A Global Biodiversity Observing System to unite monitoring and guide action

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Short summary

The rate and extent of global biodiversity change is surpassing our ability to measure, monitor and forecast trends. An interconnected worldwide system of observation networks – a global biodiversity observing system (GBiOS) – can meet this need by coordinating monitoring worldwide and guiding action to reach international biodiversity targets.

The Kunming-Montreal Global Biodiversity Framework (KM-GBF) provides a vision for living in harmony with nature that will have lasting benefits for humanity[1]. Attaining this vision will require ambitious and urgent action to address the drivers of biodiversity loss and improve conservation action needed to avoid the enormous social and economic costs of ecosystem degradation[2]. This will require understanding where, why, and how fast biodiversity is changing: something we have limited knowledge of today for much of the planet.

An essential part of the KM-GBF is its monitoring framework (see CBD/COP/15/5), which includes a set of indicators which will be used by nations to monitor and report their progress toward the framework's targets and goals. The indicators track actions and policies implementing the framework (such as protected area establishment) and those reducing the drivers of biodiversity loss (pollution abatement, for example). The indicators rely on monitoring to measure the outcomes for nature and people over time (e.g., measures of ecosystem service provisioning) and the risks of losing the benefits we get from nature. Aggregation of the indicators at the national level will provide insight into progress at regional and global levels. However, disparities among nations in the access and use of biodiversity observations and knowledge means that the global community is not adequately equipped to meet the information requirements of the monitoring framework[3].

To address this gap, we as members of the Group on Earth Observations Biodiversity Observation Network (GEO BON) and its partner institutions, propose the establishment of Global Biodiversity Observing System (GBiOS) that will initially interlink existing capacities and organizations to monitor how, where, and why biodiversity is changing[4,5], and progressively grow to guide the action needed to realize the targets and goals of the KM-GBF[2].

Biodiversity observations at the science-policy interface

To achieve the goals of the KM-GBF, four key components are needed to bridge science and policy: i) biodiversity observations guided by policy needs; ii) observations coordinated to form monitoring programs designed to rapidly detect change and attribute causes for biodiversity change[6]; iii) observations informing models to project biodiversity change and the loss of ecological and evolutionary resilience[7]; and iv) frequent assessments derived from monitoring to provide policy options to guide action[8]. Currently the international biodiversity science-policy interface lacks all four of these components, and so the delivery of policy-relevant knowledge about biodiversity change is slow relative to the timeline set out by the KM-GBF.

The weather forecasting and climate assessment communities have had all these components provisioning scientific knowledge to policy action for several decades. This includes daily weather forecasting, the Intergovernmental Panel on Climate Change (IPCC) created by the World Meteorological Organization (WMO) for scientific climate assessments, and the Global Observing System (GOS) to organize the international and interagency long-term strategies for operational collection of climate-relevant observations at multiple scales.

In 2012, the nations of the world established the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) – a mechanism to strengthen foundations of knowledge for policy setting through scientific assessments[8]. However, a GBiOS to complement IPBES as GOS does for the IPCC does not exist.

Emulating the Global Climate Observing System

We see GBiOS as resembling the model of the WMO's Integrated Global Observation System (WIGOS), which integrates observations made by national climate networks of the Global Observing System (https://public.wmo.int/en/programmes/global-observing-system), and the Global Climate Observing System (GCOS; https://gcos.wmo.int/), which maintains definitions of Essential Climate Variables required to systematically assess the status and trends of global climate. These systems were established to support the UNFCCC's Paris Climate Agreement; they are a remarkable example of international collaboration allowing billions of observations to be made and exchanged every day. The WIGOS is not a single, centrally managed observing system. Rather, it is a composite and federated "system of systems" linked via a set of climate-relevant observing, data-management and distribution systems and information services.

GBiOS would provide a similar service for biodiversity, connecting existing data repositories and networks for observations of biodiversity and its drivers. National biodiversity observation networks (BONs, see Box) will be key units making up GBiOS, just as national weather agencies and climate observing networks are key units in the WIGOS. Like WIGOS, a GBiOS would ensure that biodiversity observations, along with data on drivers of biodiversity change are updated frequently and available in standardized, interoperable, accurate and representative forms. The system would abide by FAIR and CARE data principles[9] and ensure that indigenous peoples and local communities can exercise prior, informed consent for data access.

