Deliverable 4.1
Report on EVs for Biodiversity and Ecosystems

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Creation date	February 08. 2019
Due date	February 28. 2019
Last revision date	January 28. 2020
Status	Draft
Type	Report
Description	This deliverable maps the relevant existing EVs regarding biodiversity and ecosystems. Also shows gaps on EVs and analyses the current status in GEO.
Right	Public
Language	English

Citation	CREAF, 2019. Report on EVs for Biodiversity and Ecosystems. GEOEssential Deliverable 4.1
Grant agreement	ERA-PLANET No 689443

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Introduction

Reducing and reversing the rate of biodiversity loss and averting harmful biodiversity change are accepted international goals. However, there is still no global, harmonized observation or data exchange system for delivering regular, timely, and readily comparable information on biodiversity change (Navarro L. M., 2017). In practice, directly measuring some biodiversity variables or some ecosystem services (e.g., pollination, pest control) is not possible; therefore, many assessments will continue to develop indicators—measurable attributes that capture important aspects of a system (Ramirez-Reyes C., 2019). In this context, the Essential Biodiversity Variables (EBV) appear which are defined following the Essential Climate Variables (ECVs) that guide implementation of the Global Climate Observing System (GCOS) by Parties to the UN Framework Convention on Climate Change (UNFCCC).

In addition to the definition of EBV's, other efforts go in the line of developing Essential Ecosystem Services Variables (EESVs) (developed by the Ecosystem Services Working Group of GEOBON) and a variety of other bespoke indicators. A better aligning landscape attributes and processes that scientists and society care about (e.g., productivity, species composition and biodiversity, carbon sequestration, ecosystem function, extent of recreational spaces) with actual observational capacity has the potential to both increase the use of EO measurements and derived products for ecosystem service assessment and to improve consistency and comparability across studies. (Ramirez-Reyes C., 2019)

Despite this, other authors (Schaepman M. E., 2015) attempt to map Ecosystem Services by directly using EBVs and outline the need of combined observations and modelling aggregated into a coherent set of Essential Biodiversity Variables.

EVs in general, could become an important and useful approach for the SDG indicators monitoring. Actually, some authors (Reyers, Stafford-Smith, Erb, Scholes, & Selomane, 2017) propose the identification of Essential SDG Variables, considering four new additional criteria for what is "essential" through an expert-based approach (Ramirez-Reyes C., 2019). These criteria are: capture system essence based on knowledge of social–ecological systems, link to system transformations, capture key areas where coordination is needed, and whether they are indispensable. (Plag & Jules-Plag, 2020), propose a goal-based approach for linking societal goals, targets and indicators to Essential Transformation Variables (ETVs), as "a minimal set of variables that are required to develop, validate, and monitor transformation policies and interventions that aim at achieving societally agreed-upon goals".

The EU-funded project GLOBIS-B "Global Infrastructures for Supporting Biodiversity research" (Kissling W.D., 2015) examined infrastructure services underpinning the EBV concept and how international cooperation among data and research infrastructure organizations can support EBV definition, the development of workflows that adequately capture and organise EBV measurements, and the subsequent management of that data. GEOEssential is also focused in the development of workflows that use or produce EBV. This deliverable aims at defining the status of EVs related to biodiversity and ecosystems, and propose some interoperability solutions for dealing with them.

Essential variables related to biodiversity and ecosystems

Essential Biodiversity Variables

EBVs, whose development by GEO BON has been endorsed by the United Nations (UN) Convention on Biological Diversity (CBD) are relevant to derive biodiversity indicators for the Aichi Targets. Although UN-CBD biodiversity indicators are designed to convey messages to policy-makers from existing biodiversity data, EBVs aim to help observation communities to harmonize the monitoring processes, by identifying how variables should be sampled and measured. EBVs help prioritize by defining a minimum set of essential measurements to capture major dimensions of biodiversity change, complementary to one another and to other environmental change observation initiatives. EBVs also facilitate data integration by providing an intermediate abstraction layer between primary observations and indicators. See Figure 1. For example, an EBV estimating population abundances for a group of species at a location sits between raw observations (e.g., from different sampling events or methods) and an aggregated population trend indicator that averages multiple species and locations. (Pereira H. M., 2013).
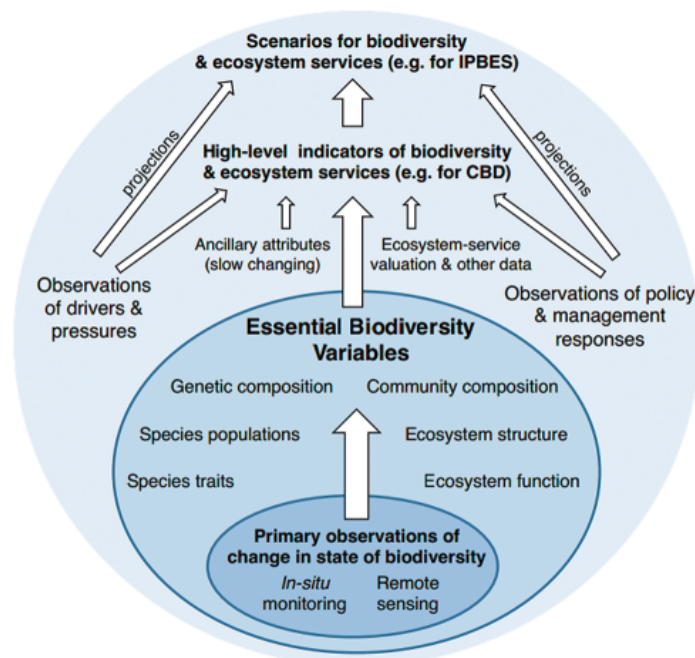

Figure 1. EBVs are the first level of abstraction between low-level primary observations and high-level indicators of biodiversity.

EBVs are a candidate set of 21 variables considered critical to representing different dimensions of biodiversity change and organized in 6 classes: genetic composition, species

populations, species traits, community composition, ecosystem function, and ecosystem structure. Raw data and biodiversity measurements collected and harmonized over space and time, supplemented with modelled estimates where interpolation/extrapolation is needed, provide the necessary data basis for EBVs, allowing interpretation into high-level indicator information for assessing biodiversity change. (Hardisty A. R., 2019)

Essential Ecosystem Variables

As said before, ECVs and EBVs were developed by two different communities to efficiently monitor the changing climate system and ongoing threats to biodiversity respectively. However, these two sets of variables are sometimes dependent on each other and also partly constrained by processes happening at the ecosystem scale. By focusing on the interactions and relations among ECVs and EBVs, we may enhance our capacity to monitor the interconnected climate-biosphere feedback system. Thus, some authors within GEOBON are proposing the definition of an emerging "Essential Ecosystem Variables'" (EEV). These can provide insights on ecosystem functioning and allow to monitor, understand and forecast climate-biosphere interactions in a changing environment. This process is now in a broad consultation among the relevant science communities and encompasses to derive EEVs, to shape upcoming integrated monitoring strategies, and most generally to (re)vitalize movement towards an "Essential Planetary Variable" framework. (GEOBON, 2016)

A symposium and a workshop led by Ecosystem Services working group GEOBON took place in 2014. Participants included leads of the Ecosystem Services Partnership working groups (ESP-indicators, mapping, modelling, valuation and trade-offs working groups), Sub-Global Assessment Network, Future Earth Core Projects (i.e. Ecoservices, Programme on Ecosystem Change and Society), Biodiversity and other CGIAR initiatives on ecosystem services (i.e. CGIAR research programs on "Water Land and Ecosystem", and "Forest Trees and Agriculture). Results from it included: identifying key ecosystem services (Provisioning: Material (pharmaceutics, timber), freshwater, food biodiversity, genetic resource; Regulating: regulation of soil productive capacity, Erosion control, carbon sequestration, flood mitigation, water purification, waste treatment; Cultural: Sense of belonging, heritage, spiritual, green spaces), identifying key criteria for the selection of those Essential Ecosystem Service Variables (e.g. high feasibility of permanent and long-term observation and a high impact regarding socio-economic and environmental issues) and the need for syntheses of results from individual services and variables. (GEOBON, 2015)

In another direction, the EU 2020 project BACI is exploring the intersection of ECVs and EBVs towards the definition of Essential Ecosystem Variables as well (see Figure 2). For BACI, EEVs are those variables essential to the monitoring of the fundamental feedbacks in the Earth System. The most exploratory part of the BACI project is developing a novelty index of change to detect (in near real-time) abrupt changes relevant to EEVs. They aim to find transitions relevant to the functioning of terrestrial ecosystems, biosphere atmosphere exchanges of matter and energy, and biodiversity related properties. The index is based on modern machine learning tools and will also detect major extreme events in data streams. (BACI, 2018)
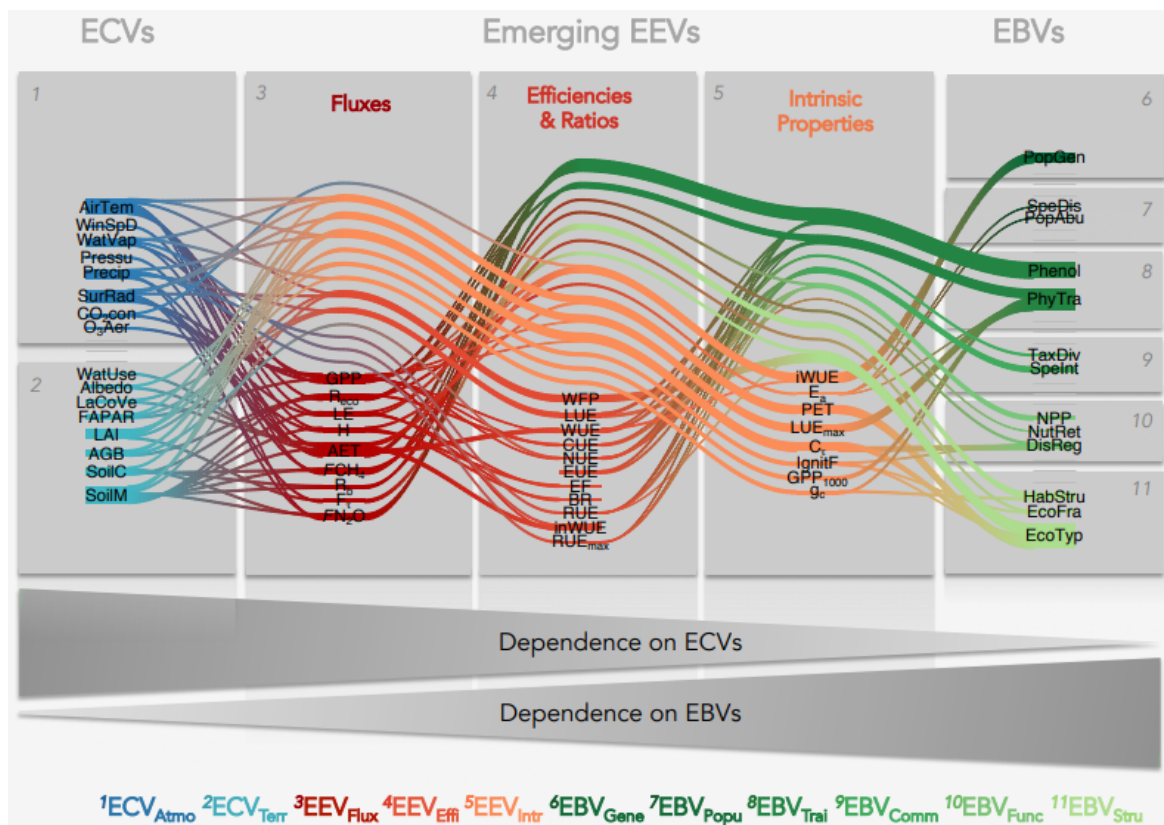
Figure 2. Fundamental interactions among ECVs and EBVs govern the states, processes and functions of ecosystems, as seen by BACI H2020.

