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COMMENTARY

An operational definition of essential biodiversity variables

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Abstract The concept of essential biodiversity variables (EBVs) was proposed in 2013 to improve harmonization of biodiversity data into meaningful metrics. EBVs were conceived as a small set of variables which collectively capture biodiversity change at multiple spatial scales and within time intervals that are of scientific and management interest. Despite the apparent simplicity of the concept, a plethora of variables that describes not only biodiversity but also any environmental features have been proposed as potential EBV (i.e.

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candidate EBV). The proliferation of candidates reflects a lack of clarity on what may constitute a variable that is essential to track biodiversity change, which hampers the operationalization of EBVs and therefore needs to be urgently addressed. Here, we propose that an EBV should be defined as a biological state variable in three key dimensions (time, space, and biological organization) that is critical to accurately document biodiversity change.

Keywords Biodiversity monitoring · Conservation policy · Biodiversity change · Essential biodiversity variables · Biological state variables

In 2013, a framework of six classes (Genetic Composition, Species Populations, Species Traits, Community Composition, Ecosystem Structure, Ecosystem Function) of 22 potential essential biodiversity variables (EBVs), inspired by the Essential Climate Variables (ECVs) (Doherty et al. 2009; Bojinski et al. 2014), was proposed (Pereira et al. 2013). The EBV concept aimed to provide an internationally recognized way to monitor essential aspects of biodiversity, such that data from many kinds of sampling programs can be integrated. Thus it would allow comparison of trends in biodiversity from local to national and global scales over time. Operationalizing the EBV concept requires a hierarchy of importance (essentialness) of candidate variables that incorporates their capacity to detect change reliably (Proença et al. 2016). Progress in EBV development has been

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hampered by a lack of clarity on what constitutes a biodiversity variable (i.e. candidate EBV). It is urgent to clarify this issue and we argue here that an EBV is a biological state variable that is measurable at particular points in time and space to document biodiversity change.

The EBV concept proposes an integrative view on biodiversity and was conceived as an intermediate layer between primary observational data and derived indicators (Pereira et al. 2013; Brummitt et al. 2016). As a refinement, an EBV can be defined as the harmonized and standardized totality of all biological data across time and space and along a third axis representing the level of biological organization (gene, individual, species, community, ecosystem, aka biological component), altogether framing an EBV cube (Fig. 1). An EBV cube encapsulates a multidimensional view of a specific biodiversity variable and consists of measurements or estimates of essential aspects of biodiversity that support comparison of the state of biodiversity across space and through time. For advancing EBV development, EBVs need to be clearly distinguished from variables describing pressures and responses of biodiversity, such as ecosystem services or disturbance regimes. For instance, the impacts of pressures such as habitat loss or exploitation can be linked to changes in biological variables, such as population abundance, species distribution or habitat structure but the pressures themselves are not biological and thus outside of our definition of an EBV. For the EBV class Ecosystem Function, disturbance regime would not fall into our definition of an EBV as it is not a biological variable, in contrast to the original paper (Pereira et al. 2013). Disturbance regime is rather a natural or anthropogenic driver of change in ecological processes such as succession and regeneration and ultimately of biodiversity states. For the EBV class Ecosystem Structure, EBVs should only cover the biological components, but should not include abiotic variables (chemical composition, slopes, climatic conditions), despite their importance to aid understanding of why an EBV may change in space and over time. This clarification is important and useful in focusing effort directed towards delivering EBVs and in delimiting the data that should be considered suitable for calculating an EBV. It would also allow partitioning the amount of biodiversity data into sub-components that can be realistically and practically addressed in the real world within the frame of existing constrains defined by, e.g., administrative borders, legislative periods, international assessment reporting periods, etc. These real-world constraints may delimit the extent and grain sizes to which EBVs should be matched. This would facilitate the measurement of EBVs anywhere, at any time, in a way that is consistent and generalizable for corresponding components of biodiversity in any biological system. To summarize:

1. EBVs *are* biological state variables: they *are not* pressure (e.g. exploitation), benefit (e.g. ecosystem services), or response (e.g. proportion of habitat in protected areas) variables. EBVs may be combined with pressure, benefit or response variables in subsequent analytical steps (Fig. 1).