Five critical issues GBiOS will address

A GBiOS will address five critical issues required to support the monitoring framework and actions needed to meet the targets of the KM-GBF (see also CBD/ID/OM/2022/1/INF/2):

1. **Gaps, biases, and standards in biodiversity data**: GBiOS would focus on addressing the gaps in the taxonomic and geographic coverage of biodiversity monitoring, both by mobilising existing data and in creating consistent approaches for monitoring going forward. Data repositories such as the Global Biodiversity Information Facility (GBIF) and the Ocean Biodiversity Information System (OBIS), and databases like BioTime[10] and PREDICTS[11] are the basis for progress but are not representative in their taxonomic and geographic coverage of Earth's biodiversity (Supplementary Figure 1). For example, occurrence records in GBIF and the OBIS cover less than 7% of the world's surface at 5 km resolution, and less than 1% for most taxa at higher resolutions and remain insufficient for informing about species status and trends[12] (Supplementary Figure 1). These major data gaps were highlighted in the Summary for Policymakers of the IPBES Global Assessment of Biodiversity and Ecosystem Services (Appendix 4 of the Summary). GBiOS would contribute to these databases and services by formally linking them to monitoring worldwide.
2. **Information for indicators**: GBiOS will provide data and information needed to assess progress towards KM-GBF's Goal A and Goal B on halting extinctions and sustainably managing biodiversity and ecosystem benefits. Biodiversity observations made by GBiOS can be used to estimate Essential Biodiversity Variables (EBV)[13,14] and Essential Ecosystem Service Variables (EESV)[15]. These essential variables underpin many of the indicators for these Goals and many associated Targets (e.g., Target 2, 3, 4, 6, 11, 12, 19.2, 20). The common use of EBVs and EESVs allows a harmonization of data sets collected by different governmental and non-governmental organizations across a BON so that they can be compared and combined for different purposes

including the calculation of indicators, models of biodiversity change and assessment tools such as Ecosystem Accounts under the UN System for Economic and Environmental Accounting.

3. **Understand biodiversity change across scales**: Realizing the actions needed to achieve the targets of the KM-GBF will require frequent monitoring of the drivers for trend attribution and forecasting over different scales[6]. Some drivers will be observed directly with biodiversity observations, such as invasive species occurrence and impact, but information about other drivers, such as climate, pollution, and land use change, will require coordination with other observation networks to understand and project how drivers interact to cause biodiversity change.
4. **Capacity and technologies:** A GBiOS can be used to assess where data gaps exist and guide the strategic implementation of monitoring technologies for observation (e.g., site-based observations and remote sensing) rapid classification, data assimilation for causal inference, and prediction to support action[6,7]. New data and monitoring standards that allow rapid updates of EBVs and EESVs would be available to national and subnational governments. This gap-filling process would support Target 20 of the KM-GBF prompting strategic investment in capacity-building, regional biodiversity observing technologies, data collection and curation services, and international cooperation (South-South, North-South and triangular cooperation) to share tools and knowledge for areas that need them most.
5. **Engagement across all sectors and knowledge systems**: The task of building and maintaining a GBiOS will be broadly collaborative, engaging national, subnational, and local governments and Indigenous Peoples and local communities, academic researchers, biological collections, non-governmental organizations (NGOs), businesses and the financial sector. Broad engagement will foster the mainstreaming of biodiversity information into decisions across all sectors of society[16]. Each sector has specific needs for biodiversity observations so the design and implementation of GBiOS should reflect the broad range of uses and decisions it will support and provide consistent and standardised time series data with baselines and reference conditions across ecosystems.

A federated network of biodiversity observation networks

Over the last decade, GEO BON (https://geobon.org/) supported and endorsed the establishment of BONs that are designed to help national and subnational governments monitor biodiversity (Figure 1). As an international network of ~2600 members spanning 141 countries, GEO BON convenes the expertise needed to inform and support the establishment of a GBiOS. Further, GEO BON has been endorsed by Parties to the Convention on Biological Diversity - most recently through invitation to support the operationalization of the monitoring framework of the KM-GBF (CBD COP decision 15/5).

