RS-enabled EBV roadmap

Roadmap for advancing remote sensing data used within the EBV framework

Against the backdrop of continuing declines in the state of biodiversity, there are increasing calls for action across scales to prevent further biodiversity loss (IPBES, 2019). However, our ability to derive robust conclusions about the intensity or spatial pattern of the drivers of biodiversity change is limited by varying quality and quantity of data across space, time and themes (Navarro et al., 2018).

To address this gap, in 2013, the Group on Earth Observations Biodiversity Observation Network (GEO BON), the biodiversity flagship of the Group on Earth Observations (GEO), introduced the Essential Biodiversity Variables (EBVs), inspired by the Essential Climate Variables (ECVs) used in Earth System Science. The EBVs represent a minimum set of variables, complementary to one another, that are needed to study, report and manage biodiversity change (Pereira et al., 2013).

Since the formulation of the EBV concept, it has been recognised that remote sensing is a key tool for providing data at the spatial and temporal scales necessary for EBVs to be useful for decision-making (Skidmore et al., 2015). The Convention on Biological Diversity (CBD) recently acknowledged space-based Earth observations (EO) as a key source of information for tracking progress against many biodiversity targets. A recent decision taken by the CBD Conference of the Parties (COP, which is the decision-making body of the Convention) recognised the value of making greater use of remote sensing for monitoring biodiversity, ecosystem functions and services (CBD/COP/DEC/14/1: https://www.cbd.int/doc/decisions/cop-14/cop-14-dec-01-en.pdf). The CBD COP has also expressed a desire for greater collaboration between the CBD and partners on remote sensing (CBD/COP/DEC/14/24: https://www.cbd.int/doc/decisions/cop-14/cop-14-dec-24-en.pdf).

Here we present a roadmap for the development and integration of Earth observation products into the EBV-framework. It is aimed to establish a process for making Earth observation products more useful for biodiversity decision making. We principally focus on EBVs that can be (partly) enabled with remote sensing, the so-called RS-enabled EBVs, and put them in context of the broader development of EBVs including in-situ approaches, RS-based approaches and the combination of both. The roadmap draws on the experiences gained during the European Space Agency's (ESA) funded GlobDiversity project, a pilot project dedicated to the development and engineering of three RS-enabled EBVs for terrestrial ecosystems.

Objectives

This roadmap has three main objectives:

1. Help to ensure remote sensed products become more useful for biodiversity decision making, and that an iterative process for increasing their usefulness continues into the future
2. Guide future projects that aim to generate operational RS-enabled EBVs to maximise the usefulness and ultimately the impact of the data that they generate, by discussing the project's experiences and positioning GlobDiversity's strategic documents (satellite observation requirements, algorithm trade-off analysis, algorithm technical baseline document, user handbook)
3. Strengthen the case for why more effort in generating remote sensing information about biodiversity can be impactful and outline the steps needed to achieve that impact.

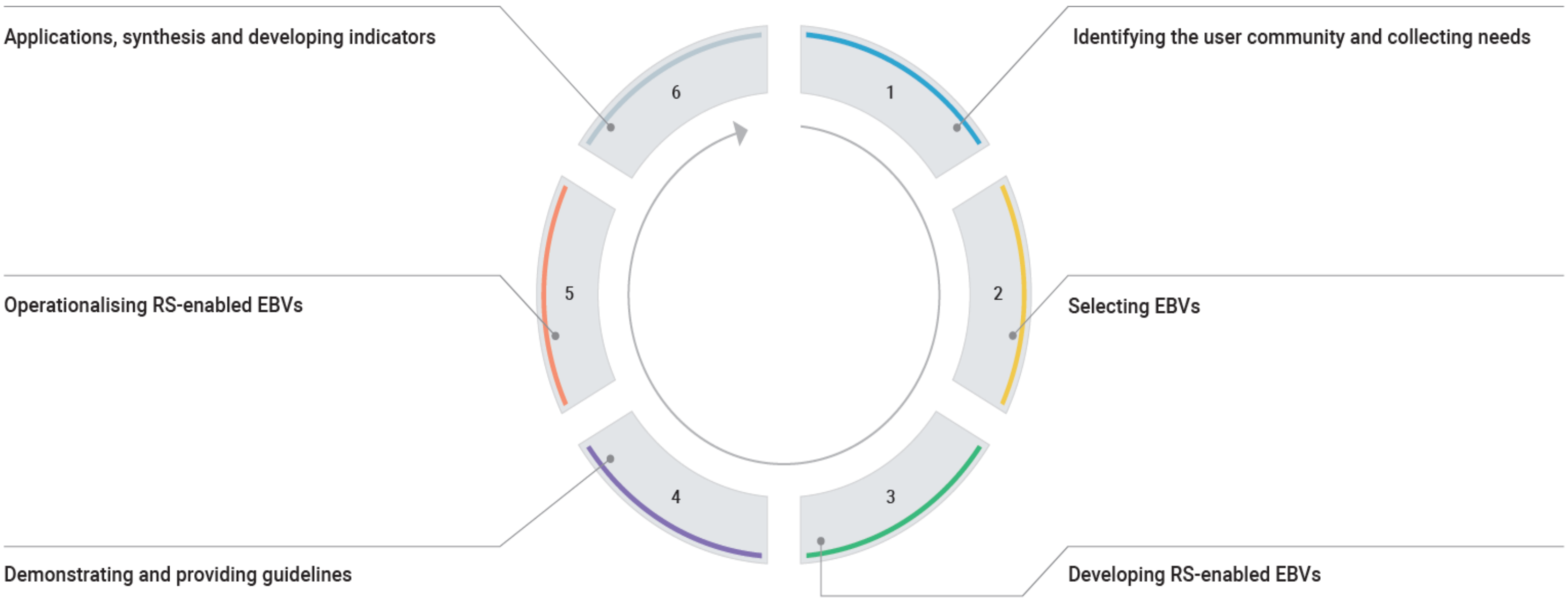

Figure 1. An overview of the RS-enabled EBV roadmap cycle.

The roadmap is organised as an iteration around, and between, 6 key steps (Figure 1). Steps 1, 2 and 6 are generic to all EBVs, whilst steps 3 - 5 are specific to individual RS-enabled EBV projects or products, and so multiple steps can be running in parallel (Figure 2). The steps are:

1. *Identifying the user community and collecting needs*. This step describes how users can be identified and discusses interaction with them to collect and document their biodiversity monitoring needs and requirements for EBVs.

2. *Selecting EBVs*. Having identified potential users and collected information about their needs, this step describes the process of defining EBVs and prioritizing them for development.

3. *Developing RS-enabled EBVs*. In this step algorithms are defined by the core remote sensing community in consultation with biodiversity experts.

4. *Demonstrating use and developing guidelines*. This section aims to develop prototypes for the RS-enabled EBVs that can be shared with wider the biodiversity and Earth observation community to gain understanding about how useful, acceptable and efficient they are.

5. *Operationalising.* The translation of developed and demonstrated RS-enabled EBV into operational products.