Essential Ecosystem Service Variables

The exponential development of the ecosystem services field has led to a wide range of variables that have and can be measured, though guidance is needed on which ecosystem service variables should be measured and monitored. In this sense, the Ecosystem Services Working Group of GEOBON (GEOBON-WG6) has been developing a conceptual and methodological framework for identifying essential ecosystem service variables through several workshops and working groups. They have developed a pathway for identifying a viable set of ecosystem services that are essential, that practitioners should measure and track across space and time measure to gauge the state and changes in Ecosystem Services. (Balvanera P., 2016)

Monitoring the "contribution" of nature to people is an important issue to consider when defining environmental policy. Data on ecosystem services lacks the same level of completeness as biodiversity data. This is further complicated by the need to integrate ecological and social data. However, there have been some promising methodological developments in recent years. These include the integration of national statistics (e.g. census data) with in situ measurements, community monitoring, remote sensing and model outputs. All these factors constitute the conceptual and operational framework for Essential Ecosystem Service Variables (EESV) and the development of multidisciplinary interoperable data standards. The EESV framework includes several classes of variables, covering the

different components of the ecosystem service, flow from ecosystems to society, the different type of values of ecosystem services, and the actual benefits obtained by society. EESVs explicitly link the monitoring of ecosystem services to identify progress towards meeting the SDGs and Aichi targets. (Navarro L. M., 2017)

These variables are not yet mature and are still under definition. No preliminary list exists for the moment.

Other essential variables related to biodiversity and ecosystems

Essential Ocean Variables

Biological EOVs address fundamental characteristics of the biological components of marine ecosystems that can be combined into indicators to (1) represent the complexity of real-world natural systems, (2) track temporal and spatial changes in the state of the environment, (3) evaluate management performance, (4) deliver information and products to scientific and policy audiences and (5) assess progress towards international goals and targets. With these criteria, GOOS defines biological/ecological EOVs as those sustained measurements that are necessary to assess the state and change of marine ecosystems, address scientific and societal questions and needs, and positively impact society by providing data that will help mitigate pressures on ecosystems at local, regional and global scales (Miloslavich P., 2018)

The EOVs with an ecosystem component are: phytoplankton biomass and diversity, zooplankton biomass and diversity, fish abundance and distribution, marine turtle, bird and mammal abundance and distribution.

The EOVs focused on habitat extent and ecosystem health are: hard coral cover and composition, seagrass cover and composition, macroalgal canopy cover and composition and mangrove cover and composition. Microbial diversity and biomass could also emerge as another EOV.

Terrestrial Essential Climate Variables

Some ECV have direct relation with biodiversity and ecosystems and, thus, having some interconnection with EBVs. According to (FAO, 2008), these are:

- **Land cover**. Land cover is defined as the observed physical cover including the vegetation (natural or planted) and human constructions that cover the earth's surface. Reliable land cover and land cover change observations and assessment are essential for the sustainable management of natural resources, understanding and mitigating climate change, modelling of ecosystems and biogeochemical cycling and for addressing other important issues such as food security.

- **FAPAR**. The systematic observation of the fraction of Absorbed Photosynthetically Active Radiation (FAPAR) is suitable to reliably monitor the seasonal cycle and inter-annual variability of vegetation activity related to photosynthesis of terrestrial surfaces. This ECV plays a critical role over a range of temporal and spatial resolutions, notably in the energy balance of ecosystems and in the estimation of the carbon balance.
- **LAI**. Monitoring the distribution and changes of Leaf Area Index (LAI) is important for assessing growth and vigour of vegetation on the planet. It is fundamentally important as a parameter in land-surface processes and parameterizations in climate models. This variable represents the amount of leaf material in ecosystems and controls the links between biosphere and atmosphere through various processes such as photosynthesis, respiration, transpiration and rain interception.
- **Fire disturbance**. Fire is an important ecosystem disturbance with varying return frequencies, resulting in land cover alteration and change, and atmospheric emissions on multiple time scales. Fire is also an important land management practice and is an important natural abiotic agent in fi re-dependent ecosystems. The Fire Disturbance Essential Climate Variable (ECV) consists of burnt-area maps, supplemented by active fires; High-Temperature Events (HTE); and Fire Radiated Power (FRP). Information on fire activity is used for global change research, estimating atmospheric emissions and developing periodic global and regional assessments, and also for planning and operational purposes (fi re management, local to national) and development of informed policies (national and international, e.g. IPCC).
- **Biomass (or Above Ground Biomass)**. Biomass is defined as mass of all organic matter per unit area at particular time (reported in g/m2 or kg/ha). It plays two major roles in the climate system: (i) photosynthesis withdraws CO_2 from the atmosphere and stores it as biomass; (ii) the quantity of biomass consumed by fi re affects CO_2, other trace gases and aerosol emissions.

Gap analysis

This analysis has been done using the information gathered in an extension of the ENEON graph done within the GEOEssential project: http://www.eneon.org/graph-EV-SDG/index_beta.htm . The information presented in the graph has been compiled using the following sources:

- The description of EBVs as they appear in their own website up to April 2019: https://geobon.org/ebvs/what-are-ebvs.
- The description of SDGs as they appear in the https://sustainabledevelopment.un.org.
- The description of the most relevant EO networks (or Research Infrastructures) related to biodiversity in a global level (global, European) as found in their official websites. Data portals (which can collect data from several networks) or the regional/national networks are excluded from this study. Only in some cases, an exception has been done, for the sake of completeness. For instance, regional/national LTER networks have been added to the graph as they directly relate and contribute to European LTER.

- Interrelations between EVs, SDGs and EO networks have been established using the own criteria of the authors as part of the work done in GEOEssential, and based upon existing literature.

In GEOEssential, we have developed another tool to analyze the graph that can be found at http://www.eneon.org/graph-vis/index.htm (see Figure 3). This new graph operates on the same json file that contains all the relations, but allowing queries among elements and analysing every relation and direction. Queries are also defined in a json file.

Figure 3. New tool developed within GEOEssential for analysing relations among EVs, SDGs and EO networks

EBVs used by some SDG indicator

Requesting the EBVs that are used in one or more SDG indicators provides the following result (also seen graphically in Figure 4):

- Allelic diversity. Connected to:
  - 2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction *(state)*
  - 15.5.1 Red List Index *(state)*
- Population genetic differentiation. Connected to:
  - 15.5.1 Red List Index *(state)*
- Population abundance. Connected to:
  - 15.5.1 Red List Index *(state)*
- Species distribution. Connected to:
  - 15.5.1 Red List Index *(state)*
- Breed and variety diversity. Connected to:
  - 2.5.1 Number of plant and animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities *(response)*

- o 2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction *(state)*
- Morphology. Connected to:
  - o 15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked *(pressure)*
- Reproduction. Connected to:
  - o 14.4.1 Proportion of fish stocks within biologically sustainable levels *(state)*
- Movement. Connected to:
  - o 15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked *(pressure)*
- Net primary productivity. Connected to:
  - o 15.4.2 Mountain Green Cover Index *(state)*
- Habitat structure. Connected to:
  - o 15.3.1 Proportion of land that is degraded over total land area *(pressure)*
- Ecosystem extent and fragmentation. Connected to:
  - o 6.6.1 Change in the extent of water-related ecosystems over time *(state)*
  - o 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type *(response)*
  - o 15.3.1 Proportion of land that is degraded over total land area *(pressure)*
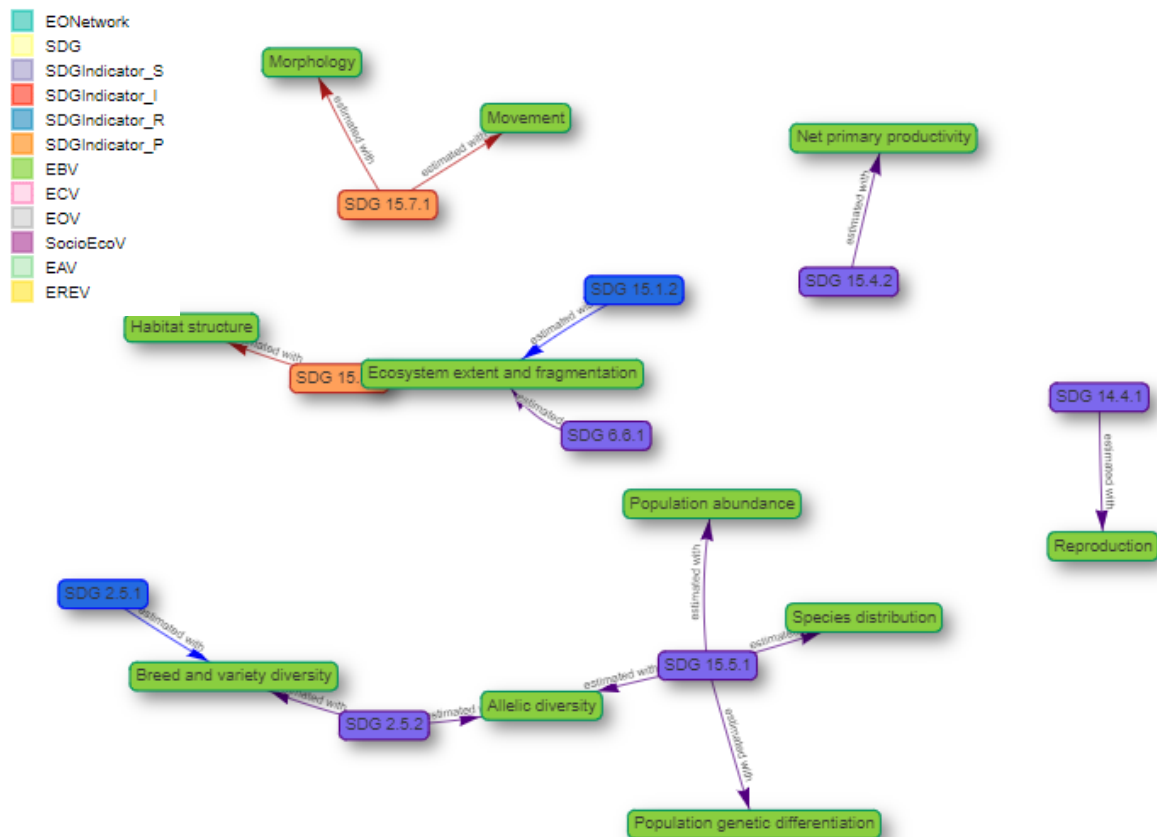
Figure 4. EBVs related to SDG indicators

