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REMOTE SENSING OF ESSENTIAL BIODIVERSITY VARIABLES

Note by the Executive Secretary

1. The Executive Secretary is circulating herewith, for the information of participants in the first meeting of the Subsidiary Body on Implementation, a document prepared by the Group on Earth Observations - Biodiversity Observation Network (GEOBON) on remote sensing of essential biodiversity variables.

2. The report is presented in the form and language in which it was received by the Secretariat.

REMOTE SENSING OF ESSENTIAL BIODIVERSITY VARIABLES

In decision XI/3 (paragraph 13) the CBD CoP invited GEO BON to continue its work on the identification of Essential Biodiversity Variables and the development of associated data sets (UNEP/CBD/SBSTTA/15/INF/8). This information note provides an update concerning one particular initiative to further define a subset of EBVs where remote sensing can play a key role.

The purpose of this information note is threefold:

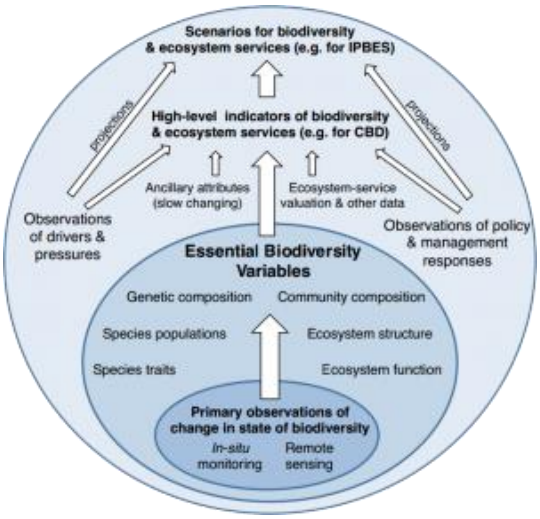
1) To briefly explain the basic concepts behind Essential Biodiversity Variables (EBVs)
2) To describe a subset of EBVs, called RS-EBVs, for which satellite remote sensing can play a key role, and suggest a path to getting these implemented by space agencies
3) To obtain feedback from CBD SBSTTA on this list of RS-EBVs.

Satellite remote sensing can play a crucial role in the measurement of EBVs, particularly for a subset of EBVs which we denote by RS-EBVs. Largely, this is because the global and periodic nature of satellite remote sensing greatly simplifies the acquisition of the needed observations, making RS an ideal method for understanding change at national as well as other scales.

This list of RS-EBVs will be updated based on comments received from SBSTTA to ensure there is good alignment with CBD needs. Demonstrating the value of these RS-EBVs, especially to policy bodies, is absolutely critical—only then can the space agencies that implement them justify expending resources on RS-EBV development.

Background

Essential Biodiversity Variable (EBVs) are defined as the key variables required to observe, understand, and report on change in the state of biodiversity. They sit as a layer between raw biodiversity observations and the biodiversity indicators used in policy (Figure 1), such as the indicators measuring progress towards the CBD Aichi Targets. They provide key guidance to the observation system in terms of what it should measure, and their intermediate position between observations and indicators isolates those indicators from changes in observation technology.



Following the general consensus developed at workshops and conference discussions EBVs tend to fall into six classes (Pereira et al. 2013; Table 1), and the EBV concept is rapidly maturing: GEO BON released a development strategy document in October 2015 and there are an increasing number of scientific and policy articles published on them.

The EBV concept was inspired by the Essential Climate Variables (ECVs) developed by the Global Climate Observing System (GCOS), which has been extraordinarily successful in defining research agendas as well as data requirements for climate observations from space. A particular accomplishment of GCOS has been the identification of approximately 50 Essential Climate Variables (ECVs), defined as the set of observations needed to generate global climate products that support climate policy, particularly the United Nations Framework Convention on Climate Change. Because most of these ECVs can be derived from satellite-based remote sensing (RS) instruments GCOS worked with CEOS (the Committee on Earth Observation Satellites, a coordinating body composed of governmental space agencies) to document these in detail. The resulting document was a key input into the European Space Agency's Climate Change Initiative, a EUR100M activity supporting the observations and products needed to generate the RS-based ECVs. ESA's Climate Change Initiative was a huge step forward for monitoring climate and is a good model for the biodiversity community to follow as they develop EBVs.

