215]; appropriate systems and software could be employed to ensure camera trap bycatch data is exploited optimally to monitor non-target species [216,217].

When new monitoring schemes are developed, it would be cost effective to maximise the taxa surveyed. For example, eDNA approaches are extremely sensitive and can increase significantly the taxonomic coverage and resolution of monitoring schemes to levels that would not have been envisaged just a few years ago, detecting even cryptic and difficult to observe species, especially in aquatic environments but increasingly in terrestrial habitats [154]. eDNA surveys of species presence should include as many taxa as possible to reduce taxonomic biases in data collection. The same applies to other methods, including terrestrial and aquatic camera and video surveys and acoustic monitoring. "Scientists should advertise less charismatic species and develop societal initiatives that specifically target neglected organisms" [107]. Indeed, some smaller species can also be flagships and promote conservation of wider ecosystems; examples proposed include beetles in the Azores [65], aquatic tenrecs in Madagascar [218], and seahorses for estuarine habitats in South Africa [219], to name just three.

A proof of concept is badly needed to demonstrate the benefits and costs of long-term monitoring of selected taxa that are currently neglected. For arthropods this should include not only classical diversity metrics (species richness, abundance, biomass) but also ecosystem services provided by arthropods (e.g., pollination, predation). Costa and Borges [68] showed that it is possible to rely on cheap, cost-effective traps in the field, supported by a well-organised academic team in a research lab to ensure the long-term availability of para-taxonomists for sorting insect samples. This type of approach can be very informative, for instance to respond to concerns over insect declines and the spread of invasive alien species [220]. Furthermore, the sentinel approach can be a cost-effective method to measure ecosystem services provided by arthropods, directly measuring several ecological processes (e.g., herbivory, pollination, predation). One good example for the measurement of predation is the use of the artificial caterpillar method [221].

Understanding the diversity and range of functions in ecosystems of poorly studied and monitored organisms could maximise the benefits, synergies, and potential solutions for conservation provided by modern bioinformatic and molecular tools (e.g., multiplex barcoding). However, while such tools have clearly revolutionised taxonomy and whole organism community metabarcoding [222] and increased the rates of descriptions of new species, estimates of the number of undescribed taxa still account for significant proportions of total biodiversity for all animals (>80%([223], plants (~17%) [224] and fungi (>94%) [225]. Moreover, it has been estimated that more than half of all described but data deficient species are threatened with extinction [226]. It is therefore imperative we broaden the taxonomic scope of monitoring efforts.

4.3. Facilitate the Use of Appropriate Technologies to Improve Data Collection

Modern tools and technologies, which include satellite-based remote sensing, camera trapping and other forms of still and video cameras, bioacoustics, and eDNA, need to be used at larger scales to help fill taxonomic and geographic gaps in data, especially in the tropics, in marine and freshwater biomes, and for plants, fungi and invertebrates.

Every monitoring method has its advantages and disadvantages [227–229]. Each tool is becoming the go-to option for the monitoring of certain elements of biodiversity: SRS for habitat cover and land use change and threats; camera traps for terrestrial large mammals and baited remote underwater video systems for fish assemblages; acoustic monitoring for vocal terrestrial and marine vertebrates (especially bats and cetaceans), and eDNA for aquatic species presence/absence, as well as other cryptic, ephemeral, fungal or microbial species. However, each tool is also gradually being adapted for use with species formerly covered by others: SRS can now monitor some species as well as habitats; camera traps can be used to detect threats such as poaching, illegal fishing and bycatch; baited remote underwater video has been extended from reefs to the deep sea and open-ocean habitats; acoustic monitoring is being used more for invertebrates and can detect forest degradation and poaching; and eDNA has proven successful in some terrestrial settings [230], including biodiversity surveys, diet analyses and niche partitioning assessments. Technological advancements open up the possibility of monitoring marine species that were neglected before through, for example, the passive acoustic monitoring of marine mammals [231,232], animal-borne telemetry systems such as the Integrated Marine Observing System's Animal Tracking Facility [233], and video-based sampling methods [117].

Data collectors need more guidance on the choice of tool, which should be determined by the goals of the monitoring scheme, the indicators being measured, the target taxa, biome and habitat type, and the available capacity and budget [228]. More lessons and the pros and cons of different tools, as well as the advantages of using tools together in integrated monitoring systems, need to be shared to help people learn and choose what is right for their needs.

Technological and software developments are gradually reducing the time required to analyse data and should be applied wherever possible. For example, the use of machine learning is making progress in the analysis of camera trap images [234], as well as in the identification of fish species using underwater video footage from drones [235], and in the use and exchange of data for coral reef monitoring [236]. Artificial intelligence tools are progressively being integrated into web-based platforms that aid all steps of camera-trap monitoring, from cloud storing and filtering of blank images, to species annotation and soon-to-come automatised analytics [237,238]. Image-based identification systems running as mobile applications on smartphones have the advantages of accessibility and portability. The apps can partially address the shortage of taxonomic expertise, especially in less developed countries [239].

While many of the main technological advances in species monitoring have favoured larger animals and risk perpetuating existing data biases [228], some emerging technologies are helping with smaller taxa. For example, computer vision, radar and molecular methods are improving insect monitoring [240]; eDNA is also powerful for smaller organisms [154].