There are 9 EBVs identified as related to the retrieval of some SDG indicators. Most of them are related to *SDG 15. Protect, restore and promote sustainable use of terrestrial ecosystems,*

sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss, followed by *SDG 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture*. See Figure 5.
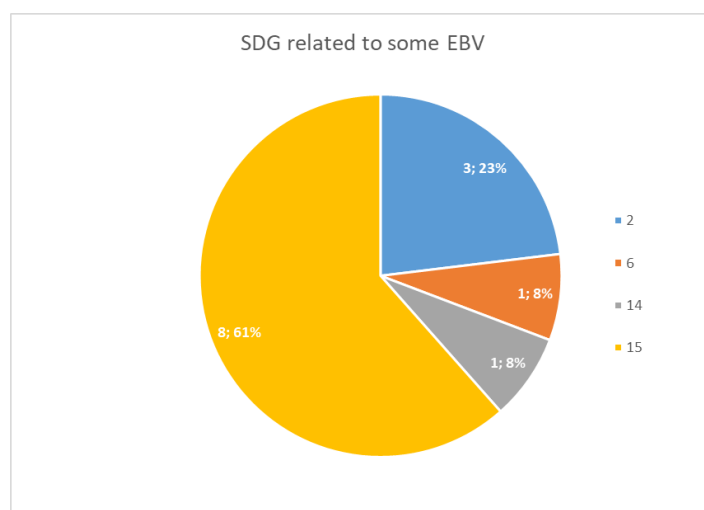
Figure 5. Number of EBVs interactions per SDG (SDG 2, SDG 6, SDG 14 and SDG 15)

The SDG indicators have been classified following the characterization of DPSIR framework (Driving Forces-Pressures-State-Impacts-Responses) according to (Masó J., 2019). This is an expected result as state indicators are the most "feasible" to be monitored and so are the indicators with more possible related EVs (see Figure 6).
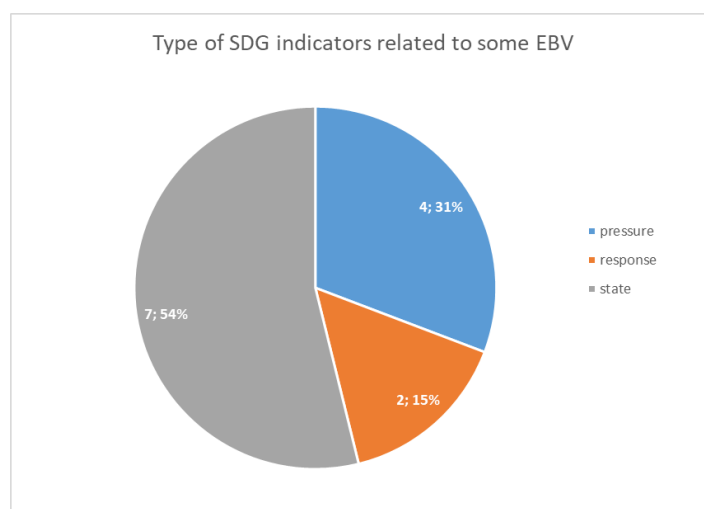
Figure 6. Number of EBVs interactions per SDG indicator type (pressure, response, state)
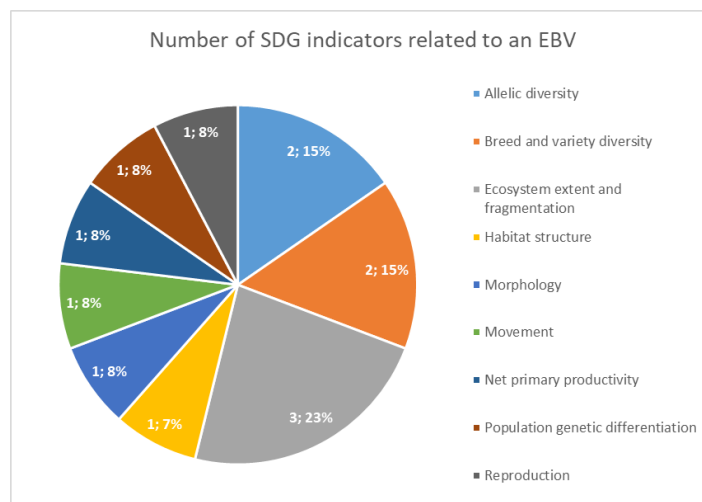
Figure 7. Number of SDG indicators interactions per EBV

EBVs NOT used by any SDG indicator

Requesting the EBVs that are no used in SDG indicators provides the following result (also seen graphically in Figure 8):

- Co-ancestry
- Population structure by age/size class
- Phenology
- Physiology
- Taxonomic diversity
- Species interactions
- Secondary productivity
- Nutrient retention
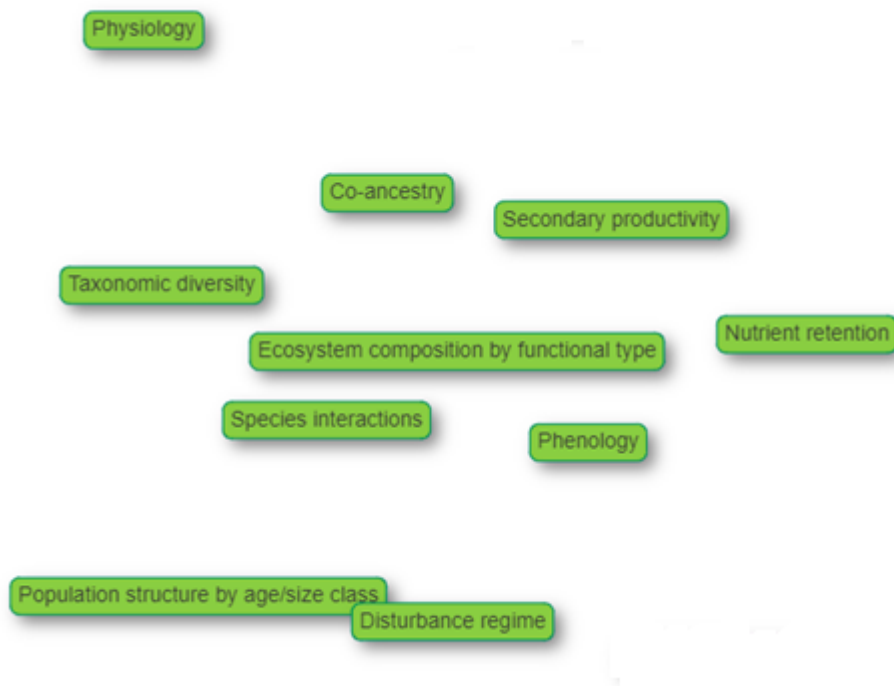- Disturbance regime
- Ecosystem composition by functional type

Figure 8. EBVs with no interactions to any SDG indicators

There are 10 EBV that could not currently be used as a proxy to derive or monitor an SDG indicator. These could be considered as **gaps** in SDGs indicators as SDG framework is not using this information to derive indicators. Since the SDG indicator framework is reviewed every five years, we recommend to study the applicability of these EBV in the SDG framework.

EBVs connected to some EO network

Requesting the EBVs that are connected to EO networks provides the following result (also seen graphically in Figure 9). The most "connected" EBV, or the EBV with more sources of information, is "Disturbance regime" with 45 networks, followed by "Habitat structure" and "Ecosystem extent and fragmentation" with 12 and 10 networks, respectively. "Reproduction", "Breed and variety diversity", and "Ecosystem composition by functional types" are the less connected EBVs. See Figure 10.
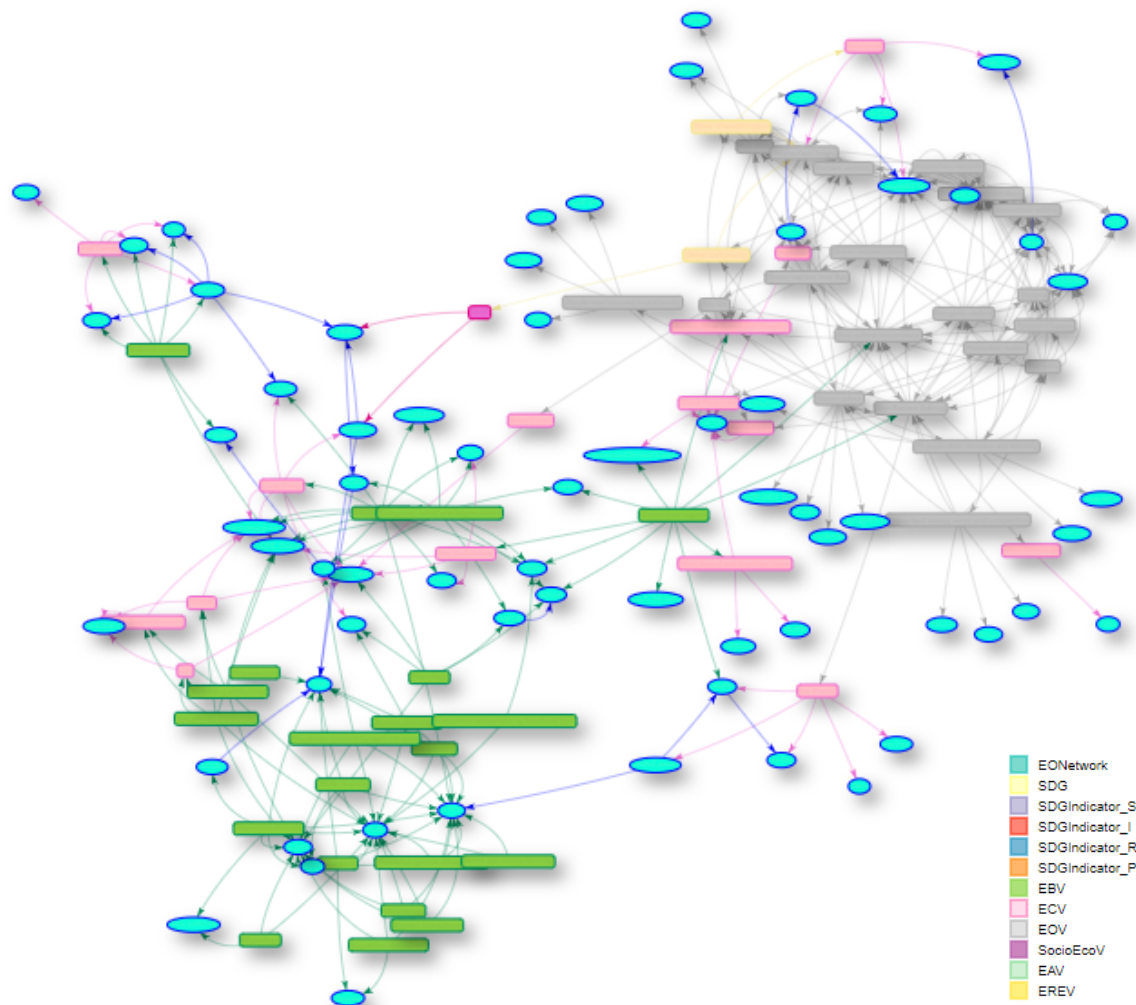
Figure 9. Overall picture of the interconnection between EBVs and EO networks coming from ENEON graph