Figure 1. Contextual diagram showing how EBVs fit into the broader picture (Pereira et al 2013)

Like ECVs, a subset of EBVs have strong potential for measurement using satellite remote sensing observations. Because of this potential these EBVs, referred to here as "RS-EBVs", have some special characteristics that make them easier to implement than EBVs that can be measured only through *in situ* observation. This makes RS-EBVs especially valuable for monitoring change in biodiversity. In particular they are characterised by global, periodic observations that are spatially contiguous; also, the number of data providers is fewer (primarily national space agencies), which makes coordination easier, and many of the observations already exist or are in an advanced stage of planning. Additionally, RS-EBVs can often help fill the spatial and temporal gaps left by *in situ* observations.

Given the success of the ECV concept, its impact on the availability of RS-based ECVs, the ongoing development of EBVs, and the characteristics of RS-EBVs, an RS-EBV development approach has been suggested that is analogous to that used for ECVs (Skidmore et al. 2015). That approach is explained in more detail here.

Candidate RS-EBVs

Using the EBV framework as a baseline (Pereira et al. 2013) two GEO BON workshops were held to discuss current and future satellite missions and their ability to provide observations useful for generating EBVs. The goal was to create a list of candidate RS-EBVs by carefully considering, amongst others, factors such as ability to meet policy needs, priority, feasibility, implementation status, spatial resolution and temporal frequency. That list, subsequently updated as additional information became available, is in Table 1.

EBV Class	Candidate RS-EBV	Potential support for Aichi targets
Species populations	Species distribution*	4,5,7,9,10,11,12,14,15
Species populations	Species abundance*	5,7,9,12,14,15
Species traits	Phenology (e.g., leaf-on and leaf-off dates; peak season)	5,9,11,12,14,15
Species traits	Plant traits (e.g., specific leaf area, leaf nitrogen content)	7,9,12,14
Community composition	Taxonomic diversity	8, 10, 12, 14
Community composition	Functional diversity	5,7,10,12,14,15
Ecosystem function	Productivity (e.g., NPP, LAI, FAPAR)	5,7,10,12,14,15
Ecosystem function	Disturbance regime (e.g., fire and inundation)	7,9,10,12,14,15
Ecosystem structure	Habitat structure (e.g., height, crown cover and density)	5,7,9,14,15
Ecosystem structure	Ecosystem extent and fragmentation	5,11,12,14,15
Ecosystem structure	Ecosystem composition by functional type	5,7,10,12,14,15

Table 1: Candidate EBVs that can be measured by remote sensing; the related Aichi Targets that each EBV may be able to support are also listed to highlight their relevance to global policy efforts. Each candidate is described in more detail in Annex 1. Note that inclusion in the list does not imply that RS measurements alone can be used to generate every EBV; for example, *in situ* data are needed to validate and calibrate RS products.

* Spaceborne RS is increasingly used to map the distribution and abundance of particular species; these species could be a component of the overall Species Distribution or Species Abundance EBV.

The list contains RS-EBVs that are continuous and biophysical such as leaf area index, as well as others that use somewhat arbitrary class boundaries, such as land cover. Also, like some ECVs, some RS-EBVs are actually groups of related variables that describe a phenomenon of interest (eg, plant traits, phenology, disturbance).

Taking RS-EBVs from concept to implementation

With this list as a starting point, the next steps in the process can begin, with the ultimate goal of putting a plan in place to acquire the needed RS observations to generate the related EBVs. The current approach for this process is described below and depicted in Figure 2 (noting that the overall process is very iterative). The key organizations for this are the CBD, IPBES, CEOS, and GEO BON, with GEO playing a facilitative role, however the broader biodiversity community is also very important. A key goal is to meet as many as possible of the reporting needs that CBD signatory countries have for the Aichi targets.