We are gradually seeing the corporate sector implement and support new monitoring technologies too. Examples include Nespresso working with the Cornell Lab of Ornithology to monitor birds around coffee farms using passive acoustic recording devices [241]. Oil and gas companies are using eDNA in environmental management activities [242]; for example, in Australia eDNA is being used to determine impacts from oil and gas platforms at sea [243]. Underwater cameras have demonstrated their scope to improve monitoring of fisheries [244]. Unilever is in the process of tracking and mapping its impact on forests through identifying palm oil commodity sourcing using spatial data and analytics [245].

4.4. Enhance Adoption of Best Practices in Data Collection, Sharing and Use

All stakeholders need to be more thorough in following best monitoring practices. Adopting the pressure-state-response-benefit indicator framework, as applied for the CBD and the SDGs and as advocated for the business sector [37], will help tell a story through linked measures. Use of scalable goals and linked indicator frameworks, sensu Sparks et al. [31] and Stephenson [2], allows the monitoring of responses, pressures, biodiversity state and benefits to people along a project's theory of change, facilitating the identification of actual and potential reasons for success [246]. Using similar, harmonised indicators, such as those proposed for the CBD [24] or EBVs [26,247] including marine EBVs [248], across projects and organisations will also help share data and aggregate results. Flexibility should always be maintained to adapt to local and regional data needs while maintaining a set of core measurements for comparison across regions.

The monitoring of pressures is especially important in ensuring the success of species conservation projects [249], and only through measuring a change in state of biodiversity (improving population levels, health or conservation status) can we measure true impact [2,250]. Monitoring schemes need to make more effort to include benefit indicators, and use standard methods such as Basic Necessities Surveys [251] and other household surveys [252] to assess how conservation has impacted local people's livelihoods.

Stakeholders need to explore ways of including indigenous, traditional, local and under-utilised ecological knowledge in the mix of data collected and used, building on examples seen, for example, in monitoring forests and carbon [253,254] and taking account of the caveats involved [255]. Implementation of the SDGs should encourage more "regular, standardised data collection", as well as the integration of indigenous and traditional knowledge [134]. Various tools of relevance exist. Since local people living with wildlife in remote locations are often the first to notice changes in their surroundings, the pooling local expert opinion (PLEO) method [256], helps wildlife managers understand the status of wildlife populations in a quick and reliable way by tapping into that local knowledge without having to conduct animal counts. This provides opportunities for collaboration between researchers and local communities [255,257] and complements conventional monitoring methods [258]. This example further underlines the fact that human observers and local knowledge can play a role in biodiversity monitoring just as much as new technologies.

While many conservation donors have elaborate reporting requirements for their grantees, the quality of reports and the data within them is not usually specified. Donor agencies could therefore play a more active role to encourage monitoring best practices by linking fund disbursement to the provision of adequate biodiversity data for tracking project performance and impact. Financial institutions could place similar conditions on their investments in companies.

There are a range of considerations to take into account in planning and implementing biodiversity monitoring. Key principles, based on Lindenmayer & Likens [179], Jones et al. [259] and Stephenson & Carbone [37], include:

1. Use standardised methodologies, following established protocols.
2. Integrate satellite-based and ground-based remote sensing methods with in situ observations.
3. Choose appropriate statistical approaches to allow correct inferences about change, including independent sampling and random transect selection.
4. Account for differing detectability of different species in different habitats, using appropriate software as necessary (e.g., DISTANCE for distance sampling, PRESENCE for occupancy, SPECRICH for species richness).
5. Choose appropriate monitoring frequencies based on the target species. Note that "for a rare species it is more efficient to survey more sampling units less intensively, while for a common species fewer sampling units should be surveyed more intensively" [260]
6. Apply adaptive monitoring, improving indicators as necessary and altering methods or the timing of data collection to take account of lessons learned as the monitoring work advances.
7. Ensure monitoring is applied for a long enough period of time to see long-term change in the indicators.
8. Ensure that the most effective detection methods are used.

Impact evaluations [261], including the use of randomised control trials [262] and before after control intervention (BACI) analyses [263], can be implemented to measure a project's success against counterfactuals that enhance attribution of results from project actions. Methods must always be adapted for the species and habits and biomes being measured. For example, in marine environments, a before-after gradient design may be more effective than BACI at detecting meaningful change [187]. Many social survey methods to assess community benefits also encourage the use of counterfactuals from control villages [264].

4.5. Make Data More Openly and Freely Available

Many data users need to improve internal data sharing. For example, national governments should ensure better communication of data and information between departments and ministries, which in turn could facilitate improved inter-sectoral policy coherence. Conservation NGOs should have information management systems to facilitate data flow between staff in different projects and at different management levels. Impediments to biodiversity data sharing between organisations include lack of professional recognition of scientific data publishing efforts [265], compounded by a lack of infrastructure for easy data sharing [266]. Therefore, it is necessary "to motivate and reward the contribution of data to international integrated databases by bringing such data into the mainstream of respected scientific publication" [267]. This will involve the development of "mechanisms for data citation and indices of data access comparable to those for citation systems in print journals" [268]. The IUCN Red List [91] sets a good example, where each assessment is saved and allocated a DOI (digital objective identifier) to make the data for a given species a citable publication. Several other databases, such as the Living Planet Index [269], the Global Biodiversity Information Facility [270] and TurtleNet [271], also encourage data contributions through their website. GBIF datasets also generate a DOI. Other options include working towards the mainstreaming of data papers by making the publishing of data mandatory in research project proposals and performance assessments [272], and adopting standards related to data citation, accessibility, metadata, and quality control in order to facilitate integration of data across data sets [267,273,274]. One recent example is the AZORES BIOTA collection of DATA Papers created in the PENSOFT Biodiversity Data Journal Platform [275].