6. *Applications, synthesis and developing indicators*. The last section discusses how the RS-enabled EBVs can be brought back into the broader EBV framework and to end-users. Furthermore, it discusses what is needed for these products to be used in decision-making.

The roadmap sections are laid out in a logical order, with each step producing outputs that broadly-speaking become the inputs of the subsequent step. In practice, iteration around the full cycle is expected and has the benefit of i) continual learning and improvement in our levels of knowledge, and so contribute to making better decisions, and ii) improving the systems and processes available to generate new information to fill knowledge gaps. Iteration between steps, in the clusters 1-2-6, is important for close communication with the user community that can lead to new or amended user requirements and so requirements for the software, for example, a specific biome has been omitted from a product and requires tailored development of the algorithms underpinning the product. Whilst iteration between steps in the cluster 3-4-5 is important for the accumulation of understanding that makes algorithms robust and acceptable, and that can be drawn upon in step 5 to develop a fully operational piece of software for the production of RS-enabled EBVs on a regular, operational basis.

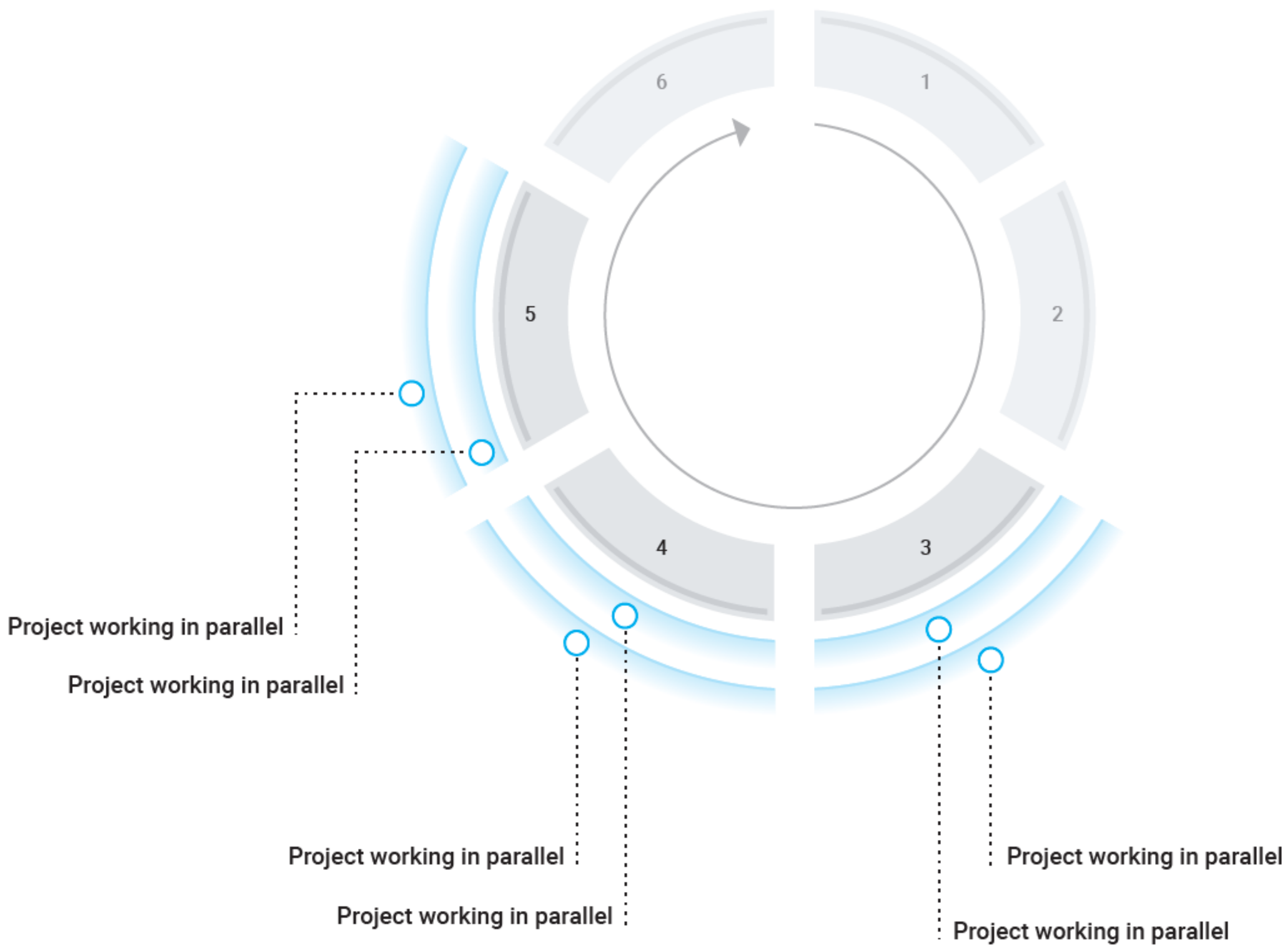

Figure 2. Projects working in parallel for steps 3 - 5.

Step 1: Identifying the potential user community and documenting user needs

Purpose: to identify EBV users with whom projects might interact and engage in a dialogue to document their needs (Figure 3).