- Co-ancestry. Connected to:
    - Conservation of Arctic Flora and Fauna *(CAFF)*
    - Global Biodiversity Information Facility *(GBIF)*
    - Pan-European Species directories Infrastructure *(PESI)*
- Allelic diversity. Connected to:
    - Conservation of Arctic Flora and Fauna *(CAFF)*
    - European Life-science Infrastructure for Biological Information *(Elixir)*
    - Global Biodiversity Information Facility *(GBIF)*
    - Pan-European Species directories Infrastructure *(PESI)*
- Population genetic differentiation. Connected to:
    - Conservation of Arctic Flora and Fauna *(CAFF)*
    - European Life-science Infrastructure for Biological Information *(Elixir)*
    - Pan-European Species directories Infrastructure *(PESI)*
- Breed and variety diversity. Connected to:
    - Conservation of Arctic Flora and Fauna *(CAFF)*
    - Pan-European Species directories Infrastructure *(PESI)*
- Species distribution. Connected to:
    - Conservation of Arctic Flora and Fauna *(CAFF)*
    - European Citizen Science Association *(ECSA)*

- o International Union for Conservation of Nature's Red List of Threatened Species (*IUCN-RedList*)
- o Global Biodiversity Information Facility *(GBIF)*
- o Pan-European Species directories Infrastructure *(PESI)*
- Population abundance. Connected to:
  - o BirdLife International *(BirdLife)*
  - o Conservation of Arctic Flora and Fauna *(CAFF)*
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Pan-European Species directories Infrastructure *(PESI)*
  - o International Union for Conservation of Nature's Red List of Threatened Species (*IUCN-RedList*)
- Population structure by age/size class*.* Connected to:
  - o Conservation of Arctic Flora and Fauna *(CAFF)*
  - o Forest Observation System *(FOS)*
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Pan-European Species directories Infrastructure *(PESI)*
- Phenology. Connected to:
  - o CEOS Land Product Validation (LPV) *(CEOS-LPV)*
  - o European Citizen Science Association *(ECSA)*
  - o Global Wetland Observing System *(GWOS)*
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Satellite-based Wetland Observation Service *(SWOS)*
- Morphology. Connected to:
  - o Conservation of Arctic Flora and Fauna *(CAFF)*
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Pan-European Species directories Infrastructure *(PESI)*
- Reproduction. Connected to:
  - o Global Biodiversity Information Facility *(GBIF)*
- Movement. Connected to:
  - o BirdLife International *(BirdLife)*
  - o Conservation of Arctic Flora and Fauna *(CAFF)*
  - o Global Biodiversity Information Facility *(GBIF)*
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Pan-European Species directories Infrastructure *(PESI)*
- Physiology. Connected to:
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Pan-European Species directories Infrastructure *(PESI)*
  - o Synthesis of Systematic Resources *(SYNTHESYS)*
- Taxonomic diversity. Connected to:
  - o Conservation of Arctic Flora and Fauna *(CAFF)*
  - o Consortium of European Taxonomic Facilities *(CETAF)*
  - o European Life-science Infrastructure for Biological Information *(Elixir)*
  - o Global Biodiversity Information Facility *(GBIF)*
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Pan-European Species directories Infrastructure *(PESI)*
  - o Synthesis of Systematic Resources *(SYNTHESYS)*
- Species interactions. Connected to:
  - o Conservation of Arctic Flora and Fauna *(CAFF)*
  - o International Long-Term Ecosystem Research in Europe *(ILTER)*
  - o Pan-European Species directories Infrastructure *(PESI)*
- Net primary productivity. Connected to:

- CEOS Land Product Validation (LPV) *(CEOS-LPV)*
- Copernicus Land Monitoring Service *(CopernicusLand)*
- FLUXNET *(FLUXNET)*
- Global Observation for Forest Cover and Land Dynamics *(GOFC-GOLD)*
- International Long-Term Ecosystem Research in Europe *(ILTER)*
- Pan-European Species directories Infrastructure *(PESI)*

- Secondary productivity. Connected to:
  - CEOS Land Product Validation (LPV) *(CEOS-LPV)*
  - Copernicus Land Monitoring Service *(CopernicusLand)*
  - FLUXNET *(FLUXNET)*
  - Global Observation for Forest Cover and Land Dynamics *(GOFC-GOLD)*
  - International Long-Term Ecosystem Research in Europe *(ILTER)*
  - Pan-European Species directories Infrastructure *(PESI)*

- Nutrient retention. Connected to:
  - European Network on Soil Awareness *(ENSA)*
  - European Soil Bureau Network *(ESBN)*
  - European Soil Data Centre *(ESDAC)*
  - European Soil Partnership *(ESP)*
  - Global Observation for Forest Cover and Land Dynamics *(GOFC-GOLD)*
  - International Soil Moisture Network *(ISMN)*
  - Amazon Forest Inventory Network *(Rainfor)*

- Disturbance regime. Connected to:
  - AErosol RObotic NETwork Ocean Color *(AERONET-OC)*
  - Arctic Monitoring and Assessment Programme *(AMAP)*
  - Infrastructure for Analysis and Experimentation on Ecosystems *(Anaee)*
  - Argo *(Argo)*
  - Arctic Council *(ArcticCouncil)*
  - Buoy for the acquisition of long-term optical time series (BOUée pour l'acquiSition d'une Série Optique à Long termE) *(BOUSSOLE)*
  - California Cooperative Oceanic Fisheries Investigations *(CalCOFI)*
  - CEOS Land Product Validation (LPV) *(CEOS-LPV)*
  - Coastal & Oceanic Plankton Ecology, Production, & Observation Database *(COPEPOD)*
  - Copernicus Climate Change Service *(CopernicusClimateChange)*
  - Data Buoy Cooperation Panel *(DBCP)*
  - European Forest Fire Information System *(EFFIS)*
  - Everyone's Gliding Observatories *(EGO)*
  - European Environment Information and Observation Network *(EIONET)*
  - European infrastructure for Argo *(Euro-Argo)*
  - Global Alliance of Continuous Plankton Recorder Surveys *(GACS)*
  - Global Climate Observation System *(GCOS)*
  - GEO Global Network for Observation and Information in Mountain Environments *(GEO-GNOME)*
  - Global Forest Observations Initiative *(GFOI)*
  - Global Sea Level Observing System *(GLOSS)*
  - Global Observation for Forest Cover and Land Dynamics *(GOFC-GOLD)*
  - Global Ocean Observing System *(GOOS)*
  - The Global Ocean Ship-Based Hydrographic Investigations Program *(GO-SHIP)*
  - GCOS Reference Upper-Air Network *(GRUAN)*
  - Global System of Ecosystem Observatories *(GSEO)*
  - Global Terrestrial Network *(GTN)*

- o GCOS Upper-Air Network *(GUAN)*
  - o Harmful Algal Information System *(HAEDAT)*
  - o International Group for Marine Ecological Time Series *(IGMETS)*
  - o Integrated Marine Observing System *(IMOS)*
  - o Infrastructure for Spatial Information in the European Community *(INSPIRE)*
  - o International Network for Terrestrial Research and Monitoring in the Arctic *(Interact)*
  - o Japan Fisheries Research and Education Agency *(JFRA)*
  - o Kelp Ecosystem Ecology Network *(KEEN)*
  - o Marine Mammals Exploring the Oceans Pole to Pole *(MEOP)*
  - o Marine Optical Buoy *(MOBY)*
  - o National Data Buoy Center *(NDBC)*
  - o OceanSITES *(OceanSITES)*
  - o Ocean Colour Radiometry-Virtual Constellation *(OCR-VC)*
  - o OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM *(OSTST)*
  - o Partnership for Interdisciplinary Studies of Coastal Oceans *(PISCO)*
  - o Sustaining Arctic Observing Networks *(SAON)*
  - o Svalbard Integrated Earth Observing System *(Sios)*
  - o Satellite-based Wetland Observation Service *(SWOS)*
  - o Trends of Phytoplankton in the Ocean *(TrendsPO)*
- Habitat structure. Connected to:
  - o Conservation of Arctic Flora and Fauna *(CAFF)*
  - o CEOS Land Product Validation (LPV) *(CEOS-LPV)*
  - o Copernicus Land Monitoring Service *(CopernicusLand)*
  - o European Citizen Science Association *(ECSA)*
  - o ECOSCOPE - A national forum for biodiversity research observatories *(ECOSCOPE)*
  - o European Forest Fire Information System *(EFFIS)*
  - o Forest Observation System *(FOS)*
  - o Global Forest Observations Initiative *(GFOI)*
  - o Global Observation for Forest Cover and Land Dynamics *(GOFC-GOLD)*
  - o Global System of Ecosystem Observatories *(GSEO)*
  - o Infrastructure for Spatial Information in the European Community *(INSPIRE)*
  - o Land use and land cover survey *(LUCAS)*
- Ecosystem extent and fragmentation. Connected to:
  - o Infrastructure for Analysis and Experimentation on Ecosystems *(Anaee)*
  - o Copernicus Land Monitoring Service *(CopernicusLand)*
  - o Digital Observatory for Protected Areas *(DOPA)*
  - o ECOSCOPE - A national forum for biodiversity research observatories *(ECOSCOPE)*
  - o Forest Observation System *(FOS)*
  - o Global Forest Observations Initiative *(GFOI)*
  - o Global Observation for Forest Cover and Land Dynamics *(GOFC-GOLD)*
  - o Global System of Ecosystem Observatories *(GSEO)*
  - o Global Wetland Observing System *(GWOS)*
  - o Satellite-based Wetland Observation Service *(SWOS)*
- Ecosystem composition by functional type. Connected to:
  - o Global System of Ecosystem Observatories *(GSEO)*
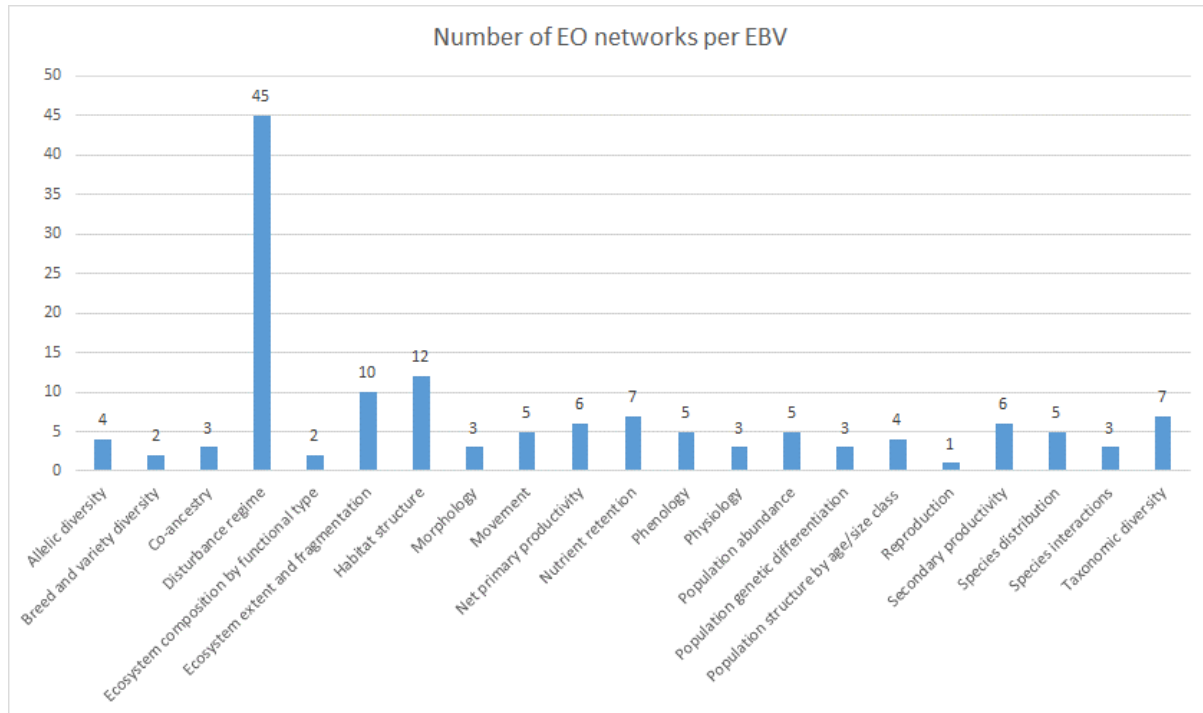 - o Pan-European Species directories Infrastructure *(PESI)*

