ECOLOGY

Essential Biodiversity Variables

A global system of harmonized observations is needed to inform scientists and policy-makers.

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Reducing the rate of biodiversity loss and averting dangerous biodiversity change are international goals, reasserted by the Aichi Targets for 2020 by Parties to the United Nations (UN) Convention on Biological Diversity (CBD) after failure to meet the 2010 target (*1*, *2*). However, there is no global, harmonized observation system for delivering regular, timely data on biodiversity change (*3*). With the first plenary meeting of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) soon under way, partners from the Group on Earth Observations Biodiversity Observation Network (GEO BON) (*4*) are developing—and seeking consensus around—Essential Biodiversity Variables (EBVs) that could form the basis of monitoring programs worldwide.

Despite progress in digital mobilization of biodiversity records and data standards (*5*), there is insufficient consistent national or regional biodiversity monitoring and sharing of such information. Along with inadequate human and financial resources (*6*), a key obstacle is the lack of consensus about what to monitor. Many initiatives collect data that could be integrated into an EBV global observation network (see the table), though important gaps remain. Different organizations and projects adopt diverse measurements, with some important biodiversity dimensions, such as genetic diversity, often missing (*7*).

The EBV process is inspired by the Essential Climate Variables (ECVs) that guide implementation of the Global Climate Observing System (GCOS) by Parties to the UN Framework Convention on Climate Change (UNFCC) (*8*). EBVs, whose development by GEO BON has been endorsed by the CBD (Decision XI/3), are relevant to derivation of biodiversity indicators for the Aichi Targets (*9*). Although CBD biodiversity indicators are designed to convey messages to policy-makers from existing biodiversity data (*1*), EBVs aim to help observation communities harmonize monitoring, by identifying how variables should be sampled and measured.

Given the complexity of biodiversity change (*3*), the challenge of developing a global observation system can appear insurmountable. Nearly 100 indicators have been proposed for the 2020 CBD targets (ongoing work seeks to identify a more limited subset) (*9*). Two-thirds of reports recently submitted by Parties to the CBD lacked evidence-based information on biodiversity change (*10*).

EBVs help prioritize by defining a minimum set of essential measurements to capture major dimensions of biodiversity change, complementary to one another and to other environmental change observation initiatives. EBVs also facilitate data integration by providing an intermediate abstraction layer between primary observations and indicators (fig. S1). An EBV estimating population abundances for a group of species at a location sits between raw observations (e.g., from different sampling events or methods) and an aggregated population trend indicator that averages multiple species and locations.

Essential Biodiversity Variables in Practice

We define an EBV as a measurement required for study, reporting, and management of biodiversity change. Hundreds of variables potentially fit this definition. We developed and tested a process, still ongoing, to identify the most essential (*11*). Dozens of biodiversity variables were screened to identify those that fulfill criteria on scalability, temporal sensitivity, feasibility, and relevance. These variables were scored for importance, checked for redundancy, and organized into six classes on the basis of commonalities, general enough for use across taxa and terrestrial, freshwater, and marine realms (see the table).

Often, it is not possible to generalize observations from point locations to regional scale. Variables selected as EBVs harness remote sensing (RS) to measure continuously across space (e.g., habitat structure), or local sampling schemes that can be integrated to enable large-scale generalizations. For instance, citizen scientists contribute locally to species population monitoring across extensive regions (*12*). Ecosystem function or community composition variables often need intensive in situ measurements feasible only at a few locations, but models and proxies detectable by RS can be used to extrapolate from point locations to the regional scale (*13*, *14*). Such models are also important to predict the response of EBVs (e.g., species distributions) to environmental drivers (*15*), and can be used to develop scenarios exploring different policy options (*16*), a core activity of IPBES.

Many biodiversity assessments emphasize species inventories, e.g., identification of all species in a region, and there have been calls for redoubled efforts to describe all species in the world (*17*). The EBV framework instead emphasizes repeated measures for the same taxa at the same locations or regions mainly at short-term intervals (1 to 5 years), although a few may be medium term (10 to 50 years).

Key determinants of observation system feasibility are the number of variables that need monitoring and their measurability. Although determination of the 50 ECVs requires elaborate observation and modeling systems, the end result is often outwardly simple (e.g., air temperature or pressure) (*8*). This is also true of some EBVs, particularly those related to ecosystem structure and func-

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Examples of candidate Essential Biodiversity Variables

EBV class	EBV examples	Measurement and scalability	Temporal sensitivity	Feasibility	Relevance for CBD targets and indicators (*1*,*9*)
Genetic composition	Allelic diversity	Genotypes of selected species (e.g., endangered, domesticated) at representative locations.	Generation time	Data available for many species and for several locations, but little global systematic sampling.	Targets: 12, 13. Indicators: Trends in genetic diversity of selected species and of domesticated animals and cultivated plants; RLI.
Species populations	Abundances and distributions	Counts or presence surveys for groups of species easy to monitor or important for ES, over an extensive network of sites, complemented with incidental data.	1 to >10 years	Standardized counts under way for some taxa but geographically restricted. Presence data collected for more taxa. Ongoing data integration efforts (Global Biodiversity Information Facility, Map of Life).	Targets: 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15. Indicators: LPI; WBI; RLI; population and extinction risk trends of target species, forest specialists in forests under restoration, and species that provide ES; trends in invasive alien species; trends in climatic impacts on populations.
Species traits	Phenology	Timing of leaf coloration by remote sensing by RS, with in situ validation.	1 year	Several ongoing initiatives (Phenological Eyes Network, PhenoCam, etc.)	Targets: 10, 15. Indicators: Trends in extent and rate of shifts of boundaries of vulnerable ecosystems.
Community composition	Taxonomic diversity	Consistent multitaxa surveys and metagenomics at select locations.	5 to >10 years	Ongoing at intensive monitoring sites (opportunities for expansion). Metagenomics and hyperspectral RS emerging.	Targets: 8, 10, 14. Indicators: Trends in condition and vulnerability of ecosystems; trends in climatic impacts on community composition.
Ecosystem structure	Habitat structure	RS of cover (or biomass) by height (or depth) globally or regionally.	1 to 5 years	Global terrestrial maps available with RS (e.g., Light Detection and Ranging). Marine and freshwater habitats mapped by combining RS and in situ data.	Targets: 5, 11, 14, 15. Indicators: Extent of forest and forest types; mangrove extent; seagrass extent; extent of habitats that provide carbon storage.
Ecosystem function	Nutrient retention	Nutrient output/input ratios measured at select locations. Combine with RS to model regionally.	1 year	Intensive monitoring sites exist for N saturation in acid-deposition areas and P retention in affected rivers.	Targets: 5, 8, 14. Indicators: Trends in delivery of multiple ES; trends in condition and vulnerability of ecosystems.