Data will also be made more accessible if data sets are fused or integrated [276] and more effort is made to integrate non-Western data sources into biodiversity databases [83]. It is clear that all actors need "to collaborate in harmonising databases and platforms and in enhancing interoperability and version control between them" [113]. This will involve using Application Programming Interfaces (APIs) to enhance connections and interoperability between databases. Using standardised data management systems will also help. For example, GBIF recommends using the Ecological Metadata Language (EML) for datasets and Darwin Core for occurrence data. In addition to standardising data collection formats, meta-repositories, such as Coastwatch [277], offer the possibility of linking and translating different data bases to allow greater interoperability, as well as facilitating the search and discovery of data [278,279]. Making software for data management open access is as important as making the data itself freely available. Furthermore, greater effort is required in connecting georeferenced biodiversity data to corporate areas of operation and supply chains to facilitate science-informed decision-making by businesses.

For satellite data, policies for free and open access are important [165,280]. For example, when the US Geological Service adopted this policy for Landsat data in 2008, it led to a sudden increase in use of Landsat data, demonstrating the value of open data policies which have been followed elsewhere, such as by the European Copernicus Programme. Because satellite-based remote sensing of biodiversity requires good in situ data for ground truthing, more open and accessible in situ data would improve SRS-derived products and increase their geographic scope.

FAIR Data Principles have been developed [281,282], featuring 15 facets corresponding to the four letters of FAIR: Findable, Accessible, Interoperable, Reusable. If FAIR principles were implemented more widely there would not be a data sharing or access issue. Making data shareable may mean ensuring proper standards are met. It also means an appropriate host for the data must be found or the potential provider must host it themselves. Social factors are at play. For example, a potential provider may feel they have not yet extracted full value from the data, or they may fear criticism if faults are detected in the data. Improving publishing practices, including waiver of open access charges, as well as information management and archiving, would also help make monitoring results more accessible for policy development and decision-making. However, this will require a change in the way databases are funded and the business models employed. For example, it is estimated that USD 12 million are required annually to maintain four global biodiversity databases: The IUCN Red List of Threatened Species, Protected Planet, the World Database of Key Biodiversity Areas, and the IUCN Red List of Ecosystems [283]. These databases are of immense use to all stakeholders, including the business sector [37,284], so a better way of sharing the costs will be needed if open access is to be ensured.

4.6. Provide and Disseminate Guidelines and Tools and Share Lessons in Their Use

Several guidelines, principles, tools and indicator sets have been developed for different sectors that, if rolled out at scale, could help improve monitoring. Table 1 presents some examples.

Table 1. Some examples of standards, guidelines and tools that, if rolled out at scale, could help improve biodiversity monitoring across stakeholder groups in different biomes.

Guideline/Tool	Lead Agency	Reference
Conservation Standards	Conservation Measures Partnership	CMP [250] [1]
PRISM–Toolkit for evaluating the outcomes and impacts of small/medium-sized conservation projects	Cambridge Conservation Initiative	Dickson et al. [285]
GCOS Monitoring Principles	GCOS–Global Climate Observing System	GCOS [286]
GEO Handbook on Biodiversity Observation Networks	GEOBON-Group on Earth Observations Biodiversity Observation Network	Walters & Scholes [287]
Ecological Census Techniques	University of Cambridge	Sutherland [288]
Design and Analysis of Long-Term Ecological Monitoring Studies	University of Cambridge	Gitzen & Millspaugh [289]
Fungi inventory and monitoring methods	Various	Mueller et al. [290]
General Ocean Survey and Sampling Iterative Protocol (GOSSIP)	Nekton and others	Woodall et al. [291]
NESP guidelines for BRUVS sampling	National Environmental Science Program-Australia	Bouchet et al. [292]
Spatial Monitoring and Reporting Tool (SMART)	SMART Partnership	SMART [293]
Guide2.0 to the Modified Basic Necessities Survey	Wildlife Conservation Society & USAID	Detoeuf et al. [251]
Natural Capital Protocol-Biodiversity Guidance & Navigation Tool	Capitals Coalition	Capitals Coalition [294]
Guidelines for Planning & Monitoring Corporate Biodiversity Performance	IUCN	Stephenson & Carbone [37]
Science-based Targets for Nature Initial Guidance for Business	Science-based Targets Network	SBTN [295]
Biological Diversity Protocol	Biodiversity Disclosure Project hosted by Endangered Wildlife Trust	Endangered Wildlife Trust [296]

[1] Related guidance includes Stephenson & Reidhead [297], Salafsky et al. [298], WWF-Chile [299] and Salafsky & Margoluis [300].

There needs to be a more concerted effort to share lessons and case studies from implementing biodiversity monitoring schemes [1,2,301] and from developing monitoring capacity [208]. Data users may be more encouraged to adopt best practices and use key guidelines and tools if they see them in action, have access to other users' lessons and experience and can understand which ones are relevant to them.

There are several case studies to build on. For example, the Conservation Measures Partnership [302] maintains an online open access library of case studies and examples of products produced using the Conservation Standards. Conservation Evidence [303] and the Collaboration for Environmental Evidence [304] maintain online libraries containing systematic reviews and various evidence of the effectiveness of conservation actions which can help people decide what approaches to take and what responses to monitor. Similar libraries are also maintained for some business sectors. For example, the WREN Knowledge Base [305] shares over 3,600 documents related to the environmental effects of land-based and offshore wind energy, many of them geotagged and viewable on a map viewer function. Many of the papers in the database include data that may be of use for monitoring. Similarly, the UK government shares data in this sector through the Marine Data Exchange [306].

