Journal of Applied Ecology

Journal of Applied Ecology 2015 doi: 10.1111/1365-2664.12417

MODEL-ASSISTED MONITORING OF BIODIVERSITY

Bridging the gap between biodiversity data and policy reporting needs: An Essential Biodiversity Variables perspective

Ilse R. Geijzendorffer[1]*†, Eugenie C. Regan[2]†, Henrique M. Pereira[3,4], Lluis Brotons[5,6], Neil Brummitt[7], Yoni Gavish[8], Peter Haase[9,10], Corinne S. Martin[2], Jean-Baptiste Mihoub[11], Cristina Secades[2], Dirk S. Schmeller[11], Stefan Stoll[9,10], Florian T. Wetzel[12] and Michele Walters[13,14]

[1]Institut Méditerranéen de Biodiversité et d'Ecologie marine et continentale (IMBE), Aix Marseille Université, CNRS, IRD, Avignon Université, Technopôle Arbois-Méditerranée, Bât. Villemin – BP 80, F-13545 Aix-en-Provence Cedex 04, France; [2]United Nations Environment Programme World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge CB3 0DL, UK; [3]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Deutscher Platz 5e, 04103 Leipzig, Germany; [4]Institute of Biology, Martin Luther University Halle Wittenberg, Am Kirchtor 1, 06108 Halle (Saale), Germany; [5]European Bird Census Council (EBCC) & Forest Science Centre of Catalonia (CEMFOR-CTFC), 25280 Solsona, Spain; [6]Center for Ecological Research and Forestry Applications (CREAF), 08193 Bellaterra, Spain; [7]Department of Life Sciences, The Natural History Museum, London SW7 5BD, UK; [8]School of Biology, Faculty of Biological Sciences, University of Leeds, Leeds LS2 9JT, UK; [9] Department of River Ecology and Conservation, Senckenberg Research Institute and Natural History Museum Frankfurt, Clamecystrasse 12, 63571 Gelnhausen, Germany; [10]Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt am Main, Germany; [11]Department of Conservation Biology, Helmholtz Centre for Environmental Research – UFZ, Permoserstrasse 15, 04318 Leipzig, Germany; [12]Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Invalidenstr. 43, 10115 Berlin, Germany; [13]Council for Scientific and Industrial Research (CSIR), Natural Resources and Environment, PO Box 395, Pretoria 0001, South Africa; and [14]Centre for Wildlife Management, University of Pretoria, Pretoria 0002, South Africa

Summary

1. Political commitment and policy instruments to halt biodiversity loss require robust data and a diverse indicator set to monitor and report on biodiversity trends. Gaps in data availability and narrow-based indicator sets are significant information barriers to fulfilling these needs.

2. In this paper, the reporting requirements of seven global or European biodiversity policy instruments were reviewed using the list of Essential Biodiversity Variables (EBVs) as an analytical framework. The reporting requirements for the most comprehensive policy instrument, the United Nation's Strategic Plan for Biodiversity 2011–2020, were compared with the indicator set actually used for its reporting, to identify current information gaps. To explore the extent to which identified gaps could be bridged, the potential contribution of data mobilization, modelling and further processing of existing data was assessed.

3. The information gaps identified demonstrate that decision-makers are currently constrained by the lack of data and indicators on changes in the EBV classes Genetic Composition and, to a lesser extent, Species Populations for which data is most often available. Furthermore, the results show that even when there is a requirement for specific information for reporting, the indicators used may not be able to provide all the information, for example current Convention of Biological Diversity indicators provide relatively little information on changes in the Ecosystem Function and Ecosystem Structure classes. This gap could be partly

*Correspondence author. E-mail: ilse.geijzendorffer@imbe.fr
†Authors contributed equally.

closed by using existing indicators as proxies, whereas additional indicators may be computed based on available data (e.g. for EBVs in the Ecosystem Structure class). However, for the EBV class Genetic Composition, no immediate improvement based on proxies or existing data seems possible.

4. *Synthesis and applications*. Using Essential Biodiversity Variables (EBVs) as a tool, theory-driven comparisons could be made between the biodiversity information gaps in reporting and indicator sets. Analytical properties, such as an identification of which data and indicator (s) are relevant per EBV, will need to be addressed before EBVs can actually become operational and facilitate the integration of data flows for monitoring and reporting. In the meantime, a first analysis shows that existing indicators and available data offer considerable potential for bridging the identified information gaps.

Key-words: biodiversity data, Biodiversity indicator partnership, Convention on biological diversity, data mobilization, data sources, indicators, instrument, monitoring, policy, reporting

Introduction

Globally, biodiversity continues to be lost (Tittensor *et al.* 2014) and, due to its importance for human well-being, an increasing number of political commitments aim to halt this loss of biodiversity. This has resulted in the 'greening' of existing policy instruments (e.g. in the case of the European Common Agricultural Policy), the establishment of new collaborative platforms [e.g. the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)] and the continuation of existing efforts for global biodiversity conservation [e.g. the convention on the Conservation of Migratory Species of Wild Animals (CMS)]. In line with this trend, the Parties to the Convention on Biological Diversity (CBD) adopted the Strategic Plan for Biodiversity 2011–2020, which includes a shared mission and 20 targets, collectively known as the Aichi Biodiversity Targets (CBD 2010).