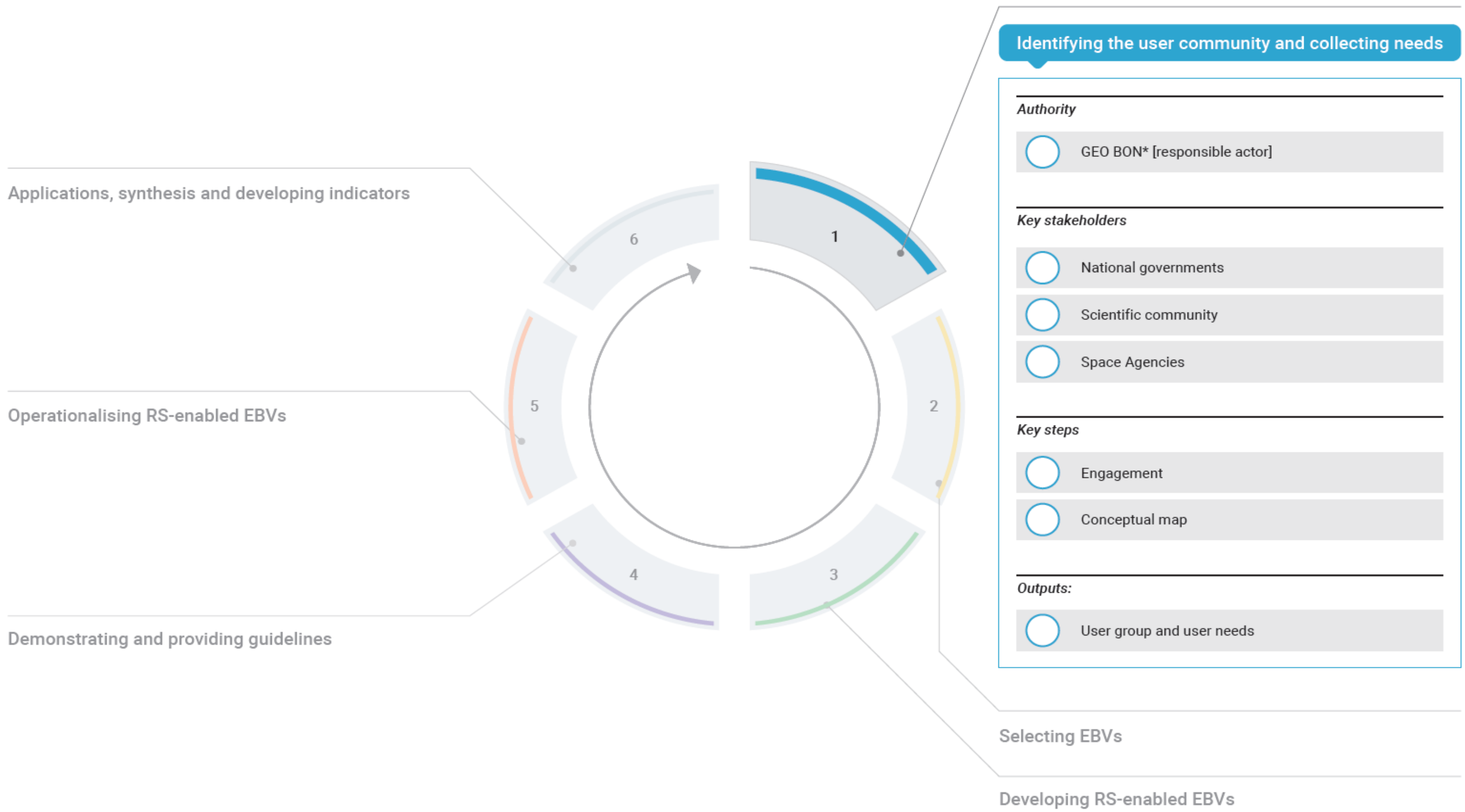

Figure 3: Step 1 of the RS-enabled EBV roadmap cycle: identifying users and collecting needs

The user community

In general, we suggest that projects should broadly define potential users, to include all people and institutions developing or potentially using EBVs. As the originators of the EBV concept and coordinators of the EBV community, GEO BON is the authority in this space and a key stakeholder for projects to engage with. GEO BON is part of GEO, the Group on Earth Observations, a partnership of national governments and participating organisations. GEO BON is working through a network of biodiversity and remote sensing scientists to link biodiversity data to decision makers. As mentioned above, GEO BON has been formally recognised as a key partner by the CBD. The GEO BON community has perhaps the best current understanding of what the current Earth observation data gaps are, and as we discuss later under Step 2, should be empowered to play a stronger role in mapping the gaps and possibilities for Earth observation.

The GEO BON community has also conducted a mapping exercise to identify biodiversity observation data users. In this mapping, national governments were identified as the most important user group, owing to their ability to change and implement policies which address pressures on biodiversity. They are also the parties to the major intergovernmental processes relating to biodiversity: CBD, the Convention on Wetlands (Ramsar Convention), the Convention on the Conservation of Migratory Species of Wild Animals (CMS), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The ability to address the needs of national governments can therefore be magnified or transfered, to provide information to other parties of these processes.

The Biodiversity Indicators Partnership (BIP) is a global initiative to promote and coordinate the development and delivery of biodiversity indicators for use by the CBD and so is a key organisation linking scientific outputs to the CBD and other biodiversity-related conventions, including IPBES, the Sustainable Development Goals (SDGs) and national and regional agencies. It is therefore another organisation that projects should consider engaging with as they seek to generate valuable information..

The scientific community was identified as another key user group, because they contribute EBV datasets and use them to conduct analyses of the state and drivers of biodiversity change. Moreover, they have a need for biodiversity data of greater quantity and quality to reach more robust conclusions.

Lastly, another major user group for EBVs is the remote sensing community including, but not limited to, the space agencies that provide the space-based Earth observation data fundamental to RS-enabled EBVs.

Key components

Engagement

There are numerous opportunities for engagement with the EBV user community. Engagement with GEO BON is encouraged, particularly with the GEO BON working groups. These working groups, Biodiversity Observation Networks (BONs) and Task Forces reflect the different classes of EBV variables as well as other activities in support of the EBV concept. These include the EBV classes: genetic composition, species populations, species traits, community composition, ecosystem structure and ecosystem function. Engaging with the working groups will facilitate shared learning about users and about other EBV data products under development. Here, GEO BON Open Science meetings and workshops constitute the optimal way to engage with working groups, though working groups can also be contacted via the group leaders or GEO BON secretariat. Interaction with the GEO BON user communities operating at national and local scales, for example, through the national and regional BONs, is also strongly encouraged. A list of national and regional BONs can be found on the GEO BON website (https://geobon.org/bons/national-regional-bon/).

The ongoing process for the development of a post-2020 global biodiversity framework means that there are many valuable and timely opportunities for interactions between the Earth observation community, GEO BON and national biodiversity decision-makers. Critically, there is a need to demonstrate what information is already available, or might be in the near future. So, the RS-enabled EBV community, including past, ongoing and forthcoming projects, should engage in mapping their capabilities against the proposed frameworks' targets and indicators.

More generally, the Earth observation community can engage with national governments through the CBD's Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), which meets annually to provide advice to the Conference of the Parties (COP) to the CBD. Institutions can apply to be registered with observer status at the meetings.

In a similar fashion, IPBES Member States can be engaged with the IPBES Plenary meetings. Similar to the CBD SBSTTA meetings, observer status can be requested by institutions.

Conceptual map

One of the key issues governing the success of engagement is the quality of interactions between producers of (remote sensing) biodiversity data products and their users, which often include scientists and decision/policy makers. To facilitate effective interactions between these communities, there is a need for a conceptual map that defines terms and streamlines language between the Earth Observation, biodiversity science and policy communities. So, there is also a need for an accompanying “terminology road map”. As the global authority in this space we suggest that GEO BON should lead such a process to facilitate interaction between the Earth observation and biodiversity science communities.

Inputs

As the starting point in the roadmap cycle, this step has more open inputs than followed steps. Firstly, project teams begin engaging with users in a dialogue. Secondly, project-level analysis and communication with the GEO BON working groups, BONs and task forces, will establish what gaps might exist in the current EBV landscape. And finally, projects explore how new EBVs can be made possible, for instance by new RS products or tools that might address the users' needs.

Outputs

Step 1 should result in (1) a mapping of users to interact with throughout the course of a project; (2) a process and tools, including conceptual mapping, to enable users from different disciplines to interact effectively; (3) a collection of the user-needs relating to the biodiversity focus of variables, the relevant temporal and spatial scale, the development process, and the demonstration of the usefulness and robustness of the product. It will also result in a set of options for achieving impact in decision-making. There is, in general, a strong connection between Step 1 and the selection of EBVs (Step 2).

Step 2: Selecting EBVs

Purpose: to define and prioritize EBVs; GEO BON is recognised by CBD to lead this process with input from the user community feeding into it (Figure 4).

