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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. We propose an interconnected worldwide system of observation networks – a global biodiversity observing system (GBiOS) – to coordinate monitoring worldwide and inform 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 rapid action to address the drivers of biodiversity loss and improve conservation action to avoid the great 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 can provide insight into progress at regional and global levels.

Disparities among nations in the access and use of biodiversity observations and knowledge[3] means that the global community is not adequately equipped to meet the information requirements of the monitoring framework – to monitor the drivers of biodiversity loss and track species and ecosystem recovery and restoration and as well as assess the risks of losing the many benefits we get from nature.

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 can 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, we identified four key components 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 free, prior, informed consent for data access.

Five critical issues GBiOS can address

A GBiOS can address five critical issues 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 compiled 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**: The actions needed to achieve the targets of the KM-GBF can be supported by monitoring the drivers for trend attribution and forecasting change over different scales[6]. Some drivers may 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 could 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 is by design 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 can 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 a growing 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.

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: A long-term funding model could help 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 for the global public good. Global data production and exchange could 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 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 great benefits society receives from biologically diverse and resilient ecosystems. A GBiOS could contribute to a representative and inclusive understanding of biodiversity change and thereby support effective implementation of the policies designed to reverse biodiversity loss and achieve the global goals for nature in the coming decades.

References

1. Obura, D. et al. *One Earth*, **6**, 105-117 (2023).

2. Leadley, P., Gonzalez, A., Obura, D. et al. *One Earth,* **5,** 597-603 (2022).

3. Gonzalez, A. & Londoño, MC. *Science,* **378**, 1147 (2022).

4. Scholes, R. J., *et al*., *COSUST* **4**, 139-146 (2012).

5. Pereira, H.M. & Cooper D. H. TREE, **21**, 123-129 (2006).

6. Gonzalez, A., et al. Phil. Trans. Roy. Soc. B, **378**, 20220182 (2023).

7. Urban, M. C., et al. *Science*, **353**, aad8466 (2016).

8. IPBES, "IPBES (2019): Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services" (IPBES, Bonn, Germany, 2019), p. 1148.

9. Carroll, S. R., et al. Sci. Data. **8**, 108 (2021)

10. Dornelas, M. et al. Global. Ecol Biog., **27**, 760-786. (2018)

11. Hudson, L. N. et al. Ecol & Evol., **7**, 145-188. (2017)

12. Hughes, A. C., et al. *Ecography*, **44**, 1259-1269 (2021)

13. Pereira, H.M., et al. *Science,* **339**, 277-278 (2013)

14. Schmeller, D. S., *Biol. Revs.*, **93**, 55-71 (2018)

15. Balvanera, P., et al. *COSUST*., **54**, 101152 (2022)

16. Kühl, H. S. et al., *One Earth*, **3**, 462-474 (2020)

17. Navarro, L. et al. *COSUST*, **29**, 158-169 (2017)

18. Cavendar-Bares, J. et al. *Nat. Ecol. Evol*, **6**, 506–519 (2022)

19. Bush, A., et al. *Nat. Ecol. Evol.*, **1,** 0176 (2017)

20. Bellingham, P. J. et al., *Ecol. Sols. & Evid*., **1**, e12025 (2020)

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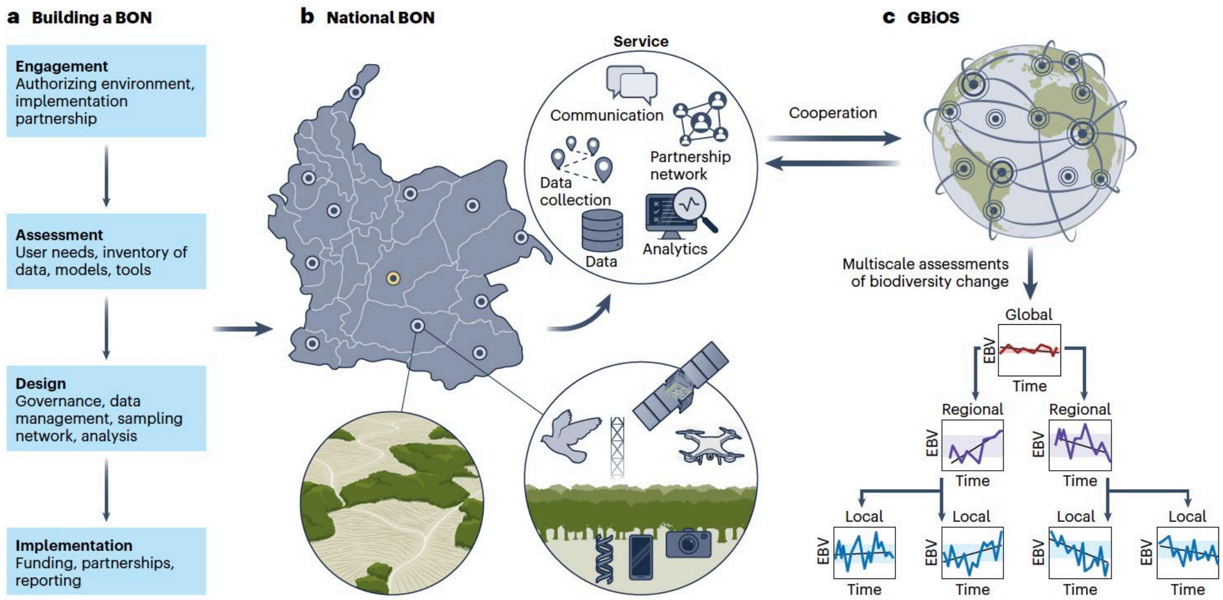
Figure 1: GBiOS as a global network of interconnected national and regional BONs to assess biodiversity trends worldwide: a) Countries without a national BON can establish and implement one following the multistep process identified by GEO BON[18]. b) Each national BON (Colombia is shown as an example) 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, data (e.g., via a Global Open Science Cloud) 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.



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