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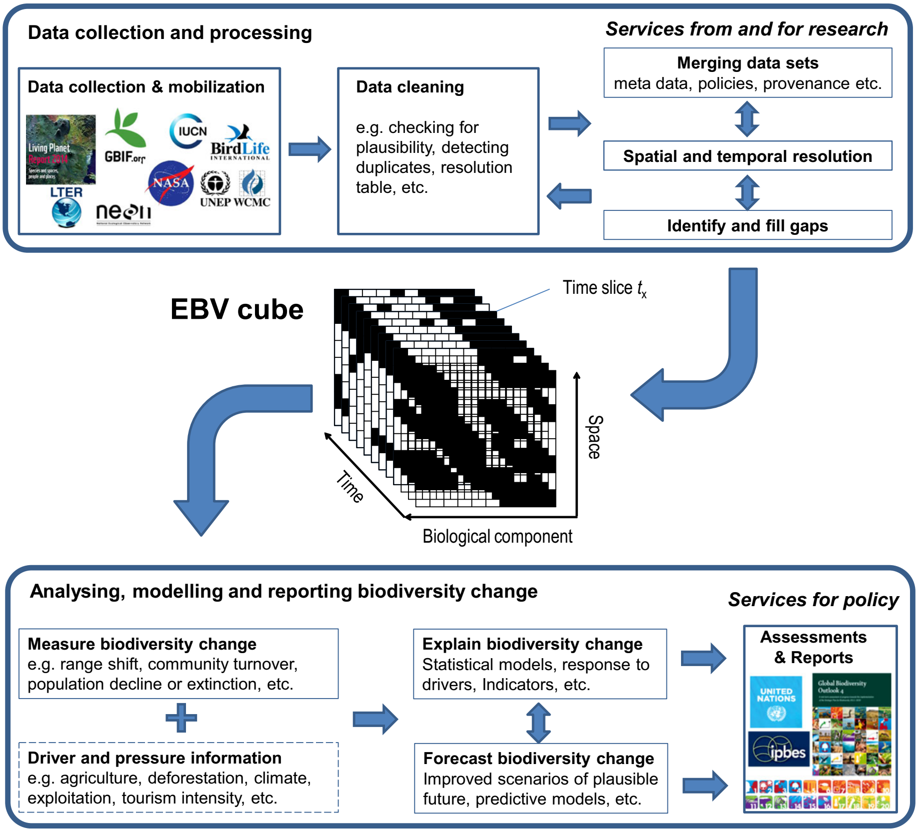

Fig. 1 The process towards operationalizing essential biodiversity variables (EBV). The filling of the EBV cube requires data collection, data mobilization and data processing as a service from and for research (*upper box*). Once the EBV cube has been populated with data, it can facilitate the measurement and modelling of biodiversity change and thereby provides services for science and especially policy (*lower box*). The whole process from raw data to an EBV cube also represents an important service to the scientific community for conducting more resource-efficient analyses of biodiversity change across large spatial extents. This includes quantifying the underlying drivers and pressures of biodiversity change (Mace and Baillie 2007) as well as anticipating and modelling the effect of biodiversity changes on ecosystem services (Oliver et al. 2015). These analyses, with periodic validation, would then feed into global and regional policy processes to explain observed biodiversity change, to improve the forecast of biodiversity change and to produce global assessment reports

2. EBVs are essential because they are selected to capture biodiversity change within a specified range of spatial and temporal grain and extent. They *are not* agnostic to spatial and temporal scale outside of this range.

In general terms, the process to generate an EBV starts with standardizing, harmonizing, and integrating raw biological observations (i.e., primary data) from different sources over space and time and ends when its spatiotemporal changes are fully documented. The development of indicators and the understanding of the causes of the documented change do not fall within the EBV framework, but are a logical next step in using the EBV data (Figs. 1, 2). Taken in combination, EBVs would be a representative set of critical components of biodiversity (Schmeller et al. in press) and thus would help to prioritize data