What is a biodiversity observation network (BON)?

A BON is a network of observation sites or stations and a network of groups producing and using biodiversity data across these sites for different needs. A BON coordinates observations and monitoring to support policy and environmental legislation prompting conservation action from National Biodiversity Strategies and Action Plans. Guidelines for network establishment are publicly available (https://geobon.org/bons/bon-development/) and describe how to create an 'enabling environment' that assembles the partnerships, human capacity and scientific infrastructure needed to build a BON.

A BON can be sub-national, national, or regional in level of operation and can cover different biomes (e.g. marine or freshwaters) and dimensions of biodiversity (such as genetics, species and ecosystems), in order to fill specific knowledge gaps (Supplementary Table 1). These needs have been recognized by the formation of Marine BON, Freshwater BON, Soil BON and Omic BON. GEO BON has developed an essential biodiversity and ecosystem variables framework as a rigorous and transparent basis for monitoring trends in different facets of biodiversity across BONs[13,14,17]. EBV data layers are available from the EBV Data Portal (https://portal.geobon.org/home). GEO BON also offers 'BON-in-a-Box', a knowledge platform that facilitates BON design and implementation (https://boninabox.geobon.org/frontend/index).

Some regional networks already exist that represent collaborations among national BONs. These include the Asia Pacific BON and the European network (EuropaBON). GBiOS can be assembled as a network of national and regional networks[4].

A GBiOS would assemble an intercommunicating system of BONs and other monitoring programs[4]. In a first phase, GBiOS can be established immediately as a globally coordinated network of BONs (Figure 1); this first phase would develop a collective assessment of current capacity to observe biodiversity and ecosystem trends, with the needs to improve it including human capacity and technologies for observations and data sharing and analysis[18].

BONs can be designed to support National Biodiversity Strategies and Action Plans (NBSAPs) to guide action by parties under the KM-GBF. BONs support long-term research sites and stations conducting observations from the ground, air, water or space[19,20]. BON development may involve investment in additional monitoring capacity at new and existing sites to reduce data gaps. The addition of new sites to the BON network can reduce uncertainty in trend detection and improve understanding of biodiversity change locally and nationally and contribute information for regional and global assessments. Other sites may be chosen to acquire the information to improve models for forecasts projecting future changes in biodiversity[7]. Research centres working with BONs will provide services for supporting the use and sharing of data, trend assessments, and predictive modeling to guide decisions for conservation and spatial planning.