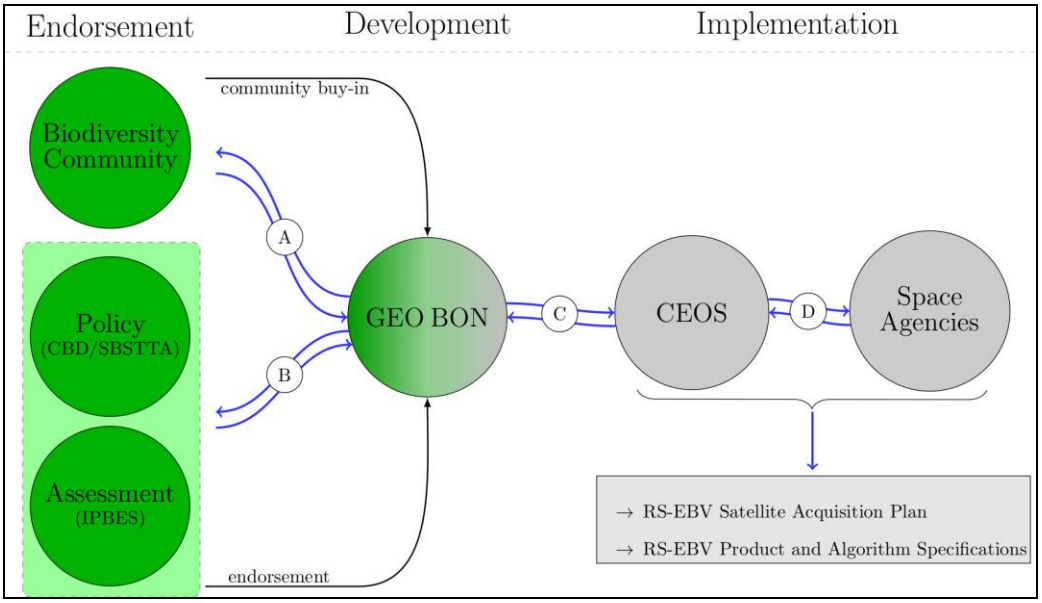


Figure 2: Key aspects of a process for refining, endorsing, and implementing RS-EBVs

A) and B) RS-EBV refinement and value confirmation by users. With the initial list of candidates available, discussion commences with the CBD (as well as IPBES; discussions continue with the broader community). These discussions result in refinement of the list and recognition of the

importance of these EBVs. Such recognition by the CBD and IPBES provides critical justification to space agencies for implementation.

C) Observation requirements identification. GEO BON, working with CEOS (and CBD and IPBES as needed, since this is all a very iterative process), identifies the specific observations needed to generate the RS-EBVs and captures them in a technical document.

D) Formal request to CEOS. GEO formally requests that CEOS provide feedback on the feasibility of implementing the observation requirements. This results in discussions within CEOS that, ultimately, lead to a realistic set of observations and/or proposed missions, captured in an "acquisition plan", plus a product specification and generation plan.

The community consultation process of steps A and B includes, among others, plans for conference sessions at Zoological Society of London (April 2016), the GEOBON Open Science Conference (July 2016), and a knowledge café workshop at the IUCN World Conservation Congress conference in Hawaii (September 2016). Also, the European Space Agency is planning a call for community assessment of RS-EBVs that includes funding for a consultative process for refining the list of candidates. An additional component of steps A and B is a journal publication that describes the EBV in detail, based on detailed feedback and expansion of this CBD Information Note. The process is also further detailed on the GEO BON white paper on the strategy for Essential Biodiversity Variables available at http://geobon.org/Downloads/Other_documents/Essential_Biodiversity_Variable_Strategy_v1.pdf.

Step C and perhaps step D can result in adjustment to the RS-EBV list in order to converge on the final output product--a realistic set of observation and processing requirements. As such, this will likely be an iterative process, one that GEO facilitates as needed.

In conclusion, it is hoped that the initial list of candidate RS-EBVs, and the overall approach outlined above, will lead to a realistic set of observations that space agencies can provide and, ultimately, useful EBV products that can support indicators and the work of CBD, IPBES, and the biodiversity and conservation communities.

References

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

Skidmore, A.K., Pettorelli, N., et al. (2015) Agree on biodiversity metrics to track from space. Nature, 523: 403-405.

