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Towards global data products of Essential Biodiversity Variables on species traits

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Appendix

Supplementary information for manuscript ‘Towards global data products of essential biodiversity variables on species traits’ by Kissling et al.

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Supplementary Note 1: Refining the EBV class ‘Species Traits’

Refining the candidate list of species traits EBVs
The current list of candidate EBVs provided by the Group on Earth Observations Biodiversity Observation Network (GEO BON) mentions a total of 22 candidate EBVs across six EBV classes (https://geobon.org/ebvs/what-are-ebvs/). This list of 22 candidate EBVs was produced as an outcome from the Frascati workshop that led to the seminal paper introducing EBVs[1], with some minor changes and improvements included afterwards (Henrique Pereira pers. comm.). In the EBV class ‘Species Traits’, a total of six candidate species traits EBVs are listed (see details in Supplementary Table S1):

- Phenology
- Body mass
- Natal dispersal distance
- Migratory behaviour
- Demographic traits
- Physiological traits

From in-depth discussions during a 3-day experts workshop in Amsterdam in March 2017, we provide detailed comments and suggestions for improving the conceptual framework for species traits EBVs (summarized in Supplementary Table S2). Based on this, we suggest five species traits EBVs:

- Phenology
- Morphology
- Reproduction
- Physiology
- Movement

EBV ‘Phenology’
Phenology, defined as the timing of periodic biological events, includes seasonal activities, developments or behaviours of individuals and populations of organisms[2]. We follow ref.[1] in the terminology of this EBV (‘Phenology’) as well as the focus on phenological status such as presence, absence, abundance or duration of seasonal activities of organisms. This includes measuring the timing of events in individuals, populations and species, e.g. timing of breeding, egg laying, migration, diapause, leaf sprouting, leaf coloration, flowering, fruiting, mosquito emergence, and bacterial infection of hosts. In contrast to ref.[1], we intentionally exclude ecosystem variables that were previously listed (i.e. shifts in ocean current patterns, river flow regimes, extent of wetlands) as they are not species-specific. As in other species traits EBVs, phenology trait measurements should conceptionally be available at the individual level (e.g. date of egg laying of an observed breeding bird pair, or presence/absence of a flowering phenophase on an individual plant at a date), or at least attributable to a population level phenomena that comprises indentifiable individuals of a single species. Hence, remote sensing of land surface phenology such as the onset of greenness[3] should not be included in the EBV class ‘Species Traits’ unless the trait measurement can be directly attributed to the individual of a species. The phenology data that relates to ecosystems or vegetation types might better fit into other ecosystem EBV classes[1,4].

EBV ‘Morphology’

Organism morphology includes measurements of the dimensions (e.g. volume, mass, height), shape and other physical attributes of individual organisms. The morphology of organisms captures the essence of form and function[5,6] and is often related to their performance and fitness[7]. This EBV is now more broadly defined than the previous EBV 'Body mass'. 'Body mass' is included as one example of organism size measurements, alongside other size measures and physical attributes. Additional trait measurements in this EBV may include the morphology of whole organisms, or components of an individual. For example, measurements could be related to the length, width, depth, height, mass, volume, circumference etc. of whole organisms, but could also reference measurements of parts of whole organisms, e.g. cell volume, leaf dimensions, leaf area, wing length (e.g. in birds, bats, insects), and colour. Raw data should be measurable at the individual level (or for groups of individuals) and may include measurements derived from remote sensing, e.g. height or canopy extent for tree individuals or remotely-sensed tree heights of multiple individuals of the same species.

EBV 'Reproduction'

Reproduction is the sexual or asexual production of new individual organisms ("offspring") from parents, and is a dominant component of fitness. Variables that quantify and describe reproduction are considered major components of life history variation[5,6]. We therefore introduce an EBV 'Reproduction' which focuses on reproduction-related biological state variables (which were previously not captured). Examples of trait measurements for this EBV include propagule/clutch/litter size, age/size at maturity, and total lifetime reproductive output[8,9]. Some of these measurements were previously included in the EBV 'Demographic traits'[1]. However, some of the demographic traits originally captured within this EBV cannot be measured on individual organisms because they reflect variables that are measured at the population level (e.g. population growth rate, generation time, survival rate)[1]. These population-level metrics are derived from surveys of population structure (e.g. by age, ontogenetic stage or size, plus whether the individuals are reproductive and how much) or by following the fates of marked individuals and can therefore be derived from data in the EBV 'Population structure by age/size class' in the EBV class 'Species Populations'. To avoid duplication of effort, we suggest that these population-level metrics should not be placed in the EBV class 'Species Traits'.