In Chile, some government departments and NGOs have adopted common approaches, following key guidelines. The Conservation Standards have become one of the main tools adopted to ensure robust planning and monitoring of different conservation strategies. For example, in 2017, the National Forest Service (CONAF) adopted the standards as the main methodological framework for planning, management, and monitoring of the National System of Wild Protected Areas. WWF-Chile has also used the Conservation Standards since 2011, not only as a reference for designing and managing its conservation project portfolio, but also to strengthen capacities and increase civil society participation. The "Guide for Planning and Managing Marine Protected Areas with Local and/or Indigenous Community Participation based on Conservation Standards" produced by WWF-Chile [299] has facilitated access to monitoring tools and practices, which will improve stakeholder participation in the planning and monitoring of protected areas and other effective area-based conservation measures.

International organisations and NGOs need to follow the examples set by the likes of Conservation International [307], Durrell Wildlife Conservation Trust [308], IUCN [301] and WWF [297] and publish the details of their own indicators and monitoring schemes and the lessons learned of relevance to others. This may also encourage a more harmonised approach to monitoring in the civil society sector and enhanced collaboration on data collection and sharing.

The IUCN Species Survival Commission (SSC) is a global network of scientists and volunteer experts who support delivery of IUCN's mission. The SSC produces and promotes various tools relevant for monitoring through its specialist groups. For example: the IUCN SSC Species Monitoring Specialist Group provides access to databases on global datasets for monitoring [309] and on species monitoring schemes [310], as well as a list of key monitoring tools and guidelines [311]; the IUCN SSC Conservation Planning Specialist Group [312] provides a selection of science-based tools including the Species Conservation Toolkit; the IUCN SSC Marine Turtle Specialist Group [313] has a webpage for research and management techniques that includes population and habitat assessment techniques and data collection techniques; the IUCN SSC Primate Specialist Group published guidelines for monitoring great apes [314]; and the IUCN SCC Seahorse, Pipefish and Seadragon Specialist Group [315] encourages collection of seahorse records through the citizen science webpage and app iSeahorse.

4.7. Increase Corporate Sector Engagement in Biodiversity Monitoring

The impacts of business on biodiversity are significant, through both direct operations and supply chains. The economic value of ecosystem services is around USD 150 trillion and the decline of ecosystems is costing the global economy USD 5 trillion a year [18]. While companies are starting to engage in biodiversity monitoring, there is a need for them to ramp up their investment to map, trace, and manage their impact on biodiversity in their operations and along their supply chains. Doing so will help them not only mitigate their impact on biodiversity loss and adapt to it, but also consider how to regenerate nature and build resilience.

Frameworks, such as the Taskforce on Nature-related Financial Disclosures or TNFD [316], assess the risk of nature loss for business through their dependencies on nature, and at the same time identify business opportunities as investments for moving into nature positive outcomes. These types of framework enable companies to integrate nature into decision-making, and are especially useful for the investment and insurance community.

Many businesses, such as those in ecotourism, agriculture and food commodities, have dependencies on biodiversity, relying on healthy and productive ecosystems for their operations [317]. For example, production of many crops is dependent on the pollinator services provided by insects, valued at 235–577 billion USD [318], and soil health driven by fungi and microbe. The presence of native forests, birds and other animals can enhance the volume or quality of crops such as coffee and wine grapes [319,320]. This further emphasises the need to monitor species and habitats and collect and use spatiotemporal biodiversity data.

Stephenson & Walls [17] note signs of change, with many companies shifting towards a new “biodiversity paradigm”. These signs include businesses being more engaged with, and integrated into, global biodiversity processes than they were a decade ago and having access to a growing selection of harmonised guidelines and tools. Companies are also increasingly disclosing environmental information. Such non-financial corporate sustainability reporting and disclosure remains largely voluntary, but mandatory disclosure and regulation is rapidly on the rise. For example, in Europe 104 voluntary and 141 mandatory sustainability disclosure provisions existed as of 2020 [321].

The emphasis for companies should not only be on mitigating negative impacts on biodiversity, but also on moving towards nature-positive solutions if we are to address biodiversity loss effectively. Key recommendations from Stephenson & Walls [17] include the need for companies to work with scientists and bodies such as IUCN, the Natural Capital Coalition and the Science-based Targets Network to develop science-informed biodiversity goals, move toward a nature-positive agenda linking biodiversity and climate change, improve reporting frameworks, and leverage new forms of data and technology.

Specifically, there is an urgent need to design metrics of biodiversity that work for business and facilitate pragmatic planning and decision-making, learning from the conservation community and adopting similar indicators [17]. This means reducing the complexity of biodiversity monitoring approaches and working towards a convergence of measurements across the many different types of reporting criteria and tools. In particular, businesses need to build skillsets for the use of geospatial and spatiotemporal data, either through building capacity internally and through business schools, or by hiring experts from the environmental sciences sector, as investment and insurance companies are doing. Businesses rallying around the new CBD indicators would be a good start.