Figure 10. Number of EO networks per EBV

There's **no EBV that is not connected to some EO network**, so for all EBV it should be possible to get information for their monitoring, directly or indirectly through the existing networks. In these cases, a concrete workflow should be defined to go from the raw data captured by EO Networks (or Research Infrastructures) to the EBV. We know that some EBV related datasets are still not available, although this result reveals that there is no need for other EO networks but instead they need to get the necessary resources to define the methodology for observing the pending EBV and put this methodology in practice.

Going in depth for each EBV, these connections are as follows:

EBV class: Genetic composition

- Co-ancestry (pairwise relatedness among individuals or inbreeding coefficient of selected species, within and among populations of each species).
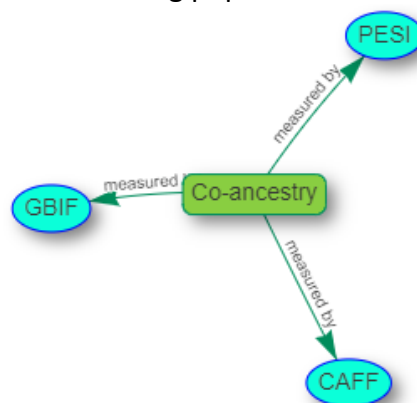
Figure 11. EO networks related to Co-ancestry EBV

- Allelic diversity (allelic richness from genotypes of selected species (e.g. endangered species and domesticated species) at multiple locations (statistically representative of the species distribution)).
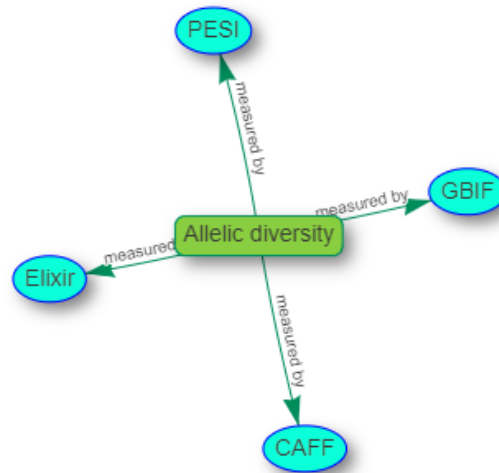
Figure 12. EO networks related to Allelic diversity EBV

- Population genetic differentiation (gene frequency differentiation (Fst and other measures) among populations or of a subpopulation compared to the meta-population of selected species)
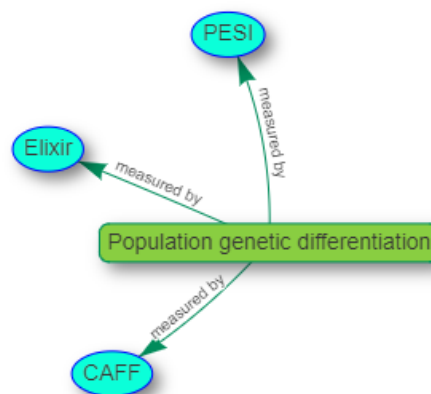

Figure 13. EO networks related to Population genetic differentiation EBV

- Breed and variety diversity (number of animals of each livestock breed and proportion of farmed area under each local crop variety, at multiple locations)
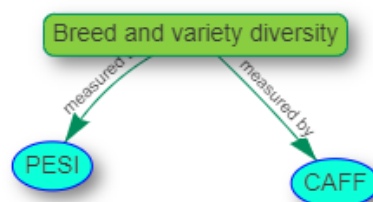
Figure 14. EO networks related to Breed and variety diversity EBV

EBV class: Species populations

- <u>Species distribution</u> (presence surveys for groups of species easy to monitor, over an extensive network of sites with geographic representativeness. Potential role for incidental data from any spatial location).
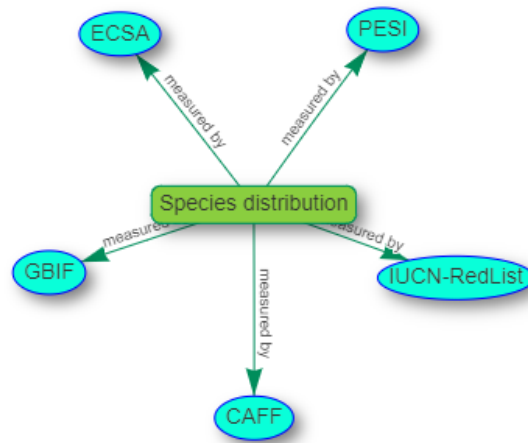
Figure 15. EO networks related to Species distribution EBV

- <u>Population abundance</u> (population counts for groups of species easy to monitor and/or important for ecosystem services, over an extensive network of sites with geographic representativeness).
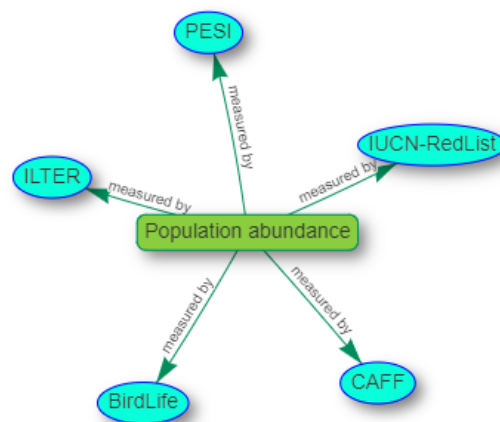
Figure 16. EO networks related to Population abundance EBV

- <u>Population structure by age/size class</u> (quantity of individuals or biomass of a given demographic class of a given taxon or functional group at a given location).
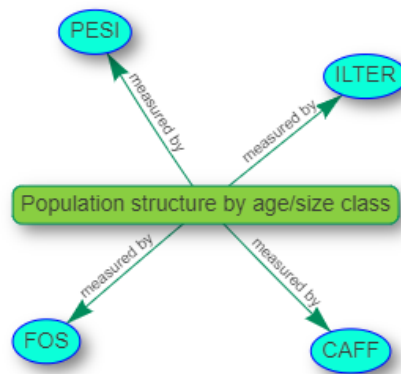
Figure 17. EO networks related to Population structure by age/size class EBV

EBV class: Species traits

- <u>Phenology</u> (presence, absence, abundance or duration of seasonal activities of organisms. Examples: Timing of breeding, flowering, fruiting, emergence, host infection).
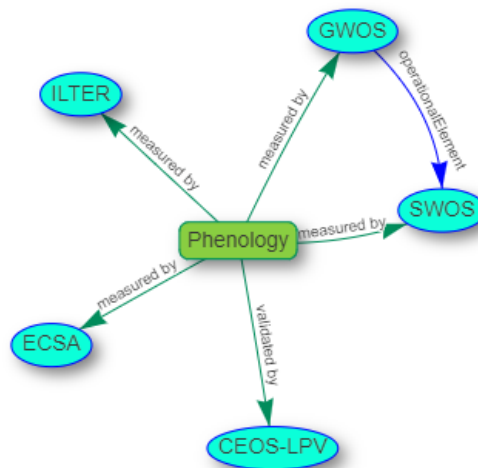

Figure 18. EO networks related to Phenology EBV

- <u>Morphology</u> (dimensions (for example, volume, mass and height), shape, other physical attributes of organisms, for example: body mass, plant height, cell volume, leaf area, wing length, colour).
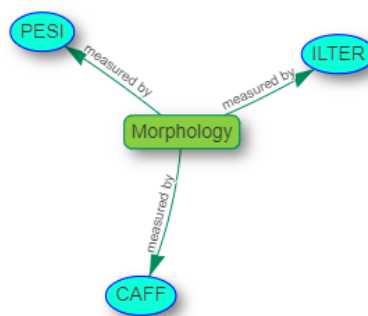
Figure 19. EO networks related to Morphology EBV

- Reproduction (sexual or asexual production of new individual organisms ('offspring') from parents. Examples: age at maturity, number of offspring, lifetime reproductive output).
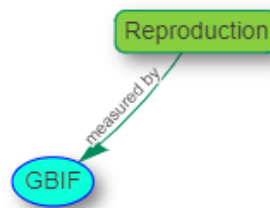

Figure 20. EO networks related to Reproduction EBV

- Movement (behaviours related to the spatial mobility of organisms. Examples: natal dispersal distance, migration routes, cell sinking of phytoplankton).
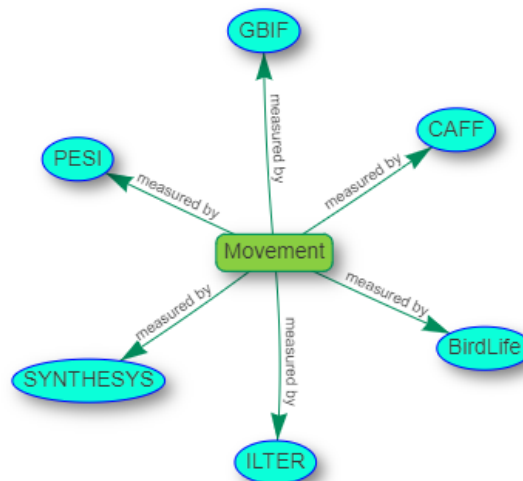