EBV 'Physiology'

Physiology reflects the way organisms or their parts carry out chemical or physical functions that determine their fitness. It is of key relevance to describe how the physiology of organisms underpins their response to environmental variation[10,11]. We retain the previous EBV 'Physiological traits' [1] but simplify its name to 'Physiology'. Examples of trait measurements in this EBV include photosynthesis and respiration rate, thermal tolerance, tolerance of other abiotic stresses, disease resistance, or variables that describe stoichiometry (e.g. N and P concentrations, body condition/fat content, ð15N signatures, polyphenol content, leaf or canopy chlorophyll content). Some fundamental physiological variables are not biological states but rather rates (e.g. respiration rates, photosynthetic rates, metabolic rates). We suggest that such rates should be included as trait measurements in this EBV because the temporal resolution at which they are commonly measured (e.g. seconds, hours, or days) is usually much finer than the temporal resolution (e.g. 1 to >10 years) relevant for measuring changes in EBVs to inform policy and management, and because they underpin the individual-level fitness, as shown by metabolic theories in ecology[7,11,12]. For example, gross primary production rate of individual plants (a potential species trait measurement for this EBV) can be estimated by measuring net photosynthesis and respiration rates.

EBV 'Movement'

Movement characterizes behaviours that are related to the spatial mobility of organisms. It is one of the key mechanisms shaping biodiversity because it determines how organisms exploit resources in their environment and how they disperse or respond to changing environmental conditions[13]. In the initial list of species traits EBVs[1], two movement EBVs ('Natal dispersal distance' and 'Migratory behaviour') were included in the EBV class 'Species Traits'. We suggest that both EBVs can be represented within the EBV 'Movement' and that other EBVs related to movement behaviours can be added. Examples of movement-related trait measurements include natal dispersal distance, migration routes/distances, movement velocity, and cell sinking of phytoplankton. We suggest that timing-related variables (e.g. migratory timing, i.e. the timing of recurrent movement events) fit better into the EBV 'Phenology' (see above). Hence, only non-timing movement events should be included in this EBV (e.g. presence/absence/destinations/pathways of migrant taxa, dispersal distances).

Supplementary Note 2: Societal relevance of species traits EBVs

Essential Biodiversity Variables and policy targets
Essential Biodiversity Variables (EBVs) based on species traits should ultimately be relevant for national and international policy goals such as the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD), National Biodiversity Strategic Action Plans (NBSAPs), and Sustainable Development Goals (SDGs)[1,14-16]. However, the specific relationship between EBVs and such policy targets remains little explored. For species traits EBVs, the seminal EBV paper[1] listed their relevance for Aichi Biodiversity Targets 4–12 and 15, but a quantification of their relative importance and a detailed exploration of their relevance is lacking. Moreover, the relevance of trait EBVs for SDGs was not explored[1]. In a more recent paper[16], the relationship between EBVs and 42 indicators as currently used by the Biodiversity Indicators Partnership (BIP, www.bipindicators.net) to inform the reporting to the Convention on Biological Diversity (CBD) was assessed. This revealed that species traits EBVs are currently not well represented in biodiversity indicators, probably reflecting a lack of consideration rather than limited relevance of species traits to policy targets. Species traits are also currently not yet considered in the global biodiversity change indicators developed by GEO BON and partners[17].