Reporting on biodiversity changes is required for tracking and evaluating the progress of biodiversity-oriented policy instruments, as well as informing decision-makers of possible positive or negative side effects of other policy decisions (Niemelä 2000; Osinski *et al.* 2003; Pullin *et al.* 2009), such as those resulting from urbanization, land abandonment, bio-energy production or the industrialization of marine fisheries. All biodiversity-related assessments face similar challenges regarding indicator selection and data availability (Collen *et al.* 2008; Walpole *et al.* 2009; Lindenmayer *et al.* 2012; Tittensor *et al.* 2014), leading to a gap between the information that would ideally be used to assess biodiversity trends, and the biodiversity information which actually is used.

There is much scientific literature on what constitutes an ideal indicator and on indicator set selection for biodiversity monitoring. In reality, however, the indicators actually implemented for reporting depend on many more factors than mere scientific criteria (Noss 1990; Feest 2013), for example stakeholder interests, data availability and practical *ad hoc* solutions for immediate needs. In addition, very few biodiversity data sets of sufficient quality across broad taxonomic, temporal and spatial scales are available for official reporting, all of which result in a reduced ability to reliably detect biodiversity change. This leads to information gaps and geographical, temporal and taxonomic biases in reporting efforts worldwide; for example, most data come from less biodiverse areas such as North America and Europe rather than biodiversity-rich areas such as parts of the tropics (Collen *et al.* 2008; Mora, Tittensor & Myers 2008; Pereira, Navarro & Santos Martins 2012). Similarly, vertebrates are much better covered than other taxa (Pereira, Navarro & Santos Martins 2012) and many marine habitats and species are under-represented (Costello *et al.* 2010). In global assessments such as the Global Biodiversity Outlook 4 (CBD 2014), this leads to the predominant use of bird data for many biodiversity indicators, while data for more threatened vertebrate groups are often absent (Pereira, Navarro & Santos Martins 2012). These biases not only undermine the comprehensiveness of reporting, but also influence policy responses based on these reports.

Information gaps and biases can originate from the indicator set used or a lack of robust and reliable data. Limited availability of biodiversity data can, for instance, be due to data confidentiality, usage restrictions, limited accessibility of data sets, the remoteness of ecosystems [e.g. the deep sea and marine areas beyond national jurisdiction, (Webb, Vanden Berghe & O'Dor 2010)] or data integration and quality issues [e.g. sampling bias, taxonomic inconsistencies (Henry *et al.* 2008)]. These practical barriers require increased efforts before biodiversity data can be used in assessments. Further mobilization of existing data and the collection of new data could help to bridge current information gaps (Kot *et al.* 2010). The potential for data mobilization is internationally recognized, and a number of long-term initiatives have focused on mobilizing biodiversity data and metadata (e.g. the Global Biodiversity Information Facility (GBIF), and the Ocean Biogeographic Information System). These initiatives aim to connect data owners with each other, to fill gaps and to simultaneously build bridges between citizen volunteers, scientists and policymakers (Jetz, McPherson & Guralnick 2012). Apart from long-term initiatives, project-based incentives are funded to provide technical and organizational infrastructures as a backbone for scientific and voluntary efforts (for instance in Europe with the EU BON project (Hoffmann *et al.* 2014), EBONE (Bunce *et al.* 2011) and EU MON (Schmeller *et al.* 2009).

Monitoring and interpreting biodiversity trends are complex tasks. Following the example of the climate community and their Essential Climate Variables (GCOS 2003), the Group on Earth Observations Biodiversity Observation Network (GEO BON, https://www.earthobservations.org/geobon.shtml) has developed a tentative list of Essential Biodiversity Variables (EBVs) (Pereira *et al.* 2013). The list comprises a set of key variables for detecting major dimensions of biodiversity change. The concept of EBVs was developed to facilitate data integration by providing an intermediate abstraction layer between primary observations, indicators and assessment possibilities, that is providing a theory-driven rather than a data-driven approach (Niemeijer 2002) (see Appendix S1 in Supporting Information). To this end, the EBVs are an academic concept undergoing continuous development, and GEO BON welcomes contributions on further improvements and implementation. EBVs could potentially be used as a tool to identify existing biases in policy reporting and indicator use, through which comprehensiveness of biodiversity reporting can be enhanced. Additionally, the use of EBVs could help prioritize data mobilization and modelling efforts to facilitate data integration over large spatial scales and across a broad taxonomic spectrum, improving information on past and current biodiversity change at all biological levels (genes, populations, species and ecosystems). For example, the Population Abundance EBV refers to the raw observation data on population abundances of specific species at particular locations, whereas an aggregated population trend indicator uses the data of this EBV on trends across multiple species and locations. In this way, different countries may monitor populations of a variety of threatened taxa while allowing the observations to be aggregated into a relevant EBV (e.g. Population Abundance). This would facilitate the quantification of a biodiversity indicator regardless of which species were monitored, and will help to provide an index of national, regional and global trends in species populations [for an example using bird data see Gregory *et al.* (2005) or for marine data Duffy *et al.* (2013)].

The objective of this study is to use the EBV concept as a framework with which to evaluate information requirements for biodiversity reporting, identify information gaps and identify where data could be mobilized to bridge these gaps. For this objective, a first analysis identified the comprehensiveness of reporting under a selection of existing policy instruments at global and European level by relating information requirements to EBVs. In a second analysis, the information gap between the information actually provided by the indicators and the information asked for the reporting under the CBD was determined. Finally, the potential for bridging these gaps was explored by identifying indicators that could be used as proxies for other EBVs and by determining which EBV classes could be quantified using existing data sets, through data mobilization, integration and modelling. The three EBV-based analyses presented in this paper are indicated by black arrows in Appendix S1. Finally, suggestions are made for the further improvement of the EBVs during their ongoing development.