Figure 21. EO networks related to Movement EBV

- Physiology (chemical or physical functions promoting organism fitness and responses to environment. Examples: thermal tolerance, disease resistance, stoichiometry (for example, chlorophyll content)).
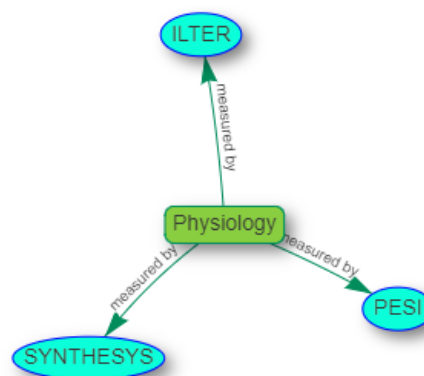

Figure 22. EO networks related to Physiology EBV

EBV class: Community composition

- Taxonomic diversity (multi-taxa surveys (including by morphospecies) and metagenomics at selected in situ locations at consistent sampling scales over time. Hyper-spectral remote sensing over large ecosystems).
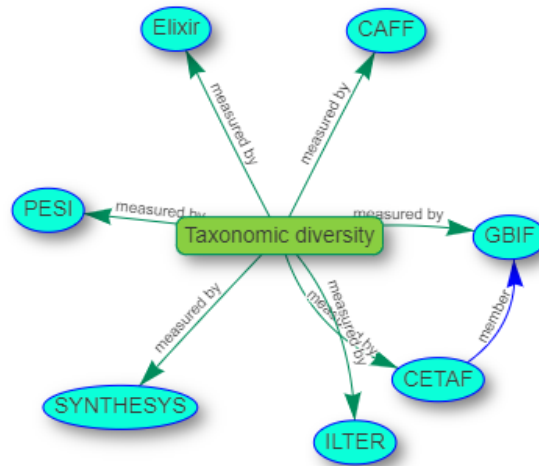
Figure 23. EO networks related to Taxonomic diversity EBV

- <u>Species interaction</u> (studies of important interactions or interaction networks in selected communities, such as plant-bird seed dispersal systems).
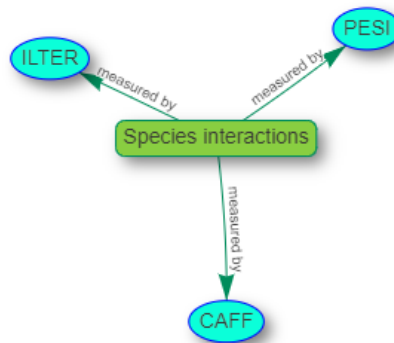

Figure 24. EO networks related to Species interactions EBV

EBV class: Ecosystem function

- <u>Net primary productivity</u> (global mapping with modeling from remote sensing observations (FAPAR, ocean greenness) and selected in-situ locations (eddy covariance)).
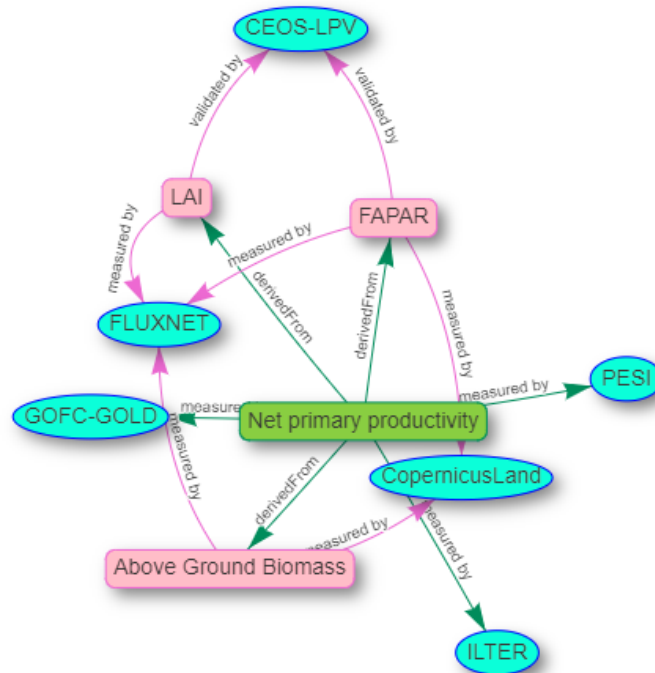
Figure 25. EO networks related to Net primary productivity EBV

- <u>Secondary productivity</u> (measurement of secondary productivity for selected functional groups, combining in-situ, remote sensing, and models. Example functional groups include: fisheries; livestock; krill; herbivorous birds).
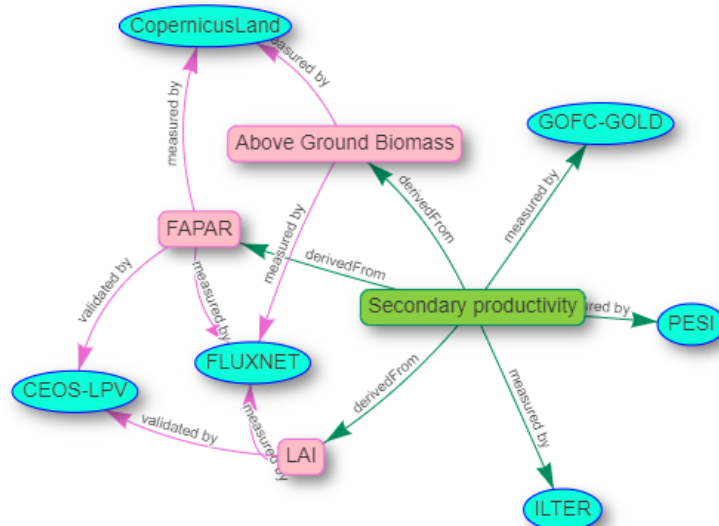

Figure 26. EO networks related to Secondary productivity EBV

- <u>Nutrient retention</u> (ratio of nutrient output from the system to nutrient input, measured at selected in situ locations. Can be combined with models and remote sensing to extrapolate regionally).
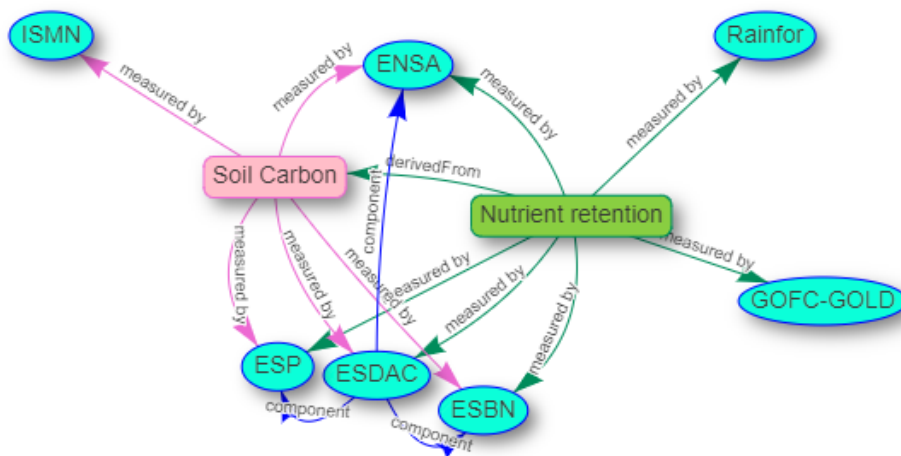
Figure 27. EO networks related to Nutrient retention EBV

- Disturbance regime (type, seasonal timing, intensity and frequency of event-based external disruptions to ecosystem processes and structure. Examples: sea surface temperature and salinity (RS); scatterometry for winds (RS); trawling pressure (in situ); flood regimes (in situ); fire frequency (in situ, RS); cultivation/harvest (RS); wind throw; pests (in situ)).
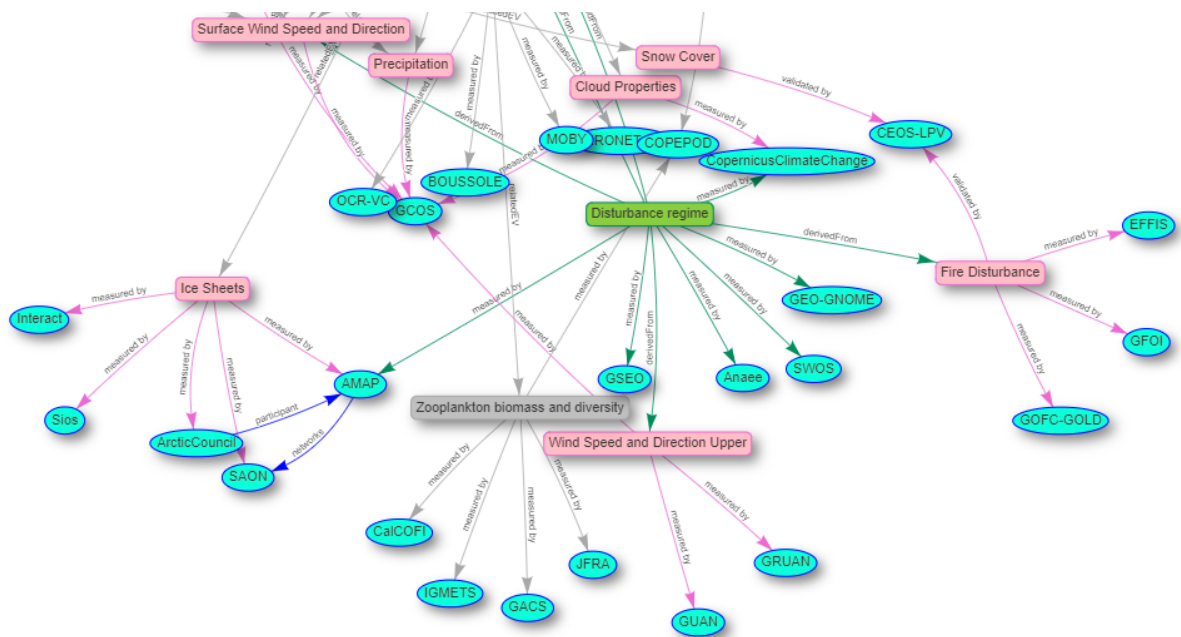