Assessing the importance of species traits for Aichi Biodiversity Targets and Sustainable Development Goals
To provide insights into the societal and policy relevance of species traits EBVs, a systematic inventory on their importance for Aichi Biodiversity Targets and SDGs was set out among the co-authors of this manuscript. These co-authors represent a well-mixed group of experts on species traits and contained 17 respondents with backgrounds in ecology, physiology, and taxonomy/systematics as well as with knowledge on fauna, flora and microorganisms. While the sampling strategy of this inventory may have led to artefacts in the final scores, we believe that this expert assessment is useful to gain insights into the societal relevance of species traits.

We pre-selected a number of Aichi Biodiversity Targets (5–12, 14, 15) and SDGs (2, 3, 13–15) for which we considered a potential link to species traits and eliminated those for which we did not foresee any direct role of species traits. This selection was based on (1) information in the seminal EBV paper[1], (2) feedback from workshop participants before the workshop, (3) discussions during the workshop about the importance of species traits for these targets, and (4) a screening of the targets as listed on the websites of the Aichi Biodiversity Targets (https://www.cbd.int/sp/targets/) and SDGs (http://www.un.org/sustainabledevelopment/sustainable-development-goals/). Each correspondent received a score sheet with explanation (available upon request from the first author), indicating to score the relative importance of each species traits EBV for each Aichi Biodiversity Target and SDG, using scores of 0–3, considering an "average" species trait within each species traits EBV and/or the average performance of species traits within each species traits EBV and using integer scores only. The score form also contained an explanation about the species traits EBVs (following the refined definition as presented in the main manuscript), including examples of species traits.

Our assessment revealed substantial variation in the policy importance of traits within and across targets (see below Supplementary Table S3). Despite excluding targets that did not have any particular relevance to species traits before the assessment, some species traits EBVs were clearly more related to particular targets than others. For instance, species traits related to ‘reproduction’ and ‘morphology’ were most strongly related to Aichi target 6 (sustainable harvesting of fish and invertebrate stocks and aquatic plants) whereas 'reproduction' and 'movement' were most strongly related to Aichi target 9 (invasive species control, see bold values in Supplementary Table S3). Similarly, 'physiology' was considered highly relevant for Aichi target 8 (pollution and nutrient excess), target 10 (effects of climate change or ocean acidification on coral reefs), and target 15 (enhance carbon stocks). For SDGs, especially the species traits related to 'phenology', 'morphology' and 'reproduction' were considered to be important (see bold values in Supplementary Table S3).

Across policy targets, SDGs 14 and 15 (life below water and life on land) and Aichi targets 6 and 9 (related to fish/invertebrate stocks and aquatic plants, and invasive species control) were most strongly reated to traits (Supplementary Table S3). Aichi targets 5 (habitat loss and forest fragmentation), 8 (pollution and nutrient excess), 11 (need for protected areas) and 14 (ecosystem restoration) and SDG 3 (human health) scored as being only weakly related to species traits.

Different species traits EBVs also differed in their importance across targets (Supplementary Table S3). For instance, 'movement' was not considered to be of high importance for most targets. However, it was of high importance for Aichi target 9 (invasive species control), together with trait measurements for the EBV 'reproduction'. This reflects that dispersal distances and pathways as well as high reproductive output are critical components of alien species to become invasive[18-20]. The other species traits were more often considered of high relevance to a particular target than 'movement', but each species traits EBV had a unique combination of links to specific targets (Supplementary Table S3). For instance, 'morphology' is a strong indicator for overfishing[21,22] and hence most strongly related to Aichi target 6, while 'phenology' is strongly affected by climate change[2] and hence connected to the corresponding SDG 13 (Supplementary Table S3). This implies that each species traits EBV contains important information with societal and policy relevance that cannot be substituted by other species traits EBV.

Supplementary Note 3: Openness of species trait data

Assessing openness of individual species traits datasets

Many trait databases have become available in the last decade (Supplementary Table S4). Trait datasets that may be used in building EBV data products should be interoperable at the semantic, technical and legal level[23]. As legal interoperability in the EBV context is most easily secured with open, accessible and machine-readable (meta)data[24,25], we here reviewed a small number of species traits datasets to assess their relative level of openness. The goal of this exercise was not to evaluate whether or not trait datasets are designated open, as it has been done for other biodiversity data[26], but to highlight the full and complex spectrum of legal interoperability issues pertaining to open access. We focused this exercise on trait datasets that were represented with expert knowledge during a 3-day experts workshop in Amsterdam (Supplementary Table S4), and selected datasets (i) with sufficient size and geographic scope to merit inclusion in EBV calculations; (ii) for which commitment to openness was expressed by the research team; and (iii) to cover a diversity of open access in practice. See Supplementary Table S4 for more details about these trait databases.

