The essential role of essential variables in biodiversity and ecosystem services reporting within and across jurisdictions

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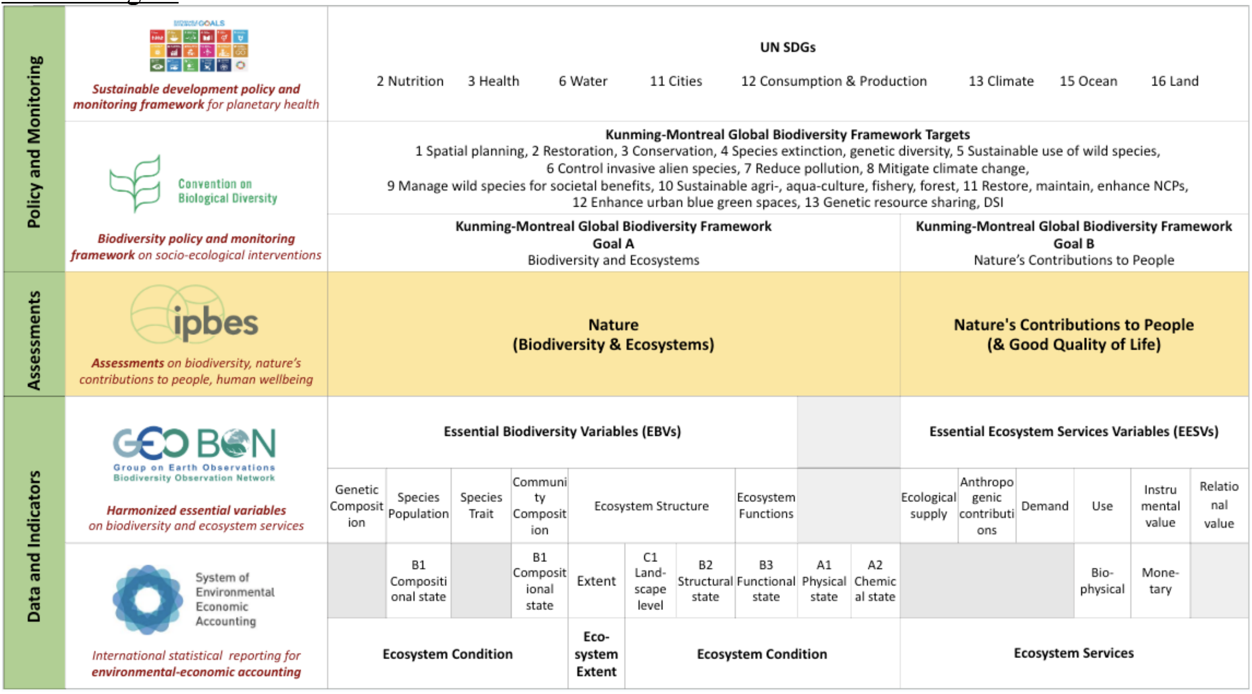
Abstract:
Fragmented systems for monitoring and assessing biodiversity and ecosystem services limit countries' ability to track progress across multilateral environmental agreements, coordinate actions, and thus meet agreed upon global commitment. This paper initiates to address this gap through integrated data-to-decision workflows for more synergistic implementation of global goals. We propose Essential Biodiversity Variables (EBVs) and Essential Ecosystem Service Variables (EESVs) as integrative tools to harmonize monitoring, indicator development, and reporting across frameworks such as the Kunming-Montreal Global Biodiversity Framework and the System of Environmental-Economic Accounts Ecosystem Accounting, while providing the foundational data for knowledge synthesis in the assessments of the Intergovernmental Platform on Biodiversity and Ecosystem Services. Through three case studies, we demonstrate the use of EBVs and EESVs in national assessments, modelling, and scenario analyses for strategic policy and spatial planning, using scalable and repeatable workflows from primary data to indicators. The paper highlights the value of an integrated use of science, policy, and data frameworks in implementing biodiversity conservation and sustainable development goals. We call for the global community to identify and agree upon minimum facets of biodiversity to monitor with national observation agencies to improve the rigour of data, models, and indicators.

Abstract figure:



Key messages:

- EBVs and EESVs can be used for socio-ecological monitoring to support MEA implementation.
- Data to indicators workflows should be reproducible and multiscalable for global monitoring and reporting.
- EBVs and EESVs can be interoperable with SEEA EA and can be synergistically used in indicator development for MEA monitoring frameworks.
- There are use cases where EBVs and EESVs are being identified and applied in national data-to-decision workflows to inform policy and spatial planning and global goal tracking.
- This paper renews the call for the global community to agree upon a minimum set of variables to monitor with national observation agencies to improve the rigour of data, indicators and models.

Keywords: multilateral environmental agreements, biodiversity monitoring, national accounting, essential variables, biodiversity policy, indicators, EBV, EESV, SEEA, KM-GBF

1. Introduction

The sustainable governance of socio-ecological systems requires meaningful and achievable goals and targets that reflect the interconnections between societal and ecological systems, and an understanding of these systems that is based on robust scientific observation and local knowledge. Such goals and targets are typically set in major *multilateral environmental agreements* (MEA) endorsed and supervised by their Conference of Parties and/or relevant United Nations (UN) organisations. MEAs often include a *reporting framework* consisting of *monitoring indicators* that are regularly assessed and reported across the parties (countries), to provide a consistent overview of the state of the governed system and to track progress towards the achievement of goals and targets. For example, the Kunming-Montreal Global Biodiversity Framework (KM-GBF) of the UN Convention on Biological Diversity (CBD) contains 4 overarching goals on the state of nature, benefit sharing and resources for implementation, underpinned by 23 action-oriented targets covering threats to biodiversity, meeting people's needs, and enabling conditions for mainstreaming and achieving goals (SCBD, 2022). The KM-GBF is supported by a monitoring framework, currently consisting of 42 headline, 52 component, 110 (unique) complementary and 15 binary indicators (SCBD, 2025). The headline indicators will be a core element of the reporting process as there is a legal obligation for the parties to report on their progress under the Convention (SCBD, 2022).

Another reporting framework that is key to the MEAs, though through the indirect/distant means of national accounting and the economic system, is the System of Economic Environmental Accounts (SEEA), created by the Statistical Division of the United Nations (UNSD) and applied by national statistical offices worldwide (Hein et al., 2020). The SEEA has endorsed Ecosystem Accounting (SEEA EA) as a global statistical reporting standard (United Nations, 2021). This aims to present the state and trends in the ecosystems in a similar way as the System of National Accounts (also coordinated by UNSD) does for macroeconomic indicators such as the Gross Domestic Product (GDP). SEEA EA consists of five main 'accounts' designed to track the state and trajectories of socio-ecological systems based on a set of principles, standardised definitions and typologies, and supporting guidelines (Edens et al., 2022; United Nations, 2024). Each account is a structured set of reporting indicators designed to provide a representative (and ideally comprehensive) overview of a central 'topic': *ecosystem extent, ecosystem condition, ecosystem services (physical flow), ecosystem services (monetary flow),* and *monetary ecosystem asset*.

Unlike the monitoring framework of the KM-GBF, which specifies concrete reporting indicators linked to the goals and targets, SEEA EA only sets the structures and principles of reporting, including the main classes of indicators and how they should be selected and/or developed, thus ensuring consistency while leaving clear zones of flexibility and responsibility to the countries implementing the accounts. This makes it, to some degree, possible for each country to tailor the indicators to ecological characteristics and national priorities, while ensuring compatibility and comparability through the application of the common structures and principles. Today, SEEA EA reporting indicators are being developed in 41 countries worldwide (United Nations, 2023).

A key challenge for all these international reporting frameworks, however, is the availability of relevant data in clearly structured and regularly updated reproducible data streams. The lack of data, often even of basic observations, has consequences for the implementation of the MEAs including the SDGs (Campbell et al., 2020; UNEP, 2021, 2019). For example, according to Xu et al. (2021) the dearth of reporting measures contributed to the failure of achieving the Aichi Biodiversity Targets by 2020 (SCBD, 2020). This challenge is intensified by the inherent complexity of biological systems: there are always more species than it is possible to monitor, and higher organisational units (like a 'forest') can be defined and delineated in multiple ways. Accordingly, setting up data flows and monitoring systems demands structure and coordination (Gonzalez et al., 2023b). Furthermore, while the MEAs (and their reporting frameworks) are global in scope, the reporting indicators are implemented and assessed at national and subnational levels, which necessitates structure and coordination across the countries already at the level of monitoring activities and data flows (Bhatt et al., 2020; Bubb, 2013).

While this paper focuses on addressing challenges faced by MEAs and other relevant international reporting frameworks such as the UN SEEA, it is worth noting that similar challenges are also being faced by those developing nature-related reporting frameworks within the corporate sector. Most notable are the 'core disclosure metrics' proposed by the Taskforce on Nature-related Financial Disclosures (TNFD, 2023), and the draft 'state of nature metrics' proposed by the Nature Positive Initiative (NPI, 2025). In addition, with focus on the use of scenarios and models, the Network on Greening Financial System (NGFS) is developing a conceptual framework and methodological guide for national central banks to utilize scenario-based approach to assessing and mitigating nature-related risks (NGFS, 2024, 2023). While these financial institutions have slightly different focus and approaches, their main interest is in being able to forecast and report on financial risks stemming from biodiversity loss and ecosystem degradation, and it requires an improved understanding and use of biophysical data, models, and indicators for rigorous and accurate assessment of the risks and interventions for preventing them. It is therefore crucial to recognize the broader benefits of well-structured and coordinated biodiversity monitoring and data-to-decision processes—not only for MEAs and their reporting frameworks, but also to build a foundation that can respond and adapt to evolving needs of the broader society.

One potential approach to mitigate and overcome these challenges has been proposed through the identification, development and use of *essential variables* in national and global data-to-indicator workflows (Fernández et al., 2020; Navarro et al., 2017). The essential variables encompass a minimum set of key and complementary characteristics or attributes that can give a comprehensive yet parsimonious description of the state and trajectories of the studied system (Lehman et al., 2020). This idea was first implemented in the climate community, which now has an established set of 55 Essential Climate Variables (ECV) to improve the coordination of observations and modelling (Bojinski et al., 2014; Ostensen et al., 2008). Following the success of ECVs, the Group on Earth Observations Biodiversity Observation Network (GEO BON) established six classes of Essential Biodiversity Variables (EBVs) with 22 subclasses (EuropaBON, 2024; GEO BON, 2025; Pereira et al., 2013; SCBD, 2013), which was later complemented by six classes of Essential Ecosystem Service Variables (EESVs) to be used combinatorially with a typology of ecosystem services or Nature's Contributions to People (Balvanera et al., 2022). Nevertheless, while ECVs specify concrete variables, EBVs and EESVs are defined in a more flexible way, as key *classes* and *subclasses* of data and data products (Lehman et al., 2020). This difference reflects the inherent complexity of biological systems, which requires a much higher number of (potentially yet unknown) elements (e.g. species, biotic and abiotic conditions) and their interactions than physical systems for a full system description. Hence, by providing an intermediate layer of standardized data product between primary observations (raw data) and indicators of state and trends, the EBVs and EESVs can be extremely useful for coordinated planning and decisions about monitoring systems, data infrastructures, and indicator development (Geijzendorffer et al., 2016; Gonzalez et al., 2023b). There are other complementary essential variables such as the Essential Ocean Variables (EOVs) that was initiated to help organize the monitoring system for the ocean (Miloslavich et al., 2018).

In this paper, we explore how essential variables, more specifically EBVs and EESVs, can support the reporting needs for the achievement of multiple MEAs by providing harmonised data flows among and across their reporting frameworks. In particular, we focus on two recent major global monitoring and reporting frameworks – the KM-GBF and SEEA Ecosystem Accounting (EA) – given their central consideration by global science policy interfaces such as the CBD and the IPBES. These global frameworks aim to improve the implementation efficiency and evidence base for biodiversity conservation and the development of data flows for national accounting systems through an internationally standardized framework that integrates natural capital data into the economic system. We crosswalk EBV and EESV classes and subclasses to the SEEA EA reporting framework and EBV- and EESV-based indicators to the KM-GBF monitoring framework and examine how essential variables can improve data flows across scales for synergistic conservation efforts. Finally, we present three distinct examples to illustrate the potential implementation and use of EBVs/EESVs in national MEA reporting and spatial planning.

2. Essential variables for socio-ecological monitoring

The EBV framework establishes six main *classes* that describe a dimension of biodiversity, designed to provide a comprehensive yet complementary minimum set for ecological observations that can detect and attribute changes in species distributions or traits, their genetic diversity or community composition, or in the extent, distributions and functions of different ecosystems (EuropaBON, 2024; GEO BON, 2025; Pereira et al., 2013, see Supplementary Material (SM) Table S1 for the exact definition of classes and subclasses of essential variables and Table S2 for selection criteria). Some of the classes describe system characteristics that are measurable at the level of species (i.e., genetic composition, species population, species traits), while other classes are "organised" at the ecosystem level (i.e., community composition, ecosystem structure, ecosystem function). For species distribution EBV, which is a *subclass* under the species population *class*, there will be as many spatial data layers of species as there is data for in a region or the globe. EBVs can therefore be further specified by identifying the taxonomic scope and spatio-temporal resolution of the ecological system to be described in a format of a data product (Pereira et al., 2017; Quoß, 2025). As such, a *generic* EBV variable (equivalent to *subclass)* can be further specified by defining the taxonomic scope, spatial resolution, and temporal resolution and produce *specific* EBV variables, or metrics (Table 1). The main principle for the selection of *specific* EBV variables is that they would together be representative of the studied dimension of biodiversity and ecosystems. In this paper, the hierarchy of the EBV data structure is: six main *classes* (e.g. species population, ecosystem structure), 22 *subclasses* equivalent to *generic* EBV variables (e.g. species distribution, ecosystem distribution), and *specific* EBV variables (e.g. distribution of *Panthera tigris,* distribution of tropical rainforests).

EBV variables typically rely on sparse observations in space and time, and therefore, they are often *interpolated* into "space-time-biology" data cubes where gaps are filled with predictions from the available data with auxiliary information (e.g. environmental conditions) using predictive models (Fernández et al., 2020). Unlike space and time, "biology or ecological entity" is not identical across all EBV classes, corresponding to a species for the species-focused EBVs and to a community (of species) or ecosystem for the ecosystem-focused EBVs (Table 1, Fernández et al., 2020). The individual EBV variable can be presented as a time series if there are repeated observations at one location or as maps if synchronous observations are made at multiple locations. A transparent handling of data dimensions supports repeatable *aggregation* condensating the multidimensional complexity of socio-ecological systems into policy-relevant indicators (Allain et al., 2018). Detailed descriptions about the identification of relevant metrics, the interpolation of data cubes, as well as data-to-indicators workflows are available for the following EBV classes: *species populations* (Jetz et al., 2019; Kissling et al., 2018a), *species traits* (Kissling et al., 2018b), and *genetic composition* (Hoban et al., 2022). The EBV framework has recently been used to co-design a continental biodiversity monitoring system in Europe covering 84 *specific essential variables* across the terrestrial, freshwater and marine realms (Kissling et al., 2024).

With shared principles, the EESVs were introduced on ecosystem services more recently, complementary to the EBVs. The six EESV *classes* correspond to the main stages in the flow of ecosystem services from nature towards human society that are relevant for assessing and monitoring these services' flows across space and time (Balvanera et al., 2022, see SM Table S3 for exact definition of classes). Two of these classes characterise the generation of the ecosystem services: *ecological supply*, which covers the ecosystems' capacity to provide ecosystem services, and *anthropogenic contributions,* encompassing the human contributions to the supply of ecosystem services (Schröter et al., 2021). Two classes characterise the human appropriation of the ecosystem services, specifically *demand* describing the human need for an ecosystem service, and *use* describing the amount of ecosystem services flow that is actually realised (appropriated) by people (Brauman et al., 2020). Finally, there are two classes corresponding to benefits (values) that the ecosystem services generate in the society: *instrumental values* relating to the value of nature as an instrument of human benefits, and *relational values* referring to principles embedded or emerging from reciprocal and relational interactions between people and nature (Díaz et al., 2018; IPBES, 2022; Pascual et al., 2017).

There is an important additional "socio-ecological dimension" to EESVs in data cube, corresponding to the specific type of service itself (Table 1). In an applied socio-ecological system, there are actual types of ecosystem services such as pollination services, water regulation, and recreational benefits similarly to the typologies of ecosystem service in frameworks such as the Common International Classification of Ecosystem Services (CICES) and the Nature's Contributions to People (NCP) (Díaz et al., 2018; Haines-Young and Potschin, 2018). Accordingly, a comprehensive set of EESVs can be conceptualized as a single four-dimensional data cube, with a *spatial*, *temporal*, *ecosystem service type* and an *EESV class* as dimensions. EESV *classes* can also align closely with the *levels* of the ecosystem service "cascade" model in literature (Haines-Young and Potschin, 2010; Heink and Jax, 2019; Zhang et al., 2022). For some EESV class-ecosystem service type combinations, there may be multiple valid metrics while other combinations may not be derivable (cf. Czúcz et al., 2020 where this is described similarly as "cascade" level).

Clearly, the EBV and EESV frameworks are interlinked, as characteristics and functions of biodiversity underpin the ecological supply of ecosystem services, the use of which, in turn, affects biodiversity (Chaplin-Kramer et al., 2025). For example, the distribution or abundance of each pollinator species (*species population* EBV) and the diversity of pollinator species (a *community composition* EBV) influence the amount and efficiency of pollination (i.e., the *ecological supply* EESV) provided to pollination-dependent crops (Garibaldi et al., 2016; Greenleaf and Kremen, 2006). Likewise, species richness of birds and other charismatic or rare vertebrate species supply wildlife viewing opportunities and has been linked to higher frequencies of recreation or tourism (i.e., *relational value* EESV) (Echeverri et al., 2022).

With complementary socio-ecological monitoring capabilities, EBVs and EESVs can inform directly on the two elements at the heart of the IPBES framework – *Nature* and *Nature's Contributions to People* (Díaz, 2015; Díaz et al., 2018). The EBV framework was for instance used to guide the assessment on the state of nature in the Global Assessment of IPBES (IPBES, 2019). Balvanera et al. (2022) also identified indicators used in the regional, thematic, and global IPBES assessments, such as "economic importance of wildlife-based tourism" and "total [fisheries] catch globally", that map to *instrumental value* class of the EESV framework. Efforts to further integrate the use EBVs and EESVs will enhance ongoing work that emphasizes the importance of accounting for the dynamic changes in biodiversity and ecosystem services. Works are under way with the use of the Nature Futures Framework – a new scenario modelling framework developed by the IPBES that bring *intrinsic, instrumental and relational* values of nature integratively in the development of future scenarios and modelling (Durán et al., 2023; Kim et al., 2023; Pereira et al., 2020). A few example studies include the spatial prioritization of land use and conservation accounting for biodiversity and ecosystem services values more comprehensively (Dou et al., 2023; Haga et al., 2023; O'Connor et al., 2021) and for assessing the potential of biodiversity and ecosystem services values in meeting the demands of the society equitably (Chaplin-Kramer et al., 2024).