Inputs

This step relies on (1) a collection of user requirements, (2) a set of users to iterate with (identified in Step I), (3) standardised conceptual tools for facilitating discussions, and (4) selection criteria, including feasibility. Given this information, a selection exercise can be performed that determines what EBV(s) to move forward for development.

The process of making a selection

As in Step 1, we suggest that GEO BON is the key actor in mapping the EBV landscape, and as such, should take the lead in defining and prioritising the EBVs. Critically, the inputs from Step 1 make it easier for GEO BON to support a dialogue with the remote sensing community about what types of information can be measured from Earth Observation. This information can be brought together with the needs identified from the range of users to prioritize essential and important EBVs.

When selecting EBVs to take forward for development, projects can learn from the framework proposed by GEO BON for the development of biodiversity observation networks (Navarro et al., 2018) . The framework proposes a 9 step engagement, assessment, design and implementation process. The engagement and assessment of EBV user needs have already been articulated in Step 1, and provide inputs to Step 2 in our roadmap. We then propose that Step 2 should consider the inventory of other data, tools and platforms that impact on the feasibility of meeting the defined user requirements. It is critical that this selection process is done interactively and iteratively with users.

Typically, most emphasis will be on the potential applications of the EBV. However, from a project perspective, clearly defining the requirements for the development and demonstration processes may be equally important.

In many cases, user engagement might reveal different needs across scales, including geographic space or time (Guerra et al., 2019). Hence, considering the extent to which generated EBV data can be adapted to these differing needs is important.

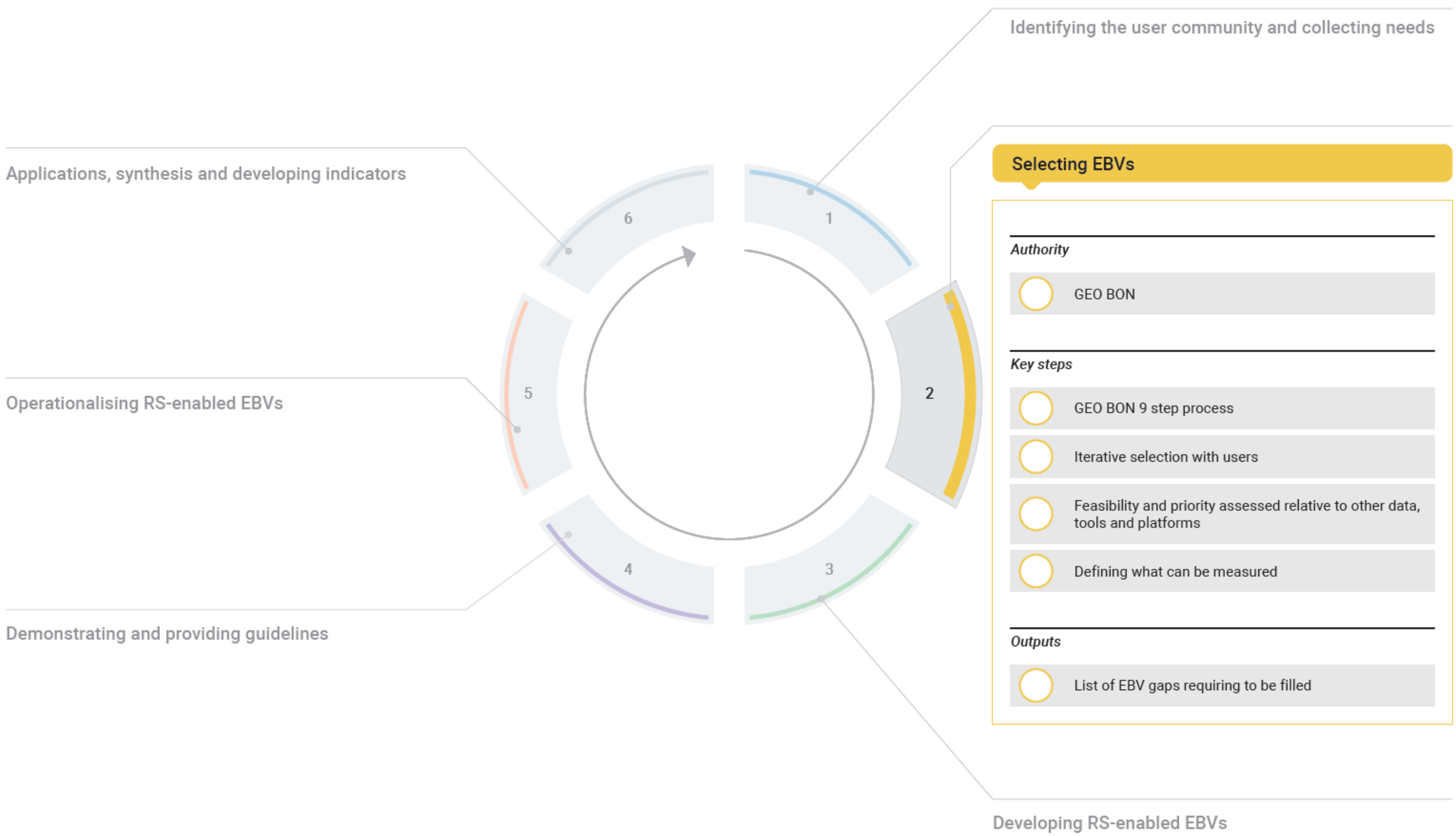

Figure 4. Step 2 of the RS-enabled EBV roadmap cycle: Selecting and prioritising EBVs

Outputs

A list of priority EBV needs (that are required by the user community, and that are feasible and measurable). These EBVs should be accompanied by user requirements and any specifications for the process of the EBV development, demonstration and application. The process can here be split into the purely *in-situ* based development of EBVs and/or RS-based development, or a combination of both. Each of the techniques can contribute to an overall assessment of the EBV, and more generally to a biodiversity monitoring system.

Recommendations

The EBV community as a whole, and especially the growing RS-enabled EBV community, would benefit from a mapping exercise to identify what EBVs are needed by which users, and how these EBVs might be generated with currently available data; and hence identify what EBVs are missing that remote sensors could help to address. A detailed gap analysis of already available information versus user needs might give a transparent picture where most effort should be invested to fill these gaps. Vice versa, the EBV user community would benefit from a discussion with the Earth Observation community about what information it is currently, or might be in the near-future, capable of measuring, in order to meet their needs. We recommend that GEO BON is the best-positioned entity to perform this task.

Step 3: Developing RS-enabled EBVs

Purpose: Identifying user and system requirements and prioritizing core algorithms to develop the selected RS-enabled EBVs (Figure 5).