TraitBank

All data in TraitBank (Encyclopedia of Life) can be freely accessed, downloaded, shared, and repurposed. Most data sets are in the public domain, and some datasets carry a Creative Commons Attribution (CC BY) license. TraitBank data downloads are generally the result of queries across several different datasets and therefore contain records from multiple sources. Much of the data and metadata remain to be standardized and are therefore opaque to machine interpretation. Nevertheless, data provenance is documented through references and several layers of attribution, mapped to Dublin Core elements[27] (source, bibliographicCitation, contributor). To reflect the position that individual measurements and other facts are not subject to copyright, terms of use and licensing information are not provided at the data record level. A new version of the TraitBank platform with more advanced tools for machine access to the data is scheduled for launch at the time of writing this information (mid 2018).

VertNet

VertNet states that the ideal is for all datasets to be published in the public domain (i.e. under the designation of a CC0 waiver) to clearly prevent any restrictions on re-use. In practice, most (but not all) of the datasets in VertNet include a CC license (in human and/or machine-readable form) or open source designation (CC0). VertNet supports a robust metadata scheme with documentation on the record and dataset level. Metadata for each individual VertNet record contains a field for license and a field for record citation. The standardized metadata for each dataset includes a field for license, a field for record citation, and, for many data sets, a field labelled “rights” which links to data licenses in machine-readable form. Despite this supporting cyberinfrastructure, VertNet recognizes that “in some cases, data publishers have published using non-standard terms of use. These terms could be located in many possible locations in the dataset.”

USA-NPN

The USA-NPN terms of use state that the all data resources are openly and universally available to all users under a CC BY license, enabling users to share and adapt the data for any purpose, as long as appropriate credit is given. Several options for appropriate citation are provided. Observers who contribute to the USA-NPN datasets maintain ownership of their contributions, but grant the public license to reuse and alter the data in any way that is consistent with the USA-NPN mission.

NEON

According to posted data policies, NEON allows the use of all published data “free of charge, to any person or organization…to use, reproduce, display, distribute, publish, execute, and transmit the NEON Data Products” subject to including a copyright notice and disclaimer. While NEON’s data policy aligns with the CC BY license, no machine-readable license is currently present on the NEON website. NEON does not release identifying information on federally- or state-listed species because of legal or ethical concerns (sensitivity to threatened and endangered species). Such data are instead post-processed to obscure taxa information to a higher taxonomic level. In addition, landowners (including US federal agencies) may request redaction of rare taxa within their jurisdiction, which results in not all data being open.

COMPADRE and COMADRE

The project website characterizes both matrix databases as open-access, though citation in a particular format is requested. Recognizing that many of the datasets in COMPADRE and COMADRE are digitized derivations from peer-reviewed publications, database managers also suggest citing the initial source, and note that the ultimate source for each matrix population model in the databases is indicated in the metadata. To that end, the databases include information and are associated with R scripts that facilitate data use and the citation of the used works. Accessing this information currently requires downloading the data in Rdata format, which requires a level of data literacy that may hinder some potential users, although the data can also be transformed into open-access csv format with tools provided by the database github page (https://github.com/jonesor/compadreDB). There is an on-going effort to develop a user-friendly database with an application programming interface (API). While COMPADRE and COMADRE’s open access policy aligns with the CC BY license, no machine-readable license is present on the website. An on-going effort will include this capability soon.