Annex 1: Candidate Remote Sensing-derived Essential Biodiversity Variables

Species distribution	Plant species distribution mapping directly via remote sensing is an operational technique using airborne hyperspectral and lidar systems, proven in biomes as diverse as rainforest, savannah, grassland and saltmarsh; planned launches of next generation satellites will allow upscaling towards global monitoring. Both animal and plant distribution may also be inferred by various other means that utilize RS data (e.g., species distribution modelling). Although spaceborne observations using very high resolution commercial instruments have been used for directly observing large animals (e.g. elephants) or conspicuous and gregarious ones (e.g. seal and penguin colonies on ice) this has mostly not proved to be cost-effective. Similarly, the spread of invasive plant species can be managed using very high resolution imagery, but at present image costs can be prohibitive. As spaceborne hyperspectral and Lidar instruments become more available, species distribution monitoring from space will become increasingly common and viable. Species distribution is important because changes may indicate a decline or threat.
Species abundance	Species abundance can be estimated from space for certain plant species. Although spaceborne observations using very high resolution commercial instruments have sometimes been used for directly observing large animals or colonies, and thus for estimating population size, RS has mostly not been cost-effective. Abundance is important because changes in it can indicate species decline.
Phenology	This is a family of related sub-variables on the timing of biological events, and most phenological parameters based on spaceborne remote sensing will be those of plants. Although the exact variables defining phenology are still under discussion they include : • Leaf-on and leaf-off dates • Start, end, and peak of season • Difference in greenness between leaf-on and leaf-off • Rate of greening up and senescence These phenological parameters are extracted from image time series during the vegetation growing season using a measure of "greenness" such as the normalised difference vegetation index (NDVI). NDVI is calculated for each pixel at every date in the time series and then used to calculate the phenological variable(s) of interest such as leaf on and leaf off dates. Global data sets of NDVI are available such as from the NASA MODIS and ESA SPOT image data sets--for example see

	https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod13q1_v006
Plant Traits	Many plant traits can be ascertained from remote sensing and so can contribute to the Plant Traits EBV. Traits are important because differences between species, such as leaf shape or chlorophyll concentration, can affect competitive ability, level of specialization, and community diversity. Plant species traits comprise numerous variables that may be directly obtained from remote sensing and include for example: *Vegetation nitrogen content* has a significant role in ecosystem processes and the functional aspects of biodiversity because it is often a limiting factor for plant growth. It is a primary regulator for many leaf physiological processes such as photosynthesis, is strongly linked to net primary production and the carbon cycle, and is an important parameter for ecosystem process models. *Specific Leaf Area (SLA)* is defined as the leaf area per unit of dry leaf mass (m^2/kg) and is important for assessing functional diversity. It is a key parameter in ecosystem modelling, linking plant carbon and water cycles and is an indicator for plant physiological processes such as growth rate and light capture. Thus it provides information on the spatial variation of photosynthetic capacity and leaf nitrogen content. SLA has been obtained from Sentinel-2. Other traits successfully retrieved from remote sensing include leaf dry matter content (LDMC), leaf and canopy chlorophyll concentration, leaf polyphenols, leaf angle and leaf clumping, etc.
Taxonomic diversity	Spaceborne remote sensing has been used to estimate the taxonomic diversity of plants. This is important because changes in taxonomic diversity can indicate threats such as climate change and can result in biodiversity loss as well as changes in ecosystem services. Taxonomic discrimination will increase as hyperspectral and Lidar sensors become more widely available.
Functional diversity	Functional diversity refers to the variety of biological processes or functions of an ecosystem. It reflects the biological complexity of that ecosystem and can be thought of as the amount of variety in the work (functions) done by it. Functional diversity is important because, for example, functionally diverse ecosystems may be more resilient to perturbations, and thus loss of functional diversity can make an ecosystem more vulnerable. Functional diversity is the component of biodiversity influences ecosystem dynamics, productivity, nutrient balance and other aspects of ecosystem functioning. Functional diversity from remote sensing can be assessed by measuring species traits that are associated with certain functions, for example by measuring the productivity of the different structural components of an ecosystem. Less direct approaches can also be used, based on using species traits measured *in situ* to estimate the functional structure of different communities. Functional attributes can be used to