Material and methods

EBVS AS AN ANALYTICAL FRAMEWORK

The candidate list of EBVs is grouped into six main classes, each consisting of multiple variables, which are (abbreviation and number of variables indicated in brackets) as follows: Genetic Composition (GC, $n = 4$), Species Populations (SP, $n = 3$), Species Traits (ST, $n = 6$), Community Composition (CC, $n = 2$), Ecosystem Structure (ES, $n = 4$) and Ecosystem Function (EF, $n = 3$; see Appendix S2 and Pereira *et al.* 2013). As with the Essential Climate Variables, the EBVs will be continuously revised and developed to remain relevant to changes in biodiversity monitoring in all realms.

BIODIVERSITY DATA REQUIREMENTS FOR REPORTING UNDER POLICY INSTRUMENTS

For the first analysis of biodiversity data requirements for reporting, policy instruments were selected based on two criteria. First, biodiversity data had to be required for reporting under the objectives of the policy instrument. Secondly, the policy instrument had to be an international convention that had been implemented. As a first priority, global policy instruments were selected which were then complemented by European policy instruments. For each of the selected instruments, biodiversity information needs for reporting were identified and then linked to specific EBVs. Biodiversity elements not covered by the EBVs were noted. Detailed tables of information reporting requirements per policy instrument were compiled and circulated to additional experts with in-depth knowledge of specific policy instruments for feedback. Results for each policy instrument were summarized as the percentage of EBVs needed for reporting per EBV class and per policy instrument (Table 1).

THE CBD BIODIVERSITY INDICATOR SET

The second analysis addressed the link between the proposed EBVs and the set of biodiversity indicators used for the reporting to the CBD, namely those developed by the partners of the Biodiversity Indicators Partnership (BIP, www.bipindicators.net/). These indicators were selected for this analysis since the Aichi Targets can be considered as the most important and inclusive biodiversity instrument globally. There are currently 42 BIP indicators providing information for the 20 Aichi Targets, and

Table 1. Biodiversity information reporting requirements of selected biodiversity policy instruments, expressed as the percentage of EBVs required per EBV class. The EBV classes are Genetic Composition (GC), Species Populations (SP), Species Traits (ST), Community Composition (CC), Ecosystem Function (EF) and Ecosystem Structure (ES)

		EBV classes					
Policy instruments*	Geographic scope	GC	SP	ST	CC	EF	ES
CBD (CBD 2010)	Global	100%	100%	100%	100%	100%	100%
Ramsar (Ramsar 2012)	Global	50%	100%	100%	100%	100%	100%
CMS (UNEP-CMS 2014)	Global	75%	100%	67%	50%	100%	100%
Habitats Directive (EC 2011)	EU	0%	67%	0%	0%	25%	65%
Birds Directive (EEA 2011)	EU	0%	100%	50%	0%	25%	67%
MSFD (EC 2008, 2010)	EU	0%	100%	17%	100%	75%	100%
WFD (EC 2000)	EU	0%	100%	33%	100%	50%	67%

*Policy instrument abbreviations explained: CBD, Convention on Biological Diversity; Ramsar, Ramsar convention on Wetlands; CMS, Convention on the Conservation of Migratory Species of Wild Animals; MSFD, Marine Strategy Framework Directive and WFD, European Water Framework Directive. The darker the cell colour, the higher the percentage displayed.

individual indicators may be applied to more than one target (http://www.bipindicators.net/globalindicators). For the analysis, scores were attributed to individual BIP indicators to identify the overlap and complementarity between the BIP indicator set and the EBV framework. A direct score (D) was attributed when the BIP indicator was identified as representative for and using data from an EBV. An indirect score (I) was attributed when the BIP indicator could be used to indirectly measure and quantify an EBV after additional steps of data consolidation and processing. If the indicator did not have any relevance for any of the EBVs, no score was attributed. The scores were thereafter sent out to the partners of the BIP for feedback. Here, a subset of results is presented. The relation of the indicators to each EBV class is represented as the percentage of direct or indirect BIP relevant indicators for EBVs per EBV class (Table 2, complete list in Appendix S3). This analysis clarified the discrepancy between the reporting requirements for the CBD and the information provided by the current BIP indicators, the complementarity between the BIP indicators and the EBVs, and the potential of existing BIP indicators to address current biodiversity reporting gaps.

DATA AVAILABILITY FOR EBVS

The third analysis was based on the underlying assumption that if data are currently available for EBVs for which there are biodiversity reporting gaps, then data mobilization, development of data integration methods and modelling efforts could be used to address these gaps. If data were not available for certain EBVs, then additional monitoring efforts might be required.

As availability of different data types might differ between spatial scales, data availability for EBV classes was estimated based on a range of known existing data sources at global, regional and national spatial scales. For the latter two spatial scales, Europe and European Member States were used, respectively, for illustrative purposes. Data sources were defined in the paper as either data set holders or data providers that offer direct access to biodiversity data sets. Selection of data sources was based on two criteria. First, to allow for data harmonization and interoperability, the data source should have metadata available in addition to the biodiversity data themselves. Secondly, to allow for independent use, only data sources that offered data sets with unrestricted access, or at least offered access to parts of the data sets, were considered. Although open data access is increasingly recognized as important (Costello *et al.* 2014), the second criterion was a significant restriction on the number of potential data sources considered for the analysis. The final selection of data sources (Appendix S4) aimed to represent the current spectrum of biodiversity data sets available and contained 17 global, 15 multinational or European-level, and 11 national (European Member State) data sources.