BIOTIC

As documented in the footer of each page, use conditions for both BIOTIC and MarLIN note that “the information…is licensed under a Creative Commons Attribution-Non-Commercial-Share Alike (CC BY-NC-SA) license”. While CC BY-NC-SA is not typically considered an open data license due to the non-commercial limitation, this license is offered in machine-readable form. Perspective commercial data users are also encouraged to contact the MarLIN team for permission. In order to retrieve information on species traits, researchers must upload a species list in Excel sheet version, or copy and paste a species list into a free-text box. A traits matrix for the matching species will then be available for download as a CSV file. The MarLIN terms and conditions further clarify that “any data (e.g. survey data or records) presented via the MarLIN website are managed and hosted by DASSH, and are subject to DASSH’s terms and conditions.” DASSH, which is the UK Archive for Marine Species and Habitats Data, provides digital archiving facilitates for a range of data on species and habitats, including images. The terms and conditions of data access and use for DASSH are similar, but not identical, to the use conditions for BIOTIC.

TRY

Plant trait data in TRY version 5.0 (established 2018) and upwards are open access under the Creative Commons Attribution (CC-BY) licence. License information is offered in machine-readable form. However, TRY allows for a temporarily limited periode of restricted availability (embargo preiod). Requesting data requires login to the TRY website to facilitate structured requests and data release. According to the CC-BY license, TRY requests citation of both the original reference under which data are provided to TRY, and for the TRY initiative itself. Data provenance is documented through references and several layers of attribution. Metadata on the level of individual trait records (trait, species, sampling location and date, name of contributor and dataset) are open, accessible and machine-readable.

Summary of openness of trait datasets

The overview above provides a snapshot from 2017/2018 for a fast changing domain. It shows that many researchers and data providers are committed to making trait data openly available and are heading towards more standardized open access approaches. TraitBank, VertNet, USA-NPN, NEON, COMPADRE/COMADRE, BIOTIC and TRY all share commitments to collaboration, express openness as a value, and/or provide access to research data. Some data providers, including NEON, VertNet, TRY and COMPADRE/COMADRE, also promote re-use by providing clear guidelines for citation when attribution is requested. However, despite these commitments the actual levels of open and FAIR access to trait data are still lagging behind the ideal, and beyond what would be necessary for human and machine users to take full advantage of the information that could contribute to species traits EBVs.

First, even when data policies designate a resource as "open," this information is rarely presented in a form that computer systems can read. The FAIR principles explicitly mention accessibility by both humans and machines[24], and the CC website (https://creativecommons.org) provides code for hyperlinking or otherwise providing various licenses in machine-readable form. The lack of machine-readable licenses may not only prevent automated identification and compilation of trait information[25], but also confuse human researchers because exact language on openness and citation as included in data policies rarely aligns between datasets.

Second, as with BIOTIC, the trait data collected by biodiversity researchers is often hosted or otherwise supported by cyberinfrastructure at other institutions. This will impede interoperability when institutional policies conflict. For example, a user accessing data and information through BIOTIC or MarLIN and reading the CC BY-NC-SA license in the footer of these websites may assume any non-commercial use is permitted with attribution. But partner repositories and aggregators, such as DASSH, may have slightly different conditions. On the one hand, listing data in multiple places offers more points of access for potential users. On the other, the conditions set forth by different data portals may impede reuse in practice beyond what is initially intended by researchers themselves.

Third, data providers often require prospective users to formally register or request permission via email to a principal investigator of a project. This may be motivated by a desire to demonstrate that value of a data set through documented use, to secure attribution or co-authorship in line with motivations and norms of the scientific research community, or even to make the data downloading process possible or more user-friendly (e.g. in Traitbank and TRY). Regardless of the reason, requiring registration or email request can be an impediment to human users and is, in all cases, an impediment to machine-access[24]. This requirement therefore constrains the openness of data despite having some benefits.

Fourth, there are a range of reasons for obscuring or omitting certain types of information shared in open datasets. Based on the limited review above, reasons for restricting information include compliance with the policies of data contributors and funders, sensitivity to threatened, endangered, or otherwise vulnerable species, and respect for the privacy of a human data provider. Such restrictions are generally common in biodiversity data, and apply equally (or more so) to data on, for example, species abundance and distribution[25]. In many cases where restrictions are imposed (e.g. in NEON), the hosting researcher or institution maintains the full data set, but only makes limited data available as open access for external researchers to use.