Table 1. The most important data dimensions of EBV and EESV classes and subclasses that a comprehensive data cube would need to cover (see also (Quoß, 2025). X: directly required data dimension, (x): auxiliary or indirectly required data dimensions (Examples: Morphology = f(taxonomy, trait), i.e., minimal data cube describing EBV subclass morphology should assign a number to each relevant taxonomic unit (species) for each relevant trait. A more comprehensive data cube describing morphology could additionally characterise changes in morphology within space and time, i.e. Morphology= f(taxonomy, trait, location, time).

	Relevant data cube dimensions*						
	spatial	temporal	entity			other relevant dimensions	Example attributes or metrics
EBV / EESV classes and subclasses			species	community, ecosystem	ecosystem service types		
Essential Biodiversity Variables							
Genetic Composition (GC)							
Intraspecific genetic diversity	(x)	X	(x)			populations	alleric richness, heterozygosity
Genetic differentiation	(x)	X	(x)			populations	genetic units, distance
Inbreeding	(x)	X	(x)			populations	ideal size population
Effective population size	(x)	X	(x)			populations	degree of relatedness
Species Populations (SP)							
Species distribution	X	X	X				area of suitable habitat
Population abundance	X	X	X				estimated counts of individual species
Species Traits (ST)							
Morphology	(x)	(x)	X			trait types	volume, mass, height
Physiology	(x)	(x)	X			trait types	adaptive capacity
Phenology	X	X	X			phenological events	timing of colonization or fructification
Movement	X	X	X			movement types	dispersal ability
Reproduction	X	X	X			trait types	age at maturity
Community Composition (CC)							
Community abundance	X	X	X	(x)			number of species
Taxonomic/phylogenetic diversity	X	X	X	(x)			diversity of species
Trait diversity	X	X	X	(x)		trait types	diversity of traits
Interaction diversity	X	X	X	(x)		interaction types	multitrophic interaction
Ecosystem Structure (ES)							
Ecosystem distribution	X	X		X			forest cover
Live cover fraction	X	X		X		vegetation/canopy layers	vegetation/canopy layers
Vertical profile	X	X		X			vegetation volume/biomass
Ecosystem Functions (EF)							
Primary productivity	X	X	(x)	X			net primary productivity
Ecosystem phenology	X	X	(x)	X		phenological events	phytoplankton bloom
Ecosystem disturbances	X	X	(x)	X		disturbance event types	fire, flood, soil erosion, algal bloom
Essential Ecosystem Service Variables							
Ecosystem Services							
Ecological supply	X	X	(x)	(x)	X		megafauna-based recreational opportunities
Anthropogenic contribution	X	X	(x)	(x)	X		infrastructure to support wildlife viewing
Demand	X	X	(x)	(x)	X		consumer demand for wildlife viewing
Use	X	X	(x)	(x)	X		wildlife watching experiences
Instrumental value	X	X	(x)	(x)	X		revenues of the wildlife-based tourism
Relational value	X	X	(x)	(x)	X	value types	stewardship fostered through wildlife viewing

*There are **two additional dimensions** in the EBV/EESV data cube that are relevant across all EBV/EESV classes and subclasses (Quoß, 2025):
1) **metric** that allows for different measurements/estimates of an EBV/EESV for the same model/data product with potentially different units to be reported,
2) **scenario** that allows for different projections of an EBV/EESV in the state of future or pathways towards them.

3. Essential workflows from data to decision support

Most of the EBV classes are linked to observable characteristics of species or the ecosystems, hence indicators for these classes can be aggregated from a broad ranging primary data of observation networks from field surveys, remotely sensed data, environmental DNA, citizen science data, among others. The development of EBV data products often requires additional computations (*modelling*) to optimize the use of heterogeneous sources of data (Kissling et al., 2024; Lumbierres et al., 2024). EESVs on the other hand are often difficult to observe directly, so they also typically require some *modelling* in well-documented data workflows. For EESVs, the *ecological supply* and *anthropogenic contribution* classes can be derived from geospatial data available from observations and administrative sources of the region while *demand* and *use* classes require additional socioeconomic data (e.g. population, trade) that can inform on the actual need and appropriated values of ecosystem services from the region or elsewhere. The *instrumental value* and *relational value* classes require monetary or non-monetary valuation associated with the ecosystem services available or appropriated (Balvanera et al., 2022; Chaplin-Kramer et al., 2022). EBVs and EESVs generally best explain biodiversity and ecosystem services changes when used in a specific context or for a particular question.

The production of the EBV and EESV data products typically involves three key operations, which have already been mentioned briefly in the previous sections: (1) *interpolation*, to transform sparse data points into comprehensive data cubes of the same variable; (2) *modelling* (sensu stricto), to assess a new variable from previously assessed variables (and other "ancillary" information); and (3) *aggregation*, to reduce the dimensionality of the final data cubes, and to compile them into (composite) indicators requested by the policy users. These three operations can be implemented in many ways, and they can be seen as the basic blocks of essential data workflows. An important role for models is to represent the causal relationships between the system components (e.g. drivers and biodiversity responses) which allows to detect and attribute changes through a workflow. For instance, national government agencies may collect primary data from e.g. (*in-situ*) ecological surveys or remote sensing that can be used in developing harmonized interpolated EBV variables (e.g., for *species distribution* EBV) (figure 1). Then these EBV variables can be combined with other types of data (e.g. lists of priority species, *species trait* EBVs, range of species habitat) to derive indicators such as the *IUCN Red List status of threatened species.* Time series of variables for *ecosystem distribution* EBV can, for example, be used to derive indicators on changes in the area or extent of ecosystems by type, which can then be aggregated into the SEEA EA *ecosystem extent* accounts or used in an assessment of ecological networks for conservation planning and management. EESV variables can estimate the supply and use of, for instance, water provisioning services with geospatial human settlement/population data, to assess the availability of clean water and any risks associated with it for the population requiring it (Chaplin-Kramer et al., 2022, 2019). Importantly as mentioned earlier, biodiversity, ecosystems, and ecosystem services are changing dynamically, hence the integrated use of spatial and temporal EBVs and EESVs in models can, to an extent, reflect the interactive nature of an ecological system. Various EBV layers (e.g. *species distribution* and *ecosystem distribution* EBVs) are in fact used as essential input/underlying data to EESV variables through the use of ecosystem services models (e.g. InVEST). Furthermore, *specific* EBV and EESV variables (e.g., species distribution EBV of *wild-crop pollinators*, ecological supply EESV of *mangroves*) can be used in estimating a range of ecosystem services (e.g., pollination services, natural hazard reduction).

Both the essential variables, as well as the reporting (or monitoring) indicators produced with them can inform users in diverse policy and decision spaces from local to global level. For example, genetic, species or taxonomic diversity information from standardized EBVs can be used for identifying highly biodiverse areas for protection (Ferrier et al., 2024; Mokany et al., 2020). Identifying degraded ecosystems candidates for restoration using ecosystem connectivity and integrity (Hansen et al., 2021; Torres et al., 2018) or assessing the equitable sharing of benefits from natural resources using supply and demand information of ecosystem services (Chaplin-Kramer et al., 2022) are some of the practical applications of the data-to-decisions workflow (Figure 1). Furthermore, for the indicators to be useful for a broad range of uses from fine-scale spatial planning to environmental impact assessment and high-level reporting as aggregates (e.g.

a single number for a whole country), an easily repeatable and transparent computation workflow that is spatially explicit can be instrumental for successful uses across the region and scale (Figure 1).

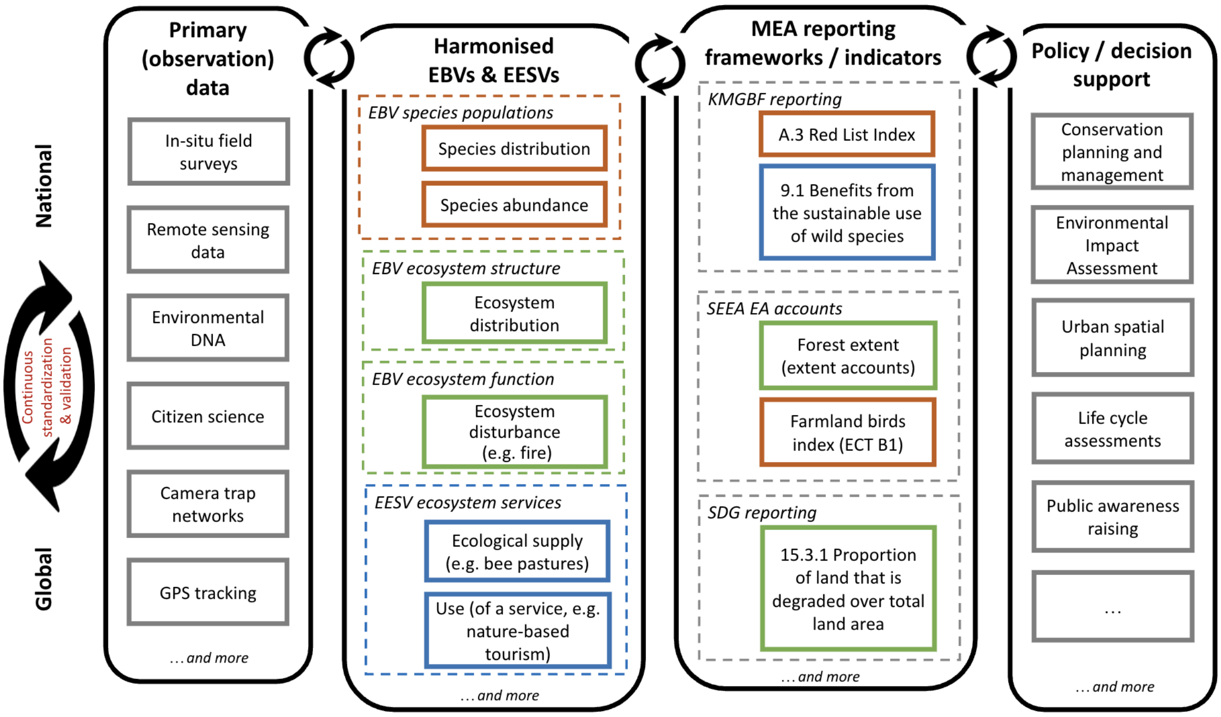


Figure 1. An illustrative generic workflow from primary data to decision support with examples of EBVs and EESVs. Colors are used to identify information flows from data to decision support at the level of species (orange), ecosystems (green), and ecosystem services (blue). A wide range of primary observation data can be used to derive EBVs and EESVs, which can be used independently or together to derive reporting indicators which can then be used for further analysis and decision support. *(Note: Some EBV and EESV data products can derive relatively simple indicators to inform policy and decision processes.)*

Importantly, the development of global EBV and EESV variables requires harmonised data collection and processing (i.e. monitoring and data workflows). In particular, the biological and socio-ecological dimension (e.g., selection of species and monitoring techniques, definition and delineation of ecosystem types) needs considerable coordination to ensure commensurability and semantic interoperability between monitoring systems and reporting frameworks (Bagstad et al., 2025). Monitoring data should ideally contribute to developing global EBV and EESV data cubes in NetCDF (Network Common Data Form, also used for *Essential Climate Variables* in climate monitoring and science), through which data format and standards can be harmonized and mobilized in an interoperable way (Quoß, 2025, http://portal.geobon.org). This will improve the rigour of global models with data gaps filled with improved accuracy through continuous cross-scale and cross-country exchange, validation and calibration (Kissling et al., 2015; Peterson and Soberón, 2018).

3.1 Essential variables for SEEA EA accounts

Similarly to EBV and EESV frameworks, SEEA EA accounts were primarily created to support and standardise reporting at a national level, the underlying definitions and principles are scale independent, so they can be applied in principle at any spatial scales from local to global (see e.g. Czúcz et al., 2025; Gorman et al., 2024; Vardon et al., 2025). Two of the five accounts in SEEA EA describe the state of the ecosystems in biophysical terms: *extent* accounts report the total area covered by different ecosystem types over an accounting area; while ecosystem *condition* accounts describe the quality of these ecosystem types in terms of their main characteristics (see SM Table S4 for the definition of SEEA EA accounts and Table S5 for selection criteria). EBV variables can be used in both *extent* and *condition* accounts in a relatively straightforward way (Table 2, SM Figure S6). Ecosystem distribution EBV can be directly used to populate ecosystem extent accounts, and it can also be used as a basis for calculating further variables in the condition accounts (e.g. landscape-level variables in ECT C1). Most of the other EBVs can also be used to calculate simple data products that meet the criteria of SEEA EA ecosystem condition accounts (Czúcz et al., 2021b), and many EBVs can even be directly used as condition variables (Table 2). Nevertheless, physical and chemical condition variables (ECT classes A1 & A2) are not covered by the scope of EBVs, which can be seen as a logical extension of the EBV framework to cover further important classes of primary data necessary for efficient environmental monitoring and governance. While the accounts in SEEA EA focus on information at the ecosystems level, EBVs at genetics and species level can underpin changes in the ecosystems and can be indirectly referred as a complementary strength.

Table 2. A crosswalk of EBV and EESV classes and subclasses to the major structural elements of SEEA Ecosystem Accounts. X: clear direct correspondence, (x): possible partial or indirect correspondence (see also SM Figure S6 for a graphical presentation).

	SEEA EA Ecosystem Extent Accounts	**SEEA EA Ecosystem Condition Accounts**						**SEEA EA Ecosystem Service Accounts**	
		A Abiotic Ecosystem Characteristics*		B Biotic Ecosystem Characteristics			C Landscape level*		
EBV / EESV classes and subclasses		A1 Physical state*	A2 Chemical state*	B1 Compo-sitional state	B2 Structural state	B3 Functional state	C1 Landscape / seascape*	Biophysical flow	Monetary flow
Essential Biodiversity Variables									
Genetic Composition**									
Intraspecific genetic diversity**				(x)					
Genetic differentiation**				(x)					
Inbreeding**				(x)					
Effective population size**				(x)					
Species Populations									
Species distribution				X			(x)		
Population abundance				X					
Species Traits**									
Morphology**					(x)				
Physiology**						(x)			
Phenology***						(x)			
Movement**							(x)		
Community Composition									
Community abundance				X					
Taxonomic/phylogen. diversity				X					
Trait diversity				X		(x)			
Interaction diversity**						(x)			
Ecosystem Structure									
Ecosystem distribution	X						(x)		
Live cover fraction					X				
Vertical profile					X				
Ecosystem Functions									
Primary productivity						X			
Ecosystem phenology						X			
Ecosystem disturbances						X			
Essential Ecosystem Service Variables									
Ecosystem Services									
Ecological supply****									
Anthropogenic contribution****									
Demand****									
Use								X	
Instrumental value									X
Relational value*****									

**Abiotic* and *landscape-level* ECTs are not covered in EBV classes (in line with its *biotic* focus). EBVs (e.g. ecosystem distribution) can however be used to calculate landscape-level ECTs.
**EBVs that primarily describe species (genetic composition and species traits) and species interactions can only indirectly be linked to ECTs (cf. Czúcz et al., 2021b).
***Species *phenology* is not considered in SEEA EA condition accounts (lack of clear directionality, cf. Czúcz et al., 2021a) but as it could have impact on functional state of ecosystems with seasonal changes e.g. under climate change, phenology information can be of potential relevance to SEEA EA condition accounts.
*****Ecological supply* (i.e., the potential/capacity of ecosystems to deliver services), *anthropogenic contributions*, and *demand* do not have dedicated 'accounts' in the SEEA EA framework, but they are all discussed in detail (SEEA EA, Chapter 6). Both *supply* and *use* in SEEA EA's "supply and use" tables refer to *use* in EESV (the actual amount of ecosystem services consumed).
*****SEEA EA monetary ES accounts exclusively cover use and *instrumental values* assessed as exchange values.

SEEA EA addresses ecosystem services in two accounts: one of them presents the supply and use of services in *biophysical units,* and the other one in *monetary units.* These two accounts correspond to the EESV classes *use* (biophysical unit) and *instrumental value* (monetary unit). In addition, SEEA EA applies so-called "*supply and use tables*", but the term *supply* has a different meaning in SEEA from the classes in the EESV framework. In the context of SEEA EA, both *supply* and *use* describe the "flow" of realised ecosystem services (i.e. the amount of the service actively or passively *appropriated* by people, which is equivalent to "*use*" in the context of EESVs), whereas *ecological supply* in the context of EESVs describes the capacity/potential of an ecosystem to deliver a service (irrespective of its actual use). In other words, *supply tables* and *use tables* in SEEA EA are two different presentations of the *same* set of numbers (the amount of the service *appropriated*) with "supply" tables being grouped by the main sources (ecosystem types) and "use: tables grouped by the main users (economic sectors and other groups of beneficiaries). This structure and terminology is inherited from economic accounting (Lequiller and Blades, 2014) and is intended to ensure compatibility with it. Therefore, as SEEA EA and EESV frameworks are developed with different main purposes, the accounts and the classes where the alignments are achievable are where the interoperability can be established to build the extension into each other's domains (i.e., economic accounting and biodiversity monitoring respectively).

Furthermore, SEEA EA's ecosystem condition accounts were also designed to accommodate a deliberative process; where experts from different backgrounds can collaborate on identifying and developing condition variables that are both context-relevant and feasible to characterize the studied ecosystem type (Czúcz et al., 2021a). SEEA EA's systematic approach towards selecting the most relevant (i.e., "essential") condition variables can also be seen as a simple operative *essential variable* framework. Similarly, SEEA EA's reference list of ecosystem services can be seen as a selection of services considered "essential" from the perspective of national accounting. In addition, SEEA EA condition accounts also propose a framework for selecting and defining meaningful reference levels for the condition variable while EBVs are intentionally value-agnostic in this respect. Hence, uses of EBVs in decision context that require reference values or levels can build on the SEEA EA's consensus-based and locally relevant approach or application as a starting point.