One feasible way for business to learn about biodiversity is via partnerships, and they are actively encouraged to work with NGOs and academic institutions on biodiversity [37]. Certification bodies can also help. For example, the Forestry Stewardship Council functioned as a bridging organisation for social learning among forestry companies in Chile [322] which have developed strong monitoring systems around biodiversity of high conservation value areas [323]. NGOs can facilitate a process of dialogue for businesses to re-evaluate how they approach biodiversity issues and collaborate with them in developing ways to address challenges related to biodiversity [324].

In addition, local communities can organise themselves to connect with local and global businesses to conserve regional ecosystems. For example, traditional communities of women in the Brazilian Amazon rainforest use community organising to develop activities around labour, products, and knowledge that allow them to build relationships with businesses and support biodiversity conservation [325]. Corporate engagement could also help resolve some monitoring capacity and resource issues, as some companies have larger budgets for data collection than NGOs and international conservation organisations. Companies can also help create fora for setting joint commitments and for lesson and information exchange [326,327].

Very little research exists in management journals on biodiversity governance and management but the interest amongst business scholars is growing. Research on biodiversity governance in accounting and environmental journals has a somewhat longer tradition and tends to focus on legitimacy or the company’s license to operate [328], or capturing the quality and quantity of biodiversity disclosure [199] or the strategies used to downplay their impact [329].

Businesses now have more opportunity than ever before to contribute to global biodiversity goals. For example, CBD’s draft Post-2020 Target 15 specifically commits businesses to increase positive impacts, and many companies are already committing to contribute to the SDGs. More tools, guidelines and indicators for the corporate sector are also being developed and tested. One key to ensuring success in corporate engagement on biodiversity is for companies to learn lessons from the conservation community and adopt many of the same planning approaches and indicators as governments and conservation agencies [17,37,330].

4.8. Engage More People in Biodiversity Data Collection

In addition to engaging the corporate sector, another way to improve biodiversity monitoring would be to increase the number of people involved in data collection. For example, schools and universities could run more practical field courses that, while training students in monitoring techniques, collect and share the data generated. This is the plan, for example, with the project led by the Centre for Biodiversity Conservation Research with support from the IUCN SSC Species Monitoring Specialist Group, where University of Ghana courses support protected area monitoring [71]. The project supported the University of Ghana's Department of Animal Biology and Conservation Science to develop a field manual that guides practical training of students in field techniques for biodiversity data collection and analysis. The systematic approach not only ensures that students will acquire relevant biodiversity monitoring skills, but also that data are collected systematically and regularly, and made available to protected area management to inform management interventions. In South Africa, Stellenbosch University encouraged high school students to participate in ant monitoring schemes in the Cape Floristic Kingdom [331], and children as young as 9 years old collected camera trap data on mammals in schools in India, Kenya, Mexico and the USA [332].

Citizen science, where people who are not trained scientists collect and share data, fosters communication and collaboration among local residents and scientists and is increasingly cited as an important means of acquiring biodiversity data [7,333]. The involvement of citizen scientists encourages more of a bottom-up as well as top-down planning of monitoring systems, integrating more data user needs into monitoring systems [113,334]. While most citizen science programmes originated in Europe or North America, there are growing examples of schemes collecting data in high-biodiversity tropical countries [7]. For example, Wotton et al. [213] collected data on bird populations in three African countries and demonstrated that, with technical support and modest investment, meaningful biodiversity indicators could be measured (Box 3). In Palau, a citizen science programme for scuba divers provided similar shark population estimates to scientific telemetry data [335].

Some of the newer monitoring technologies also lend themselves to citizen science approaches [228]. Camera trapping, in particular, offers opportunities for citizen scientists to collect data on species presence [332] or help analyse the images collected by scientists [336]. Acoustic monitoring schemes actively involve volunteers in several countries, including Canada, France and Japan [337]. "Community engagement with eDNA is feasible" [338]. For example, in New Zealand, the Wai Tuwhero o te Taiao–Open Waters Aotearoa [152] is an eDNA citizen science database where the local community is provided with eDNA test kits and then maps the results on an open access platform used by national and local government, researchers, industries and community groups. Since the early 1990s, Costa Rica has used para-taxonomists or 'barefoot scientists' to help collect floral, faunal and fungal data and work with international scientists to do a biodiversity inventory [339,340]. This work contributed to ecotourism and the conservation of tropical biodiversity [341,342]. The data and collections generated are now the basis for barcoding to enable eDNA analyses [343].

While a suitable enabling environment, such as the availability of scientists to coordinate data collection and the assessment of local data users' needs [7,344], are essential prerequisites for success, citizen science offers many possibilities. It may also be a suitable way to integrate local and indigenous people into data collection, as well as employees of companies keen to promote sustainability. For example, an Australian government programme for the conservation of flatback turtles involves businesses and indigenous people in data collection [345]. Set up as a 60-year, large-scale conservation programme funded by industry as an offset for likely biodiversity impacts of a major commercial project, priorities for the research, monitoring, education and threat mitigation components include the promotion of engagement, employment and training of indigenous people, ensuring opportunities for education and participation. The industry partners also contribute to the monitoring of turtle nesting beaches.

When properly designed, local monitoring schemes can yield reliable, locally relevant results and reinforce existing community-based natural resource management systems. They can also enhance collaboration between indigenous people and protected area authorities and lead to more socially acceptable and effective approaches to law enforcement [346]. Furthermore, locally derived data have considerable unexplored potential to elucidate global patterns of change in the status of populations and habitats, the services they provide, and the threats they face. However, more effort is needed to develop effective modalities for feeding locally derived data up to national and international levels.