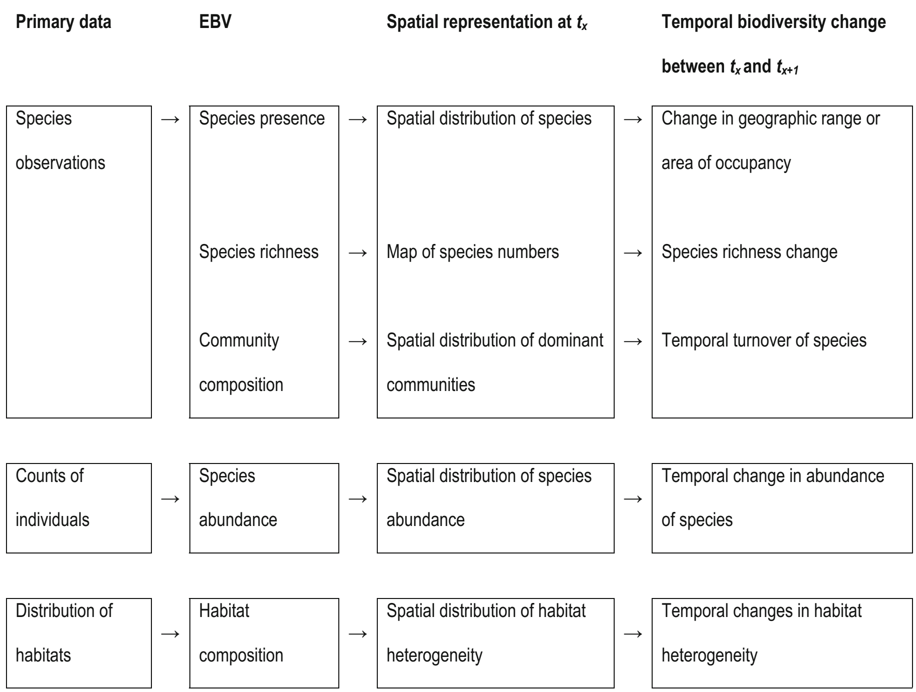

Fig. 2 Examples of potential EBVs, their representation in space for a given time step t_x, and how they might be used to document temporal changes in biodiversity when comparing different spatial representation along the temporal dimension. For example, counts of individuals at time t_x constitute one time slice of the EBV species abundance. Once several of these time slices are available, temporal change in species abundance across space can be documented. Analyses combining available data on drivers and pressures and the observed change can then inform the policy sphere on the underlying causes of that change (Fig. 1)

collection methods, management and publication. The final EBV suite would need to be evaluated based on the added benefit (essentialness) of each EBV to all others using a set of objective criteria such as representativity, complementarity, policy relevance, predictive ability, significance of change, sensitivity to change, and applicability across biological realms. The essentialness of an EBV then could be used to prioritise on which EBV to focus efforts on for the measurement and operationalization across sampling programs. It is also important to recognize that different stakeholders and groups of scientists are likely to hold differing views on the suite of candidate EBVs that should be operationalized: policy-makers might favour a narrow set of EBVs that produces unambiguous signals of change based on streamlined infrastructure (data flow pipelines etc.). Scientists have an important role in this debate, to ensure that the final set captures the critical variables to understand the state of and change in biodiversity (Schmeller et al. in press).

In conclusion, our refinement of the EBV concept is an important step towards the operationalization of EBVs. Providing a clear frame what an EBV is (or should be) by its *intrinsic nature* is at least as important for operationalizing it than developing technical, analytical, legal ways to produce an EBV along a workflow. Otherwise, any environmental variable would be included in the EBV concept, weakening the potential impact of the concept considerably. A weakened concept would threaten the potential of EBVs to empower and coordinate biodiversity monitoring globally (Schmeller et al. 2015), to provide an integrative view of biodiversity and delivering stakeholders with clear and simple information about biodiversity change (Brummitt et al. 2016). Along with our suggestion to frame EBVs as strict biological state variables, we urge biodiversity scientists to embrace a more transparent definition of biodiversity variables, be it similar or different to our proposition. We also encourage scientists to develop complementary essential environmental variables that would capture other critical aspects of our changing planet that are not directly related to biodiversity, such as the valuation of ecosystem services or the chemical composition of soil and water. Once implemented, the EBV framework would allow quantification of past trends and providing key data for forecasting future changes in biodiversity so as to inform meaningful, policy relevant and comprehensive indicators and projections.

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