	quantify and qualify ecosystem services.
Productivity (Net primary Productivity—NPP; Leaf area index—LAI; Photosynthetically Active Radiation--fAPAR)	While there are various types of productivity and related variables, all of them relate to how much carbon an ecosystem assimilates. Net Primary Productivity (NPP) is basically a measure of the net rate of photosynthesis by an ecosystem and indicates the net rate of carbon accumulation. It is important because, among other things, changes in NPP reflect changes in the health of an ecosystem, it is a key component of the carbon cycle, and it represents the amount of energy available to an ecosystem. NPP can be estimated from satellites using time series of the normalised difference vegetation index (NDVI) from, for example, AVHRR and MODIS (see https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod17a3h_v006). NPP has also been estimated using physical models of productivity derived from time series of ESA MERIS and SPOT image data sets. For example see https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod17a3h_v006 or http://land.copernicus.eu/global/ Leaf area index (LAI) is an indication of the surface area available for photosynthesis, defined as the ratio of the one-sided area of the leaf per unit ground area. Higher LAIs generally have greater NPP; LAI is important because it allows exchange of carbon, water, and energy between atmosphere and leaves to be estimated and it has an important role in ecosystem processes and functions. It has been widely modeled using remote sensing data and is a key input for climate and large-scale ecosystem models and also is a key structural characteristic of forest ecosystems. Global data sets of LAI have been generated using AVHRR, Landsat, SPOT and MODIS (e.g., http://land.copernicus.eu/global/). The fraction of absorbed photosynthetically active radiation (also known as FAPAR, fAPAR or fPAR) is the fraction of the incoming solar radiation absorbed by the plant canopy. It is important because it is directly related to primary productivity and can also be used to estimate the uptake of carbon by vegetation. It is derived from the normalized difference vegetation index (NDVI) time series such as from AVHRR,

	SPOT and MODIS (e.g., see http://land.copernicus.eu/global/).
Disturbance regime (e.g., fire and inundation)	Disturbance regimes characterize many ecosystems such as savannas, grasslands, chaparral, wetlands and coastal ecosystems. Monitoring these regimes is important because changes in them are likely to cause changes in the ecosystems that depend upon them. Monitoring of fire occurrence and extent are globally available from existing satellite observation systems such as NASA MODIS and even geostationary systems such as GOES. For example see https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/v1-vnp14imgt. Coastal as well as inland wetland inundation is routinely mapped and monitored using synthetic aperture radar as well as optical systems like MODIS, SPOT, and Landsat.
Habitat structure (height, crown cover and density)	Forest canopy height, crown cover and density are important because they are key to understanding and estimating a variety of parameters including biomass, vegetation coverage, and biodiversity. Canopy density, or canopy cover, is the ratio of vegetation to ground as seen from above, while canopy height measures how far above the ground the top of the canopy is. Lidar can be used to determine these structural variables, however, existing satellite systems do not include suitable Lidar instruments. Even so, an increasing number of countries have blanket lidar coverage from airborne systems and satellite-based Lidar systems are under discussion. Some vegetation structural elements can be retrieved using currently available radar, for example, basal area.
Ecosystem extent and fragmentation	This EBV captures the geographic boundaries and areal extent of ecosystems and the degree to which a previously contiguous ecosystem has been divided. It is important because changes in these parameters have implications for biodiversity and ecosystem services and are an indicator of driving forces such as climate and land use change. Ecosystem extent indicates the physical boundaries and areal size of an ecosystem, which may change, for example, as the climate changes or due to human activites such as a forest being converted to cropland. Satellite remote sensing is commonly used to map land cover, which can correspond to ecosystems if the land cover classes are selected accordingly. There are limits to the ability to discriminate between different ecosystem types from space, though as hyperspectral and Lidar instruments, for example, become more widely available discrimination capabilities will increase. Combining satellite RS with other types of datasets, such as soils and elevation models, also increase ecosystem discrimination capabilities, for example, see http://rmgsc.cr.usgs.gov/outgoing/ecosystems/Global/. Fragmentation is the level of discontinuity in a once-continuous ecosystem, a highly fragmented ecosystem thus being composed of small patches. Fragmentaton is important because it can directly affect both the distribution and abundance of species

	as well as a variety of ecosystem functions. Satellite remote sensing is commonly used to estimate fragmentation through spatial statistics and techniques such as FragStats, wavelets and Fourier analysis.
Ecosystem composition by functional type	Ecosystem functional types are vegetation units with similar functional characteristics of productivity as measured over time. It is an inherently remote sensing based methodology with examples generated using NOAA-AVHRR, MODIS and Landsat. These approaches use the seasonal dynamics of spectral indices related to ecosystem dynamics such as primary production, radiative balance, thermal exchange and/or water exchange. Functional attributes can be used to quantify and qualify ecosystem services.

List of experts and contributing authors

Many scientific experts have contributed to the discussion and formulation of remote sensing based Essential Biodiversity Variables and the preparation of this information note, including:

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