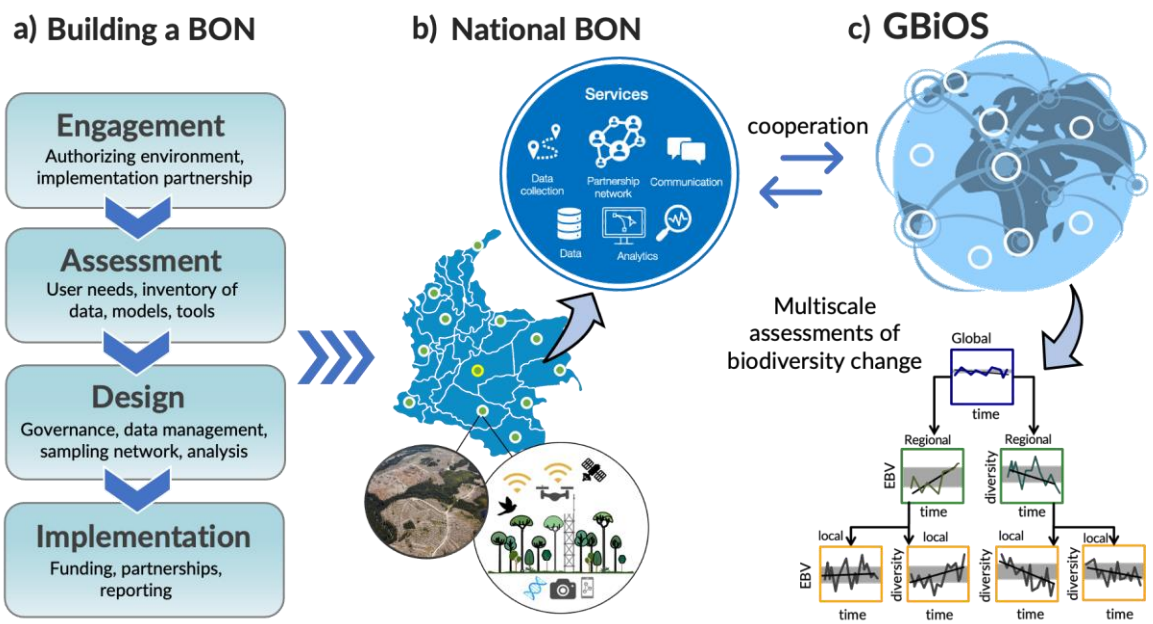

Figure 1: ***GBiOS as a global network of interconnected national and regional BONs to assess biodiversity trends worldwide****: a) Countries without a national BON can establish and implement one following the multistep process identified by GEO BON[18]. b) Each national BON (Colombia is shown as an example) follows harmonized methods and coordinated activities for biodiversity observations, data curation and sharing, trend detection and attribution, modeling, and policy-decision support that forms a BON service. c) In the proposed GBiOS, national and regional BONs (white circles) form an international network, sharing technologies and information about biodiversity trends (EBVs and EESVs) and ecological events and in so doing allowing the global community to make rapid multiscale assessments of progress toward international biodiversity targets and goals.*

Next steps

Several next steps are needed to establish the governance model, funding, the deployment of technologies and other resource needs, and investment in careers to support GBiOS activities in the long-term.

Co-sponsorship and governance: A proposal for a governance model should be elaborated along with identification of the partner organizations – from both public and private sectors – that can co-sponsor GBiOS. One option is to follow the solution taken by the GCOS that is co-sponsored by several intergovernmental organizations: the World Meteorological Organization, the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization, the United Nations Environment Programme, and the International Science Council.

Assessment of resource needs and added value: At this point, an assessment of the technical and financial investment is needed. This includes: the necessary technologies and data infrastructure (including existing large repositories such as GBIF, OBIS, GenBank) needed to support long-term monitoring and make the data available in a secure manner; mechanisms for governance and financing; and the existing national and regional BON components that can be integrated to form the first phase of the GBiOS implementation. This assessment would include the knowledge and capacity needs, and the

economic costs and benefits (return on investment) arising from an initial investment in GBiOS, followed by alternative pathways for progressive development of its capacity by 2030 and beyond.

Funding GBiOS for the long-term: Funding is required to support nations with the establishment of their BONs, to conduct standardised biodiversity monitoring and publish data into national and international data repositories (e.g. GBIF and OBIS) within weeks to months. An integrated system of observations for biodiversity will connect to observing systems for climate and other human drivers and pressures. One way to fund GBiOS would be a UN coalition fund like the Systematic Observations Financing Facility (SOFF) for GCOS. Data from GBiOS would support ecosystem accounts under the UN SEEA EA and guide investments to create local social and economic benefits and thereby deliver a major global public good. Global data production and exchange would be an important measure of success, along with use by private sector for financial disclosures and impact assessments. A GBiOS SOFF could contribute to strengthening societal adaptation and resilience across the globe, benefitting the most vulnerable peoples and countries.

A GBiOS is a key missing piece of the science-policy puzzle needed to support the realization the KM-GBF the Sustainable Development Goals, and other multilateral environmental agreements and protocols. The global community is increasingly aware of the enormous benefits society receives from biologically diverse and resilient ecosystems. A GBiOS will deliver a representative and inclusive understanding of biodiversity change. This knowledge will be critical to the effective implementation of the policies designed to reverse biodiversity loss and achieve the global goals for nature in the coming decades.