Based on this assessment, we encourage researchers and data providers to increase openness and accessibility of trait data and metadata. We recommend to consider the following:

- Use a license to designate data as open access (e.g. through CC BY) or in the public domain (e.g. CC0).
- Include each license in machine-readable form, by using hyperlinks or more complex embedded code, both in metadata and on project websites.
- Facilitate citation and other forms of attribution of compiled data resources, and/or source data, by providing the relevant references for the given data points or globally unique and persistent identifier such as Digital Object Identifier (DOI).
- Ensure that all access points to data and metadata have consistent and compatible data policies that avoid placing restrictions on use.

Supplementary Table S1: Current list of candidate species traits EBVs from GEO BON

Supplementary Table S1: The current list of six candidate EBVs in the EBV class 'Species traits' from the Group on Earth Observations Biodiversity Observation Network (GEO BON). The list was provided by the GEO BON secretariat and is also available on the GEO BON website (https://geobon.org/ebvs/what-are-ebvs/).

EBV	Measurement and scalability	Temporal sensitivity	Feasibility	Relevance and related CBD 2020 targets
Phenology	Timing of periodic biological events for selected taxa/phenomena at defined locations. Examples include: timing of breeding, leaf coloration, flowering, migration, oceans flow pattern shifts, intermittent flows in rivers, extant of wetlands.	1 year	Several ongoing initiatives (Phenological Eyes Network, PhenoCam, ClimateWatch, etc.), some making use of citizen science contributions.	Phenology is expected to change with climate change. Targets: 10, 15.
Body mass	Body mass (mean and variance) of selected species (e.g. under harvest pressure), at selected sites (e.g. exploitation sites).	1-5 year	Data available for many important marine fisheries, but little data available for bushmeat and other exploited species groups.	There is evidence that mean body mass of some species may be changing in response to pressures such as harvesting. Targets: 6, 7.
Natal dispersal distance	Record median/frequency distribution of dispersal distances of a sample of selected taxa. In marine species larval lifetime it may be a useful surrogate.	>10 years	Banding/marking and observation data available for some birds, mammals, turtles, fish, temperate trees	Required in order to assess the impact of habitat fragmentation on species, project the spread of invasive species, project the impact of climate change on species and to combine with abundance data to assess extinction risk. Targets: 5, 6, 9, 10, 11, 12, 15.
Migratory behaviour	Presence/ absence/ destinations/ pathways of selected migrant taxa.	1 to >10 years	Banding/ marking/ tagging and observation data available for some birds, mammals, turtles, fish and butterflies.	Migratory behaviour is expected to change under climate change and habitat fragmentation. Riverine migrations are expected to be susceptible to damming etc. Targets: 5, 6, 10, 11, 12.
Demographic traits	Effective reproductive rate (e.g. by age/size class) and survival rate (e.g. by age/size class) for selected taxa at selected locations.	1 to >10 years	Data available for some fisheries, birds, mammals, reptiles, plants, and other taxa, but little trend data available.	Necessary to combine with other factors for assessing extinction risk and vulnerability to threats. Targets: 4, 6, 8, 9, 12, 15.
Physiological traits	For instance, measurement of thermal tolerance or metabolic rate. Assess for selected taxa at selected locations expected to be affected by a specific driver.	1 to >10 years	Some data available for corals, lizards, amphibians and insects.	May determine susceptibility to climate change impacts and may change under climate change.Targets: 4, 6, 8, 9, 12, 15.

Supplementary Table S2: Suggestions for improving the EBV framework on species traits

Supplementary Table S2: Suggestions for improving the framework for the EBV class 'Species Traits'. The initial list of candidate EBVs within the EBV class 'Species Traits' (see Supplementary Table S1) was discussed in detail during a 3-day experts workshop in Amsterdam (March 2017) which resulted in the listed comments and suggestions for refining the framework for species traits EBVs.