Figure 28. EO networks related to Disturbance regime EBV

EBV class: Ecosystem structure

- Habitat structure (remote sensing measurements of cover (or biomass) by height (or depth) classes globally or regionally, to provide a 3-dimensional description of habitats).
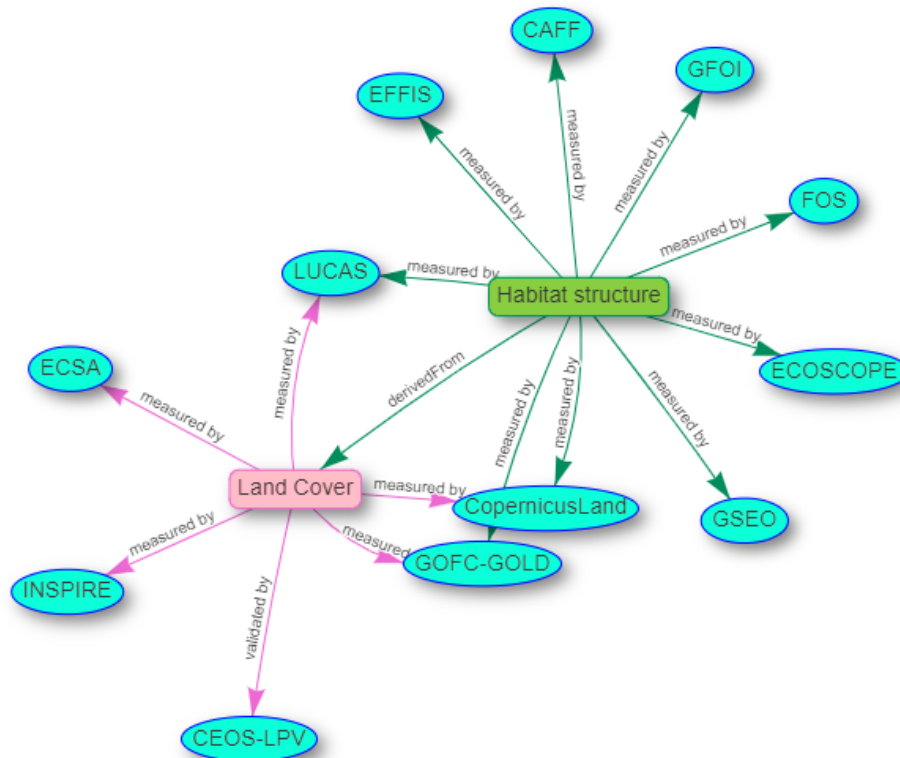
Figure 29. EO networks related to Habitat structure EBV

- <u>Ecosystem extent and fragmentation</u> (Local (aerial photo and in-situ monitoring) to global mapping (satellite observations) of natural/semi-natural forests, wetlands, free running rivers, coral reef live cover, benthos cover, etc.).
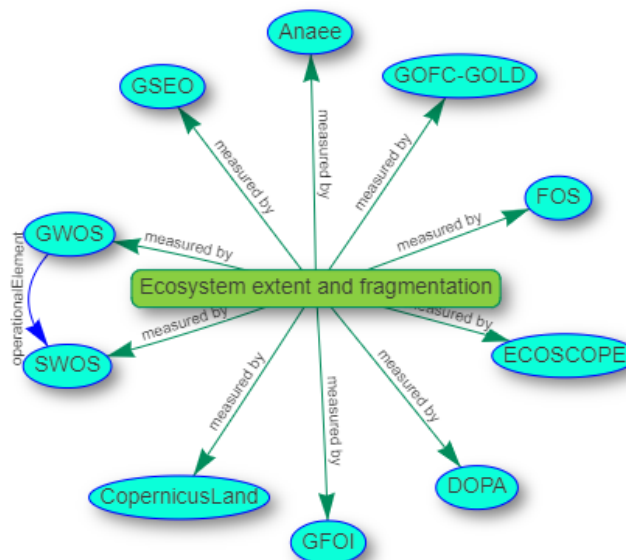
Figure 30. EO networks related to Ecosystem extent and fragmentation EBV

- <u>Ecosystem composition by functional type</u> (Functional types can be directly inferred from morphology (in situ) or from remote sensing).
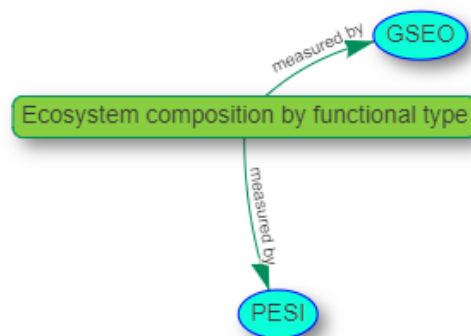
Figure 31. EO networks related to Ecosystem composition by functional type EBV

EBVs related to other EVs

Requesting the EBVs that are linked to other EVs provides the following result (also seen graphically in Figure 32):
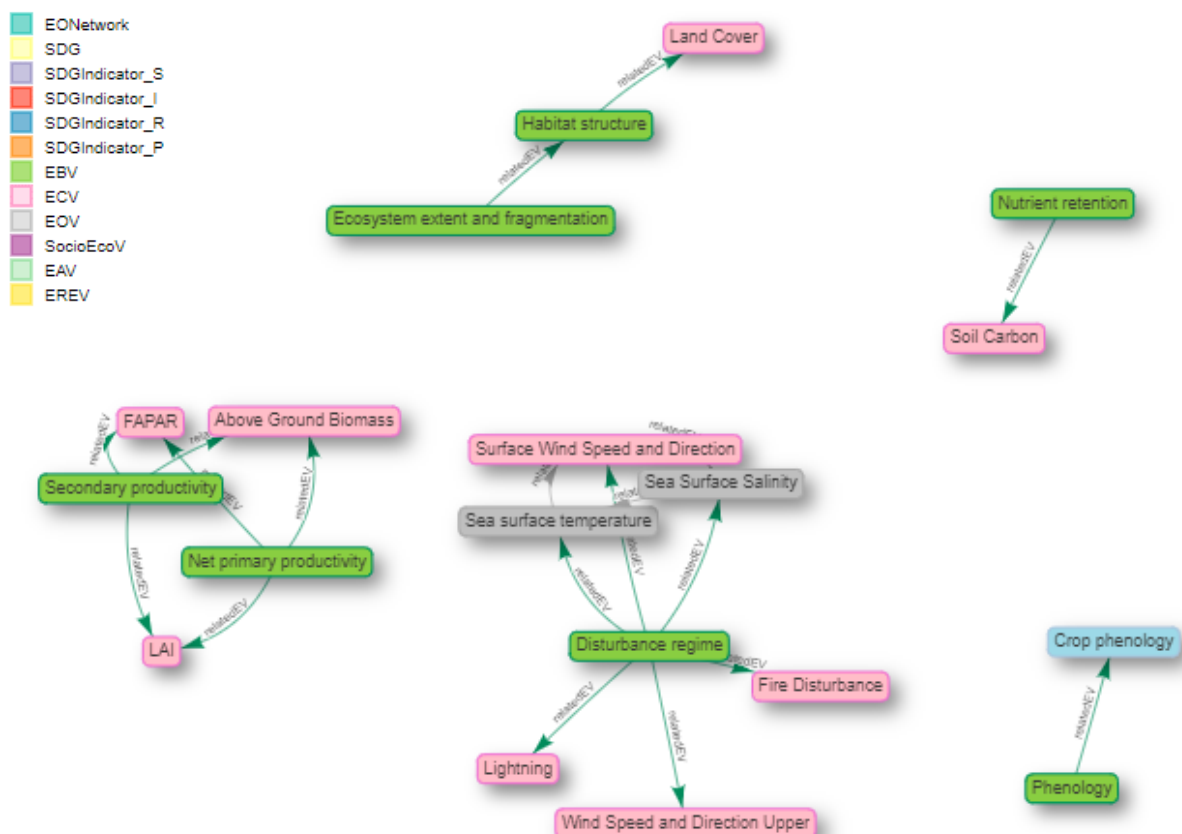
Figure 32. EBVs with interrelations to other EVs

Some interactions exist between EBVs and other EVs. Most of them are within ECV (9/12), but also with EOV (2/12) and EAV (1/12). One EBV is connected to another EBV: "Ecosystem extent and fragmentation" could be derived from "Habitat structure", which at the same time could be derived from "Land cover", an ECV. See Figure 33.

- Net primary productivity. Connected to:
  - Above Ground Biomass (AGB) → ECV
  - Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) → ECV
  - Leaf Area Index (LAI) → ECV
- Secondary productivity. Connected to:
  - Above Ground Biomass (AGB) → ECV
  - Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) → ECV
  - Leaf Area Index (LAI) → ECV
- Nutrient retention. Connected to:
 - Soil Carbon → ECV
- Disturbance regime. Connected to:
  - Surface Wind Speed and Direction → ECV
  - Lightning → ECV
  - Wind Speed and Direction Upper → ECV
  - Fire Disturbance → ECV
  - Sea surface temperature (SST) → EOV
  - Sea Surface Salinity (SSS) → EOV
- Habitat structure. Connected to:
  - Land Cover → ECV
- Ecosystem extent and fragmentation. Connected to:
  - Habitat structure → EBV
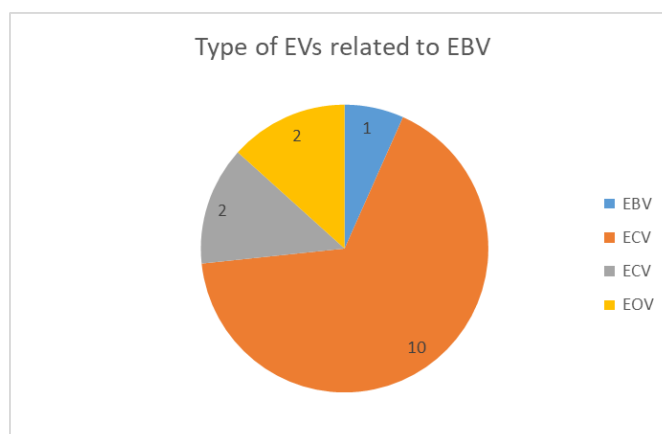
Figure 33. Type of EVs that have interactions with EBV

Situation in GEO

Making EBVs operational requires a globally interoperable, trans-national information systems from local to global extent (Hardisty A. R., 2019). GEOSS could provide this framework where GEOBON operates.

The challenge is to agree on how to build a dependable and stable body of sufficiently comprehensive data, and how to package and deliver it in a manner that can be easily used to facilitate assessment and forecasting. Such agreement must be based upon cooperation, practicality and interoperability among those collecting and mobilising data with EBV potential, those processing, modelling and organising data, and those publishing and

preserving data (Kissling W.D., Towards global interoperability for supporting biodiversity research on essential biodiversity variables (EBVs), 2015). This can be compared with the situation currently prevailing for climate data, where stable, dependable essential climate variable (ECV) data are coming from the Global Observing System for Climate (GCOS. (Hardisty A. R., 2019). In fact, GEOBON is working for establishing the necessary arrangements to regularly produce EBV products at the global scale. GEOBON has also worked toward a common portal for discovering and accessing EBVs.
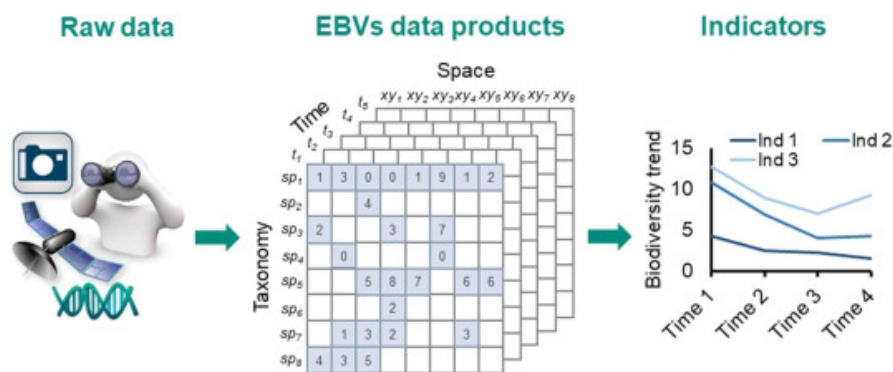

Figure 34. Essential Biodiversity Variables (EBVs) are derived from raw data (i.e., primary observations) obtained, for example, from camera traps, field surveys, satellite remote sensing, and DNA sequencing. Harmonized, standardized and organised as packaged EBV data products, they provide the building blocks for indicator development. EBV data products can be conceptualized as cubes with dimensions of time, space and biology (taxonomy for example). Modified figure from (Kissling W.D., Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale, 2018).