While citizen science is, by definition, a local process, several global citizen science data collection schemes exist, such as eBird [74], Wildlife Insights [73] and iNaturalist [128], that collate data from around the world using freely available applications running on standard mobile devices. These schemes should be promoted but they also need to strive to be more taxonomically and geographically inclusive in the data collected and orientate more towards potential data user needs. NeMO-Net [347], developed by NASA, is an example of an app-based system that allows global users to participate in analysing remote sensing imagery of coral reefs to train supercomputing machine learning to characterise subtidal reef ecosystems and track impacts such as bleaching events.

4.9. Make and Sell the Case for Monitoring and a Results-Based Management Culture

Monitoring should be standard best practice for project management. However, several authors have suggested that its application requires key enabling conditions to be in place which, besides the obvious pre-requisite of resources and capacity, include a suitable results-based management and lesson-learning culture [2,185,348]. Such a culture could be defined as an openness to use and share data and lessons, and create a safe environment to fail. Many donors would rather a conservation project reported a challenge or problem that could then be addressed through adaptive management than sharing only good news stories and successes (PJS, personal observation).

Since attaining results-based management is largely an organisational rather than a technical challenge [349], the first step is making a strong case for its adoption. Part of making such a case is elaborating on (and providing examples of) the importance of: demonstrating conservation outcomes and impacts rather than outputs and activities (to demonstrate what difference you are making); adaptive management and lesson learning (to adapt and improve your conservation delivery); non-financial disclosure for businesses that is oriented towards measuring impact (to reflect corporate sustainability, reduce risk and regenerate nature); and investing appropriate resources in monitoring (to ensure funds and energy are not wasted on ineffective actions).

Stronger arguments are needed as to why a larger selection of taxa need to be monitored (Box 4). In some cases, any efforts to make an argument for monitoring will need to be preceded by a concerted effort to raise awareness of why organisms other than large mammals, birds and trees need conserving. People are unlikely to monitor fungi and insects, for example, if they do not understand the need. There also needs to be more effort to promote taxonomic inclusivity in conservation monitoring; a start would be to encourage wider adoption of the term “fauna, flora and funga” [350–352].

Box 4. A sample of reasons why neglected taxa need to be monitored. Note that these are a random selection of examples to highlight key issues, not an exhaustive list.

Inter-relationships between taxa. The health of most trees and shrubs is dependent on biotrophic relationships with mycorrhizal and endophytic fungi. These relationships increase plant nutrition and health through increased disease resistance, drought tolerance and reduced predation [353,354]. In turn, some fungi are dependent on mammals for their dispersal and so fungal and floral survival is linked to these mammals. For example, Australia has the highest rate of mammal extinctions of any continent [355]. Many of the extinctions have been small ground-dwelling marsupials, so called 'ecosystem engineers', including bettongs, potoroos and bandicoots [356], whose digging contributes to decreased flammability and increased nutrient cycling and seedling growth [357]. In addition, since these marsupials are adapted to eat fungi, particularly truffle-like fungi, they play a key role in dispersing fungal spores. The conservation of fungal specialists is therefore imperative to maintaining ectomycorrhizal fungal diversity and healthy plant–mycorrhizal relationships [358]. If land managers better understood the beneficial relationships between plants, fungi and mammals, and the threats they face, they might be more motivated to monitor them.

The importance for ecosystem services. Cardoso et al. [8] noted: "Describing and understanding the roles and ecosystem services provided by different species could help linking invertebrate conservation with human well-being. This link is critical for increasing the public, political and even scientific support for invertebrate conservation . . . Only by preserving all species and guaranteeing interactions and ecosystem services may we reach the goal of overall biodiversity conservation." Data on pollinating insects has already demonstrated their value to humans through the ecosystems services they provide and the importance of their conservation. While crops dependent on pollinators such as insects contribute to 35 per cent of global crop production volume, in Europe alone populations are declining for 37 per cent of bees and 31 per cent of butterflies [318]. Poorly studied cetaceans also play key roles in their ecosystems that have implications for overall ocean productivity, as well as potentially for carbon storage and sequestration. These roles include "effects on ocean productivity from moving oceanic organic matter and nutrients vertically in the water column and horizontally from foraging grounds to nutrient poor, low latitude feeding grounds, a local increase of primary production through contribution to marine biogeochemical cycles, and predator-prey relationships" [8].

Potential commercial value. Understanding a broader selection of taxa will help identify opportunities for discovery of novel bioactive compounds for use in areas such as nutraceuticals, pharmaceuticals, and bioremediation. Approximately 53% of all approved anti-tumour drugs are either natural products or directly derived therefrom [359]. Naturally derived compounds also account for significant proportions of approved anti-microbial, anti-fungal and anti-viral pharmaceuticals.

To encourage monitoring a broader range of taxa, awareness will need to be raised in specific target groups of data users. For example, the editors and referees of scientific journals should be encouraged "to consider their own biases–including their level of interest in different kinds of organisms–when they evaluate manuscripts during the peer-review process" [87]. In addition to publications, grant-making schemes should also ensure that decisions on scientific quality are made by groups of people that encompass a diversity of taxonomic expertise. This suggests a rethink on how governance bodies are selected with more taxonomic inclusion essential if we are to address ongoing data biases.