Scores were attributed to data sources based on the metadata of data sets. The data sources were considered to contain data that could be used to quantify a specific EBV class (value 1) or not (value 0). Additionally, the data sets were described according to (i) the spatial scale covered (global, regional or national levels); (ii) the realms covered (marine, terrestrial or freshwater); and (iii) the accessibility, namely if access was unrestricted or partly unrestricted. Based on this information, strengths, possibilities and limitations of existing biodiversity data sets were identified in relation to the EBV classes (Table 3).

Two important notes of caution regarding this analysis and the EBV framework need to be highlighted here. First, due to the current development state of the EBV framework, this analysis could not advance further on spatial, temporal or biome gap assessments. It has to, therefore, be taken into account that a considerable number of data sets included in the final selection can in fact only be used to quantify baselines and not indicators of biodiversity change because they do not comprise successive measurements through time. Secondly, EBVs currently do not provide instructions for data use for specific EBVs, posing another limitation to the extent of analysis. This means that regarding the scoring, most data sets contained data for only some specific EBVs and not necessarily for all EBVs within that EBV class.

Results

The data requirements for reporting under the selected policy instruments differed across instruments and the representation of EBV classes showed instrument-specific patterns. Of all the policy instruments examined, reporting for the Aichi Targets, Ramsar and the Convention on the CMS were found to be the most comprehensive in their biodiversity data requirements, requiring data from all EBV classes (Table 1). In contrast, reporting for the well-known European Birds and Habitats Directives had

Table 2. Examples of indicators currently used for CBD reporting and the proportion (%) of EBVs they represent relative to EBV class (for the full list of Biodiversity Indicators Partnership (BIP) indicators Appendix S3). Indicators were considered to be a direct measure of an EBV if no additional computation steps are required. An indicator could potentially to be an indirect measure of an EBV when the indicator and its data could be used as a proxy after additional data consolidation and processing. The darker the cell colour, the higher the percentage displayed

		Essential biodiversity variables classes											
		Genetic composition		Species populations		Species traits		Community composition		Ecosystem function		Ecosystem structure	
BIP indicator	Aichi target (s)	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
Ex-situ crop collections	13	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Extent of forests and forest types	5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	66%	0%
Extent of marine habitats	5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	66%	33%
Forest fragmentation	5	0%	0%	0%	33%	0%	0%	50%	0%	0%	0%	33%	66%
Genetic diversity of terrestrial domesticated animals	13	25%	0%	0%	66%	0%	0%	0%	0%	0%	0%	0%	0%
Living Planet Index	5,6,12	0%	0%	66%	33%	0%	33%	0%	50%	0%	0%	0%	0%
Marine Trophic Index	6	0%	0%	0%	100%	0%	17%	50%	50%	0%	25%	0%	66%
Proportion of fish stocks in safe biological limits	6	0%	0%	66%	33%	0%	17%	0%	50%	0%	0%	0%	0%
Red List Index	5,6,10,12,14	0%	0%	100%	0%	66%	0%	50%	0%	0%	0%	33%	0%
River fragmentation and flow regulation	5	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	33%	33%
Wild Bird Index	5,6,12	0%	0%	66%	33%	33%	0%	0%	50%	0%	0%	0%	0%
Wildlife Picture Index	5,12	0%	0%	33%	66%	0%	33%	0%	50%	0%	0%	0%	0%

Table 3. Selected data sets containing biodiversity information at various scales and representing different EBV classes: Genetic Composition (GC), Species Populations (SP), Species Traits (ST), Community Composition (CC), Ecosystem Function (EF), Ecosystem Structure (ES). The scoring indicates whether the data set contained data of direct relevance for the EBV class (1) or not (0). Topical realm coverage includes Marine (M), Terrestrial (T) and Freshwater (F). Data access was described as unrestricted (U) or partly restricted (P) access to data

Data source	Scale	Realm	Access	GC	SP	ST	CC	EF	ES	URL
GBIF	Global	M/T/F	U	0	1	0	0	0	0	http://www.gbif.org
GenBank	Global	M/T/F	U	1	0	0	0	0	0	http://www.ncbi.nlm.nih.gov/genbank/
IUCN Knowledge Products										
– Red list's spatial data	Global	M/T/F	U	0	1	1	0	0	1	http://www.iucnredlist.org/
Biofresh	Global	F	P	0	1	0	0	0	0	http://data.freshwaterbiodiversity.eu/
Pangaea	Global	M/T/F	P	0	1	0	0	1	1	http://www.pangaea.de/
Fishbase	Global	M/F	U	0	1	1	0	0	0	http://www.fishbase.org/
Trait data bases (Polytraits, Try, YouTHERIA …)	Global	M/T/F	P	0	1	1	1	0	1	(i) http://polytraits.lifewatchgreece.eu, (ii) http://www.try-db.org/TryWeb/Home.php, (iii) http://www.utheria.org
Movebank	Global	M/T/F	P	0	1	1	0	1	0	https://www.movebank.org/
Landsat	Global	M/T/F	U	0	0	0	1	1	1	http://landsatlook.usgs.gov/
ENVISAT	Global	M/F/T	U	0	0	0	1	1	1	https://earth.esa.int/web/guest/pi-community
LTER	Regional*	M/T/F	P	1	1	0	1	1	1	https://portal.lternet.edu/nis/home.jsp, http://deims.enveurope.eu/search/dataset
ICES (Datras)	North East Atlantic	M	U	0	1	1	1	1	0	http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx
Delivering Alien Invasive Species Inventories for Europe (DAISIE)	Europe	M/T/F	P	0	1	1	0	0	0	http://www.europe-aliens.org/
Pan-European Species directories Infrastructure (PESI)	Europe	M/T/F	P	0	1	0	1	0	0	http://www.eu-nomen.eu/portal/
European Red deer genetic monitoring program	Europe	T	P	1	1	0	0	0	0	Please find more information in the EuMon Database http://eumon.ckff.si/monitoring/