3.2. Essential variables for KM-GBF reporting and monitoring

The implementation of the CBD KM-GBF monitoring framework relies on several indicators for which EBVs and EESVs can provide major underlying data products (Figure 2). EBVs and EESVs relate directly to Goal A (on the state of nature) and Goal B (on benefits for society), respectively, and a suite of KM-GBF indicators can be constructed directly from EBVs, with necessary aggregation. As illustrative examples**,** comparatively simple indicators such as Extent of Ecosystem by Type derived from the *ecosystem distribution* EBV can inform the "area" component of Goal A on ecosystems. Indicators such as Red List Indices derived with *species and ecosystem distribution* EBVs can inform the "species extinction" or "the status of threatened species" component of Goal A on biodiversity (Figure 2). Indicators such as the Biodiversity Habitat Index and the Bioclimatic Ecosystem Resilience Index - both derived from *taxonomic/phylogenetic diversity*, *ecosystem distribution*, and *live cover fraction* EBVs - can inform the assessment of action-targets such as spatial planning (Target 1), ecosystem restoration (Target 2) and climate mitigation and adaptation (Target 8).

For Goal B on nature's contributions to people, the EESV classes *supply*, *demand*, *use*, and *value* can be used to derive indicators on benefits people receive from specific ecosystem services such as pollination-based crop production and consumption, air and water quality regulation and enhancement, and disaster risk reduction from nature-based infrastructure (Figure 2). The different EESV classes (e.g., supply, demand, use, values) can inform different action-targets. For instance, the demand class/layer can inform how the wild species are being used sustainably (Target 9) while the supply class/layer of EESV can inform how nature's contributions to people are being restored, maintained and enhanced (Target 11).

As described earlier, the EBVs also inform the development of EESVs as biodiversity or ecosystem underpinning the connectivity, integrity, and resilience of ecosystems; and it often contributes directly to the *ecological supply*, which underlies the productivity and efficiency capacity/potential of ecosystem services. Since several of EBV- and EESV-derived indicators inform the Goals and Targets of KM-GBF, they can facilitate more coherent and comparable reporting and monitoring of national contributions to global goals in NBSAPs and NRs by improving standardized ecological monitoring and data production.

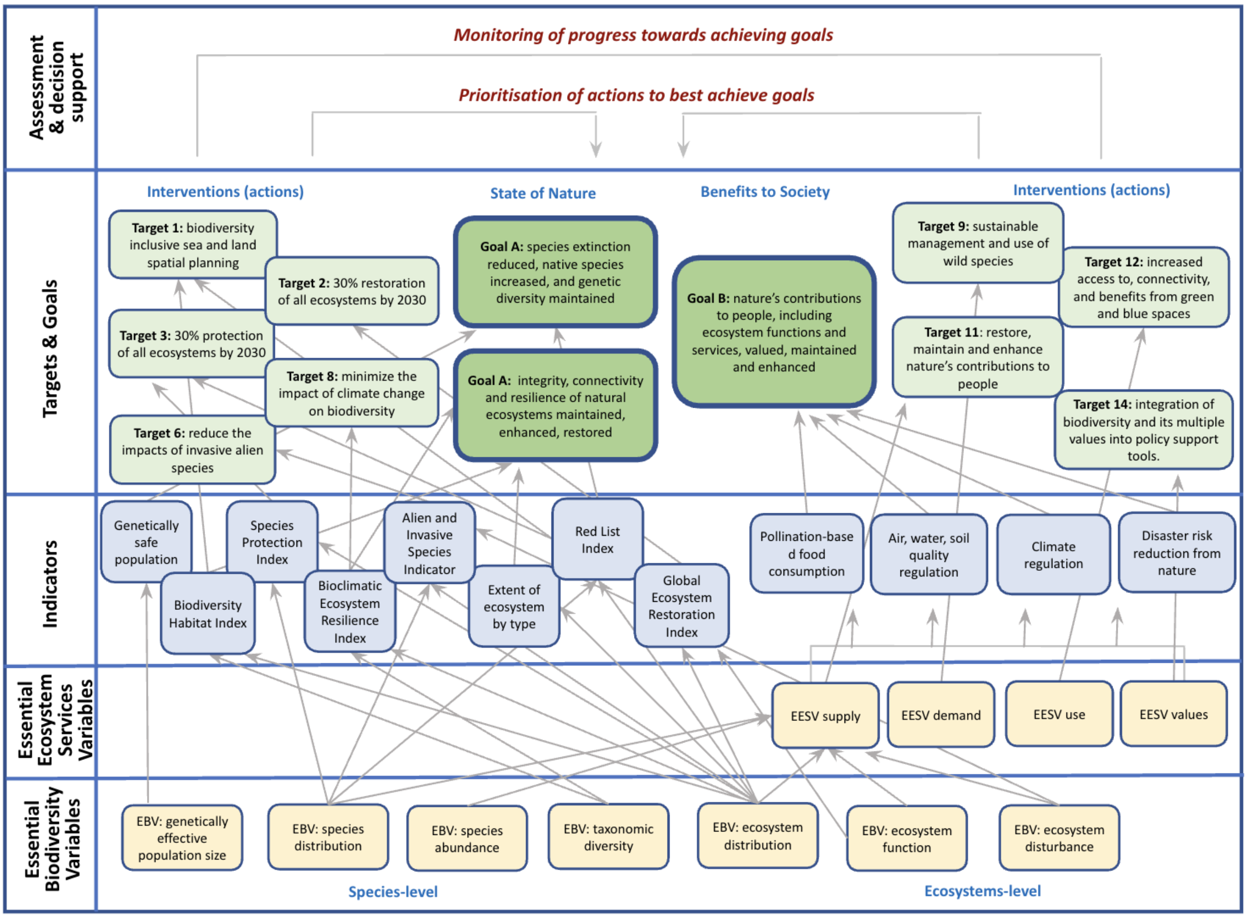


Figure 2. Linkages and interdependencies of EBVs and EESVs from species to ecosystems and ecosystem services on multiple dimensions, and the role of EBV/EESV derived indicators in informing different components of targets and goals of the KM-GBF in prioritizing actions and monitoring progress towards achieving goals. (*Note: This figure shows a selection of essential variables, indicators, targets and goals.)*

4. Illustrative use cases of EBVs/EESVs in national planning and reporting

While EBVs and EESVs have not yet been formally adopted as international standards for ecological monitoring, they are being progressively integrated into data-to-decision workflows through collaborative projects involving EBV/EESV developers, researchers, and policymakers. Here, we highlight three use cases being applied in a few regions and countries. Globally, EBV/EESV applications remain voluntary, nascent, and diverse in its context, often implemented as pilot initiatives through participatory approaches that bridge research, government, and practitioner communities.

	MEA reporting informed	Policy Context	EBV/EESV frameworks used	Data Source	Region/country
4.1	SEEA EA, KM-GBF	Spatial planning, goal tracking, accounting	EBV-based data workflows	National ecological data and maps, monitoring program	South Africa, Ghana, Uganda, South Korea, Arctic, Tropical Andes, Europe
4.2	KM-GBF, SEEA EA	Areas for protection and restoration	EBV-based index	Remote sensing and local data + BILBI model	Australia, Peru, South Korea
4.3	SDGs, KM-GBF	Water Funds	EESV-based optimization	RIOS + InVEST models	Colombia, Kenya

4.1 Identifying EBVs in data to decision workflows with stakeholders

As part of a five-year World Bank Global Environment Facility (GEF) funded project to support the mainstreaming of biodiversity information into government decision-making, NatureServe together with the South Africa National Biodiversity Institute (SANBI) and UN Environment Program World Conservation Monitoring Centre (UNEP-WCMC) collaborated with key stakeholders (government, NGO and academic) in South Africa, Ghana, and Uganda to develop and implement EBV-based workflows to repeatedly and adaptively (depending on new user needs) produce key biodiversity information products to guide biodiversity conservation. This approach was implemented using SANBI's repeatable Spatial Biodiversity Assessment methodology, which follows a workflow process (Figure 3) to facilitate national-scale spatial analysis of ecosystems by type to inform priority actions for conservation and restoration of threatened ecosystems (SANBI & UNEP-WCMC, 2016).

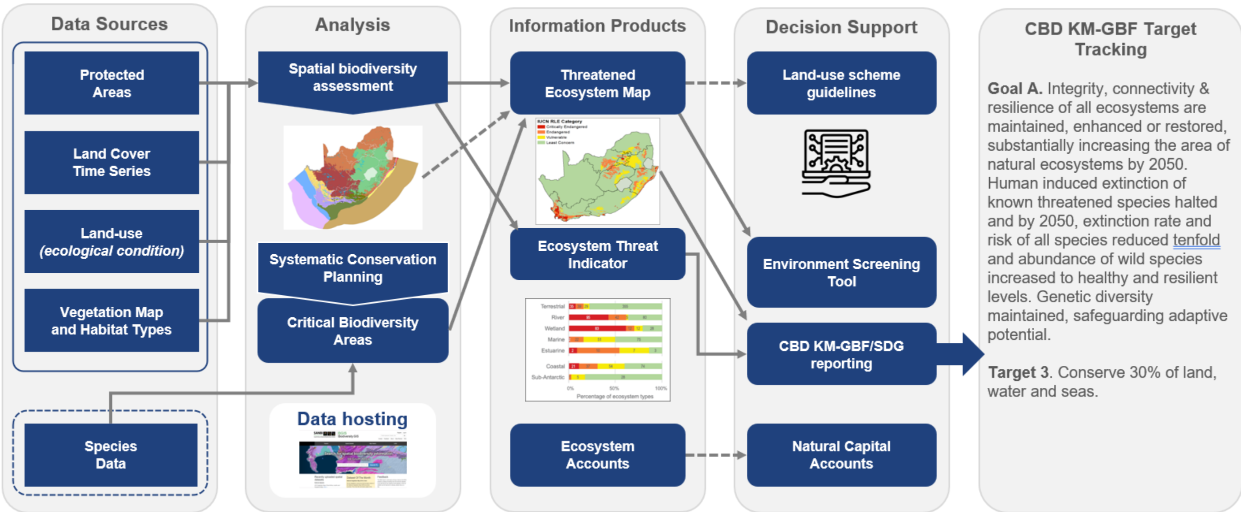


Figure 3. A repeatable workflow process for the integration of core datasets for the repeatable production of national spatial biodiversity assessments that serve multiple policy outputs. Note: solid lines depict direct outputs from the Spatial Biodiversity Assessment whereas dotted lines indicate additional outputs resulting from either additional data inputs and/or applications for policy.

In South Africa, the workflow to produce and revise national *ecosystem distribution* EBVs for spatial planning and prioritisation led to the production of national *ecosystem extent accounts* using the SEEA-EA reporting framework by simply reanalysing the foundational EBVs. This has led to the production of the first national SEEA EA accounts for terrestrial ecosystems in South Africa in partnership with Statistics South Africa (2020), with a range of other national satellite data products to further mainstream natural capital data into national economic decision-making, such as for the protected area estate and strategic water source areas. These accounts are intended to link changes in natural capital to changes in socio-economic potential. By facilitating this foundational development process with EBVs as core data, indicators were co-developed with stakeholders to establish a repeatable and sustained process for national indicator production, led by local experts. This approach was akin to the 9-step Biodiversity Observation Network (BON) design process, taking a user-driven approach that began by identifying priority policy entry points, possible information products (e.g. maps and indicators) to inform those identified policy objectives, and then employing a co-development and consultative process for the workflow development (Navarro et al., 2017, see SM Figure S7 for South Africa adapted data-to-decision development flow). In this project, identifying and building a community of practice that can execute and enhance the workflows over time was key. In South Africa, the national Biodiversity Planning Forum hosted by SANBI brings together a network of practitioners, policymakers, technicians and academics to further integrate biodiversity science for spatial planning (Botts et al., 2020, 2019).

In developing EBV-based data-to-decision workflows, targeted support, training and capacity building are necessary to make relevant institutions and stakeholders contribute and benefit from standardized and reproducible data workflows and streamlined reporting to multiple MEAs. This requires concerted cooperation by the funders, producers and users of the data to analyse the state and trends of biodiversity and ecosystem services. There are similar active projects in the Arctic region (Gill, M.J. et al., 2011), Tropical Andes (Valdez et al., 2023), Europe (Kissling et al., 2024), and South Korea where EBV-based indicators are being generated using national data while existing biodiversity monitoring efforts are being crosswalked to the EBV and KM-GBF monitoring frameworks to improve the alignment to global standards and to identify gap.

4.2 Developing model-based indicators with EBVs for use across region and scale

Strong interlinkages and dependencies exist between many of the goals and targets in KM-GBF, and between major components identified within each of these elements. For example, retention of species and genetic diversity will depend, at least in part, on the future area, connectivity and integrity of natural ecosystems (under Goal A). This, in turn, will be shaped by the interplay between multiple types of actions, e.g., protected-area expansion or ecosystem restoration (under Targets 1, 2, and 3). Such interlinkages pose a challenge for monitoring of progress and for assessment and prioritisation of actions (Leadley et al., 2022).

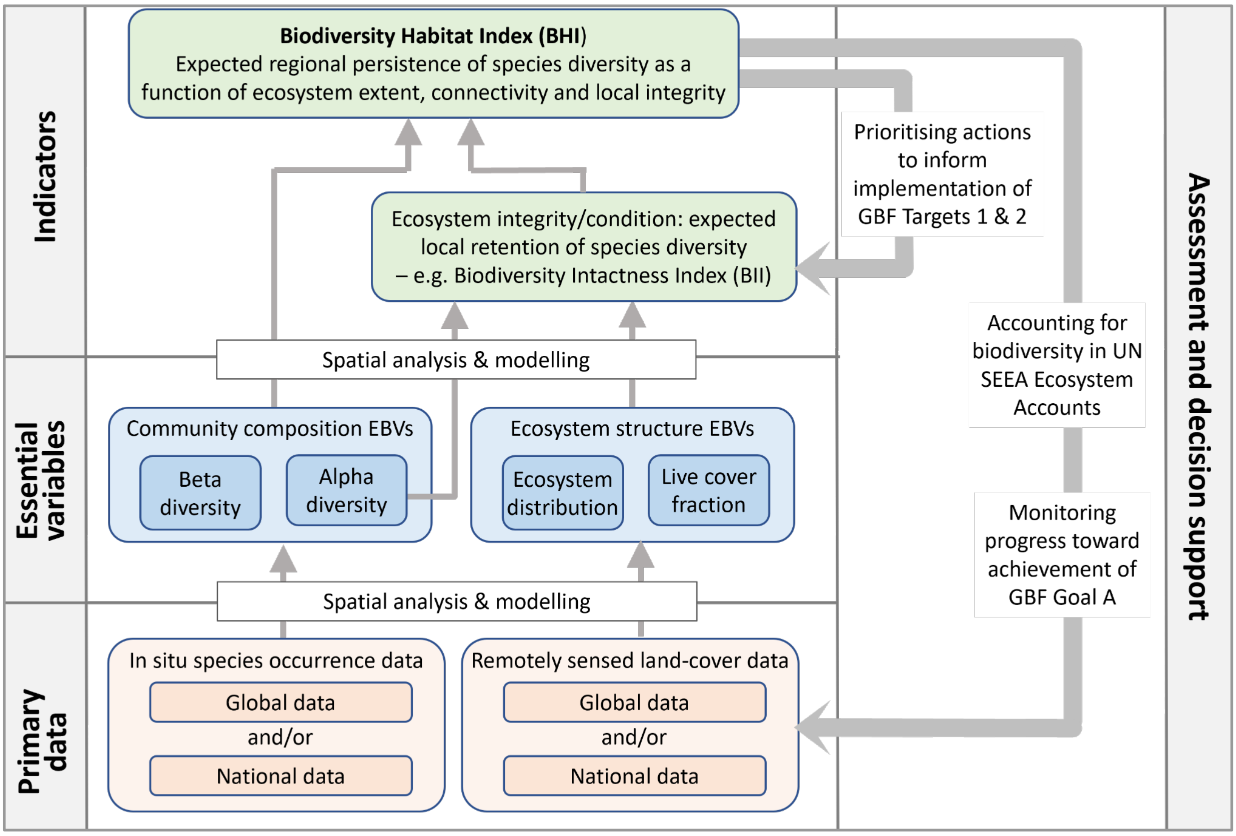


Figure 4. Biodiversity Habitat Index (BHI) data to indicators workflow for assessment decision support

Habitat-based biodiversity indicators (Ferrier, 2011; King et al., 2021) can contribute to addressing this problem. These indicators help evaluate status or scenarios on the level of species (or genetic) diversity expected to persist within a given spatial reporting unit (e.g., a country, an ecoregion, or the entire planet) as a function of the state and spatial configuration of natural ecosystems across that unit. In particular, the Biodiversity Habitat Index (BHI) assesses how changes in the condition and spatial configuration of natural ecosystems are expected to impact the persistence of species diversity within a region of interest (Ferrier et al., 2024; Hoskins et al., 2020). The BHI can be reported either as the average proportion of habitat remaining for all species in the region of interest, or as the proportion of these species expected to persist over the long term (UNEP-WCMC, 2025) while optionally accounting for the effects of habitat connectivity and climate change (Ferrier et al., 2020; Harwood et al., 2022). Recalculation of the indicator using updated remote sensing of ecosystem integrity enables monitoring of progress towards achieving goals for both ecosystems and species. Evaluation of marginal changes in the indicator expected to result from alternative spatially-explicit options for protecting or restoring habitat also provides a solid foundation for prioritising on-ground actions.

The methodological framework underpinning the BHI is purposely designed to allow the indicator to be derived from EBV datasets populated using primary observations from a wide variety of sources (Figure 4). By using EBVs to harmonise such data into the inputs needed to generate the BHI, the indicator can be derived at different scales using the same analytical 'machinery' employed globally. This approach can involve replacing global data for some, or all, of the required inputs with national or subnational data. For example, as part of a collaboration between Conservation International and the Peruvian Government piloting the application of UN SEEA Ecosystem Accounts in the San Martin region of Peru, the BHI was derived by combining community composition data from global biodiversity modelling with best-available local mapping of ecosystem structure and integrity (Grantham et al., 2016). In another typical example, highly refined modelling of spatial variation in community composition within the Pilbara region of Western Australia has enabled application of the BHI to assess the expected cumulative impact of multiple iron-ore mining operations within that region (Mokany et al., 2019). An ongoing collaboration between CSIRO (Australia's national science agency) and South Korea's National Institute of Ecology is now also generating the BHI (along with the Bioclimatic Ecosystem Resilience Index) at high spatial resolution across South Korea, using EBVs derived from best available national data for that country.

4.3 Use of EESVs in scenario analyses to support spatial planning

Throughout much of the developing world, many components of the Sustainable Development Goals (SDGs) are in competition with one another. Mounting pressure for agricultural products (meeting SDGs 1 and 2) driving land conversion in rural areas competes with growing demand for a clean and stable water supply (SDG 6) to support the resilience of growing urban populations (SDG 11). This conflict is mirrored in KM-GBF; ecosystem integrity and species diversity can be difficult to maintain while still supporting the food and water security elevated as goals for nature's contributions to people.