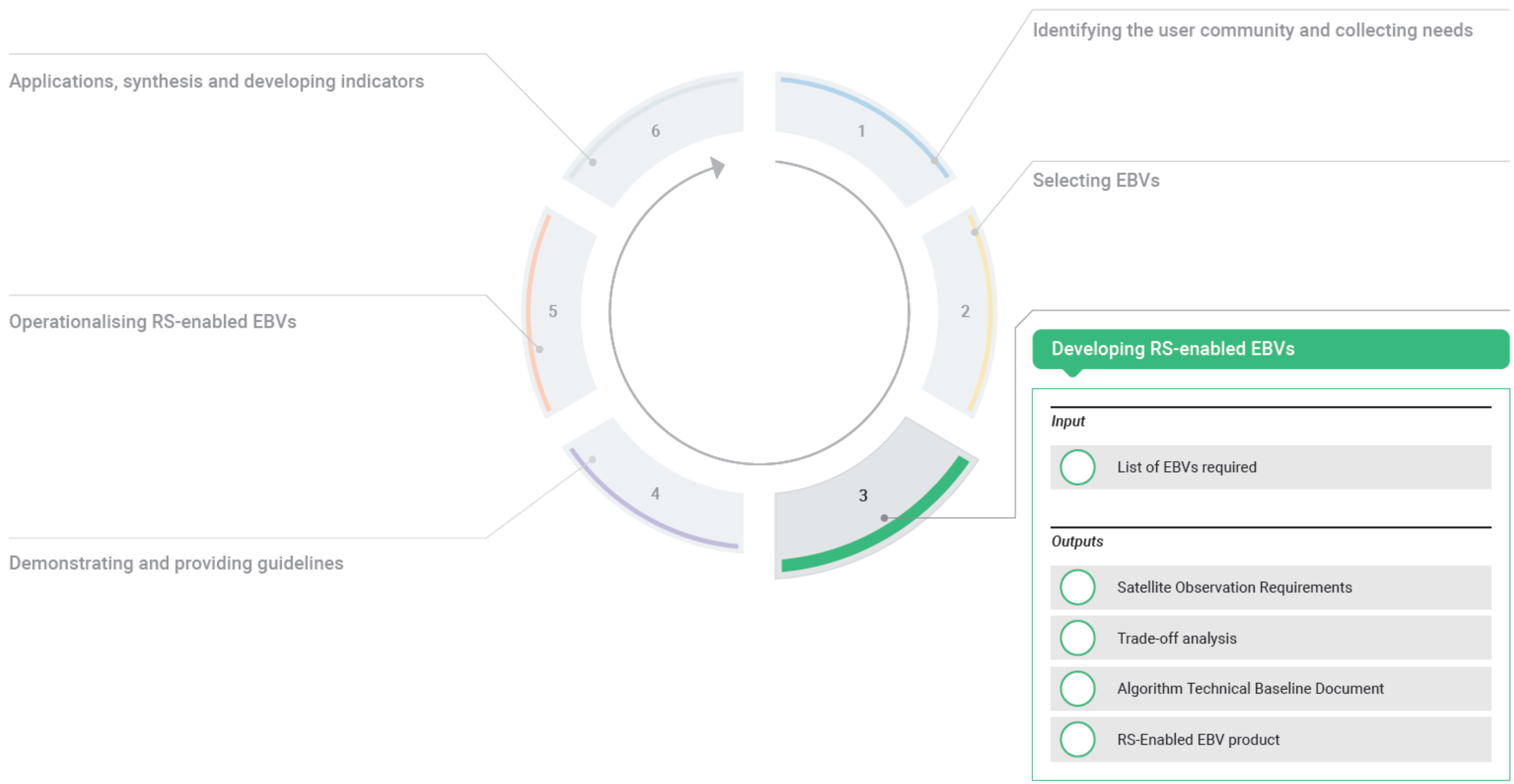

Figure 5: Step 3 of the RS-enabled EBV roadmap cycle: Developing RS-enabled EBVs

Inputs

Selected EBVs resulting from Step 2 are used as input to Step 3, which describes the process for developing RS-enabled EBVs. Here, the Committee on Earth Observation Satellites (CEOS), together with the relevant funding bodies, space agencies and research institutes, may influence the course of these developments by providing a forum for coordinating the definition of each actor's area of priorities, to develop the target RS-enabled EBVs and produce the biodiversity data sets.

Outputs: Strategic documentation on RS-enabled EBV development

Once EBVs have been prioritized in Step 2, Step 3 addresses the technical aspects related to the iterative process of algorithm development and dataset generation, focussing on RS-enabled EBVs. For example, within the frame of the GlobDiversity project, several strategic documents have been developed that can serve as a guide to the documentation for future RS-enabled EBV development projects. These documents include in particular, the i) Satellite Observation Requirement document (SOR), ii) trade-off analysis justifying algorithm selection, iii) Algorithm Technical Baseline Document (ATBD), and, iv) the documentation pertaining to the implementation and use of the actual RS-enabled EBV products.

1) Satellite Observation Requirements (SOR)

The SOR developed within the GlobDiversity project includes a general definition and structure to discuss and define requirements. This general structure can then be applied to any individual RS-enabled EBV. The SOR document focuses on describing the satellite observation requirements as seen from a user's perspective (e.g. what details should be detected). In contrast it does not define the satellite measurement requirements (e.g. required pixel size) or satellite specifications.
Within the GlobDiversity project, the proposed general structure of the SOR was defined within an expert workshop and through external review by the GEO BON working groups. The structure was then applied as an example to four different RS-enabled EBVs; the same or a similar structure can be extended to document the requirements of a catalogue of RS-enabled EBVs.
This document would benefit greatly from the inputs and findings that are defined in Step 1 of this roadmap.

2) Algorithm trade-off analysis

In the scope of a global biodiversity monitoring system, the GlobDiversity project has the aim to develop globally applicable algorithms. Many existing studies and products focus on a particular area of interest with specific characteristics. But for the development of an algorithm that can ultimately be applied globally, a trade-off analysis is required to select the most suitable and feasible one. From experience gained within the GlobDiversity project, the most important factors to account for in the evaluation are the algorithms' feasibility, usefulness and complexity This trade-off analysis can lead to the selection of an algorithm that is scientifically less complex, yet at the same time feasible for retrieval at the required scale with high resolution.

3) Algorithm Technical Baseline Document

Subsequently, a standardized Algorithm Technical Baseline Document (ATBD) was drafted for each concept RS-enabled EBV in order to document the technical details of the algorithms selected for development and implementation. This document shall ensure the full reproducibility, transferability and transparency of the selected algorithms. In addition, the ATBD summarizes the algorithms' selection criterias, mathematical background, accuracy measures and selected validation approach. Ideally, an algorithm would be available under open source licence, however, if not possible, the algorithm can be reproduced with an ATBD.

4) RS-enabled EBV products

Finally, the developed SOR, algorithm trade-off analysis and ATBD are published alongside example data products. Most important, for a transparent monitoring of biodiversity, data sets and algorithms should be easily and transparently available for everyone.

Key recommendations, experiences, remarks and open questions

Key recommendations, experiences and remarks assembled throughout the course of the GlobDiversity project are summarized below and presented for further discussion. Briefly, for this step, they include: i) Certain algorithms tested function best within, or are optimized for, certain geographical regions or biomes, or are not globally relevant. Thus, a transparent documentation is needed in order to allow the user to consider and evaluate these constraints. The fit-for-purpose geographical regions, or biomes, should be highlighted in user manuals, so as to guide potential users. ii) Same or similar documentation for the RS-enabled EBVs should be targeted in order to allow complete and transparent documentation to allow the possibility to analyse and compare different approaches and products.