Candidate EBV	Examples from list of candidate EBVs	Comments and suggestions
Phenology	Timing of periodic biological events for selected taxa at defined locations, e.g. timing of breeding, leaf coloration, flowering, migration, oceans flow pattern shifts, intermittent flows in rivers, extent of wetlands.	• Ocean and river flows as well as the extent of wetlands are ecosystem variables, not species-level traits. They should belong to other EBV classes (e.g. 'Ecosystem Function' or 'Ecosystem Structure') • Migration: timing of migration has overlap with phenology, but spatial aspects of migration such as migration routes or dispersal distances are not related to timing
Body mass	Body mass (mean and variance) of selected species (e.g. under harvest pressure), at selected sites (e.g. exploitation sites).	• Quite narrowly defined EBV compared to other EBVs (body mass is only one measurement of organismal size). Group this EBV into a broader EBV on organismal morphology
Natal dispersal distance	Record median/frequency distribution of dispersal distances of a sample of selected taxa. Larval lifetime in marine species.	• Quite narrowly defined relative to other suggested candidate EBVs (e.g. phenology, physiological traits) because natal dispersal distance is only one trait measurement of movement. Group this EBV with other movement behaviours into a movement EBV
Migratory behaviour	Presence/absence/destinations/pathways of selected migrant taxa.	• Quite narrowly defined relative to other suggested candidate EBVs (e.g. phenology, physiological traits) because migratory behaviour is only one measurement of movement. Group this EBV along with other movement behaviours into a movement EBV
Demographic traits	Effective reproductive rate (e.g. by age/size class) and survival rate (e.g. by age/size class) for selected taxa at selected locations.	• Demographic rates related to survival, mortality and population growth are population-level quantities derived from surveys of population structure (e.g. by age, ontogenetic stage or size). They are derived from data covered by the EBV 'population structure by age/size class' within the EBV class 'Species Populations', and hence can be captured in this other EBV class • Reproductive traits (e.g. seed/egg size, clutch size/seed number, age/size at maturity) would be useful but are not yet covered within demographic traits.
Physiological traits	Measurements of thermal tolerance, metabolic rate, or net primary productivity for selected taxa at selected locations.	• Could also include stoichiometry (e.g. C:N ratios) • Net primary productivity is not a species trait and should belong to another EBV class (e.g. 'Ecosystem Function')

Supplementary Table S3: Importance of traits to assess progress towards global targets

Supplementary Table S3: Importance of species traits for (a) Aichi Biodiversity Targets, and (b) Sustainable Development Goals (SDG). Scores represent average values derived from a systematic inventory among the co-authors (*n* = 17 completed forms). The highest average scores (>2) are indicated in bold. All standard deviations were low (<0.30). The systematic inventory asked co-authors to give scores (integer scores of 0–3) that represent the relative importance of a specific species traits EBV for a specific Aichi Biodiversity Target and SDG. 0 - there is no direct relationship or only very indirectly via (multiple) other processes/properties; 1 - there is a weak relationship and/or the explanatory power of this species traits EBV for this target is very low; 2- the relationship to the target is direct with a low to moderate explanatory power in the relationship to the target; and 3 - the trait in question is a prime driver of the target with moderate to strong explanatory power.

(a) Aichi Biodiversity Targets

Species traits EBV	**Target number**									
	5	6	7	8	9	10	11	12	14	15
Phenology	1.29	1.53	1.76	0.76	1.82	1.82	1.00	1.47	1.59	1.59
Morphology	1.41	**2.53**	1.47	0.94	1.12	0.82	0.94	1.76	1.41	**2.12**
Reproduction	1.59	**2.53**	2.00	1.35	**2.53**	1.71	1.18	**2.59**	1.53	1.29
Physiology	1.18	1.35	1.47	**2.35**	1.35	**2.29**	0.82	1.47	1.41	**2.18**
Movement	1.35	1.88	1.06	0.71	**2.65**	0.88	1.82	1.59	0.76	0.88

(b) Sustainable Development Goals

Species traits EBV	**SDG number**				
	2	3	13	14	15
Phenology	1.76	1.47	**2.35**	1.59	**2.06**
Morphology	**2.29**	0.76	1.29	**2.18**	1.94
Reproduction	1.71	1.12	1.18	**2.18**	**2.06**
Physiology	1.76	1.06	1.88	1.94	1.82
Movement	0.65	1.24	1.47	1.71	1.65

Supplementary Table S4: Examples of trait databases

Supplementary Table S4: Examples of trait databases. This non-exhaustive list covers examples of trait databases that were represented with expert knowledge during a 3-day experts workshop in Amsterdam (March 2017) organised by the GLOBIS-B project (http://www.globis-b.eu/). The aim was to represent trait databases from different scientific domains as well as covering different collection methods, including trait data derived from (a) mostly published literature, (b) specimen collections, (c) *in-situ* collections, (d) remote sensing, or (e) aggregation of multiple other sources.