Water funds are one policy solution to this resource conflict, providing a financial mechanism for watershed management that promotes habitat conservation, restoration, and improved agricultural practices to protect water resources for downstream users (Arias, V. et al., 2010). A return on investment depends on how the resources are invested, and spatial targeting can identify the most cost-effective places to focus efforts. Biophysical and social data can be used in tools like the Resource Investment Optimization System (RIOS; Vogl et al., 2017b) or the Restoration Opportunities Optimization Tool (ROOT; Beatty et al., 2018) to produce a portfolio of landscape interventions to maximize delivery of desired ecosystem services (Figure 5), taking into account many of the EESVs in its optimization.

The increase in the *ecological supply* of the ecosystem service under a given intervention, the location and number of beneficiaries and stakeholder preferences (as a proxy for *demand*), and budgets and activity feasibility (*anthropogenic contributions*), the resulting optimized portfolio can be treated as a scenario map in an ecosystem service modelling tool like InVEST (Sharp et al., 2016) to quantify the *benefit* that could be provided by the water fund, highlighting mostly *instrumental values*. Trade-offs between different services can be balanced by strategically locating application of best management practices or forest restoration in places that will make the greatest difference to explicit water fund goals (e.g. indicators of *use* like water quality or flood protection for communities) for the least opportunity cost to agricultural production. The land conserved or restored for ecosystem services can also provide co-benefits to biodiversity, which could be assessed through the EBVs (e.g. ecosystem structure or function supporting species and community composition, like nesting habitat for native birds, or floral resources for pollinators).

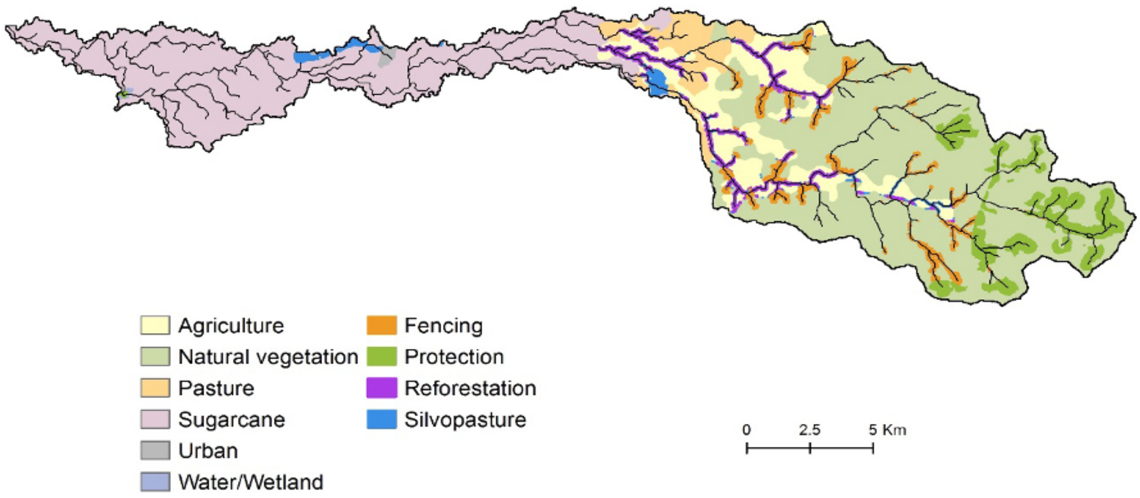


Figure 5. Example of an investment portfolio resulting from RIOS prioritization, with prioritized activities (fencing, protection, reforestation, silvopasture) in brighter colors set against the muted colors of current land use within a watershed.

Varying such prioritization exercises over different scenarios can help identify more resilient and robust investment strategies. Considering both current and future environmental conditions, including climate extremes in the Putomayo region of Colombia, revealed that areas with the highest levels of water yield today overlap with areas most susceptible to soil erosion in future climates (Suarez et al., 2011). In Kenya, evaluating the impact of different scenarios on EESVs, including a variety of assumptions in regard to the different *instrumental benefits* of the Nairobi Water Fund helped build confidence that the water fund could provide a positive return on investment (Vogl et al., 2017a). As water funds, and payments for ecosystem services more generally, have continued to expand, accounting for the full range of values in their design will be increasingly important to their durability. Recent review of the growing body of research on the topic has demonstrated that the long-term effectiveness and legitimacy of such investments also depend on the inclusion of local values, particularly the *relational* and *intrinsic* (Bremer et al., 2016).

5. Discussion

Our ability to observe biodiversity and ecosystems, estimate their state, detect changes in this state, and attribute a cause to those changes depends on the availability of robust biodiversity data and metrics (Gonzalez et al., 2023a). Similarly, the implementation of MEAs, and the monitoring of progress towards their objectives is also hindered by persistent gaps in the availability, structure, and coherence of relevant data streams. New advances in Earth observation and modelling technologies (Allard et al., 2023; Stephenson, 2020) make an increasing number of data products available reflecting diverse components of biodiversity and ecosystem services at multiple scales, which can then be used to derive a wide range of indicators for quantifying diverse values and benefits of nature (Cord et al., 2017; Pettorelli et al., 2016; Ramirez-Reyes et al., 2019). Essential variables, including EBVs and EESVs, can play a key role in this process, making it more structured, standardised, and transparent at the global scale (Gonzalez et al., 2023b).

The selection of essential variables is primarily driven by their relevance in characterizing the studied (socio-ecological) system, taking also technical and economic feasibility into consideration (Lehmann et al., 2022, 2020). This makes essential variables ideal candidates for structuring data workflows from monitoring to reporting indicators. Essential climate variables (ECVs), for example, have revolutionised the data workflows of the climate community since the emergence of the concept in the early 2000s, and most major reporting frameworks for climate policy are heavily supported by operational ECV workflows (Ballari et al., 2023; Yang et al., 2022). In a similar way, EBVs and EESVs can also serve as key building blocks supporting the design of both for effective monitoring systems and data workflows for biodiversity policy and environmental governance. Nevertheless, the implementation of standardised monitoring still faces several major scientific and technical challenges. Biological systems are inherently more complex than climatic systems (Blanchet, 2024), which means that there is a higher number of concrete variables that need to be measured, and the current set of EBVs and EESVs classes does not offer a full standardization for these concrete variables. Historical and ongoing biodiversity monitoring programmes are not always clearly aligned with EBVs and EESVs, nor with the key policy drivers (i.e., targets), and intermittent funding, data sovereignty concerns, and institutional inertia also contribute to making the global harmonisation of monitoring efforts challenging.

The development of standardised indicator workflows is also hindered by major challenges, partly fuelled by the lack of adequately standardised monitoring systems. Existing workflows are often tailored to local datasets, resulting in fragmented and inconsistent reporting systems. There are also considerable challenges related to the international coordination of data semantics and formatting standards, creating serious interoperability challenges (Bagstad et al., 2025) for all major types of data operations (interpolation, modelling, aggregation). For interpolation and aggregation techniques, there is a lack of understanding about the "downstream" impacts of particular methodological choices in a data workflow context (Allain et al., 2018; Montero et al., 2024). While there has been considerable progress during the last decades in socio-ecological modelling, several aspects of the new models (e.g. the validity of their assumptions, the propagation of uncertainty) still need to be explored in a workflow context. Current ecosystem service models are still challenged with capturing long-term ecological feedbacks like soil degradation impacts on productivity and deforestation impacts on downwind precipitation, which limits their applicability in scenario-based studies (Kim et al., 2023). Similarly, the biophysical outputs of such models are not adequately linked to dynamic economic modelling in order to represent the full value of land- and resource use decisions (Chaplin-Kramer et al., 2024). Target tracking and reporting is still also often done at different frequencies and scales by different agencies within and across the nations. More systemic or structural challenges include data sovereignty concerns, institutional inertia, and semantic misalignments even across the key reporting frameworks, such as UN SEEA EA and KM-GBF.

As EBVs and EESVs were designed to reduce the inherent complexity of biological systems, their application as key structural elements can hence simplify the complexity of monitoring and reporting systems, and reduce the challenges discussed in this paper. Standardised EBV and EESV variables and associated data standards such as those of the EBV data cubes in NetCDF format (Quoß, 2025) can provide a solid foundation for building scalable, reproducible, and interoperable data workflows for multiscale analyses and policy support (see also SM Supplement S8 on how to make EBVs and EESVs accessible and reproducible). Deployment of EBVs and EESVs as a structural component of national monitoring systems will greatly simplify and promote the harmonization of data collection and indicator production, leading to efficiencies in data curation, reporting and analytics (Seebens et al., 2020; Turak et al., 2017). Advancing models for EBVs and EESVs can also improve the causal links between the different variables, making scenario-based simulations feasible and meaningful to inform the potential impact of future policy options on biodiversity and ecosystems (IPBES, 2019, 2016). Scenario-based information generated from such models has therefore a great potential to support multi-scale policy processes with knowledge- and data-based evidence in identifying conservation actions and spatial planning at the national scale while setting future milestones in CBD NBSAPs and tracking progress on implemented policies in CBD NRs at the global scale.

Effective workflows based on essential variables can also de-mystify the indicator production process and ensure ownership of key indicators by decision-makers. Several technical and logistical challenges can possibly also be mitigated by establishing regional support centres, offering technical guidance, shared tools, and opportunities for collaboration across countries, and by promoting the integration of essential variables into national frameworks iteratively, based on capacity that expands over time. Through the exposure of the critical need for sustained production of key datasets, this approach can also become self-sustaining, driving further investments in core datasets, and thereby yielding continually refined and more accurate results over time as well as establishing baselines and time-series for the indicators in question. The workflows can also support cross-agency collaboration and serve as structural blueprints for data curation and reporting systems. As illustrated through use cases around the globe, this work is actively underway in several regions (e.g., South Korea, the Arctic, Europe, Tropical Andes) to use the EBV/EESV frameworks and EBV/EESV-based indicators to assess and align existing biodiversity observation systems with global standards and indicators. Here, standardized reporting and data structures such as EBVs and EESVs can be fundamental in delivering indicators for multiple purposes (Balvanera et al., 2022; Navarro et al., 2017; Pereira et al., 2013). Identifying and operationalizing the interlinkages and dependencies between global sectoral goals that interact closely in the implementation and monitoring would go a long way in streamlining the data-to-decision flow in countries.

The scientific community, including GEO BON, will continue to evaluate the needs of society as expressed in national, regional, and international goals and conventions and focus the development of knowledge products such as essential variables on species, ecosystems, and ecosystem services with stakeholders. EBVs and EESVs, as the backbone of a standardized ecological monitoring framework, has an essential role in informing global policy, scientific and data frameworks such as KM-GBF and SDG indicators, SEEA EA accounts and IPBES assessments. The interoperability between essential variables and SEEA EA also has an important potential for transforming the economy with nature's diverse values more thoroughly accounted for in our national accounting systems. Furthermore, an improved interoperability of data and indicators used by the corporate and financial sector through collaboration with biodiversity science and environmental economic communities will be important in progressing towards the futures where nature-related risks are mitigated through collective and concerted effort. As the global community joins arms and accelerates ambitions to achieve nature- and people-positive futures, progressing in agreeing upon a minimum set of nature's facets to monitor globally will be an essential first step towards enabling and guiding effective biodiversity conservation and safeguarding planetary boundary and human security.

References

Allain, S., Plumecocq, G., Leenhardt, D., 2018. Spatial aggregation of indicators in sustainability assessments: Descriptive and normative claims. Land Use Policy 76, 577–588. https://doi.org/10.1016/j.landusepol.2018.02.038

Allard, A., Wood, C., Norton, L., Christensen, A.A., Van Eetvelde, V., Brown, A., Persson, H., Eriksson, L., 2023. Monitoring as a field, in: Monitoring Biodiversity. Routledge, London, pp. 9–33. https://doi.org/10.4324/9781003179245-2

Arias, V., Benitez, S., Goldman, R., 2010. PES: The Case of Quito, Ecuador. TEEB D2 Case Study.

Bagstad, K.J., Balbi, S., Adamo, G., Athanasiadis, I.N., Affinito, F., Willcock, S., Magrach, A., Hayashi, K., Harmáčková, Z.V., Niamir, A., Smets, B., Buchhorn, M., Drakou, E.G., Alfieri, A., Edens, B., Morales, L.G., Vári, Á., Sanz, M.-J., Villa, F., 2025. Interoperability for ecosystem service assessments: Why, how, who, and for whom? Ecosyst. Serv. 72, 101705. https://doi.org/10.1016/j.ecoser.2025.101705

Ballari, D., Vilches-Blázquez, L.M., Orellana-Samaniego, M.L., Salgado-Castillo, F., Ochoa-Sánchez, A.E., Graw, V., Turini, N., Bendix, J., 2023. Satellite Earth Observation for Essential Climate Variables Supporting Sustainable Development Goals: A Review on Applications. Remote Sens. 15, 2716. https://doi.org/10.3390/rs15112716

Balvanera, P., Brauman, K.A., Cord, A.F., Drakou, E.G., Geijzendorffer, I.R., Karp, D.S., Martín-López, B., Mwampamba, T.H., Schröter, M., 2022. Essential ecosystem service variables for monitoring progress towards sustainability. Curr. Opin. Environ. Sustain. 54, 101152. https://doi.org/10.1016/j.cosust.2022.101152

Beatty, C., Raes, L., Vogl, A.L., Hawthorne, P.L., Moraes, M., Saborio, J.L., Meza Prado, K., 2018. Landscapes, at your service: applications of the Restoration Opportunities Optimization Tool (ROOT), 1st ed. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/iucn.ch.2018.17.en

Bhatt, R., Gill, M.J., Hamilton, H., Han, X., Linden, H.M., Young, B.E., 2020. Uneven use of biodiversity indicators in 5th National Reports to the Convention on Biological Diversity. Environ. Conserv. 47, 15–21. https://doi.org/10.1017/S0376892919000365

Blanchet, F., 2024. The value and challenges of long-term biodiversity monitoring. Universite de Sherbrooke.

Bojinski, S., Verstraete, M., Peterson, T.C., Richter, C., Simmons, A., Zemp, M., 2014. The Concept of Essential Climate Variables in Support of Climate Research, Applications, and Policy. Bull. Am. Meteorol. Soc. 95, 1431–1443. https://doi.org/10.1175/BAMS-D-13-00047.1

Botts, E.A., Pence, G., Holness, S., Sink, K., Skowno, A., Driver, A., Harris, L.R., Desmet, P., Escott, B., Lötter, M., Nel, J., Smith, T., Daniels, F., Sinclair, S., Stewart, W., Manuel, J., 2019. Practical actions for applied systematic conservation planning. Conserv. Biol. 33, 1235–1246. https://doi.org/10.1111/cobi.13321

Botts, E.A., Skowno, A., Driver, A., Holness, S., Maze, K., Smith, T., Daniels, F., Desmet, P., Sink, K., Botha, M., Nel, J., Manuel, J., 2020. More than just a (red) list: Over a decade of using South Africa's threatened ecosystems in policy and practice. Biol. Conserv. 246, 108559. https://doi.org/10.1016/j.biocon.2020.108559

Brauman, K.A., Garibaldi, L.A., Polasky, S., Aumeeruddy-Thomas, Y., Brancalion, P.H.S., DeClerck, F., Jacob, U., Mastrangelo, M.E., Nkongolo, N.V., Palang, H., Pérez-Méndez, N., Shannon, L.J., Shrestha, U.B., Strombom, E., Verma, M., 2020. Global trends in nature's contributions to people. Proc. Natl. Acad. Sci. 117, 32799–32805. https://doi.org/10.1073/pnas.2010473117

Bremer, L.L., Auerbach, D.A., Goldstein, J.H., Vogl, A.L., Shemie, D., Kroeger, T., Nelson, J.L., Benítez, S.P., Calvache, A., Guimarães, J., Herron, C., Higgins, J., Klemz, C., León, J., Sebastián Lozano, J., Moreno, P.H., Nuñez, F., Veiga, F., Tiepolo, G., 2016. One size does not fit all: Natural infrastructure investments within the Latin American Water Funds Partnership. Ecosyst. Serv. 17, 217–236. https://doi.org/10.1016/j.ecoser.2015.12.006

Bubb, P., 2013. Scaling Up or Down? LinkingGlobal and National Biodiversity Indicators and Reporting, in: Collen, B., Pettorelli, N., Baillie, J.E.M., Durant, S.M. (Eds.), Biodiversity Monitoring and Conservation. Wiley-Blackwell, Oxford, UK, pp. 402–420. https://doi.org/10.1002/9781118490747.ch17

Campbell, J., Neuner, J., See, L., Fritz, S., Fraisl, D., Espey, J., Kim, A., 2020. The role of combining national official statistics with global monitoring to close the data gaps in the environmental SDGs. Stat. J. IAOS 36, 443–453. https://doi.org/10.3233/SJI-200648

Chaplin-Kramer, R., Miller, C.R., Dee, L.E., Bennett, N.J., Echeverri, A., Gould, R.K., Gregr, E.J., Kinnaird, M.F., Leidner, A.K., Naidoo, R., Nicholas, K.A., Zhao, J., 2025. Wildlife's contributions to people. Nat. Rev. Biodivers. 1, 68–81. https://doi.org/10.1038/s44358-024-00006-9

Chaplin-Kramer, R., Neugarten, R.A., Sharp, R.P., Collins, P.M., Polasky, S., Hole, D., Schuster, R., Strimas-Mackey, M., Mulligan, M., Brandon, C., Diaz, S., Fluet-Chouinard, E., Gorenflo, L.J., Johnson, J.A., Kennedy, C.M., Keys, P.W., Longley-Wood, K., McIntyre, P.B., Noon, M., Pascual, U., Reidy Liermann, C., Roehrdanz, P.R., Schmidt-Traub, G., Shaw, M.R., Spalding, M., Turner, W.R., Van Soesbergen, A., Watson, R.A., 2022. Mapping the planet's critical natural assets. Nat. Ecol. Evol. 7, 51–61. https://doi.org/10.1038/s41559-022-01934-5

Chaplin-Kramer, R., Polasky, S., Alkemade, R., Burgess, N.D., Cheung, W.W.L., Fetzer, I., Harfoot, M., Hertel, T.W., Hill, S.L.L., Andrew Johnson, J., Janse, J.H., José V. Jeetze, P., Kim, H., Kuiper, J.J., Lonsdorf, E., Leclère, D., Mulligan, M., Peterson, G.D., Popp, A., Roe, S., Schipper, A.M., Snäll, T., Van Soesbergen, A., Soterroni, A.C., Stehfest, E., Van Vuuren, D.P., Visconti, P., Wang-Erlandsson, L., Wells, G., Pereira, H.M., 2024. Integrated modeling of nature's role in human well-being: A research agenda. Glob. Environ. Change 88, 102891. https://doi.org/10.1016/j.gloenvcha.2024.102891