Cost-effectiveness will obviously be key to the argument for more and better monitoring. The first excuse for inaction will be that there is no money. However, if every project increased the proportion of its existing budget, we would have significantly more data from existing resources [2]. Furthermore, less popular species could be integrated into many existing monitoring schemes at relatively low cost (see above). Monitoring is not necessarily expensive. For example, one estimate suggests that initiating integrated monitoring programmes for selected plant and animal species in sub-Saharan Africa could require as little as USD 50,000 per country per year [360]. Citizen science schemes may be as little as USD 30,000 per year [213]. Furthermore, many new monitoring technologies cover larger areas while costing less in training and labour costs [229].

The efficiency of monitoring will be another factor for cost-effectiveness. We cannot monitor all species everywhere so priorities will need to be developed. Criteria need to be agreed by key actors across sectors for identifying priority species for monitoring. The CBD Secretariat could take the lead. Criteria could include, for example: species identified as national, regional or global priorities (e.g., in NBSAPs and MEAs), especially where these relate to statutory requirements that will influence government and NGO monitoring needs (e.g., species that need to be monitored under the EU Habitats Directive); species that are the focus of conservation work; species being utilised to ensure sustainability (e.g., mesophotic fish that are the target of new fisheries); species listed as Data Deficient in the IUCN Red List or those close to being up-listed or down-listed; evolutionarily distinct and globally endangered species-phylogenetic and conservation priorities defined by the Zoological Society of London (ZSL) EDGE of Existence Programme [361]; functionally important species (especially for ecosystems that have limited functional redundancy such as polar systems); migratory species or transboundary populations requiring internationally coordinated conservation efforts. Return on investment could be maximised by focusing on clusters of similar species where tools can monitor multiple taxa at once.

We also need to demonstrate the transformational impact data can have. For example, the Great Barrier Reef Marine Park Long Term Monitoring Programme was largely established to document coral cover and quantify fish abundances. However, the synthesis of data collected over a decade of monitoring unveiled the role that protection from fishing played in not just increasing the diversity and abundance of fish, but in building resilience to climate change [362]. The role of such large scale unreplicated natural experiments (LUNEs) underpinned by monitoring data is increasingly recognised [363]. Another example is that monitoring protected area coverage, as well as species populations within protected areas, has helped demonstrate the failure of the previous CBD global protected areas target to conserve biodiversity [364]. In turn it has led to calls for more ambitious post-2020 targets that ensure more successful protection of habitats and species [160,365]. Monitoring data are therefore helping make the case for new and improved global biodiversity goals.

It is important to set up long-term monitoring systems and reinforce existing long-term monitoring systems now so that data are available in the future. In doing so, we need to make sure that the perfect does not become the enemy of the good. We will never be able get perfect data sets on all species. For example, for many marine species, we will likely never have the data needed to detect significant declines in time to act and turn around trends. Insisting on evidence in some cases could stall conservation efforts and hinder government investment in threat mitigation measures. Therefore, we need to demonstrate how incomplete data can still be used. This highlights the value of processes such as Red List assessments of species that can still provide useful measures of conservation status without perfect data sets; indeed, the Green Status of Species [366] allows scope to develop counterfactuals by using expert views when data are lacking.

There remain a number of commonly encountered myths and commonly repeated excuses about why monitoring is not relevant or important and these need to be countered if we are to make a strong case. For example, findings from one study into conservation practitioners' opinions and experiences found that the reasons people felt they were unable to demonstrate conservation impact included not having the right tools "to effectively assess conservation initiatives because progress is not fast or linear and therefore impacts can be difficult to measure" [367]. They also noted that "reasons for success may not be obvious, making it difficult to define and report on them", leading the authors to conclude that "there is no satisfactory method for measuring impact consistently or attributing benefits to specific interventions" [367]. Such findings have been labelled "oft-repeated excuses" that fail to take account of the numerous monitoring tools and approaches that exist [246] (Table 2). Clearly, any argument needs to dispel key myths and excuses.

Table 2. Debunking some common monitoring myths and excuses encountered by the authors.

Myth/Excuse	Reality
Monitoring wastes limited conservation resources	Monitoring in parallel with conservation efforts demonstrates what works and what needs changing, thereby ensuring conservation resources are not wasted on ineffective actions.
Available monitoring and data management methods are inadequate	There is an abundance of guidance on monitoring methods and tools to collect data (see the earlier sections of this paper). There are also comprehensive standard data management systems (e.g., Darwin Core; Ecological Metadata Language-EML) that facilitate pooling of data, as well as computer assisted algorithms and systems for data cleaning.
Impacts (changes in biodiversity state) are too difficult to measure	In small, short-term projects, outcomes measured by a change in pressure may be adequate, but most projects should be able to monitor changes in biodiversity state if an adequate proportion of the budget is set aside for data collection.
You cannot attribute your impact so why bother measuring it	Attribution should be considered "an aspiration not a hindrance" [2]. There are three main ways of dealing with it: you can provide evidence of the impact of your actions by demonstrating what happened where conservation was not applied (using counterfactuals); by relating your results to a theory of change you can show that what was expected to happen is happening, and make assumptions about the impact of your actions; if you look at similar projects applying similar strategies and demonstrating similar results, you can infer the impact of your actions.
Change does not happen fast enough to detect	Ensure monitoring systems are planned to take account of the questions asked and the time required. If the project lasts less than 3 years, monitoring may be better focused on outcomes and outputs. However, at least some change will be measurable in a project's lifespan.
Long-term monitoring is too expensive	This does not need to be the case. There are more and more initiatives for frugal monitoring, especially using open access technology and data. Monitoring also does not have to cover everything at once-there is value in using an incremental approach when developing long-term monitoring, starting with the taxa of highest priority for data users.
Monitoring is not material to business	Without using appropriate measures for monitoring, businesses are missing key data to assess their materiality and impacts on nature. Partnerships and data sharing can help reduce costs and result in better materiality assessments.
Addressing climate change is more urgent than addressing biodiversity loss	Climate change and biodiversity loss are interlinked and mutually reinforcing; climate change causes species and habitat loss and species and habitat loss exacerbates climate change. Both processes threaten all life on Earth and the ecosystems services we all depend on. Therefore, they need to be tackled together and monitored. Nature-based solutions [368] are critical to fighting climate change.