*Mainly North America and Europe.

the lowest EBV coverage. EBVs from the classes Species Populations, Ecosystem Function and Ecosystem Structure were most often required for reporting, whereas EBVs from the class Genetic Composition were least often required for reporting.

The detailed analysis of policy instruments also showed that some biodiversity dimensions were not covered by any of the EBVs, for example societal awareness (e.g. the Biodiversity Barometer in Appendix S3), the spatial extent of protected areas, or the structure and function of protected habitats (required for reporting under the European Habitats Directive). Information on drivers and pressures on biodiversity (e.g. Nitrogen deposition in Appendix S3), required for reporting under the CBD, are also currently not captured by EBVs although they are essential for biodiversity trend interpretation.

For each of the EBV classes, there was at least one BIP indicator that could be considered to be relevant, although it should be noted that this does not mean that the indicator was relevant to each EBV within the class considered (Table 2, Appendix S3). Conversely, some BIP indicators are focused on only one Aichi Target, but they could be considered to represent several EBV classes (e.g. the 'Marine Trophic Index' is relevant for three EBV classes).

The EBV class measured most directly by BIP indicators and for which data were found to be most widely available was Species Populations (Table 3, Appendix S3). For the EBV classes Ecosystem Function and Ecosystem Structure, few BIP indicators were considered relevant, even though these classes are often required for reporting. For the EBV class Genetic Composition, only one out of four EBVs was represented by a BIP indicator (Genetic diversity of terrestrial domesticated animals). A number of BIP indicators were considered to provide proxies for three EBV classes, in particular Community Composition, Ecosystem Structure and Ecosystem Function.

The analysis of the selected existing data sources showed a highly heterogeneous group in terms of their spatial and temporal resolutions, geographical coverage and the ecosystems considered (Table 3; Appendix S4). For the class Species Populations, spatial coverage of data sources ranged from global (e.g. GBIF, the IUCN Red List of threatened species), to regional initiatives such as European data bases, for example on taxonomy (e.g. PESI which includes Fauna Europaea, Euro+Med PlantBase and the European Register of Marine Species) or data bases covering species with a specific thematic focus, like DAISIE, for European alien invasive species.

Data sources most often contained relevant data sets for two EBV classes: Species Populations and Community Composition, namely 37 and 26 out of 43, respectively. It has to be noted, however, that the actual data processing and modelling efforts required to render the data usable are not taken into account here. There were also multiple data sets for plants, mammals and even bristle worms available for the EBV class Species Traits, with 16 out of 43 data sources (see for examples the extended list in Appendix S4). Comparatively few data sets were publicly available for the class Genetic Composition (five out of 43).

Discussion

The biodiversity information required for reporting purposes and used to inform decision-makers does not show a uniform distribution across EBV classes. For instance, information on the changes in Species Populations is required more often than information on the changes in Genetic Composition. The information gap between the reporting requirements for the Aichi Targets and the BIP indicator set comprised three of the six EBV classes. The analysis of the BIP indicators also indicated that there might be an information overlap between EBV classes. Based on the results presented, the following options to bridge the information gaps were identified: (i) for some EBV classes, there may be existing data available that require mobilization, integration or modelling efforts (e.g. Ecosystem Structure); (ii) EBV classes lacking primary data require additional monitoring efforts (e.g. Genetic Composition), but (iii) the reporting could already be improved by using existing BIP indicators as proxies for some EBVs (e.g. for Community Composition, Ecosystem Structure and Ecosystem Function). Finally, it was found that the current state of development of the EBV framework strongly constrains the performed coverage analysis with regard to spatial, temporal and realm analyses. Further, certain types of information which are important for interpreting changes in biodiversity and which are required for reporting are not included in the EBV framework.

STRENGTHENING THE INFORMATION BASIS OF BIODIVERSITY REPORTING

Henle *et al.* (2013) proposed reducing existing data bias in reporting by prioritizing data collection efforts within the focus of the policy instrument based on topical (habitats and species) and geographical criteria. Although this would very likely reduce the reporting bias, the EBV analysis in this paper has illustrated that this would not address the existing information gaps across and outside the scope of individual policy instruments. The EBV perspective provides this additional and complementary information. In the EBV open consultation round of 2013, respondents estimated the importance of coverage of all EBVs for biodiversity monitoring, by ranking all EBVs at 3 and above (on a scale of 1 = unimportant to 5 = critical). However, the current EBV framework did not allow for an adequacy analysis. Therefore, it is not clear whether information for all EBVs should be provided equally or whether a certain threshold value per information type is required.

Initiatives such as IPBES would be a suitable forum for addressing the information gaps identified by EBVs.