Chaplin-Kramer, R., Sharp, R.P., Weil, C., Bennett, E.M., Pascual, U., Arkema, K.K., Brauman, K.A., Bryant, B.P., Guerry, A.D., Haddad, N.M., Hamann, M., Hamel, P., Johnson, J.A., Mandle, L., Pereira, H.M., Polasky, S., Ruckelshaus, M., Shaw, M.R., Silver, J.M., Vogl, A.L., Daily, G.C., 2019. Global modeling of nature's contributions to people. Science 366, 255–258. https://doi.org/10.1126/science.aaw3372

Cord, A.F., Brauman, K.A., Chaplin-Kramer, R., Huth, A., Ziv, G., Seppelt, R., 2017. Priorities to Advance Monitoring of Ecosystem Services Using Earth Observation. Trends Ecol. Evol. 32, 416–428. https://doi.org/10.1016/j.tree.2017.03.003

Czúcz, B., Haines-Young, R., Kiss, M., Bereczki, K., Kertész, M., Vári, Á., Potschin-Young, M., Arany, I., 2020. Ecosystem service indicators along the cascade: How do assessment and mapping studies position their indicators? Ecol. Indic. 118, 106729. https://doi.org/10.1016/j.ecolind.2020.106729

Czúcz, B., Keith, H., Driver, A., Jackson, B., Nicholson, E., Maes, J., 2021a. A common typology for ecosystem characteristics and ecosystem condition variables. One Ecosyst. 6, e58218. https://doi.org/10.3897/oneeco.6.e58218

Czúcz, B., Keith, H., Maes, J., Driver, A., Jackson, B., Nicholson, E., Kiss, M., Obst, C., 2021b. Selection criteria for ecosystem condition indicators. Ecol. Indic. 133, 108376. https://doi.org/10.1016/j.ecolind.2021.108376

Czúcz, B., Simensen, T., Skrindo, A.B., Rusch, G.M., Nybø, S., Grainger, M., Töpper, J.P., 2025. No net loss accounting: Aligning biodiversity offsets with ecosystem accounts. Ecol. Solut. Evid. 6, e70006. https://doi.org/10.1002/2688-8319.70006

Díaz, S., 2015. The IPBES Conceptual Framework — connecting nature and people. Curr. Opin. Environ. Sustain. 16.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S., Shirayama, Y., 2018. Assessing nature's contributions to people. Science 359, 270–272. https://doi.org/10.1126/science.aap8826

Dou, Y., Zagaria, C., O'Connor, L., Thuiller, W., Verburg, P.H., 2023. Using the Nature Futures Framework as a lens for developing plural land use scenarios for Europe for 2050. Glob. Environ. Change 83, 102766. https://doi.org/10.1016/j.gloenvcha.2023.102766

Durán, A.P., Kuiper, J.J., Aguiar, A.P.D., Cheung, W.W.L., Diaw, M.C., Halouani, G., Hashimoto, S., Gasalla, M.A., Peterson, G.D., Schoolenberg, M.A., Abbasov, R., Acosta, L.A., Armenteras, D., Davila, F., Denboba, M.A., Harrison, P.A., Harhash, K.A., Karlsson-Vinkhuyzen, S., Kim, H., Lundquist, C.J., Miller, B.W., Okayasu, S., Pichs-Madruga, R., Sathyapalan, J., Saysel, A.K., Yu, D., Pereira, L.M., 2023. Bringing the Nature Futures Framework to life: creating a set of illustrative narratives of nature futures. Sustain. Sci. https://doi.org/10.1007/s11625-023-01316-1

Echeverri, A., Smith, J.R., MacArthur-Waltz, D., Lauck, K.S., Anderson, C.B., Monge Vargas, R., Alvarado Quesada, I., Wood, S.A., Chaplin-Kramer, R., Daily, G.C., 2022. Biodiversity and infrastructure interact to drive tourism to and within Costa Rica. Proc. Natl. Acad. Sci. 119, e2107662119. https://doi.org/10.1073/pnas.2107662119

Edens, B., Maes, J., Hein, L., Obst, C., Siikamaki, J., Schenau, S., Javorsek, M., Chow, J., Chan, J.Y., Steurer, A., Alfieri, A., 2022. Establishing the SEEA Ecosystem Accounting as a global standard. Ecosyst. Serv. 54, 101413. https://doi.org/10.1016/j.ecoser.2022.101413

EuropaBON, 2024. EBV Description.

Fernández, N., Ferrier, S., Navarro, L.M., Pereira, H.M., 2020. Essential Biodiversity Variables: Integrating In-Situ Observations and Remote Sensing Through Modeling, in: Cavender-Bares, J., Gamon, J.A., Townsend, P.A. (Eds.), Remote Sensing of Plant Biodiversity. Springer International Publishing, Cham, pp. 485–501. https://doi.org/10.1007/978-3-030-33157-3_18

Ferrier, S., 2011. Extracting More Value from Biodiversity Change Observations through Integrated Modeling. BioScience 61, 96–97. https://doi.org/10.1525/bio.2011.61.2.2

Ferrier, S., Harwood, T.D., Ware, C., Hoskins, A.J., 2020. A globally applicable indicator of the capacity of terrestrial ecosystems to retain biological diversity under climate change: The bioclimatic ecosystem resilience index. Ecol. Indic. 117, 106554. https://doi.org/10.1016/j.ecolind.2020.106554

Ferrier, S., Ware, C., Austin, J.M., Grantham, H.S., Harwood, T.D., Watson, J.E.M., 2024. Ecosystem extent is a necessary but not sufficient indicator of the state of global forest biodiversity. Conserv. Lett. 17, e13045. https://doi.org/10.1111/conl.13045

Garibaldi, L.A., Carvalheiro, L.G., Vaissière, B.E., Gemmill-Herren, B., Hipólito, J., Freitas, B.M., Ngo, H.T., Azzu, N., Sáez, A., Åström, J., An, J., Blochtein, B., Buchori, D., García, F.J.C., Oliveira da Silva, F., Devkota, K., Ribeiro, M. de F., Freitas, L., Gaglianone, M.C., Goss, M., Irshad, M., Kasina, M., Filho, A.J.S.P., Kiill, L.H.P., Kwapong, P., Parra, G.N., Pires, C., Pires, V., Rawal, R.S., Rizali, A., Saraiva, A.M., Veldtman, R., Viana, B.F., Witter, S., Zhang, H., 2016. Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. Science 351, 388–391. https://doi.org/10.1126/science.aac7287

Geijzendorffer, I.R., Regan, E.C., Pereira, H.M., Brotons, L., Brummitt, N., Gavish, Y., Haase, P., Martin, C.S., Mihoub, J.-B., Secades, C., Schmeller, D.S., Stoll, S., Wetzel, F.T., Walters, M., 2016. Bridging the gap between biodiversity data and policy reporting needs: An Essential Biodiversity Variables perspective. J. Appl. Ecol. 53, 1341–1350. https://doi.org/10.1111/1365-2664.12417

GEO BON, 2025. What are EBVs?

Gill, M.J., K. Crane, R. Hindrum, P. Arneberg, I. Bysveen, N.V. Denisenko, V. Gofman, A. Grant-Friedman, G. Gudmundsson, R. Hopcroft, K. Iken, A. Labansen, O.S. Liubina, I.A. Melnikov, S.E. Moore, J.D. Reist, B.I. Sirenko, J. Stow, F. Ugarte, D. Vongraven, 2011. Arctic Marine Biodiversity Monitoring Plan, CAFF Monitoring Series. CAFF International Secretariat, Akureyri, Iceland.

Gonzalez, A., Chase, J.M., O'Connor, M.I., 2023a. A framework for the detection and attribution of biodiversity change. Philos. Trans. R. Soc. B Biol. Sci. 378, 20220182. https://doi.org/10.1098/rstb.2022.0182

Gonzalez, A., Vihervaara, P., Balvanera, P., Bates, A.E., Bayraktarov, E., Bellingham, P.J., Bruder, A., Campbell, J., Catchen, M.D., Cavender-Bares, J., Chase, J., Coops, N., Costello, M.J., Czúcz, B., Delavaud, A., Dornelas, M., Dubois, G., Duffy, E.J., Eggermont, H., Fernandez, M., Fernandez, N., Ferrier, S., Geller, G.N., Gill, M., Gravel, D., Guerra, C.A., Guralnick, R., Harfoot, M., Hirsch, T., Hoban, S., Hughes, A.C., Hugo, W., Hunter, M.E., Isbell, F., Jetz, W., Juergens, N., Kissling, W.D., Krug, C.B., Kullberg, P., Le Bras, Y., Leung, B., Londoño-Murcia, M.C., Lord, J.-M., Loreau, M., Luers, A., Ma, K., MacDonald, A.J., Maes, J., McGeoch, M., Mihoub, J.B., Millette, K.L., Molnar, Z., Montes, E., Mori, A.S., Muller-Karger, F.E., Muraoka, H., Nakaoka, M., Navarro, L., Newbold, T., Niamir, A., Obura, D., O'Connor, M., Paganini, M., Pelletier, D., Pereira, H., Poisot, T., Pollock, L.J., Purvis, A., Radulovici, A., Rocchini, D., Roeoesli, C., Schaepman, M., Schaepman-Strub, G., Schmeller, D.S., Schmiedel, U., Schneider, F.D., Shakya, M.M., Skidmore, A., Skowno, A.L., Takeuchi, Y., Tuanmu, M.-N., Turak, E., Turner, W., Urban, M.C., Urbina-Cardona, N., Valbuena, R., Van De Putte, A., Van Havre, B., Wingate, V.R., Wright, E., Torrelio, C.Z., 2023b. A global biodiversity observing system to unite monitoring and guide action. Nat. Ecol. Evol. 7, 1947–1952. https://doi.org/10.1038/s41559-023-02171-0

Gorman, C.E., Martini, F., Conroy, K., King, E., Mcleod, R., Obst, C., Stout, J.C., Donohue, I., Buckley, Y.M., 2024. A decision methodology for site-level ecosystem accounting. J. Environ. Manage. 366, 121814. https://doi.org/10.1016/j.jenvman.2024.121814

Grantham, H., Juhn, D., Larsen, L., Ferrier, S., 2016. Case study of species accounts San Martin, Peru, in: Exploring Approaches for Constructing Species Accounts in the Context of the SEEA-EEA. UNEP, Cambridge, UK, pp. 145–151.

Greenleaf, S.S., Kremen, C., 2006. Wild bees enhance honey bees' pollination of hybrid sunflower. Proc. Natl. Acad. Sci. 103, 13890–13895. https://doi.org/10.1073/pnas.0600929103

Haga, C., Maeda, M., Hotta, W., Matsui, T., Nakaoka, M., Morimoto, J., Shibata, H., Hashimoto, S., Saito, O., Okayasu, S., Kim, H., Peterson, G., 2023. Modeling desirable futures at local scale by combining the nature futures framework and multi-objective optimization. Sustain. Sci. https://doi.org/10.1007/s11625-023-01301-8

Haines-Young, R., Potschin, M., 2010. The links between biodiversity, ecosystem services and human well-being, in: Raffaelli, D.G., Frid, C.L.J. (Eds.), Ecosystem Ecology. Cambridge University Press, pp. 110–139. https://doi.org/10.1017/CBO9780511750458.007

Haines-Young, R., Potschin, M.B., 2018. Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.

Hansen, A., Noble, B., Veneros, J., East, A., Goetz, S., Supples, C., Watson, J., Jantz, P., Pillay, R., Jetz, W., 2021. Towards monitoring ecosystem integrity within the Post-2020 Global Biodiversity Framework (preprint). Life Sciences. https://doi.org/10.32942/OSF.IO/EYQW5

Harwood, T., Love, J., Drielsma, M., Brandon, C., Ferrier, S., 2022. Staying connected: assessing the capacity of landscapes to retain biodiversity in a changing climate. Landsc. Ecol. https://doi.org/10.1007/s10980-022-01534-5

Hein, L., Bagstad, K.J., Obst, C., Edens, B., Schenau, S., Castillo, G., Soulard, F., Brown, C., Driver, A., Bordt, M., Steurer, A., Harris, R., Caparrós, A., 2020. Progress in natural capital accounting for ecosystems. Science 367, 514–515. https://doi.org/10.1126/science.aaz8901

Heink, U., Jax, K., 2019. Going Upstream — How the Purpose of a Conceptual Framework for Ecosystem Services Determines Its Structure. Ecol. Econ. 156, 264–271. https://doi.org/10.1016/j.ecolecon.2018.10.009

Hoskins, A.J., Harwood, T.D., Ware, C., Williams, K.J., Perry, J.J., Ota, N., Croft, J.R., Yeates, D.K., Jetz, W., Golebiewski, M., Purvis, A., Robertson, T., Ferrier, S., 2020. BILBI: Supporting global biodiversity assessment through high-resolution macroecological modelling. Environ. Model. Softw. 132, 104806. https://doi.org/10.1016/j.envsoft.2020.104806

IPBES, 2022. Methodological assessment of the diverse values and valuation of nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Zenodo. https://doi.org/10.5281/ZENODO.6522522

IPBES, 2019. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany.

IPBES, 2016. The methodological assessment report on scenarios and models of biodiversity and ecosystem services. Intergovernmental Platform on Biodiversity and Ecosystem Services.

Jetz, W., McGeoch, M.A., Guralnick, R., Ferrier, S., Beck, J., Costello, M.J., Fernandez, M., Geller, G.N., Keil, P., Merow, C., Meyer, C., Muller-Karger, F.E., Pereira, H.M., Regan, E.C., Schmeller, D.S., Turak, E., 2019. Essential biodiversity variables for mapping and monitoring species populations. Nat. Ecol. Evol. 3, 539–551. https://doi.org/10.1038/s41559-019-0826-1

Kim, H., Peterson, G.D., Cheung, W.W.L., Ferrier, S., Alkemade, R., Arneth, A., Kuiper, J.J., Okayasu, S., Pereira, L., Acosta, L.A., Chaplin-Kramer, R., Den Belder, E., Eddy, T.D., Johnson, J.A., Karlsson-Vinkhuyzen, S., Kok, M.T.J., Leadley, P., Leclère, D., Lundquist, C.J., Rondinini, C., Scholes, R.J., Schoolenberg, M.A., Shin, Y.-J., Stehfest, E., Stephenson, F., Visconti, P., Van Vuuren, D., Wabnitz, C.C.C., José Alava, J., Cuadros-Casanova, I., Davies, K.K., Gasalla, M.A., Halouani, G., Harfoot, M., Hashimoto, S., Hickler, T., Hirsch, T., Kolomytsev, G., Miller, B.W., Ohashi, H., Gabriela Palomo, M., Popp, A., Paco Remme, R., Saito, O., Rashid Sumalia, U., Willcock, S., Pereira, H.M., 2023. Towards a better future for biodiversity and people: Modelling Nature Futures. Glob. Environ. Change 82, 102681. https://doi.org/10.1016/j.gloenvcha.2023.102681

King, S., Vardon, M., Grantham, H.S., Eigenraam, M., Ferrier, S., Juhn, D., Larsen, T., Brown, C., Turner, K., 2021. Linking biodiversity into national economic accounting. Environ. Sci. Policy 116, 20–29. https://doi.org/10.1016/j.envsci.2020.10.020

Kissling, W. D., Ahumada, J.A., Bowser, A., Fernandez, M., Fernández, N., García, E.A., Guralnick, R.P., Isaac, N.J.B., Kelling, S., Los, W., McRae, L., Mihoub, J.-B., Obst, M., Santamaria, M., Skidmore, A.K., Williams, K.J., Agosti, D., Amariles, D., Arvanitidis, C., Bastin, L., De Leo, F., Egloff, W., Elith, J., Hobern, D., Martin, D., Pereira, H.M., Pesole, G., Peterseil, J., Saarenmaa, H., Schigel, D., Schmeller, D.S., Segata, N., Turak, E., Uhlir, P.F., Wee, B., Hardisty, A.R., 2018. Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale. Biol. Rev. 93, 600–625. https://doi.org/10.1111/brv.12359

Kissling, W.D., Breeze, T.D., Liquete, C., Lyche Solheim, A., McCallum, I., Maes, J., Hirsch, T., Lumbierres, M., Van Grunsven, R.H.A., Beja, P., Smets, B., Capinha, C., Ceia-Hasse, A., Fernández, N., Moreira, F., Junker, J., Leese, F., Hammond, E., Brotons, L., Morán Ordóñez, A., Potts, S.G., Santana, J., Valdez, J., Kühn, I., Milanović, M., Schmidt-Kloiber, A., Bormpoudakis, D., Villero, D., Haase, P., Meissner, K., Bruelheide, H., Buchhorn, M., Calderon-Sanou, I., Fernandez, M., Gamero, A., Gobin, A., Guerrero, I., Jandt, U., Klvaňová, A., Viti, M.M., Moe, S.J., Bonn, A., Pereira, H., 2024. Towards a modern and efficient European biodiversity observation network fit for multiple policies. https://doi.org/10.32942/X2K34F

Kissling, W.D., Hardisty, A., García, E.A., Santamaria, M., De Leo, F., Pesole, G., Freyhof, J., Manset, D., Wissel, S., Konijn, J., Los, W., 2015. Towards global interoperability for supporting biodiversity research on essential biodiversity variables (EBVs). Biodiversity 16, 99–107. https://doi.org/10.1080/14888386.2015.1068709

Kissling, W. Daniel, Walls, R., Bowser, A., Jones, M.O., Kattge, J., Agosti, D., Amengual, J., Basset, A., van Bodegom, P.M., Cornelissen, J.H.C., Denny, E.G., Deudero, S., Egloff, W., Elmendorf, S.C., Alonso García, E., Jones, K.D., Jones, O.R., Lavorel, S., Lear, D., Navarro, L.M., Pawar, S., Pirzl, R., Rüger, N., Sal, S., Salguero-Gómez, R., Schigel, D., Schulz, K.-S., Skidmore, A., Guralnick, R.P., 2018. Towards global data products of Essential Biodiversity Variables on species traits. Nat. Ecol. Evol. 2, 1531–1540. https://doi.org/10.1038/s41559-018-0667-3

Leadley, P., Obura, D., Archer, E., Costello, M.J., Dávalos, L.M., Essl, F., Hansen, A., Hashimoto, S., Leclère, D., Mori, A.S., Nicholson, E., Purvis, A., Rondinini, C., Shannon, L., Shen, X., Turak, E., Verburg, P.H., Visconti, P., 2022. Actions needed to achieve ambitious objectives of net gains in natural ecosystem area by 2030 and beyond. PLOS Sustain. Transform. 1, e0000040. https://doi.org/10.1371/journal.pstr.0000040