A cultural change is required among the organisations that contribute to the conservation of species, from governments to NGOs to businesses, so that they see the value and connection between monitoring and an increase in the effectiveness of the conservation interventions they are promoting and implementing. Only through monitoring is it possible to collect evidence that allows for the review and adjustment of the conservation decisions that are being made. Donors and investors need to ensure monitoring budgets are funded and become stricter at holding project managers accountable, while at the same time allowing the space to fail, learn and adapt [246].

5. Conclusions

We have summarised a number of long-standing problems with biodiversity monitoring that need to be addressed urgently. While many are undeniably challenging, we have proposed nine recommendations to help resolve them. Key actions needed include capacity building, especially for monitoring neglected taxa in high-biodiversity countries, scaling up the use of new technologies and monitoring best practices, enhanced sharing of data, and the rollout of suitable guidelines and tools. This will include the making and selling of a strong case for enhanced biodiversity monitoring and engaging more people in data collection, especially through citizen science and increased corporate sector involvement. Such advances will require action from all the key public, private and civil society stakeholders and needs to be a global effort if we are to succeed in enhancing data collection and use and improving biodiversity conservation.

However, we are not starting from scratch and there exist numerous efforts worldwide that can be built on, as highlighted in many of the sections above. In particular, we would underline the important opportunities provided by MEAs and their associated global biodiversity targets for rallying interest, and the range of modern monitoring tools and technologies becoming available. Several global databases, regional databases and specialised databases for specific taxonomic groups also help provide a solid foundation to start from.

We also need to build momentum from the good signs we see. For example: since 2000, there has been a sharp increase in the number of new species monitoring schemes in lower- and middle-income countries and in megadiverse countries [82]; corporate disclosures to the CDP (previously the Carbon Disclosure Project) on the topics of water and forestry increased dramatically from 2010 to 2020 [17]; investment, insurance and business data companies are starting to ramp up their in-house GIS expertise.

There is also a lot of technical expertise and knowledge available to move us forward in key programmes, institutions and partnerships. Such data management and support bodies (Figure 1) helping find monitoring solutions and drive change include research and academic institutions as well as international organisations like IUCN, the Group on Earth Observations Biodiversity Observation Network–GEOBON, the UN Environment World Conservation Monitoring Centre, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services and the World Business Council for Sustainable Development. Several regional data hubs like CONABIO in Mexico and SANBI in South Africa are providing the means for local change. There are also several standardised approaches to monitoring that can be rolled out worldwide (Table 1).

There are several well-established national protected areas monitoring schemes and associated guidelines to build on, from New Zealand [44] to Nepal [369] to the Philippines [370] to the USA [42]. For Brazil, the Brazilian Biomonitoring System of Protected Areas–the Monitora Program–assesses the effectiveness of the national protected areas networks through in situ biodiversity monitoring. Managed by the Chico Mendes Institute for Biodiversity Conservation–ICMBio, the programme covers all biomes (marine, aquatic and terrestrial) and focuses on 24 monitoring targets, including species of birds, mammals, fish, frugivorous butterflies, Odonata, plants, sea turtles and others. The status of different biodiversity metrics is accessed from a set of minimum modular common protocols [371], applied by data collectors with varied educational levels. This is just one example of where existing national efforts can be built on and expanded.

There is also a growing volume of work to address neglected taxa. For example, islands have a disproportionate number of unique species and Borges et al. [1] proposed a Global Island Monitoring Scheme for the long-term coordinated monitoring of forest biota across islands. As well as standard methods for monitoring certain arthropod taxa (e.g., butterflies [372]), quantitative methods are now available based on standardised approaches [373] to monitor several ecosystem processes that depend on the activity of arthropods, such as natural pest control, pollination, herbivory, seed predation and decomposition. Countries with active trades in wild fungi for food are being encouraged to engage in responsible trade practices like the FairWild's certification scheme for fungi [352]. Furthermore the connections between food and fungi are being used as an educational opportunity to raise awareness of the importance of the ecosystem services provided by fungi.

Citizen science continues to expand. For example, approximately 10 million observations are added monthly to eBird [113]. Similarly, several camera trapping schemes have been coordinated by volunteers through "Snapshot" projects in the US and Europe [238] and machine learning is being applied to citizen science identification of camera trap data through ZSL's Instant Wild platform [374]. The RedMap has compiled continental scale citizen science data on range shifts of a wide diversity of marine taxa [129]. There is clearly scope for more people to help with monitoring.

With governments soon to commit to the post-2020 global biodiversity framework, and more businesses adopting biodiversity guidelines and standards, the time is right to make a concerted push on monitoring. However, transformative action is needed now and at scale if we are to enhance results-based management adequately to conserve the biodiversity and ecosystem services we all depend on.

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