Although the IPBES research program for the coming 3 years (Decision IPBES-2/5) currently focuses on EBVs for which data are more readily available, it could in the future focus on existing reporting gaps. The comprehensiveness of reporting under individual instruments could also be improved by using models and aggregated indicators developed for standardized EBVs to harmonize and streamline data and indicators for multiple reports. For example, the EBV Phenology could be based on a selected number of taxa (e.g. plant, bird and butterflies) which could be integrated into a global indicator describing phenological changes in response to climate change. This indicator could contribute to future CBD reporting.

IDENTIFYING AND BRIDGING THE INFORMATION GAP

Whereas EBVs are a theory-driven approach, the BIP indicator set for Aichi 2020 is a more data-driven approach. The BIP indicator set result from an original indicator set which was adapted to take into account both the information requirements for the Aichi Targets, as well as data availability to actually quantify the indicators. As such, both approaches are complementary for improving policy reporting. The BIP indicator provides information that is not covered by the EBVs. Some of these could be considered non-biodiversity dimensions, because they measure the progress of implementation rather than biodiversity itself, such as public awareness and policy implementation (CBD Strategic goal A, Appendix S3) and the drivers of change of biodiversity (e.g. management effectiveness of protected areas). Simultaneously, the BIP indicators covered certain EBV classes much better than others. Interestingly, this bias was not always reflecting the information requirements for reporting, resulting in an information gap. Notably, two of four of the EBVs in the class Ecosystem Function were only directly represented by five BIP indicators, whereas this class is much demanded for reporting. This information gap between the information required and the actual coverage could be due to the lack of data, but the analysis of data sources showed that this gap could be bridged through the mobilization of data, integration of data sets and modelling efforts.

Additionally, the quantity and diversity of BIP indicators that could serve as indirect proxies for EBVs (Table 2) suggest that information gaps in reporting could already be bridged to a certain extent by incorporating proxies for missing EBVs. Although the use of the same indicator for multiple reporting objectives could theoretically help harmonize reporting and monitoring efforts, limited literature is available to support this (but see Osinski *et al.* 2003 and Geijzendorffer & Roche 2013). However, proxies must be used in a transparent manner to avoid augmentation of the existing bias on more readily available data.

Many data sources within the selection considered in this paper demonstrated potential for bridging the information gap by providing data for several EBV classes (Table 3). This suggests that if data sets from different data sources could be mobilized, integrated or included in modelling efforts, an increase in information covering all dimensions of biodiversity change could be achieved (Chavan & Penev 2011). Recognizing this potential, the European Commission has funded research projects such as EU BON (Hoffmann *et al.* 2014) to develop methods for data mobilization and integration of relevant biodiversity data.

For successful data mobilization, data standards need to be developed across spatial scales, data sets and the full spectrum of biodiversity (Duffy *et al.* 2013), such as those that have been developed by the Biodiversity Information Standards (http://www.tdwg.org/) and the Genomic Standards Consortium (http://gensc.org/). In addition, limitations, such as gaps in spatial and temporal coverage, may be solved by integrating different data sets and modelling efforts (Weber, Hintermann & Zangger 2004; Henry *et al.* 2008; Lengyel *et al.* 2008). Data set integration methods for quantifying indicators are increasingly available (Duffy *et al.* 2013), and bird and butterfly data have already been used to demonstrate the added value of data set integration for species abundance trends at broad geographical scales (e.g. De Heer, Kapos & Ten Brink 2005; Gregory *et al.* 2005, 2009). In addition to the interoperability and quality of data sets, limited access is a key barrier for data mobilization that is recognized by both funding bodies and scientific initiatives (Chavan & Penev 2011; Costello *et al.* 2014).

Although the options of data integration, modelling and the identification of relevant proxies are important options to bridge the information gap, in the absence of primary data, these options can only add limited value. Additional data collection efforts are still needed. However, exploring postcollection data processing and modelling options to fill gaps in knowledge could be used to optimize and prioritize monitoring efforts.

EBVS: FUTURE USE AND DEVELOPMENT

For the analyses in this paper, EBVs were used as a framework to identify the current information gap between biodiversity reporting requirements and the information actually available and used. Although it worked well overall, some challenges were identified that need to be addressed if EBVs are to be used as a future assessment.

The current state of development of the EBVs posed several limitations to the analyses that could be performed in this manuscript. First, the robustness of EBV use could currently not be indicated in the EBV assessments. For instance, a data set, which is able to quantify an EBV for one taxon at one location currently, has the same score as a data set which can quantify the same EBV across many taxa and over a long period of time. Coverage of data sets and indicators of various spatial and temporal dimensions and taxa have been highlighted as important barriers for the reporting under global instruments, but these currently remain unidentified. With regard to the development of EBVs, the ongoing work defining the appropriate spatial and temporal scales should include the potential contribution of modelling efforts to bridging spatial and temporal data gaps.

Additionally, for certain policy targets, data requirements seemed to be directed at EBV class level, while a relevant individual EBV was not included in the current list. For instance, ecosystem service-related targets seem to require data from the class Ecosystem Function, but apart from Biomass Provision, EBVs for other specific ecosystem functions were missing (e.g. pollination or soil decomposition rates).