Lehman, C., Loberg, S., Clark, A.T., Schmitter, D., 2020. Unifying the Basic Models of Ecology to Be More Complete and Easier to Teach. Bioscience 70, 415–426. https://doi.org/10.1093/biosci/biaa013

Lehmann, A., Masò, J., Nativi, S., Giuliani, G., 2020. Towards integrated essential variables for sustainability. Int. J. Digit. Earth 13, 158–165. https://doi.org/10.1080/17538947.2019.1636490

Lehmann, A., Mazzetti, P., Santoro, M., Nativi, S., Masò, J., Serral, I., Spengler, D., Niamir, A., Lacroix, P., Ambrosone, M., McCallum, I., Kussul, N., Patias, P., Rodila, D., Ray, N., Giuliani, G., 2022. Essential earth observation variables for high-level multi-scale indicators and policies. Environ. Sci. Policy 131, 105–117. https://doi.org/10.1016/j.envsci.2021.12.024

Lequiller, F., Blades, D., 2014. Understanding National Accounts: Second Edition. OECD. https://doi.org/10.1787/9789264214637-en

Lumbierres, M., Abecasis, D., Alcaraz-Segura, D., Alison, J., Álvarez-Presas, M., Anderle, M., Avci, F., Bajocco, S., Baldo, M., Beja, P., Bergamini, A., Bergami, C., Blanco-Aguiar, J.A., Boada, J., Bonn, A., Borges, P., Borgwardt, F., Borja, A., Breeze, T., Brotons, L., Brucet, S., Bruelheide, H., Buttigieg, P.L., Buzan, E., Calderón-Sanou, I., Camacho, A., Camacho-Santamans, A., Campanaro, A., Cani, A., Cariñanos, P., Carvalho, L., Castellan, G., Castro, A., Ceia-Hasse, A., Chianucci, F., Chowdhury, S., C. Lima, A., Costa, V., Crespo, D., Crepaz, H., Dahlkamp, A., De Knijf, G., De Koning, K., Demars, B.O.L., De Stefano, M., Desmet, P., Diem, A., Díaz-Delgado, R., Díaz Martín, B., Drakare, S., Eljasik, P., Falaschi, M., Fernandes, I., Fernández Bejarano, S.J., Fernandez, N., Fernández-López, J., Ferrara, C., Ferré Codina, A., Fiegenbaum, H., Floccia, F., Galbusera, P., Galdies, J., Gañán, M., Garcia-Gonzalez, F., Garzoli, L., Gundersen, H., Haysom, K.A., Hedenås, H., Heremans, S., Hilpold, A., Hinojo, B., Holmgren, K., Hunger, S., Huybrechts, P., Hvilsom, C., Ilarri, M., Illa-Bachs, E., Isaac, N., Jandt, U., Jankauskaite, G., Junker, J., Kahlert, M., Kamilaris, A., Kasmi, Y., Kiran, H., Koma, Z., Kranstauber, B., Kopatz, A., Lanzén, A., Lecegui Carnero, V., Lever, J.J., Liquete, C., Luque, S., Madon, B., Majaneva, M., Manea, E., March, D., Marco, M., Martínez-López, J., Martinez-Vicente, V., McCallum, I., Méndez, M., Milanovic, M., Moe, S.J., Morant, D., Muir, M.A.K., Müllerová, J., Múrria, C., Musche, M., Nascimbene, J., Nestola, E., Oggioni, A., Oikonomou, A., Oldoni, D., Ott, D., Pace, G., Padubidri, C., Palomino Gaviria, Á.P., Paniccia, C., Pereira, H.M., Pérez-Girón, J.C., Pérez-Haase, A., Petriccione, B., Philipson, P., Pit, I.R., Pladevall-Izard, E., Pop, D.A., Puerta-Piñero, C., Quaranta, M., Radoux, J., Rasmussen, J.J., Renan, I., Reubens, J., Roeoesli, C., Rolph, S., Rūsiņa, S., Samoila, C., Santana, J., Schakel, J.K., Schepers, L., Schletterer, M., Schmidt-Kloiber, A., Seeber, J., Shi, Y., Shinneman, S., Smets, B., Soares, J., Soccodato, A., Solé-Medina, A., Sorvari, J., Sousa, R., Souza, A.T., Souza Dias, A., Spinosa, A., Strasser, T., Thulin, S.M., Trottet, A., Turicchia, E., Uriarte, A., Vagenas, G., Valdez, J., Vallefuoco, F., Van de Putte, A.P., Van Grunsven, R.H.A., Vicente, J., Villegas-Rios, D., Villero, D., Viti, M.M., Vriend, S.J.G., Walentowitz, A., Ward, R.J., Wijesingha, J., Zhang, J., Ziemba, A., Zimmermann, J., Kissling, W.D., 2024. EuropaBON EBV workflow templates. https://doi.org/10.5281/ZENODO.10680435

Miloslavich, P., Bax, N.J., Simmons, S.E., Klein, E., Appeltans, W., Aburto-Oropeza, O., Andersen Garcia, M., Batten, S.D., Benedetti-Cecchi, L., Checkley, D.M., Chiba, S., Duffy, J.E., Dunn, D.C., Fischer, A., Gunn, J., Kudela, R., Marsac, F., Muller-Karger, F.E., Obura, D., Shin, Y., 2018. Essential ocean variables for global sustained observations of biodiversity and ecosystem changes. Glob. Change Biol. 24, 2416–2433. https://doi.org/10.1111/gcb.14108

Mokany, K., Ferrier, S., Harwood, T.D., Ware, C., Di Marco, M., Grantham, H.S., Venter, O., Hoskins, A.J., Watson, J.E.M., 2020. Reconciling global priorities for conserving biodiversity habitat. Proc. Natl. Acad. Sci. 117, 9906–9911. https://doi.org/10.1073/pnas.1918373117

Mokany, K., Harwood, T.D., Ferrier, S., 2019. Improving links between environmental accounting and scenario-based cumulative impact assessment for better-informed biodiversity decisions. J. Appl. Ecol. 56, 2732–2741. https://doi.org/10.1111/1365-2664.13506

Montero, D., Kraemer, G., Anghelea, A., Aybar, C., Brandt, G., Camps-Valls, G., Cremer, F., Flik, I., Gans, F., Habershon, S., Ji, C., Kattenborn, T., Martínez-Ferrer, L., Martinuzzi, F., Reinhardt, M., Söchting, M., Teber, K., Mahecha, M.D., 2024. Earth System Data Cubes: Avenues for advancing Earth system research. Environ. Data Sci. 3, e27. https://doi.org/10.1017/eds.2024.22

Navarro, L.M., Fernández, N., Guerra, C., Guralnick, R., Kissling, W.D., Londoño, M.C., Muller-Karger, F., Turak, E., Balvanera, P., Costello, M.J., Delavaud, A., El Serafy, G., Ferrier, S., Geijzendorffer, I., Geller, G.N., Jetz, W., Kim, E.-S., Kim, H., Martin, C.S., McGeoch, M.A., Mwampamba, T.H., Nel, J.L., Nicholson, E., Pettorelli, N., Schaepman, M.E., Skidmore, A., Sousa Pinto, I., Vergara, S., Vihervaara, P., Xu, H., Yahara, T., Gill, M., Pereira, H.M., 2017. Monitoring biodiversity change through effective global coordination. Curr. Opin. Environ. Sustain. 29, 158–169. https://doi.org/10.1016/j.cosust.2018.02.005

NGFS, 2024. Nature-related Financial Risks: a Conceptual Framework to guide Action by Central Banks and Supervisors (Technical Document). Network for Greening the Financial System.

NGFS, 2023. Recommendations toward the development of scenarios for assessing nature-related economic and financial risks (Technical Document). Network for Greening the Financial System.

NPI, 2025. State of Nature Metrics.

O'Connor, L.M.J., Pollock, L.J., Renaud, J., Verhagen, W., Verburg, P.H., Lavorel, S., Maiorano, L., Thuiller, W., 2021. Balancing conservation priorities for nature and for people in Europe. Science 372, 856–860. https://doi.org/10.1126/science.abc4896

Ostensen, O., O'Brien, D., Cooper, A., 2008. "Measurements to Know and Understand Our World." Review of ISO Focus.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R.T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S.M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y.S., Amankwah, E., Asah, S.T., Berry, P., Bilgin, A., Breslow, S.J., Bullock, C., Cáceres, D., Daly-Hassen, H., Figueroa, E., Golden, C.D., Gómez-Baggethun, E., González-Jiménez, D., Houdet, J., Keune, H., Kumar, R., Ma, K., May, P.H., Mead, A., O'Farrell, P., Pandit, R., Pengue, W., Pichis-Madruga, R., Popa, F., Preston, S., Pacheco-Balanza, D., Saarikoski, H., Strassburg, B.B., van den Belt, M., Verma, M., Wickson, F., Yagi, N., 2017. Valuing nature's contributions to people: the IPBES approach. Curr. Opin. Environ. Sustain. 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Pereira, H.M., Belnap, J., Böhm, M., Brummitt, N., Garcia-Moreno, J., Gregory, R., Martin, L., Peng, C., Proença, V., Schmeller, D., van Swaay, C., 2017. Monitoring Essential Biodiversity Variables at the Species Level, in: Walters, M., Scholes, R.J. (Eds.), The GEO Handbook on Biodiversity Observation Networks. Springer International Publishing, Cham, pp. 79–105. https://doi.org/10.1007/978-3-319-27288-7_4

Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Hoft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M., Wegmann, M., 2013. Essential Biodiversity Variables. Science 339, 277–278. https://doi.org/10.1126/science.1229931

Pereira, L.M., Davies, K.K., Belder, E., Ferrier, S., Karlsson-Vinkhuyzen, S., Kim, H., Kuiper, J.J., Okayasu, S., Palomo, M.G., Pereira, H.M., Peterson, G., Sathyapalan, J., Schoolenberg, M., Alkemade, R., Carvalho Ribeiro, S., Greenaway, A., Hauck, J., King, N., Lazarova, T., Ravera, F., Chettri, N., Cheung, W.W.L., Hendriks, R.J.J., Kolomytsev, G., Leadley, P., Metzger, J., Ninan, K.N., Pichs, R., Popp, A., Rondinini, C., Rosa, I., Vuuren, D., Lundquist, C.J., 2020. Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework. People Nat. pan3.10146. https://doi.org/10.1002/pan3.10146

Peterson, A.T., Soberón, J., 2018. Essential biodiversity variables are not global. Biodivers. Conserv. 27, 1277–1288. https://doi.org/10.1007/s10531-017-1479-5

Pettorelli, N., Wegmann, M., Skidmore, A., Mücher, S., Dawson, T.P., Fernandez, M., Lucas, R., Schaepman, M.E., Wang, T., O'Connor, B., Jongman, R.H.G., Kempeneers, P., Sonnenschein, R., Leidner, A.K., Böhm, M., He, K.S., Nagendra, H., Dubois, G., Fatoyinbo, T., Hansen, M.C., Paganini, M., de Klerk, H.M., Asner, G.P., Kerr, J.T., Estes, A.B., Schmeller, D.S., Heiden, U., Rocchini, D., Pereira, H.M., Turak, E., Fernandez, N., Lausch, A., Cho, M.A., Alcaraz-Segura, D., McGeoch, M.A., Turner, W., Mueller, A., St-Louis, V., Penner, J., Vihervaara, P., Belward, A., Reyers, B., Geller, G.N., 2016. Framing the concept of satellite remote sensing essential biodiversity variables: challenges and future directions. Remote Sens. Ecol. Conserv. 2, 122–131. https://doi.org/10.1002/rse2.15

Quoß, 2025. EBVCube-format. Github.

Ramirez-Reyes, C., Brauman, K.A., Chaplin-Kramer, R., Galford, G.L., Adamo, S.B., Anderson, C.B., Anderson, C., Allington, G.R.H., Bagstad, K.J., Coe, M.T., Cord, A.F., Dee, L.E., Gould, R.K., Jain, M., Kowal, V.A., Muller-Karger, F.E., Norriss, J., Potapov, P., Qiu, J., Rieb, J.T., Robinson, B.E., Samberg, L.H., Singh, N., Szeto, S.H., Voigt, B., Watson, K., Wright, T.M., 2019. Reimagining the potential of Earth observations for ecosystem service assessments. Sci. Total Environ. 665, 1053–1063. https://doi.org/10.1016/j.scitotenv.2019.02.150

SANBI & UNEP-WCMC, 2016. Mapping biodiversity priorities: A practical, science-based approach to national biodiversity assessment and prioritisation to inform strategy and action planning. SANBI & UNEP-WCMC, UNEP-WCMC, Cambridge, UK.

SCBD, 2025. Decision adopted by the Conference of the Parties to the Convention on Biological Diversity on 27 February 2025.

SCBD, 2022. DECISION ADOPTED BY THE CONFERENCE OF THE PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY 15/4. Kunming-Montreal Global Biodiversity Framework.

SCBD, 2020. USE OF INDICATORS FOR TRACKING PROGRESS (Issue Brief).

SCBD, 2013. ESSENTIAL BIODIVERSITY VARIABLES.

Schröter, M., Egli, L., Brüning, L., Seppelt, R., 2021. Distinguishing anthropogenic and natural contributions to coproduction of national crop yields globally. Sci. Rep. 11, 10821. https://doi.org/10.1038/s41598-021-90340-1

Seebens, H., Clarke, D.A., Groom, Q., Wilson, J.R.U., García-Berthou, E., Kühn, I., Roigé, M., Pagad, S., Essl, F., Vicente, J., Winter, M., McGeoch, M., 2020. A workflow for standardising and integrating alien species distribution data. NeoBiota 59, 39–59. https://doi.org/10.3897/neobiota.59.53578

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, N., Lacayo, M., Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., Douglass, J., 2016. InVEST +VERSION+ User's Guide, The Natural Capital Project. Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Statistics South Africa, 2020. Natural Capital 1: Land and Terrestrial Ecosystem Accounts, 1990 to 2014. Statistics South Africa, Pretoria.

Stephenson, P., 2020. Technological advances in biodiversity monitoring: applicability, opportunities and challenges. Curr. Opin. Environ. Sustain. 45, 36–41. https://doi.org/10.1016/j.cosust.2020.08.005

Suarez, C.F., West, N., Naranjo, L.G., Ilvia Niño, Bhagabati, N., Candelo, C., Rosenthal, A., Mckenzie, E., 2011. Climate Adaptation in Colombia: designing an adaptive compensation and rewards program for ecosystem services. https://doi.org/10.13140/2.1.1385.3449

TNFD, 2023. Taskforce on Nature-related Financial Disclosures (TNFD) Recommendations.

Torres, A., Fernández, N., zu Ermgassen, S., Helmer, W., Revilla, E., Saavedra, D., Perino, A., Mimet, A., Rey-Benayas, J.M., Selva, N., Schepers, F., Svenning, J.-C., Pereira, H.M., 2018. Measuring rewilding progress. Philos. Trans. R. Soc. B Biol. Sci. 373. https://doi.org/10.1098/rstb.2017.0433

Turak, E., Brazill-Boast, J., Cooney, T., Drielsma, M., DelaCruz, J., Dunkerley, G., Fernandez, M., Ferrier, S., Gill, M., Jones, H., Koen, T., Leys, J., McGeoch, M., Mihoub, J.-B., Scanes, P., Schmeller, D., Williams, K., 2017. Using the essential biodiversity variables framework to measure biodiversity change at national scale. Biol. Conserv. 213, 264–271. https://doi.org/10.1016/j.biocon.2016.08.019

UNEP, 2021. Measuring Progress: Environment and the SDGs (No. DEW/2353/NA). United Nations Environment Programme, Nairobi, Kenya.

UNEP, 2019. Global environment outlook GEO 6: Healthy Planet, Healthy People.

UNEP-WCMC, 2025. Biodiversity Habitat Index Metadata Factsheet.

United Nations, 2024. System of Environmental-Economic Accounting. United Nations, New York.

United Nations, 2023. 2023 Global Assessment Results.

United Nations, 2021. System of Environmental-Economic Accounting— Ecosystem Accounting (SEEA EA).