Step 4: Demonstrating and providing guidelines

Purpose: Prototyping RS-enabled EBVs to produce demonstration products that are shared with the user community. Gathering feedback on the relevance and suitability of these products and the algorithms used to develop them through case-studies specific manuals and toolkits (Figure 6). Use this feedback to refine requirements and redesign, recode and retest the algorithm where necessary.

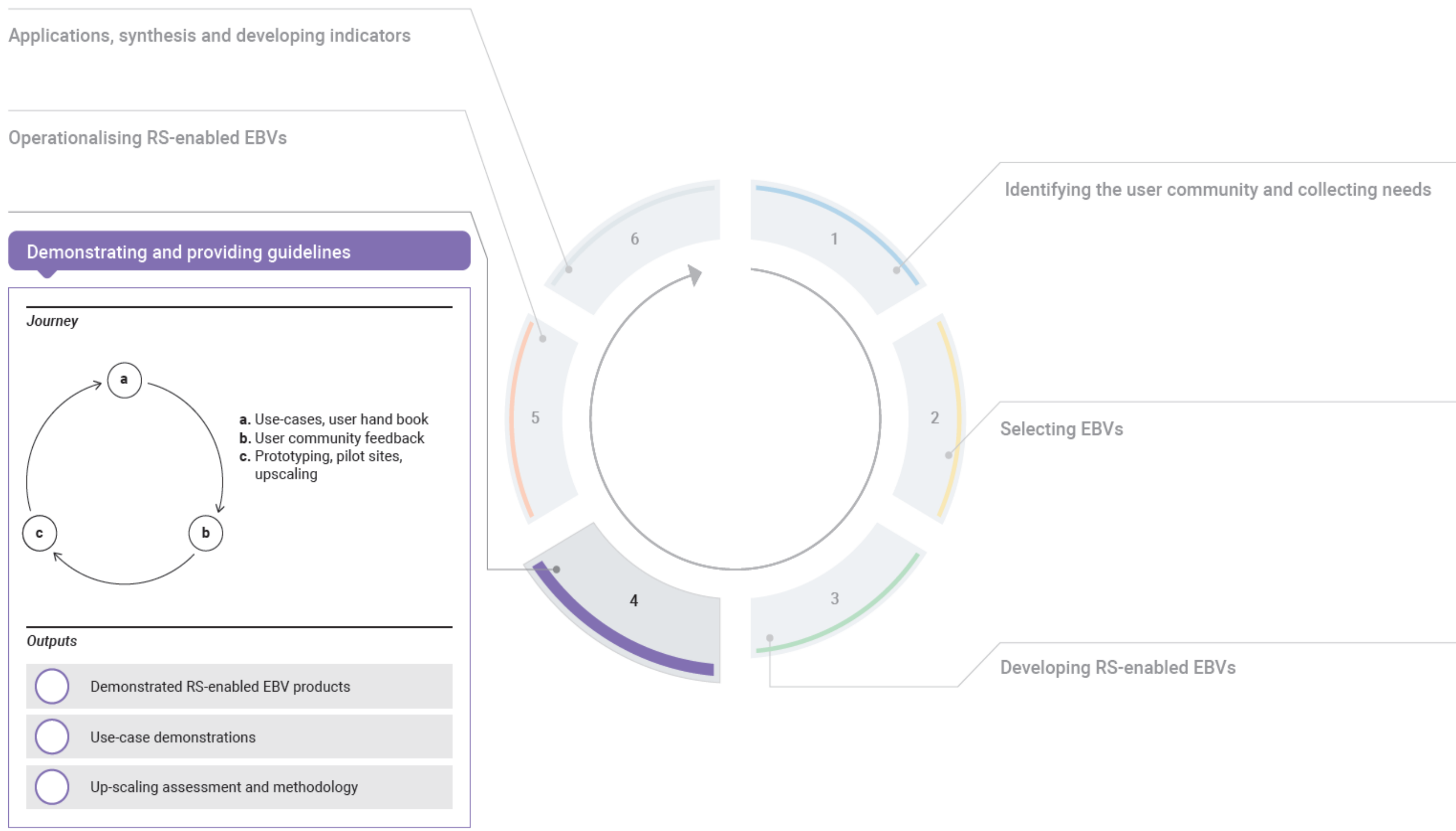

Figure 6. Step 4 of the RS-enabled EBV roadmap cycle: Demonstrating and providing guidelines

Inputs

Inputs to this section includes, the SOR, ATBD, algorithm tradeoff analysis and the user and system requirements consolidated from Step 3, as well as collections of ancillary datasets expected to be used in conjunction with RS-enabled EBVs.

Case studies

Via case studies, the relevance, suitability and applicability of RS-enabled algorithms, as well as its derived products, can be evaluated and demonstrated within the context of applied biodiversity studies, in close collaboration with conservation practitioners. Such case study demonstrations shall highlight the applications of the algorithms and products, as well as necessary improvements, while also contributing to fostering their acceptance by the wider scientific, conservation and policy communities. This step can require several rounds of iteration between developers and users. Ultimately it aims to identify a full system requirements (including, data inputs/outputs, technical and user interfaces, and processing platforms) to be carried forward to Step 5.

As part of the GlobDiversity project, extensive documentation was drafted, detailing how the products are to be used and demonstrating their effectiveness in applied biodiversity conservation studies. These case studies are synthesized within a User Hand Book, which is recommended to be reviewed by experts within GEO BON and the wider EBV community. Here, the key outcome is the showcasing of the uses and relevance of RS-enabled EBV products for biodiversity monitoring.

Up-scaling towards large-scale applications

Within the GlobDiversity project, the RS-enabled EBV algorithms were developed for global application but are applied only on certain geographic regions. If this is the case within a given RS-enabled EBV project processing chain, an up-scaling exercise is certainly useful to test the algorithms for global applicability, and for the identification of limitations and challenges when producing a global data set.

Key recommendations, experiences, remarks and open questions

Key recommendations, experiences, remarks and open questions, with regard to the RS-enabled EBV demonstration and guideline production, assembled throughout the course of the GlobDiversity project are summarized below for further discussion. Open questions include: i) What is the process by which an algorithm can be defined as a standard or benchmark, and concurrently, be accepted by the user community? ii) Is such a question expected to be resolved through various demonstration case studies, across a range of different regions and projects, or would it require extensive scientific journal article publication, or a combination of several approaches?.

The experience from GlobDiversity case studies points to weak linkages between remote sensors, scientists, software developers, policy makers and conservation practitioners, probably hindered by a lack of common terminology. Defining a conceptual map and accompanying terminology road map (step 1) would reduce this limitation.

Finally, a key recommendation issued from the GlobDiveristy project includes: EBVs need to be developed from the bottom up, for example, in collaboration with users such as conservation practitioners. As such, producing open and reproducible algorithms is critical in order to facilitate the incorporation of feedback from these users. Feedback may include the critical evaluation of the applicability of an algorithm in a particular case study and biome.