The analysis of the BIP indicators showed that reporting requires additional indicators on non-biodiversity variables as well as measures of biodiversity *per se* (Walpole *et al*. 2009; Tittensor *et al*. 2014), to inform a specific objective of a policy target (e.g. progress in policy implementation, public awareness, and policy and management responses) or to provide an interpretation of detected changes in biodiversity (e.g. pollution, management intensification). For instance, the Marine Strategy Framework Directive requires indicators for the identity of the driver of impact (recognized threats and pressures) and the actual positive or negative impact on species, habitats and ecosystems [for an example, see Descriptor 5 'Eutrophication' (EC 2010)]. These non-biodiversity variables are not covered by the EBV list, as the EBVs were explicitly developed solely for 'state' and 'biological' variables (Pereira *et al*. 2013). Clearly, comprehensive interpretation of biodiversity trends requires the integration of other topical data, notably on drivers and pressures for biodiversity. Feest (2013) faced a similar challenge in his analysis of the SEBI (Streamlining European Biodiversity Indicators, biodiversity.europa.eu/topics/sebi-indicators) for CBD reporting. In that paper, Feest opted to weight non-biodiversity indicators based on the proof of their impact and connection to biodiversity. This, however, does not provide a coherent framework to answer the particular need to better integrate EBVs and environmental change assessments for improved reporting of biodiversity change. That challenge remains as a challenge for a future study.

Acknowledgements

For the validation of the result tables, we would like to thank the expert reviewers for their valuable comments: Albert Bleeker, Stuart Butchart, Rainer Froese, Alessandro Galli, Ian Harrison, Sergi Herrando, Louise McRae, Rania Spyropoulou, Nicolas Titeux and Evelyn Underwood. We would also like to thank Anke Hoffman and Matt Walpole for commenting on the manuscript. This paper was financed by the EU BON project that is a 7th Framework Programme funded by the European Union under Contract No. 308454.

Data accessibility

All data used in this manuscript are presented in the Supporting Information.

References

Bunce, R.G.H., Bogers, M.M.B., Roche, P., Walczak, M., Geijzendorffer, I.R. & Jongman, R.H.G. (2011) *Manual for Habitat and Vegetation Surveillance and Monitoring: Temperate, Mediterranean and Desert Biomes*. Alterra Report 2154, Alterra, Wageningen.

CBD (2014) *Global Biodiversity Outlook 4*. CBD, Montréal.

CBD (Convention on Biodiversity Diversity) (2010) *Decision X/2. The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets*. UNEP/CBD/COP/DEC/X/2, CBD (Convention on Biodiversity Diversity), Nagoya.

Chavan, V. & Penev, L. (2011) The data paper: a mechanism to incentivize data publishing in biodiversity science. *BMC Bioinformatics*, **12**, S2.

Collen, B., Ram, M., Zamin, T. & McRae, L. (2008) The tropical biodiversity data gap: addressing disparity in global monitoring. *Tropical Conservation Science*, **1**, 75–88.

Costello, M.J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H. & Miloslavich, P. (2010) A census of marine biodiversity knowledge, resources, and future challenges. *PLoS ONE*, **5**, e12110.

Costello, M.J., Appeltans, W., Bailly, N., Berendsohn, W.G., de Jong, Y., Edwards, M. *et al*. (2014) Strategies for the sustainability of online open-access biodiversity databases. *Biological Conservation*, **173**, 155–165.

De Heer, M., Kapos, V. & Ten Brink, B.J.E. (2005) Biodiversity trends in Europe: development and testing of a species trend indicator for evaluating progress towards the 2010 target. *Philosophical Transactions of the Royal Society B*, **360**, 297–308.

Duffy, J.E., Amaral-Zettler, L.A., Fautin, D.G., Paulay, G., Rynearson, T.A., Sosik, H.M. & Stachowicz, J.J. (2013) Envisioning a marine biodiversity observation network. *BioScience*, **63**, 350–361.

EC (2008) *Marine Strategy Framework Directive*, 2008/56/EC, Official journal of the European Union, L164/19.

EC (2010) *Criteria and methodological standards on good environmental status of marine waters*, 2010/477/EU. Official journal of the European Union, L232/14.

EC (2011) *Assessment and reporting under Article 17 of the Habitats Directive*. Art.17 Reporting Formats for the period 2007–2012. https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp, last accessed on 13/02/2015.

EC (European Commission) (2000) *Water Framework Directive*, 2000/60/EC. Official journal of the European Union, L327/1.

EEA (2011) *Reference Portal for Birds Reporting* (art. 12 of the Birds Directive). http://bd.eionet.europa.eu/activities/Reporting/Article_12/reference_portal, last accessed on 13/02/2015.

Feest, A. (2013) The utility of the Streamlining European Biodiversity Indicators 2010 (SEBI 2010). *Ecological Indicators*, **28**, 16–21.

GCOS (2003) *The Second Report on the Adequacy of the Global Observing System for Climate in support of the UNFCCC*. Report GCOS – 82 (WMO/TD No. 1143), World Meteorological Organization.

Geijzendorffer, I.R. & Roche, P.K. (2013) Can biodiversity monitoring schemes provide indicators for ecosystem services? *Ecological Indicators*, **33**, 148–157.

Gregory, R.D., Van Strien, A.J., Voříšek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B. & Gibbons, D.W. (2005) Developing indicators for European birds. *Philosophical Transactions of the Royal Society B*, **360**, 269–288.

Gregory, R.D., Willis, S.G., Jiguet, F., Voříšek, P., Klvaňová, A., Van Strien, A. *et al*. (2009) An indicator of the impact of climatic change on European bird populations. *PLoS ONE*, **4**, e4678.