tion. However, EBVs relating to species populations or traits and to genetic or community composition require representative sampling across taxonomic groups or community types. These EBVs need to balance specificity and generality, enabling valid aggregation of data from multiple monitoring programs, while allowing for flexibility in the species or taxonomic groups addressed by these programs.

Variables selected as EBVs fill a niche not covered by global observation initiatives looking at environmental pressures [e.g., GCOS (*8*), Essential Ocean Variables (*18*)]. An EBV such as species abundance provides data for indicators such as the Living Planet, Wild Bird, and Red List indices (LPI, WBI, and RLI) (see the table). Assessing ecosystem services (ES) requires knowledge of changes in beneficial species, functional groups, or ecosystem processes; additional physical, social, and economic data (fig. S1) can be obtained from valuation studies, surveys, and national statistics (*19*). Complementary spatial information on responses implementation (e.g., coverage of protected areas) can inform indicators of the effectiveness of policy and management (fig. S1). This fundamental, but flexible, role of EBVs confers robustness to the system: EBVs are insulated from changing technologies at the observation level and from changing approaches at the indicator level.

Building Consensus and Capacity

Identification of EBVs and definition of sampling protocols are done by an open process that requires engagement of scientific, policy, and other communities. Major roles can be played by IPBES, national biodiversity authorities, space agencies, nongovernmental organizations, and citizen-science communities. Information on the EBV process is updated at (*11*); written contributions can be sent to GEO BON. Side events will be organized in scientific and policy meetings over the next year. This will refine the EBV list, which, once stable, will periodically be updated by GEO BON in a process similar to that used for ECVs (*8*).

Coordination of sampling schemes by GEO BON across countries and scales can minimize costs and improve spatial representativeness. Developing suitable financial mechanisms to share costs between developing countries, where most biodiversity occurs, and developed countries, which share in the benefits but drive many of the pressures (*20*), will play a key role in the development of a truly global system. We hope that EBVs will catalyze investment in biodiversity observations, as ECVs have done for climate.

References and Notes

1. S. H. M. Butchart *et al.*, *Science* **328**, 1164 (2010).
2. CBD, Decision X/2, The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets, Nagoya, Japan, 18 to 29 October 2010.
3. H. M. Pereira, L. M. Navarro, I. S. Martins, *Annu. Rev. Environ. Resour.* **37**, 25 (2012).
4. R. J. Scholes *et al.*, *Curr. Opin. Environ. Sustain.* **4**, 139 (2012).
5. R. P. Guralnick *et al.*, *Ecol. Lett.* **10**, 663 (2007).
6. L. J. Martin *et al.*, *Front. Ecol. Environ* **10**, 195 (2012).
7. C. K. Feld *et al.*, *Oikos* **118**, 1862 (2009).
8. GCOS, *Implementation Plan for the Global Observing System for Climate in Support of the UNFCC* (*2010 Update*) (World Meteorological Organization, Geneva, 2010), p. 180; www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf.
9. Secretariat of the CBD, *Report of the Ad Hoc Technical Expert Group on indicators for the Strategic Plan for Biodiversity 2011–2020* (SCBD, Montreal, Canada, 2011); www.cbd.int/doc/meetings/sbstta/sbstta-15/information/sbstta-15-inf-06-en.pdf.
10. P. Bubb *et al.*, *National Indicators, Monitoring and Reporting for the Strategic Plan for Biodiversity 2011–2020* (UNEP-WCMC, Cambridge, 2011).
11. GEO BON, EBVs; www.earthobservations.org/geobon_ebv.shtml.
12. R. D. Gregory *et al.*, *Philos. Trans. R. Soc. B Biol. Sci.* **360**, 269 (2005).
13. D. P. Turner, *Front. Ecol. Environ* **9**, 111 (2011).
14. S. Ferrier, *Bioscience* **61**, 96 (2011).
15. W. Jetz *et al.*, *Trends Ecol. Evol.* **27**, 151 (2012).
16. H. M. Pereira *et al.*, *Science* **330**, 1496 (2010).
17. E. O. Wilson, *Science* **289**, 2279 (2000).
18. IOC, A framework for ocean observing—Consultative draft v.7 (UNESCO, Paris, 2011), p. 26; http://unesdoc.unesco.org/images/0021/002112/211260e.pdf.
19. H. Tallis *et al.*, *Bioscience* **62**, 977 (2012).
20. M. Lenzen *et al.*, *Nature* **486**, 109 (2012).

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Supplementary Materials

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