Valdez, J.W., Pereira, H.M., Morejón, G.F., Acosta-Muñoz, C., Bonet Garcia, F.J., Castro Vergara, L., Claros, X.R., Gill, M.J., Josse, C., Lafuente-Cartagena, I., Langstroth, R., Sheppard, S.N., Orihuela, G., Prieto-Albuja, F.J., Quillahuaman, N., Terán, M.F., Zambrana-Torrelio, C.M., Navarro, L.M., Fernandez, M., 2023. Tailoring evidence into action: Using a co-design approach for biodiversity information in the Tropical Andes. Conserv. Sci. Pract. 5, e13035. https://doi.org/10.1111/csp2.13035

Vardon, M., Normyle, A., Lynch, J.J., Burnett, P., Gibbons, P., 2025. Using natural capital accounting for biodiversity offset policy: a case study from the Australian Capital Territory. Environ. Sustain. Indic. 100687. https://doi.org/10.1016/j.indic.2025.100687

Vogl, A.L., Bryant, B.P., Hunink, J.E., Wolny, S., Apse, C., Droogers, P., 2017a. Valuing investments in sustainable land management in the Upper Tana River basin, Kenya. J. Environ. Manage. 195, 78–91. https://doi.org/10.1016/j.jenvman.2016.10.013

Vogl, A.L., Goldstein, J.H., Daily, G.C., Vira, B., Bremer, L., McDonald, R.I., Shemie, D., Tellman, B., Cassin, J., 2017b. Mainstreaming investments in watershed services to enhance water security: Barriers and opportunities. Environ. Sci. Policy 75, 19–27. https://doi.org/10.1016/j.envsci.2017.05.007

Xu, H., Cao, Y., Yu, D., Cao, M., He, Y., Gill, M., Pereira, H.M., 2021. Ensuring effective implementation of the post-2020 global biodiversity targets. Nat. Ecol. Evol. 5, 411–418. https://doi.org/10.1038/s41559-020-01375-y

Yang, C., Cagnazzo, C., Artale, V., Buongiorno Nardelli, B., Buontempo, C., Busatto, J., Caporaso, L., Cesarini, C., Cionni, I., Coll, J., Crezee, B., Cristofanelli, P., De Toma, V., Essa, Y.H., Eyring, V., Fierli, F., Grant, L., Hassler, B., Hirschi, M., Huybrechts, P., Le Merle, E., Leonelli, F.E., Lin, X., Madonna, F., Mason, E., Massonnet, F., Marcos, M., Marullo, S., Müller, B., Obregon, A., Organelli, E., Palacz, A., Pascual, A., Pisano, A., Putero, D., Rana, A., Sánchez-Román, A., Seneviratne, S.I., Serva, F., Storto, A., Thiery, W., Throne, P., Van Tricht, L., Verhaegen, Y., Volpe, G., Santoleri, R., 2022. Independent Quality Assessment of Essential Climate Variables: Lessons Learned from the Copernicus Climate Change Service. Bull. Am. Meteorol. Soc. 103, E2032–E2049. https://doi.org/10.1175/BAMS-D-21-0109.1

Zhang, C., Li, J., Zhou, Z., 2022. Ecosystem service cascade: Concept, review, application and prospect. Ecol. Indic. 137, 108766. https://doi.org/10.1016/j.ecolind.2022.108766

Supplementary Materials

The essential role of essential variables in biodiversity and ecosystem services reporting within and across jurisdictions

Table S1. EBV classes and subclasses, and their definitions

(Sources: (EuropaBON, 2024; GEO BON, 2025; Pereira et al., 2013; SCBD, 2013)

EBV class and subclasses	Definition/description
Genetic composition	EBV class that captures metrics of within-species genetic variation across space and time. It Includes four generic EBVs: Infraspecific genetic diversity, Genetic differentiation, Effective population size, Inbreeding (Hoban et al., 2022).
Infraspecific genetic diversity	The level of genetic variability within species populations. It is typically captured by two complementary metrics: the number of alleles in a population (richness) and the expected and observed proportion of heterozygotes in a population at equilibrium (evenness).
Genetic differentiation	The divergence in the frequencies of alleles between populations of the same species.
Effective population size	The size of an ideal population that loses genetic variation at the same rate as the focal population.
Inbreeding	Degree of relatedness between individuals of a population.
Species populations	EBV class that accesses the spatial and temporal variability in the species populations. This includes two generic EBVs: Species distribution, Species abundance (Jetz et al., 2019).
Species distribution	The probability of occurrence of a species or group of species, measured (or modeled) along contiguous spatial and temporal units. In some cases it may be just a binary variable corresponding to the presence/absence of the species, in others it may refer to the probability that the cell is occupied by the species of interest in a given time period.
Species abundance	The estimated count of individuals or relative abundance of a species or group of species, measured (or modeled) over contiguous spatial and temporal units.
Species traits	EBV class that captures the spatial and temporal variation in trait measurements within species. This includes five generic EBVs: Morphology, Physiology, Reproduction, Phenology, Movement (Kissling et al., 2018)
Morphology	The volume, mass, height or other traits defining the form of organisms grouped by species, measured (or modeled) over contiguous over contiguous spatial and temporal units.
Physiology	Values of biochemical or physical quantities (e.g., thermal tolerance, disease resistance) describing functions of organisms grouped by species, measured (or modeled) over contiguous over contiguous spatial and temporal units.
Reproduction	Age at maturity, number of offspring and other reproduction traits of organisms grouped by species, measured (or modeled) over contiguous spatial and temporal units.
Phenology	The timing of cyclical biological phenomena, such as the presence, absence, abundance, or duration of seasonal activities of organisms, measured (or modeled) for each species over contiguous spatial and temporal units. This can include the date of emergence of leaves and flowers, the first flight of butterflies, the first appearance of migratory birds, the date of leaf coloring and fall in deciduous trees, the dates of egg-laying of birds and amphibia, or the timing of the developmental cycles of honey bee colonies.
Movement	Spatial mobility attributes of species, measured (or modeled) over contiguous spatial and temporal units (e.g. natal dispersal distance, migration routes).
Community composition	EBV class that captures inter-specific variability in trait measurements across space and time. This includes four generic EBVs: Community abundance, Taxonomic/phylogenetic diversity, Trait diversity, Interaction diversity (Mason et al., 2005; Pugh and Field, 2022).

Community abundance	The number or biomass of all individuals (belonging to one or more species) in a given community, measured (or modeled) over contiguous spatial and temporal units.
Taxonomic/phylogenetic diversity	The diversity of species and/or phylogenetic distances of organisms in ecological assemblages, measured (or modeled) over contiguous spatial and temporal units. There are several metrics that can be used, such as species richness, different Hill numbers, phylogenetic diversity, etc.
Trait diversity	The diversity of traits of organisms (including those whose species identity is unknown) within ecological assemblages, measured (or modeled) over contiguous spatial and temporal units. Typically this requires a direct measurement of the whole community for each trait of interest, providing a distribution of the trait values in a community, often in a multidimensional trait space. This trait distribution is often summarized in a single metric (e.g. functional divergence or functional richness. Alternatively, independent measurements of abundance or presence of each of the organisms in a community and a trait matrix describing the trait values for each species can be used to reconstruct the trait distribution in trait space.
Interaction diversity	The diversity and structure of multi-trophic interactions between organisms within ecological assemblages, measured (or modeled) over contiguous spatial and temporal units. Measurements of interaction diversity could include those derive from ecological networks and food web analyses.
Ecosystem structure	EBV class that captures the spatial and temporal variability of ecosystem units and the organisms defining these units. This includes three generic EBVs: Live cover fraction, Ecosystem distribution, Ecosystem vertical profile.
Ecosystem distribution	The area or probability of occurrence of one or more discrete ecosystem types, measured (or modeled) over contiguous spatial and temporal units. In some cases, this could be just a binary variable (presence/absence) or correspond to the output of a probabilistic model for one or more ecosystem types.
Live cover fraction	The ratio of the horizontal projection area covered by living organisms, such as vegetation, macroalgae or live hard coral, measured (or modeled) over contiguous spatial and temporal units.
Ecosystem vertical profile	Vertical distribution of vegetation volume and biomass in an ecosystem of interest, measured (or modeled) over contiguous spatial and temporal units.
Ecosystem function	EBV class that captures the spatio-temporal variability of the collective performance of organisms that determines the functioning of an ecosystem. This includes three generic EBVs: Primary productivity, Ecosystem phenology, Ecosystem disturbance.
Primary productivity	Estimated rate at which energy is converted to organic matter by photosynthetic producers, measured (or modeled) over contiguous spatial and temporal units.
Ecosystem phenology	The timing of cyclic processes observed at the ecosystem level, such as the start or duration of vegetation activity or phytoplankton blooms, measured (or modeled) over continuous spatial and temporal units.
Ecosystem disturbance	The amount of deviance in the functioning of each ecosystem from its regular dynamics, measured (or modeled) over contiguous spatial and temporal units. Examples include fire, flood, soil erosion.

Table S2: Suggested criteria for developing concrete metrics for an EBV class

(Sources:

Criteria	Definition / description
Biological	An EBV should reflect an aspect of the biological character of a level of biodiversity (genetic, species, ecosystem, or in between, as appropriate). Even though non-biological variables have their role in models and scenarios of biodiversity change they should nonetheless not be considered as EBVs.
State	While Drivers and Pressures are crucial to understand or project biodiversity change, EBV indicators must characterize an aspect of the "State" of biodiversity (in the sense of the DPSIR framework). For example, the extent of forest is an EBV product (for the EBV "ecosystem extent"), while the rate of deforestation or natural regeneration are not.
Sensitive to change	Static variables, or variables that change over long timescales, while biologically relevant, will not be useful to assess change and its impact and should thus not be considered.
Ecosystem inclusive	Ideally, an EBV should be applicable in all types of marine, freshwater, and terrestrial habitats.
Feasible	Technically feasible, scientifically proven, and economically viable to sustainably monitor the underlying biodiversity observations.
Scalable	The variable should be aggregated or disaggregated from the local to the national, regional and global scale.
Relevant	The variable should address one to multiple users' needs (e.g. scientific, policy, societal). This criterion also influences the likelihood of a community buy-in of the EBVs and EBV products.
Data available	The availability of primary observation itself, and their ability to be mobilized with common standards and integrated with other existing datasets.

Table S3: EESV classes and their definitions

(Source: (Balvanera et al., 2022)

EESV Class	Definition / description
Ecological supply	It refers to the ecosystem structure and functions that underlie the potential capacity of eco- systems to provide ecosystem services. It accounts for the potential or capacity of ecosystems and their functions.
Anthropogenic contribution	It refers to the efforts that humans invest to enhance ecological supply and to make use of ecosystem services. Anthropogenic contributions and ecological supply interact through the process of co-production through complex social-eco- logical processes, in which humans contribute knowledge, effort, time, financial resources, materials and technology to the flow of ecosystem services.
Demand	It refers to the explicitly or implicitly expressed human desire or need for an ecosystem service, in terms of its quantity or quality, irrespective of whether aware- ness exists about such need. Different stakeholder groups may differ in such demands.
Use	It refers to the active or passive appropriation of an ecosystem service by people. These are the 'realized' benefits that arise from passive or active management, also referred to as match or flow.
Instrumental value	It refers to the importance of an ecosystem service to societies or individuals to achieve a specific end (e.g. some dimension of human well-being). It denotes how the well-being of individuals or groups of people is enhanced by ecosystem services, both in economic and sociocultural terms.
Relational value	It refers to the importance ascribed to how ecosystems contribute to desirable and meaningful interactions between humans and nature and between humans in relation to nature. These encompass the core principles embedded into the relationships between people and nature, or among people within nature, such as care, responsibility and stewardship. Relational values are embedded in the practices, knowledge and visions that support ecosystem management.

Table S4: SEEA EA accounts and sub-accounts (condition typology classes), and their definitions

(Sources: Czúcz et al., 2021; United Nations, 2024, 2021)

Accounts (and sub-accounts)			Definition / description
Ecosystem Extent accounts			Ecosystem extent is the size of an ecosystem asset in terms of spatial area.
Ecosystem Condition accounts	**Abiotic Ecosystem Characteristics**	**Physical state characteristics**	The class physical state characteristics hosts the physical descriptors of the abiotic components of the ecosystem (soil, water, air…). Physical stocks that are typically being degraded (depleted) due to human pressures (e.g. soil organic carbon, water table level, impervious surfaces) are good choices, as they are sensitive to changes, and relevant for policy interpretation
		Chemical state characteristics	The class chemical state characteristics contains the variables and indicators related to the chemical composition of the abiotic ecosystem components. This typically involves the accumulated stocks of various pollutants in soil, water, or air, but only if the selection criteria are met (e.g. global atmospheric CO_2 concentration probably should not be seen as a condition metric). Similar to physical state characteristics, indicators should describe the state ("stocks" of pollutants) rather than the flows (emission of pollutants). This way both abiotic ECT classes accommodate major pressures in a way that is compatible with accounting (the pressures are related to the changes in the indicators).
	Biotic Ecosystem Characteristics	**Compositional state characteristics**	The class compositional state characteristics comprises a broad range of 'typical' biodiversity indicators, describing the composition of ecological communities from a biodiversity perspective. This includes the indicators based on the presence / abundance of a species or species group, or the diversity of specific species groups at a given location and time. From a location-based perspective (required by spatial consistency) the distribution of a species also boils down-to species composition (local presence). Compositional metrics can characterize the presence / absence or abundance individual species, taxonomic groups (birds, butterflies), or non-taxonomic guilds (e.g. soil invertebrates, macro-zoobenthos). However, indicators based on highly specialist functional groups, where even data collection was performed from a functional perspective (e.g. pollinators, N-fixers, etc.) should be considered either as functional state characteristics, or as ecosystem service indicators (if they are tightly connected to a single specific ecosystem service). Abundance metrics of very large guilds (e.g. trees, phytoplankton) comprising entire ecosystem compartments should be considered as structural state characteristics (biomass, vegetation).
		Structural state characteristics	The class structural state characteristics primarily focusses at the vegetation and biomass of the sites, comprising metrics describing the local amount of living and dead plant matter (vegetation, biomass) in an ecosystem. This class includes all metrics of vegetation density and cover, either related to the whole ecosystem, or just specific compartments (canopy layer, belowground biomass, litter...). For marine and freshwater ecosystems this class can include chlorophyll concentrations, phytoplankton abundance, or plant biomass (e.g., seagrasses). There is some overlap between compositional and structural state metrics, particularly for foundation-species-based ecosystems such as mangrove, or where species groups and vegetation compartments coincide (trees on savanna, lichens on mountain rocks). Such cases should be registered in this class.
		Functional state characteristics	The class functional state characteristics should host simple summary statistics (e.g. frequency, intensity) of relevant ecosystem processes which meet the selection criteria (see Annex 5.x) and which are not already covered by other indicators. Ecosystem functions is a hugely diverse umbrella concept, which is used in highly different ways by the various

			research communities. Many of the characteristics that can be seen as 'ecosystem functions' can also be seen as a compositional (e.g. species abundances), structural (e.g. plant biomass), or abiotic state descriptors (e.g. surface albedo), or even as ecosystem service indicators (ES accounts). It is a good practice to avoid placing functional characteristics into this class whenever they can find a better home in another class.
	Landscape level characteristics	**Landscape and seascape characteristics**	The class landscape and seascape characteristics comprise the characteristics of ecosystem type mosaics, typically quantifiable at large (landscape, seascape) spatial scales. The diversity of ecosystem types in a landscape ('landscape diversity'), for example, can describe the integrity of landscapes at broader spatial scales, and also exerts influence on several ecosystem services (Verhagen et al., 2016). Metrics of landscape connectivity / fragmentation measure important landscape characteristics from the perspective of a specific ecosystem type (or group of ecosystem types). Landscape connectivity can be interpreted and measured very differently in terrestrial, freshwater, and marine biomes. Furthermore, in the case of ecosystem types, which themselves are 'mosaics' of relevant subtypes (e.g. a cropland with nested seminatural vegetation fragments), the abundance or the spatial pattern (connectivity) of these subtypes can also be hosted under this class. The proposed structure of condition accounts expects that indicators be linked to specific ecosystem types. This can be achieved by linking the landscape-level metrics (which were e.g. calculated with a moving window) to the local ecosystem type. In other words, the 'landscape diversity' of a forest should be interpreted as the diversity of the landscape in which the forest is situated.
Ecosystem Service accounts	**Ecosystem Service flow accounts in biophysical terms**		Ecosystem services flow accounts in physical terms that record the supply and use of ecosystem services may be compiled for a range of reasons and purposes. These include recording and monitoring the different bundles of ecosystem services supplied by different ecosystem types, identifying the users of the services and assessing how these patterns of supply and use are changing over time. This information can underpin analysis of the significance of particular ecosystems as ecosystem service suppliers, support analysis of trade-offs between different ecosystem services as part of spatial planning and land management and provide information to support delineation of areas for specific land uses, including conservation and environmental protection.
	Ecosystem Service flow accounts in monetary terms		The ecosystem services flow account in monetary terms records the monetary value of flows of ecosystem services based on their exchange values. The data from this account can be used to understand the relative economic significance of different ecosystem services (within the valuation framing of the national accounts); support aggregation of ecosystem services for the purpose of comparing the role of different ecosystem assets; understand changes in monetary value over time; underpin comparison of the inputs of different ecosystem services to different users; and support understanding of the role of ecosystem services in different locations, for example, across countries. In addition, the use of exchange values in an accounting context requires drawing clear links between the supply of ecosystem services and the users of ecosystem services. Establishing these links can highlight both the economic costs arising from the loss of ecosystem services and the role of government as a provider of public goods.

Table S5: Suggested criteria for identifying/developing ecosystem condition variables

(Sources: (Czúcz et al., 2021b; United Nations, 2021)

Criteria	**Short description**
Conceptual criteria	
Intrinsic relevance	Characteristics and metrics should reflect existing scientific understanding of ecosystem integrity, supported by the ecological literature
Instrumental relevance	Characteristics and metrics should be related to the availability of ecosystem services (characteristics that provide most information about the highest number of services should be favoured)
Directional meaning	Characteristics and metrics need to have a potential for a consensual normative interpretation (it should be clear if a change is favourable or unfavourable)
Sensitivity to human influence	Characteristics and metrics should be responsive to known socio-ecological leverage points (key pressures, management options)
Framework conformity	Characteristics and metrics should be differentiated from other components of the SEEA ecosystem accounting framework
Practical criteria	
Validity	Metrics need to represent the characteristics they address in a credible and unbiased way
Reliability	Metrics need to be accurate, reliable, and reproducible, with potential sources of error explored and documented
Availability	Metrics covering the studied spatial and temporal extents with the required resolution need to be achievable in terms of the resources and time available
Simplicity	Metrics should be as simple as possible
Compatibility	The same characteristics should be measured with the same (compatible) metrics in the different ecosystem types and/or different ecosystem accounting areas (countries)
Ensemble criteria	
Comprehensiveness	The final set of metrics, as a whole, should cover all of the relevant characteristics of the ecosystem
Parsimony	The final set of metrics should be free of redundant (correlated) variables

Figure S6: Crosswalk of EBV/EESV frameworks to the SEEA EA framework. The possible role of the main EBV and EESV classes in populating SEEA Ecosystem Accounts. The solid lines indicate direct correspondence and dotted lines partial or indirect correspondence.