Henle, K., Bauch, B., Auliya, M., Külvik, M., Péer, G., Schmeller, D.S. & Framstad, E. (2013) Priorities for biodiversity monitoring in Europe: a review of supranational policies and a novel scheme for integrative prioritization. *Ecological Indicators*, **33**, 5–18.

Henry, P.Y., Lengyel, S., Nowicki, P., Julliard, R., Clobert, J., Celik, T. *et al*. (2008) Integrating ongoing biodiversity monitoring: potential benefits and methods. *Biodiversity and Conservation*, **17**, 3357–3382.

Hoffmann, A., Penner, J., Vohland, K., Cramer, W., Doubleday, R., Henle, K. *et al*. (2014) Improved access to integrated biodiversity data for science, practice, and policy – the European Biodiversity Observation Network (EU BON). *Nature Conservation*, **6**, 49–65.

Jetz, W., McPherson, J.M. & Guralnick, R.P. (2012) Integrating biodiversity distribution knowledge: toward a global map of life. *Trends in Ecology and Evolution*, **27**, 151–159.

Kot, C.Y., Fujioka, E., Hazen, L.J., Best, B.D., Read, A.J. & Halpin, P.N. (2010) Spatio-temporal gap analysis of OBIS-SEAMAP project data: assessment and way forward. *PLoS ONE*, **5**, e12990.

Lengyel, S., Kobler, A., Kutnar, L., Framstad, E., Henry, P.Y., Babij, V., Gruber, B., Schmeller, D. & Henle, K. (2008) A review and a framework for the integration of biodiversity monitoring at the habitat level. *Biodiversity and Conservation*, **17**, 3341–3356.

Lindenmayer, D.B., Gibbons, P., Bourke, M., Burgman, M., Dickman, C.R., Ferrier, S. *et al.* (2012) Improving biodiversity monitoring. *Australian. Ecology*, **37**, 285–294.

Mora, C., Tittensor, D.P. & Myers, R.A. (2008) The completeness of taxonomic inventories for describing the global diversity and distribution of marine fishes. *Proceedings of The Royal Society B*, **275**, 149–155.

Niemelä, J. (2000) Biodiversity monitoring for decision –making. *Annales Zoologici Fennici*, **37**, 307–317.

Niemeijer, D. (2002) Developing indicators for environmental policy: data-driven and theory-driven approaches examined by example. *Environmental Science & Policy*, **5**, 91–103.

Noss, R.F. (1990) Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, **4**, 355–364.

Osinski, E., Meier, U., Büchs, W., Weickel, J. & Matzdorf, B. (2003) Application of biotic indicators for evaluation of sustainable land use – current procedures and future developments. *Agriculture, Ecosystems & Environment*, **98**, 407–421.

Pereira, H.M., Navarro, L.M. & Santos Martins, I. (2012) Global biodiversity change: the bad, the good and the unknown. *Annual Review Environment and Resources*, **37**, 25–50.

Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J. *et al.* (2013) Essential biodiversity variables. *Science*, **339**, 277–278.

Pullin, A.S., Báldi, A., Can, O.E., Dieterich, M., Kati, V., Livoreil, B. *et al.* (2009) Conservation focus on Europe: major conservation policy issues that need to be informed by conservation science. *Conservation biology*, **23**, 818–824.

Ramsar (2012) *The Ramsar Strategic Plan 2009–2015*. Amended version of 2012. http://archive.ramsar.org/pdf/strat-plan-2009-e-adj.pdf, last accessed on 13/02/2015.

Schmeller, D.S., Henry, P.Y., Julliard, R., Gruber, B., Clobert, J., Dziock, F. *et al.* (2009) Advantages of Volunteer-Based Biodiversity Monitoring in Europe. *Conservation Biology*, **23**, 307–316.

Tittensor, D.P., Walpole, M., Hill, S.L.L., Boyce, D.G., Britten, G.L., Burgess, N.D. *et al.* (2014) A mid-term analysis of progress towards international biodiversity targets. *Science*, **346**, 241–244.

UNEP-CMS (2014) *The Strategic Plan for Migratory Species 2015–2023*. Version March 2014. http://www.cms.int/en/document/strategic-plan-migratory-species-2015-2023-consultation-draft-2-march-2014, last accessed on 13/02/2015.

Walpole, M., Almond, R.E.A., Besançon, C., Butchart, S.H.M., Campbell-Lendrum, D., Carr, G.M. *et al.* (2009) Tracking progress toward the 2010 biodiversity target and beyond. *Science*, **325**, 1503–1504.

Webb, T.J., Vanden Berghe, E. & O'Dor, R. (2010) Biodiversity's big wet secret: the global distribution of marine biological records reveals chronic under-exploration of the deep pelagic ocean. *PLoS ONE*, **5**, e10223.

Weber, D., Hintermann, U. & Zangger, A. (2004) Scale and trends in species richness: considerations for monitoring biological diversity for political purposes. *Global Ecology and Biogeography*, **13**, 97–104.

Received 13 August 2014; accepted 26 February 2015
Handling Editor: Marc Cadotte

Supporting Information

Additional Supporting Information may be found in the online version of this article.

Appendix S1. Representation of the information flow and the potential place and value of EBVs for biodiversity monitoring, data and policy instrument reporting.

Appendix S2. List of the suggested EBVs for the open consultation round in 2013.

Appendix S3. Gap analysis of the coverage of Essential Biodiversity Variables against indicators to measure the CBD Aichi Targets.

Appendix S4. Final selection of evaluated data set sources containing biodiversity information at various scales and representing the different EBV classes.