RS-enabled EBV retrieval algorithms should therefore be programmed and made available in fully open source languages and repositories, respectively, in order to minimize the costs and computational constraints associated with global up-scaling and analyses. GEO BON's *Bon in a Box* and Data Portal could provide a centralised platform and tools-set for storing and analysing RS-enabled EBV datasets such as those developed as part of GlobDiversity; for instance, via the creation of a specific "toolkit", which includes a workflow highlighting the RS-enabled EBVs' position relative to specific EBV classes and selection criteria. This could be more formally achieved following operationalisation (step 5).

Step 5: Operationalization

Purpose: Develop the integrated system drawing on the requirements developed in Steps 3 and 4 to provide robust global products (Figure 7).

Inputs

Inputs to operationalisation are the technical and user requirements identified from Steps 3 and 4 through the ATBD, system requirements and technical specifications drawing on experiences gained from the up-scaling exercises performed in Step 4.

Fully integrated operational system

The fully integrated system developed in this step addresses and finalises the core function and system requirements. It should consider the following aspects: functional completeness (including all interfaces), stability, performance, useability, reliability, scalability, testing and evaluation, and full documentation.

The up-scaling exercise in Step 4 documented, tested and demonstrated the steps and processing chains necessary for implementing the algorithms on cloud computing platforms for global computation. Here engineers compile the software and systems to deliver the up-scaled product.

The operationalisation phase follows the development and demonstration, and requires adaptation in order to compute the RS-enabled EBV products either on a wide range of cloud computing platforms, or by one particular platform providing services globally on a regular basis to the community. An example of such a service provider could be within the framework of the Copernicus services that already provide climate-relevant products.

We note that the production of global datasets requires a large effort; for example, they need a high level of validation and testing to ensure robustness, and this is both expensive and time consuming. Understanding and quantifying uncertainties is also often underestimated or even not considered, but at the same time it is critically important to communicate under what conditions the model performs well and where it is less suitable. The expense associated with formal operationalisation makes it difficult to generate products from multiple algorithms. It also implies that there may be space for less formal operationalisation, although there are risks to doing so without rigorous estimation of uncertainties and the communication of these to potential users. In summary, the implementation of standards for less formal operationalisation will be important for this approach to be successful.

Outputs

Operationalisation produces products suitable for broad use, that have been validated, tested and are fully documented. These products can exit the roadmap cycle, they are published and available for all communities to use. But they will also be fundamental to the application, synthesis and indicator development step. These products can contribute toward the compilation of national RS-enabled EBV datasets, such as those employed under the GEO BON national or regional Biodiversity Observation Networks (BONs), since the principal aims of the BONs are to facilitate the i) compilation and analysis of harmonized biodiversity observations, ii) creation of unified biodiversity monitoring programs, iii) definition of data standards, and iv) improving access to biodiversity data.

Figure 8. Step 5 of the RS-enabled EBV roadmap cycle. Operationalization.

Step 6: Applications of RS-enabled EBVs, synthesis with other data and development of indicators

Purpose: applying RS-enabled EBVs, or derived indicators, to inform decision making and to reinforce biodiversity monitoring (Figure 8).

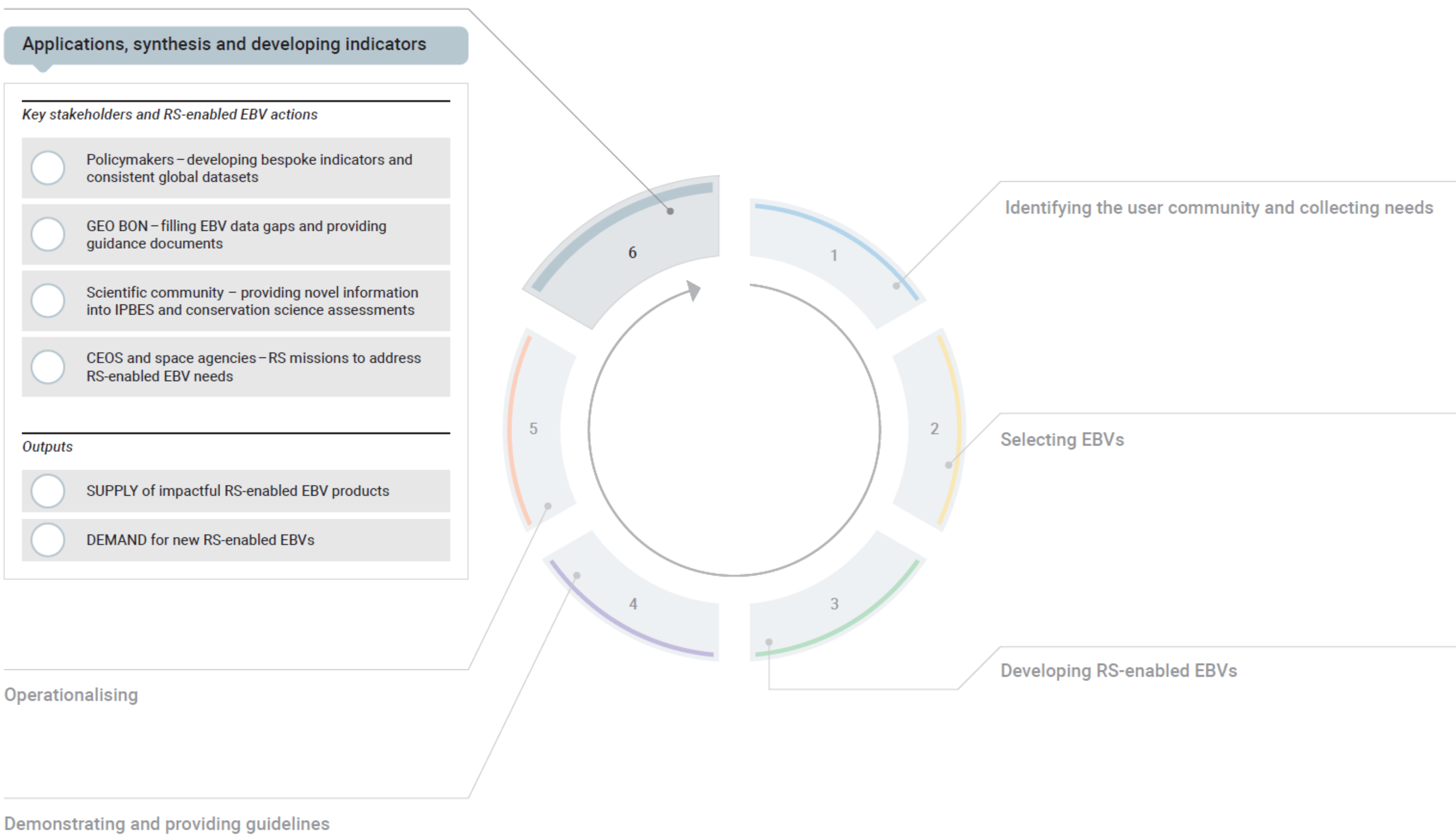

Figure 8. Step 6 of the RS-enabled EBV roadmap cycle: Applications, synthesis and development of indicators. Key stakeholder groups are listed alongside the key actions required of RS-enabled EBV project teams.