(Source: Author's own)

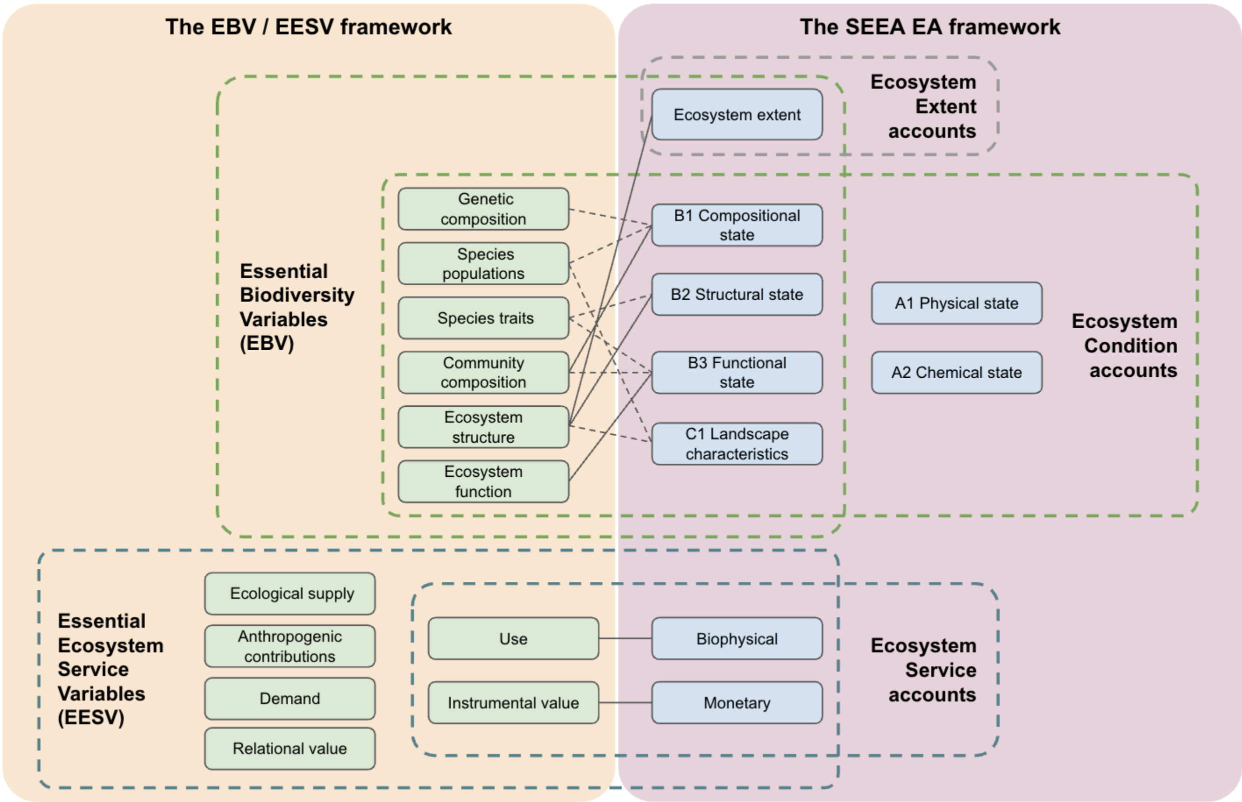
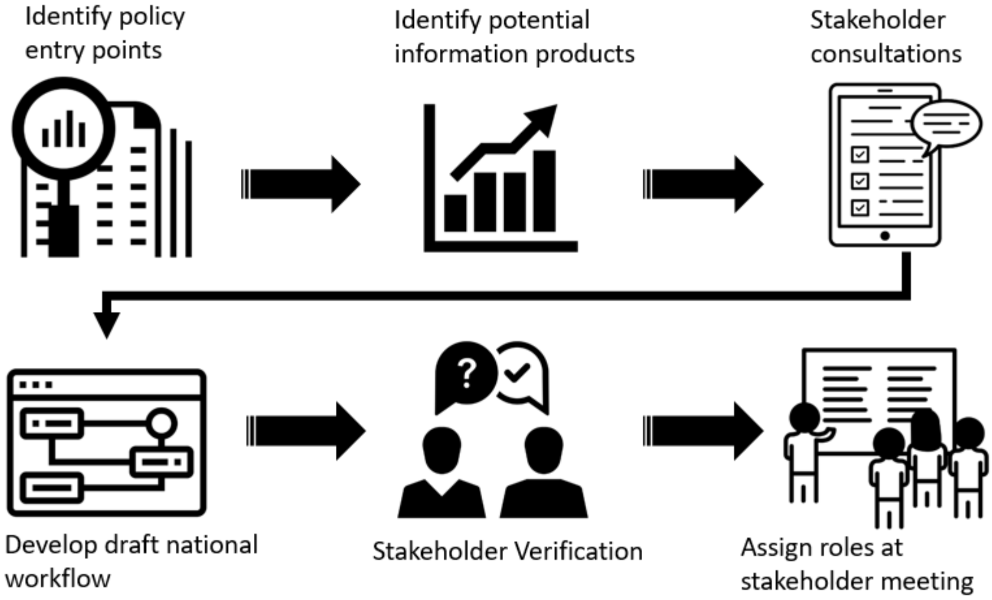


Figure S7: A process for producing user-driven workflows for priority indicators for conservation policy in South Africa.

(Source: Author's own)



Supplement S8: Making EBVs and EESVs accessible and reproducible

The diversity of producers and users of EBVs and EESVs and their derived indicators calls for versatile and flexible data streams with minimum standards for the development of data products. Below we detail key elements and approaches for the production of such products.

Providing open-access to data: The openness and accessibility of primary data and derived products such as essential variables data products or indicators, is fundamental to ensure their usability and buy-in by a diverse community of users. Open access must be complemented by the adoption of the FAIR principles, i.e., *Findable*, *Accessible*, *Interoperable* and *Re-usable,* by the data providers and data managers (Wilkinson et al., 2016). Consideration of openness and FAIRness concern primary data producers in government agencies, research institutes and academia, philanthropy as well as civil society. The interoperability itself is supported by the adoption of common standards that allows the integration of data collected or produced by different sources (e.g., (Guralnick et al., 2018) and facilitates the traceability and scalability of those products. The EBV data standard has been specifically developed to allow the proper documentation and integration of EBV data products (Quoß et al., 2022).

Publishing the workflows: The workflows describing the development and production of the EBVs and EESVs should be made available to end-users and adhere to the FAIR principles themselves (Hardisty et al., 2019). This would include both workflows implemented to document changes in one or more dimensions of biodiversity, e.g., species traits (Kissling et al., 2018) and species populations (Jetz et al., 2019), but also to describe the production of specific datasets (see (Hardisty et al., 2019) for an example on the species distribution of invasive species). Data producers must be encouraged to publish these workflows to support the reproducibility of EBVs and EESVs data products and their use at the national and subnational level for, e.g., ecosystem accounting and goal/target tracking (Kissling et al., 2024; Lumbierres et al., 2024).

Making tools available: Beyond the publication of their use within workflows, the tools and algorithms used in the development of EBVs and EESVs should be documented and made publicly available (e.g., using repositories such as GitHub). Whenever possible, capacity building (e.g., training through webinars) could be supplemented to allow the use of these tools (e.g. EBV-based indicators in Biodiversity Dashboard for the ASEAN region) by a broader range of users, in particular at the regional, national and subnational level by the implementing agencies (Han et al., 2014; Valdez et al., 2023). Notably, this medium can foster dialogue, co-design and operationalization of novel and tailored tools as exemplified by the BioModelos platform for species distribution models in Colombia (Velásquez-Tibatá et al., 2019).

EBVs and EESVs should be developed and served by anyone, in a distributed manner, be clearly documented and follow the FAIR principles. GEO BON has designed an EBV data portal (https://portal.geobon.org/) as a global repository for spatial-temporal data on biodiversity, ecosystems and ecosystem services across multiple dimensions, realms and scale. Data developers can publish their Essential Variables data products and derived indicators and document their metadata and workflow following the EBV data standard (Quoß et al., 2022), as well as the produced EBV data cubes in NetCDF format (Quoß, 2025). Developing open-cloud processing capabilities would go a long way in mainstreaming the use of data and models to users without limited access to local and expensive computing infrastructures, whether it be for research or national reporting purposes. Cloud environments for biodiversity and ecosystem services data integration tools and models are still in their infancy but advancing, including the ARIES (ARtificial Intelligence for Ecosystem Services) in support of the UN SEEA Ecosystem Accounting (Martínez-López et al., 2019) and Microsoft's Planetary Computer as part of its Artificial Intelligence (AI) for Earth effort. Projects funded by the AI for Earth include AI4EBV which uses AI to derive accurate, high-resolution maps of mountain ecosystem incorporate the latest Earth observation data to produce these maps through time for a comprehensive assessment of ecosystem change and fragmentation (https://ai4ebv.eurac.edu/) and EBV's on the Cloud AI for the National Belize Marine Habitat Map (https://www.coastalzonebelize.org/portfolio/ai-for-belize-marine-habitat-map/).

References

Balvanera, P., Brauman, K.A., Cord, A.F., Drakou, E.G., Geijzendorffer, I.R., Karp, D.S., Martín-López, B., Mwampamba, T.H., Schröter, M., 2022. Essential ecosystem service variables for monitoring progress towards sustainability. Curr. Opin. Environ. Sustain. 54, 101152. https://doi.org/10.1016/j.cosust.2022.101152

Czúcz, B., Keith, H., Driver, A., Jackson, B., Nicholson, E., Maes, J., 2021a. A common typology for ecosystem characteristics and ecosystem condition variables. One Ecosyst. 6, e58218. https://doi.org/10.3897/oneeco.6.e58218

Czúcz, B., Keith, H., Maes, J., Driver, A., Jackson, B., Nicholson, E., Kiss, M., Obst, C., 2021b. Selection criteria for ecosystem condition indicators. Ecol. Indic. 133, 108376. https://doi.org/10.1016/j.ecolind.2021.108376

EuropaBON, 2024. EBV Description.

GEO BON, 2025. What are EBVs?

Guralnick, R., Walls, R., Jetz, W., 2018. Humboldt Core - toward a standardized capture of biological inventories for biodiversity monitoring, modeling and assessment. Ecography 41, 713–725. https://doi.org/10.1111/ecog.02942

Han, X., Smyth, R.L., Young, B.E., Brooks, T.M., Sánchez de Lozada, A., Bubb, P., Butchart, S.H.M., Larsen, F.W., Hamilton, H., Hansen, M.C., Turner, W.R., 2014. A Biodiversity Indicators Dashboard: Addressing Challenges to Monitoring Progress towards the Aichi Biodiversity Targets Using Disaggregated Global Data. PLoS ONE 9, e112046. https://doi.org/10.1371/journal.pone.0112046

Hardisty, A.R., Belbin, L., Hobern, D., McGeoch, M.A., Pirzl, R., Williams, K.J., Kissling, W.D., 2019. Research infrastructure challenges in preparing essential biodiversity variables data products for alien invasive species. Environ. Res. Lett. 14, 025005. https://doi.org/10.1088/1748-9326/aaf5db

Hoban, S., Archer, F.I., Bertola, L.D., Bragg, J.G., Breed, M.F., Bruford, M.W., Coleman, M.A., Ekblom, R., Funk, W.C., Grueber, C.E., Hand, B.K., Jaffé, R., Jensen, E., Johnson, J.S., Kershaw, F., Liggins, L., MacDonald, A.J., Mergeay, J., Miller, J.M., Muller-Karger, F., O'Brien, D., Paz-Vinas, I., Potter, K.M., Razgour, O., Vernesi, C., Hunter, M.E., 2022. Global genetic diversity status and trends: towards a suite of Essential Biodiversity Variables (EBVs) for genetic composition. Biol. Rev. 97, 1511–1538. https://doi.org/10.1111/brv.12852

Jetz, W., McGeoch, M.A., Guralnick, R., Ferrier, S., Beck, J., Costello, M.J., Fernandez, M., Geller, G.N., Keil, P., Merow, C., Meyer, C., Muller-Karger, F.E., Pereira, H.M., Regan, E.C., Schmeller, D.S., Turak, E., 2019. Essential biodiversity variables for mapping and monitoring species populations. Nat. Ecol. Evol. 3, 539–551. https://doi.org/10.1038/s41559-019-0826-1

Kissling, W.D., Breeze, T.D., Liquete, C., Lyche Solheim, A., McCallum, I., Maes, J., Hirsch, T., Lumbierres, M., Van Grunsven, R.H.A., Beja, P., Smets, B., Capinha, C., Ceia-Hasse, A., Fernández, N., Moreira, F., Junker, J., Leese, F., Hammond, E., Brotons, L., Morán Ordóñez, A., Potts, S.G., Santana, J., Valdez, J., Kühn, I., Milanović, M., Schmidt-Kloiber, A., Bormpoudakis, D., Villero, D., Haase, P., Meissner, K., Bruelheide, H., Buchhorn, M., Calderon-Sanou, I., Fernandez, M., Gamero, A., Gobin, A., Guerrero, I., Jandt, U., Klvaňová, A., Viti, M.M., Moe, S.J., Bonn, A., Pereira, H., 2024. Towards a modern and efficient European biodiversity observation network fit for multiple policies. https://doi.org/10.32942/X2K34F

Kissling, W.D., Walls, R., Bowser, A., Jones, M.O., Kattge, J., Agosti, D., Amengual, J., Basset, A., van Bodegom, P.M., Cornelissen, J.H.C., Denny, E.G., Deudero, S., Egloff, W., Elmendorf, S.C., Alonso García, E., Jones, K.D., Jones, O.R., Lavorel, S., Lear, D., Navarro, L.M., Pawar, S., Pirzl, R., Rüger, N., Sal, S., Salguero-Gómez, R., Schigel, D., Schulz, K.-S., Skidmore, A., Guralnick, R.P., 2018. Towards global data products of Essential Biodiversity Variables on species traits. Nat. Ecol. Evol. 2, 1531–1540. https://doi.org/10.1038/s41559-018-0667-3

Lumbierres, M., Abecasis, D., Alcaraz-Segura, D., Alison, J., Álvarez-Presas, M., Anderle, M., Avci, F., Bajocco, S., Baldo, M., Beja, P., Bergamini, A., Bergami, C., Blanco-Aguiar, J.A., Boada, J., Bonn, A., Borges, P., Borgwardt, F., Borja, A., Breeze, T., Brotons, L., Brucet, S., Bruelheide, H., Buttigieg, P.L., Buzan, E., Calderón-Sanou, I., Camacho, A., Camacho-Santamans, A., Campanaro, A., Cani, A., Cariñanos, P., Carvalho, L., Castellan, G., Castro, A., Ceia-Hasse, A., Chianucci, F., Chowdhury, S., C. Lima, A., Costa, V., Crespo, D., Crepaz, H., Dahlkamp, A., De Knijf, G., De Koning, K., Demars, B.O.L., De Stefano, M., Desmet, P., Diem, A., Díaz-Delgado, R., Díaz Martín, B., Drakare, S., Eljasik, P., Falaschi, M., Fernandes, I., Fernández Bejarano, S.J., Fernandez, N., Fernández-López, J., Ferrara, C., Ferré Codina, A., Fiegenbaum, H., Floccia, F., Galbusera, P., Galdies, J., Gañán, M., Garcia-Gonzalez, F., Garzoli, L., Gundersen, H., Haysom, K.A., Hedenås, H., Heremans, S., Hilpold, A., Hinojo, B., Holmgren, K., Hunger, S., Huybrechts, P., Hvilsom, C., Ilarri, M., Illa-Bachs, E., Isaac, N., Jandt, U., Jankauskaite, G., Junker, J., Kahlert, M., Kamilaris, A., Kasmi, Y., Kiran, H., Koma, Z., Kranstauber, B., Kopatz, A., Lanzén, A., Lecegui Carnero, V., Lever, J.J., Liquete, C., Luque, S., Madon, B., Majaneva, M., Manea, E., March, D., Marco, M., Martínez-López, J., Martinez-Vicente, V., McCallum, I., Méndez, M., Milanovic, M., Moe, S.J., Morant, D., Muir, M.A.K., Müllerová, J., Múrria, C., Musche, M., Nascimbene, J., Nestola, E., Oggioni, A., Oikonomou, A., Oldoni, D., Ott, D., Pace, G., Padubidri, C., Palomino Gaviria, Á.P., Paniccia, C., Pereira, H.M., Pérez-Girón, J.C., Pérez-Haase, A., Petriccione, B., Philipson, P., Pit, I.R., Pladevall-Izard, E., Pop, D.A., Puerta-Piñero, C., Quaranta, M., Radoux, J., Rasmussen, J.J., Renan, I., Reubens, J., Roeoesli, C., Rolph, S., Rūsiņa, S., Samoila, C., Santana, J., Schakel, J.K., Schepers, L., Schletterer, M., Schmidt-Kloiber, A., Seeber, J., Shi, Y., Shinneman, S., Smets, B., Soares, J., Soccodato, A., Solé-Medina, A., Sorvari, J., Sousa, R., Souza, A.T., Souza Dias, A., Spinosa, A., Strasser, T., Thulin, S.M., Trottet, A., Turicchia, E., Uriarte, A., Vagenas, G., Valdez, J., Vallefuoco, F., Van de Putte, A.P., Van Grunsven, R.H.A., Vicente, J., Villegas-Rios, D., Villero, D., Viti, M.M., Vriend, S.J.G., Walentowitz, A., Ward, R.J., Wijesingha, J., Zhang, J., Ziemba, A., Zimmermann, J., Kissling, W.D., 2024. EuropaBON EBV workflow templates. https://doi.org/10.5281/ZENODO.10680435

Martínez-López, J., Bagstad, K.J., Balbi, S., Magrach, A., Voigt, B., Athanasiadis, I., Pascual, M., Willcock, S., Villa, F., 2019. Towards globally customizable ecosystem service models.

Mason, N.W.H., Mouillot, D., Lee, W.G., Wilson, J.B., 2005. Functional richness, functional evenness and functional divergence: the primary components of functional diversity. Oikos 111, 112–118. https://doi.org/10.1111/j.0030-1299.2005.13886.x

Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Hoft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M., Wegmann, M., 2013. Essential Biodiversity Variables. Science 339, 277–278. https://doi.org/10.1126/science.1229931

Pugh, B.E., Field, R., 2022. Biodiversity: The role of interaction diversity. Curr. Biol. 32, R423–R426. https://doi.org/10.1016/j.cub.2022.03.063

Quoß, 2025. EBVCube-format. Github.

Quoß, L., Fernández, N., Langer, C., Valdez, J., Fernández, M.A., Pereira, H., 2022. Building Essential Biodiversity Variable netCDFs with the ebvcube R Package. Biodivers. Inf. Sci. Stand. 6, e91215. https://doi.org/10.3897/biss.6.91215

SCBD, 2013. ESSENTIAL BIODIVERSITY VARIABLES.

United Nations, 2024. System of Environmental-Economic Accounting. United Nations, New York.

United Nations, 2021. System of Environmental-Economic Accounting— Ecosystem Accounting (SEEA EA).

Valdez, J.W., Pereira, H.M., Morejón, G.F., Acosta-Muñoz, C., Bonet Garcia, F.J., Castro Vergara, L., Claros, X.R., Gill, M.J., Josse, C., Lafuente-Cartagena, I., Langstroth, R., Sheppard, S.N., Orihuela, G., Prieto-Albuja, F.J., Quillahuaman, N., Terán, M.F., Zambrana-Torrelio, C.M., Navarro, L.M., Fernandez, M., 2023. Tailoring evidence into action: Using a co-design approach for biodiversity information in the Tropical Andes. Conserv. Sci. Pract. 5, e13035. https://doi.org/10.1111/csp2.13035

Velásquez-Tibatá, J., Olaya-Rodríguez, M.H., López-Lozano, D., Gutiérrez, C., González, I., Londoño-Murcia, M.C., 2019. BioModelos: A collaborative online system to map species distributions. PLOS ONE 14, e0214522. https://doi.org/10.1371/journal.pone.0214522

Wilkinson, M.D., Dumontier, M., Aalbersberg, Ij.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L.B., Bourne, P.E., Bouwman, J., Brookes, A.J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C.T., Finkers, R., Gonzalez-Beltran, A., Gray, A.J.G., Groth, P., Goble, C., Grethe, J.S., Heringa, J., 't Hoen, P.A.C., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S.J., Martone, M.E., Mons, A., Packer, A.L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M.A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., Mons, B., 2016. The FAIR Guiding Principles for scientific data management and stewardship. Sci. Data 3, 160018. https://doi.org/10.1038/sdata.2016.18