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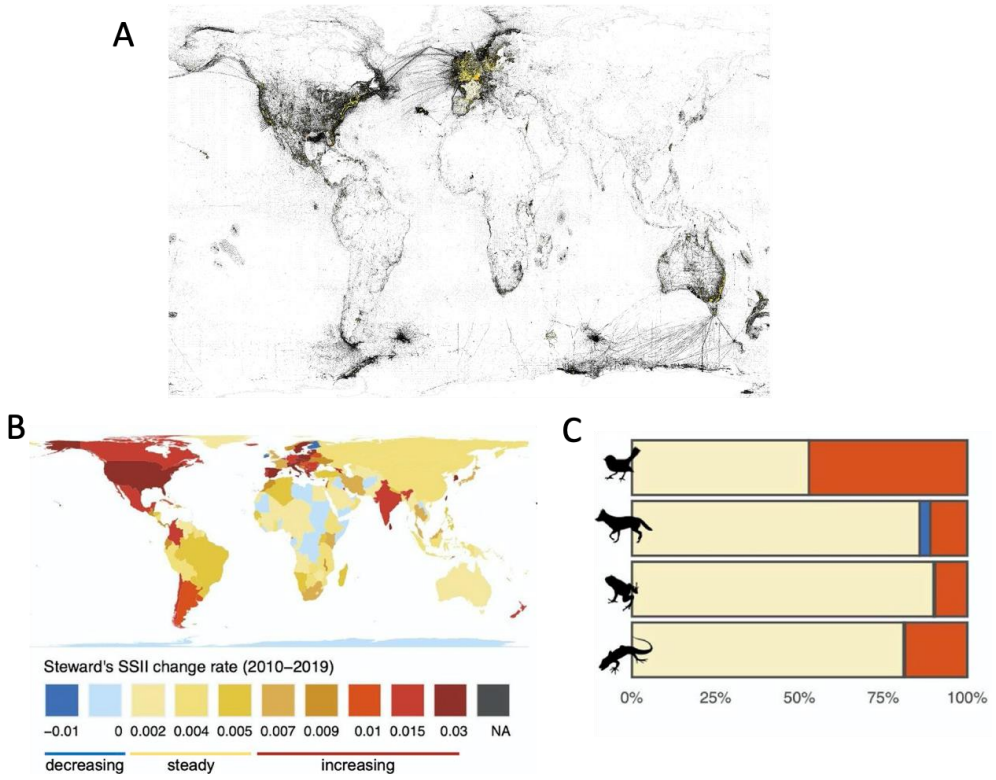
Supplementary Figure and Table



Supplementary Figure 1: *The geography of species observations and their use for assessing trends. A) Areas with records in GBIF and OBIS databases. Black dots show locations with 1-50 records. Terrestrial, freshwater, and marine systems are unsampled*[1] *(based on all databased records; figure from Hughes et al. 2021; see also*[2]*. B, and C: Trends in biodiversity data coverage by GBIF data 2000-2019 for all ca. 31,000 extant terrestrial vertebrate species. The GEO BON Species Status Information Index (SSII) measures annually how well sampled occurrence data address status and trends in species populations*[3]*. In warm colors (orange to red) are areas where the collection of taxa occurrence data contributing to monitoring species populations is increasing, and in blue where it is decreasing*.

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Supplementary Table 1: Examples of national, regional, or thematic biodiversity observation networks reviewed by GEO BON. Some networks have not yet been endorsed by GEO BON.