Trait database	**Description**	**Trait examples**	**Spatial extent**	**Web link**
(a) Mostly derived from published literature				
BIOTIC	Biological traits information of benthic species developed by the Marine Life Information Network (MarLIN)	Body size, mobility, diet, reproduction etc.	NE Atlantic	http://www.marlin.ac.uk/biotic/
Biotraits	Metabolic or metabolically driven performance of traits, including temperature-dependence.	Consumer-resource interactions (attack distance, strike rate, attack probability) and physiological traits (growth rate, body size, respiration, photosynthesis).	Global	http://biotraits.io
COMPADRE	Contains matrix population models of plant species	Vital rates of survival, growth/development/ageing, sexual/clonal reproduction allow to obtain generation time, rate of senescence, age at sexual maturity, etc.	Global	http://www.compadre-db.org/
COMADRE	Contains matrix population models of animal species	Vital rates of survival, growth/development/ageing, sexual/clonal reproduction allow to obtain generation time, rate of senescence, age at sexual maturity, etc.	Global	http://www.comadre-db.org/

FRED	Root traits of plants	Root anatomy, architecture, chemistry, dynamics, morphology, physiology, and the whole-root system, as well as microbial associations	Global	http://roots.ornl.gov/
PolyTraits	Biological traits of polychaetes (bristle worms, Polychaeta: Annelida)	Body size, other morphological, behavioural, reproductive and larval characteristics	Global	http://polytraits.lifewatchgreece.eu/
(b) Mostly from specimen collections				
VertNet	A single integrated data platform for vertebrate specimen-based biodiversity, integrating previous efforts from taxon-based communities (e.g. herpetology, HerpNET; ornithology, ORNIS; mammalogy, MaNIS)	Body mass, body length	Global	http://vertnet.org/
(c) From in-situ collections				
NEON	Trait measurements of fish, plants, small mammals, macroinvertebrates, mosquitoes, beetles, ticks, birds etc. Field spectral measurements of individuals.	Animal body size, plant size, phenology, leaf morphology and chemistry, disease status	USA	www.neonscience.org
Pan European Phenology	Phenology data of plants from *in-situ* observations by meteorological services and citizen science networks	Timing of leafing, flowering and fruiting	Europe	http://www.pep725.eu/

USA-NPN	Phenology data of plants and animals across terrestrial, freshwater, and marine systems from *in-situ* observations by professional and citizen scientists	Leafing, flowering and fruiting in plants, and activity, reproduction and development in animals	USA	https://www.usanpn.org/
(d) Remote sensing				
PhenoCam	Automated, near-surface remote sensing of canopy phenology from high-resolution digital cameras	Canopy greenness quantitative color information	USA and Canada	https://phenocam.sr.unh.edu/webcam/
(e) Aggregations from multiple other sources				
TRY	Plant functional traits from other plant trait databases and datasets, literature, natural history collections etc.	All kinds of plant traits	Global	http://www.try-db.org
EMODnet	Biological, ecological and societal traits of marine species extracted from World Register of Marine Species and other trait databases	Body size, mobility, diet, reproduction	Global	http://www.marinespecies.org/traits/
TraitBank	Aggregates structured trait data for plants, vertebrates, invertebrates, fungi, protists, other microbes etc. from other biodiversity databases, literature repositories, natural history collections, citizen science projects, and datasets derived from text mining	Body size (e.g. body/cell mass, length, volume), trophic level, diet, flower colour, generation time etc.	Global	http://eol.org/traitbank

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