EVs interoperability and workflows

Building EBV data products requires taking into account the scales (space, time, taxonomy, etc.), the attributes, and the acceptable uncertainties of raw data that can be usable for EBV purposes to be defined (Kissling W.D., Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale, 2018). Measurements must be in the desired format and should be collected and processed following standardized protocols, providing sufficient associated metadata ((Kissling W.D., Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale, 2018), (Kissling W.D., Towards global data products of Essential Biodiversity Variables (EBVs) on species traits, 2018)). Data need to be consistently quality assured, using standard tests and associated. EBV data products should also meet minimum requirement standards for structure, packaging and metadata description. According to (Hardisty A. R., 2019) such minimum standards have not yet been specified in the EBV context.

Also according to (Hardisty A. R., 2019), workflows for generating EBV data products must cover all aspects of transforming raw data into published data products, including harmonizing and modelling data, as well as publishing and preserving data product ((Kissling W.D., Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale, 2018), (Kissling W.D., Towards global data products of Essential Biodiversity Variables (EBVs) on species traits, 2018)). From the view of Research Infrastructures (IRs), or EO networks in this study, workflows should be independent of the underlying computational

and data management infrastructure so they become portable and adoptable. Raw data, the workflows and software should be traceable, allowing provenance to be tracked. EBV data production should be repeatable to allow easy updates as new data is collected. These needs can be met by using non-proprietary workflow formats, based for example, on the Common Workflow Language (CWL), and standard provenance mechanisms (such as the W3C PROV family of specifications). Resulting data products, including any component sub-parts, must be consistently structured (dimensioned, formatted, represented, packaged) and clearly described by metadata. They must be identifiable when published so they are discoverable and citable. Each data product must be preserved for the long-term as part of the dependable and stable body of EBV data. Much work remains to be done to achieve all this, keeping in mind that everything (raw data, data products, workflows, etc.) should be 'Findable, Accessible, Interoperable, Reusable', i.e., complying with the FAIR principles for scientific data management and stewardship (Wilkinson M.D., 2016). This infers that both humans and machines can easily find, understand and exploit the data they need for their work.

Conclusions

In the monitoring for biodiversity and ecosystems EVs can play an important role. They can also be useful in the retrieval of SDGs indicators. EBVs are the most directly linked variables in this field, but not only. Some EOV and ECV are also providing information regarding biodiversity and ecosystems. Scale issues should be analysed and overcome in this case. Moreover, new EVs are starting to be developed to better approach ecosystems, i.e. Essential Ecosystem Variables (EEVs) and Essential Ecosystem Service Variables (EESVs).

The ENEON graph linking EO networks, EVs and SDG indicators (http://www.eneon.org/graph-EV-SDG/index_beta.htm), has been updated and analysed in relation to usefulness of EBVs and gaps.

In this sense, there are 11 EBVs that could be used to the retrieval of some SDG indicators, these are shown in Table 1. Most of these SDG indicators are considered of "state type", followed by "response type" and "pressure type" in the DPSIR classification.

Table 1. SDG indicators related to EBVs

EBV	SDG indicator
Allelic diversity	2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction *(type: state)*
	15.5.1 Red List Index *(type: state)*
Population genetic differentiation	15.5.1 Red List Index *(type: state)*
Breed and variety diversity	2.5.1 Number of plant and animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities *(type: response)*
	2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction *(type: state)*
Morphology	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked *(type: pressure)*

Reproduction	14.4.1 Proportion of fish stocks within biologically sustainable levels *(type: state)*
Movement	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked *(type: pressure)*
Net primary productivity	15.4.2 Mountain Green Cover Index *(type: state)*
Habitat structure	15.3.1 Proportion of land that is degraded over total land area *(type: pressure)*
Ecosystem extent and fragmentation	6.6.1 Change in the extent of water-related ecosystems over time *(type: state)*
	15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type *(type: response)*
	15.3.1 Proportion of land that is degraded over total land area *(type: pressure)*
Population abundance	15.5.1 Red List Index *(type: state)*
Species distribution	15.5.1 Red List Index *(type: state)*

On the contrary, there are 10 EBV that could not currently be used as a proxy to derive or monitor an SDG indicator, which could be considered as **gaps in EBV** regarding SDGs as they can't be used to derive them. These 10 not directly or currently "useful" EBVs are:
- Co-ancestry
- Population structure by age/size class
- Phenology
- Physiology
- Taxonomic diversity
- Species interactions
- Secondary productivity
- Nutrient retention
- Disturbance regime
- Ecosystem composition by functional type

Another conclusion from the graph analysis is that there is no EBV without an EO network providing possible useful raw data to that variable. In this sense, there's no gap in terms of data providing. The EBV with more networks behind is Disturbance regime (followed by Habitat structure and Ecosystem extent and fragmentation) whereas the least represented EBVs are Reproduction, Breed and variety diversity, and Ecosystem composition by functional type.

The last conclusion of the analysis is that some interconnections (not necessary overlapping) exist between EBVs and other EVs, including other EBVs. Most of these interrelations occur between EBVs and the terrestrial ECV: Above Ground Biomass (AGB), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Leaf Area Index (LAI), Soil Carbon, Surface Wind Speed and Direction, Wind Speed and Direction Upper, Fire Disturbance, Land Cover. Few connections exist as well with EOV: Sea surface temperature (SST), and Sea Surface Salinity (SSS). Some overlap may occur between EBVs, these are: Ecosystem extent and fragmentation, and Habitat structure, which although providing different information they could be interchangeable in some cases.

Regarding the presence of EVs related to biodiversity and ecosystems in GEO, they are well covered by the communities responsible of them: GEOBON for the EBVs and GCOS and Blue Planet for ECVs and EOVs respectively. However, complete workflows going from the raw data to the EV should be promoted within GEO taking advantage of the capacities of GEOSS and following standard procedures and FAIR principles. The results on this deliverable outline some degree of interaction between different EVs and even between EBVs. It should be important to deeply know to what extent is this interaction and if there is some kind of overlapping between them (even though temporal and spatial scale issues are considered). For this reason, we encourage the creation of some activity or initiative within GEO where all EVs are considered in order to better provide coordination, best practices, interoperability issues and interactions between SBAs and communities. We consider there is currently enough maturity in EVs processes to start this challenge in EVs and GEO is the right place for doing it. This is becoming more and more important if consider EVs a relevant proxy to derive and monitor SDG indicators.

Glossary

Essential variables

EAV	Essential Agricultural Variables
EBV	Essential Biodiversity Variables
ECV	Essential Climate Variables
EESV	Essential Ecosystem Services Variables
EEV	Essential Ecosystem Variables
EOV	Essential Ocean Variables
EREV	Essential Renewable Energy Variables
ETV	Essential Transformation Variables
SocioEcoV	Essential SocioEconomic Variables

EO Networks

AERONET-OC	AErosol RObotic NETwork Ocean Color
AMAP	Arctic Monitoring and Assessment Programme
Anaee	Infrastructure for Analysis and Experimentation on Ecosystems
ArcticCouncil	Arctic Council
Argo	Argo
BirdLife	BirdLife International
BOUSSOLE	Buoy for the acquisition of long-term optical time series (BOUée pour l'acquiSition d'une Série Optique à Long termE)
CAFF	Conservation of Arctic Flora and Fauna
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CEOS-LPV	CEOS Land Product Validation - LPV
CETAF	Consortium of European Taxonomic Facilities
COPEPOD	Coastal & Oceanic Plankton Ecology, Production, & Observation Database
CopernicusClimate Change	Copernicus Climate Change Service

CopernicusLand	Copernicus Land Monitoring Service
DBCP	Data Buoy Cooperation Panel
DOPA	Digital Observatory for Protected Areas
ECOSCOPE	ECOSCOPE - A national forum for biodiversity research observatories
ECSA	European Citizen Science Association
EFFIS	European Forest Fire Information System
EGO	Everyone's Gliding Observatories
EIONET	European Environment Information and Observation Network
Elixir	European Life-science Infrastructure for Biological Information
ENEON	European Observatory of Earth Observation Networks
ENSA	European Network on Soil Awareness
ESBN	European Soil Bureau Network
ESDAC	European Soil Data Centre
ESP	European Soil Partnership
Euro-Argo	European infrastructure for Argo
FLUXNET	FLUXNET
FOS	Forest Observation System
GACS	Global Alliance of Continuous Plankton Recorder Surveys
GBIF	Global Biodiversity Information Facility
GCOS	Global Climate Observation System
GEO-GNOME	GEO Global Network for Observation and Information in Mountain Environments
GFOI	Global Forest Observations Initiative
GLOSS	Global Sea Level Observing System
GOFC-GOLD	Global Observation for Forest Cover and Land Dynamics
GOOS	Global Ocean Observing System
GO-SHIP	The Global Ocean Ship-Based Hydrographic Investigations Program
GRUAN	GCOS Reference Upper-Air Network
GSEO	Global System of Ecosystem Observatories
GTN	Global Terrestrial Network
GUAN	GCOS Upper-Air Network
GWOS	Global Wetland Observing System
GWOS	Global Wetland Observing System
HAEDAT	Harmful Algal Information System
IGMETS	International Group for Marine Ecological Time Series
ILTER	International Long-Term Ecosystem Research in Europe
IMOS	Integrated Marine Observing System
INSPIRE	Infrastructure for Spatial Information in the European Community
Interact	International Network for Terrestrial Research and Monitoring in the Arctic
ISMN	International Soil Moisture Network
JFRA	Japan Fisheries Research and Education Agency
KEEN	Kelp Ecosystem Ecology Network
LUCAS	Land use and land cover survey
MEOP	Marine Mammals Exploring the Oceans Pole to Pole
MOBY	Marine Optical Buoy

NDBC	National Data Buoy Center
OceanSITES	OceanSITES
OCR-VC	Ocean Colour Radiometry-Virtual Constellation
OSTST	OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM
PESI	Pan-European Species directories Infrastructure
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
Rainfor	Amazon Forest Inventory Network
SAON	Sustaining Arctic Observing Networks
Sios	Svalbard Integrated Earth Observing System
SWOS	Satellite-based Wetland Observation Service
SYNTHESYS	Synthesis of Systematic Resources
TrendsPO	Trends of Phytoplankton in the Ocean

Other

CBD	Convention on Biological Diversity
EO	Earth Observation
FAPAR	Absorbed Photosynthetically Active Radiation
FRP	Fire Radiated Power
HTE	High-Temperature Events
LAI	Leaf Area Index
SDG	Sustainable Development Goal
UNFCCC	UN Framework Convention on Climate Change

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