Country/region of BON	Biome/EBV/species in focus	Governance/ coordination of biodiversity monitoring
Regional BONs		
Arctic BON [1]	arctic	coordinated by CAFF, supported by Arctic Council and CBMP
Asia-Pacific BON (APBON) [2,3]	WGs covers terrestrial (forest), freshwater, and marine. boreal, temperate, sub-tropical, tropical / genetic, species, ecosystems / various taxa, phenology, ecosystem functions (e.g., carbon cycle) and services	Established in 2009 at the timing of CBD COP 10 (Nagoya, Japan). Secretariat in the Biodiversity Center of Japan, Ministry of the Environment Japan http://www.esabii.biodic.go.jp/ap-bon/index.html. Approx. +50 scientists from more than 10 countries and international institutions, universities, national institutions, NGO. Co-chairs (three-year term), Advisory Board (past co-chairs), Management committee, and three working groups. One of Asia-Oceania GEO Task Groups (https://aogeo.net/en/). AP-MBON was launched in 2019 by the Marine group in APBON. Partners: ASEAN Centre for Biodiversity, Asia-Oceania GEO, ILTER East Asia-Pacific regional network.
EuropaBON & European Biodiversity Partnership	various in the Europe, especially EBVs	regional coordination and methodological guidance by EC (top-down) and promoting monitoring across national schemes by ministries of the environment and other national networks (bottom-up) (on-going)
SASSCAL ObservationNet (regional: Angola, Namibia, South Africa, Zambia)[4]	Miombo, Savanna, Semi-Desert, Nama Karoo, Succulent Karoo	Network of Angolan, Namibian, Zambian, South African and German researchers and conservationists and paraecologists.
National and sub-regional BONs		
Australia [5,6]	Threatened species data across the taxonomic groups of birds, plants, and mammals; many EBVs by TERN	The Threatened Species Index (tsx.org.au) was developed by the National Environmental Science Program's Threatened Species Recovery Hub and in collaboration with 42 partners from the Commonwealth Government, all State and Territory governments, several large NGOs and research institutions 2016-2020; since 2021, the TSX has been operated by the Terrestrial Ecosystem Research Network (TERN).
China BON	especially species richness and abundance (birds,	400 universities, research institutes, conservation agencies and civil societies

	reptiles, mammals and butterflies)	
China, Sino BON	ecosystem structure, soils, birds, mammals, insects, invertebrates	coordinated by Chinese Academy of Sciences (CAS)
Colombia BON [7,8,9,10]	tropical, mammals, birds, amphibians, reptiles, plants, fish, insects, piloting EBVs on local scale	coordinated by the Instituto de Investigación de Recursos Biológicos Alexander von Humboldt
Finland FEO [11]	boreal and arctic, ecosystem structure and function, habitats, various taxa	coordinated by Finnish Environment Institute/ ministry of the environment, in cooperation with FinBIF, research institutes and universities
French BON	temperate, mostly terrestrial species surveys (bats, birds, butterflies, snails, plants) but also marine fish; EBV: species population abundance, community composition, demographic traits and phenology	Split between two ministries; coordinated by the National Museum of Natural History (MNHN), the French Office for Biodiversity (OFB) and the National Center for Scientific Research (CNRS), in cooperation with FRB, Sorbonne Univ., CIRAD, Irstea, Ineris, INRA, Ifremer, Montpellier Univ.
Japan BON (JBON) [2]	boreal, temperate, sub-tropical, tropical / genetic, species, ecosystems / various taxa, phenology, ecosystem functions (e.g., carbon cycle) and services alpine ecosystems, forests, grasslands, Satoyama (traditional landscapes consist of various human dominated ecosystems), lakes, wetlands, marine, coastal/island ecosystems	Established in 2009. Secretariat in National Institute for Environmental Studies, Japan. Network of networks, scientists in research institutions and universities. National component of APBON. Partners: Japan LTER network (JaLTER http://www.jalter.org/en/), JapanFlux, Japan Agency for Marine-Earth Science and Technology) The Monitoring Sites 1000 project cooperated by scientists and voluntary citizens (run by the Ministry of the Environment of Japan)
Nepal	Himalayan ecosystems, endangered species	ILK, local communities, in cooperation with AP BON and international NGOs
New Zealand [12]	temperate (terrestrial)	two national authorities: Department of Conservation (public land), Ministry for the Environment; regional councils (private land); in collaboration with research institutes, universities and Māori landowners (ILK)
Taiwan BON (TaiBON) [13,14,15]	diverse terrestrial and marine taxa (e.g.,	Monitoring: multiple agencies under the Council of Agriculture (terrestrial), Ocean Affairs Council (marine),