RS-enabled EBVs have a variety of uses depending on who the users in question are. EBVs and EBV datasets can be brought together to generate indicators that focus on particular questions, which in turn tend to be addressed across a certain scale.

Inputs

The application, synthesis and development of relevant indicators relies on having a range of RS-enabled EBVs and *in-situ* data based EBVs, at relevant spatial scales and resolutions.

Potential applications of relevance for policymakers

RS-enabled EBVs could have two key applications of relevance for policy-makers, including in the context of intergovernmental policy processes (*e.g.* CBD and IPBES):

1. As a valuable source of bespoke information for governments to measure changes in the state of biodiversity (that they can then use in the development of their national reports to different multilateral environmental agreements or other intergovernmental processes). For example, a National Aeronautics and Space Administration (NASA) project is aiming to develop and apply an EBV characterising forest vertical structure in collaboration with the Colombian Biodiversity Observation Network.
2. To provide globally consistent datasets that can be used as default data to support measurement of the state of biodiversity by governments in the absence of other information, to link national data to larger geographic extents, to enable comparison between countries and to better understand progress towards globally-agreed targets.

The application of RS-enabled EBVs at the national level is critical for the widespread acceptance of these datasets in intergovernmental policy processes, since the decisions taken by multilateral environmental agreements such as the CBD are driven by its Parties. In this regard, CBD Parties have already called to strengthen the links between the processes under the Convention and space-based remote sensing of biodiversity.

At the global scale, there is an analogy to be drawn with the SDGs, for which remotely sensed data is used as the default data source to fill information gaps in the reporting of status and trends, in the absence of national or location-specific (*in-situ*) information. Critical questions arising here include: i) what level of demonstration of the RS-enabled EBV data product is required for it to be accepted; and ii) is there scope for a quality standard, so that endorsed datasets can be used for a certain biodiversity monitoring purpose?

Despite the benefits of global data and indicators discussed above, there are downsides. Many of these global indicators, whilst having broad geographic applicability, might not be calibrated in specific ecoregions. If these ecoregions are important within a particular country, the indicator will be less suitable for use in that country. For this reason, RS-enabled EBV products need to be proved in different contexts, and as such the contexts for which they are best suited should be clarified alongside the other uncertainties associated with the dataset. More generally, data needs to be accessible, robust and reproducible. We recommend that for decision-makers to make best use of products, they should adhere to FAIR (findable, accessible, interoperable and reusable) principles.

Interaction with GEO BON

As introduced in Step 1, the GEO BON working groups provide a valuable user base through which to reach the wider biodiversity community as well as decision-makers. Cooperation is encouraged with these groups to generate indicators that fill information gaps. GEO BON also produces guidance for standardised and harmonised biodiversity monitoring methods, such as the sourcebook of Methods and Procedures for Monitoring Essential Biodiversity Variables in Tropical Forests with Remote Sensing (GOFC-GOLD, 2017) to which the GlobDiversity RS-enabled EBVs could contribute valuable information.

The EBV data portal, introduced in Step 4, is a resource of growing importance for delivering RS-enabled EBV data products to biodiversity scientists and tools for policy-makers, such as the Biodiversity Indicators Partnership. It has a high value in linking data products in order to generate indicators (see the following paragraph) and facilitate the connection of users to data. The portal also allows users to explore data and simple statistics.

Science applications

The conservation science community has a need for information on the state of biodiversity to support decision making from local-scale management to global-scale planning. Time-series data sets for RS-enabled EBVs and in-situ measurements can also provide critically important information on change, which can otherwise be very costly or impossible to generate using field observations alone. In addition, the integration of RS data and in-situ information can inform new indicators, even spanning EBV classes. For example, combinations of community composition data with ecosystem structure or function data could generate new EBVs reflecting more holistic views of ecosystem integrity. In turn, these could be used to indicate progress against globally-agreed targets relating to the area and integrity of freshwater, marine and terrestrial ecosystems, for example, in the context of the post-2020 global biodiversity framework after its adoption.

Earth Observation stakeholders

The CBD Conference of Parties' (COP) desire for greater collaboration with partners on remote sensing, for example with GEO BON and CEOS, is encouraging for the future of RS-enabled EBVs. Such interaction, alongside demonstrated demand for remote-sensed products, could help stimulate further interest in satellite instruments that are designed with biodiversity datasets and indicators in mind. An increased awareness of the opportunities for future missions to fill gaps in biodiversity knowledge is a critical need. However, even at present, there is the potential to substantially increase the capacity of some nations to use EO data to inform decisions, in particular, by making use of the large quantities of EO data already available.

Into the future: What is needed for the continuation of this roadmap?

In this last section we discuss the question of what is needed for the steps described in this roadmap to ensure remote sensed products continue to become more useful for biodiversity decision making. We suggest that there are requirements for progress, both on the supply side of the RS data and on the demand side.

On the supply side, we argue that there is a need for greater engagement in biodiversity monitoring from space agencies and from CEOS. This could make better use of the data we have already, and provide new data from which we can increase our impact on decision making. For this to happen, CEOS and the space agencies require a list of the EBV needs that they try to address. There is a critical need for a list of key EBV data gaps that the EO community could address. In Steps 1 and 2, we discussed actions that can make this happen, including constructing a conceptual map to allow more effective communication of needs and capabilities. GEO BON is the organisation that is best placed to conduct this, having a mandate from the CBD and GEO. Fully demonstrated, tested and documented products resulting from steps 3 - 5, will help to build confidence and acceptance of the products with users.

On the demand side, the important question is: what conditions are needed for RS-enabled EBVs to be widely used in decision making? We argue that there are at least two critical needs here. First, the datasets must be specifically addressed to the needs of users. For example, if RS-enabled EBVs can directly be integrated to address indicators that may be used to monitor progress towards the goals and targets of the post-2020 biodiversity framework, then this would generate widespread interest and acceptance. However, this would be contingent on the second requirement, which is for standards and processes to ensure that products are robust, transparent and validated. In this roadmap we discuss when and how RS-enabled EBV project teams should engage with users of the products they aim to generate. This process should be ongoing and if done well, will lead to continual improvements in the usefulness of these products for understanding biodiversity status and trends. This will stimulate increased demand.

GEO BON is the key organisation to ensure continuation of the process for generating remote sensing products that are useful for biodiversity decision making. It is therefore vital to empower GEO BON to provide progress on the demand and supply sides. Making GEO BON more formally responsible for providing these services to the CBD and its Parties will support the status of GEO BON. Making formal connections between CBD, GEO BON and CEOS would bridge the supply and demand aspects described above. More formal connections might facilitate the scaling up of resources needed to expand the coordination of Earth observation capabilities and EBVs needs. If this coordination can be achieved then RS-enabled EBVs can continually provide more useful information to decision-makers.

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