	terrestrial vertebrates, marine mammals, moths and butterflies, plants) and tropical/subtropical ecosystems (e.g., forests, mangroves, coral reefs)	Ministry of Economic Affairs (freshwater), and Ministry of the Interior (national parks), with collaboration with research institutes, universities and NGOs. Data integration and exchange: Taiwan Biodiversity Information Alliance, which is an interagency collaborative network for biodiversity data integration and exchange (https://www.tbiadata.tw) Indicator development and reporting: Forestry Bureau (TaiBON; https://taibon.tw/en)
South Africa BON	Cape Floristic Region(Mediterranean biome); Subtropical grassland and savanna; Temperate grasslands & shrublands; Subtropical broadleaf forest; Temperate broadleaf forest; Desert & xeric shrublands; Mangroves	a multi stakeholder process lead by two national government institutions (SANBI and SAEON); involving over 27 institutions, government, academia, NGO and commercial
Switzerland [16]	Comprehensive species lists, country wide	Federal Office for the Environment (lead) with substantial benefits for new methods. Links to national infrastructures on remote sensing (https://ares-observatory.ch/) in the make.
Thematic BONs		
MBON (marine) [17,18]	Marine, coastal and oceanic environments, and local to global scales, from microbes to whales; Essential Ocean Variables developed by GOOS from a complementary perspective with EBVs[17]	coordinated by GEO BON, MBON Pole to Pole, U.S.MBON, and MBON secretariats in Europe (AIR Centre), Asia-Pacific (, and the Americas (NOAA IOOS). MBON is a collaboration with the Intergovernmental Oceanographic Commission (IOC) of UNESCO for: a. Implementation through integration of biological and biodiversity observations into the regional alliances of ocean observing networks that constitute the Global Ocean Observing System (GOOS) b. Partnership with the Ocean Biogeographic Information System (OBIS) for data and metadata publication, curation and distribution; Partners: Global Ocean Observing System, Ocean Biogeographic Information System (OBIS), U.S. Integrated Ocean Observing System, U.S. National Marine Sanctuaries, State and federal agencies, and many more
FWBON (freshwater) [19,20]	Rivers, palustrine and lacustrine freshwater, wetlands, subterrranean aquatic ecosystems, novel freshwater ecosystems.	With members in over 70 countries in all continents except for Antarctica, FWBON serves as a Freshwater monitoring. Volunteer researcher and practitioner network

	There currently is a greater focus on multinational monitoring programs and Initiatives such as the Circumpolar Freshwater Biodiversity Monitoring Program, and the cross-Amazon Freshwater Fish and Macroinvertebrate monitoring Initiatives.	FWBON members are leading or contributing to many of the Freshwater Biodiversity Monitoring Programs that operate across large Geographic areas and influence the directions of these programs. FWBON is also collaborating with other Global Partners e.g. IUCN Freshwater Species Program and Alliance for Freshwater Life to align different monitoring initiatives towards a global assessment of Freshwater Biodiversity.
Soil BON[21]	Terrestrial ecosystems, from microbes to earthworms, including biodiversity-driven soil functions.	SoilBON has a 2-tier organization, with a international cluster of laboratories that will perform all analysis in a standard and systematic way, and a second extensive group of collaborators that both provide samples and participate from the scientific insights of the network.
OMIC BON	A thematic BON focused on the study of genes, transcripts, proteins, metabolites, and other biomolecules in organisms or environmental materials.	Omics enables biodiversity observation at the molecular scale across environments and geographies. Omic BON will complement thematic BONs focused on environments (Marine BON, Freshwater BON, Soil BON), as well as national and regional BONs. Omic BON will additionally closely work with the GEO BON Genetic Composition Working Group. Omic BON will be coordinating effort along five major axes: (1) localized omic observatories, (2) networks of observing platforms, (3) data infrastructures, (4) curated and long-term stores of biosamples, and (5) (meta)data standardization bodies.
Coral reefs/GCRMN	coral reefs/global (EBV/EOVs: hard coral cover, algal cover, fish diversity and abundance)	A GCRMN Steering Committee, Host Institution and Global Coordinator mandated under the international Coral Reef Initiative (www.icriforum.net/gcrmn). Coordination resources provided by major ICRI members/countries. Coordination through 10 operational regional networks, with resources provided by major ICRI members/countries.
Invasive alien species [22]	The subset of species introduced outside of their native range and with potential or realized negative impacts on biodiversity	National checklist updates supported by GBIF, IUCN SSC ISSG, the CBD CHM and GEO BON, modelled indicators (using EBVs) supported by a GEO BON coordinated partnership

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