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# Earth observation as a tool for tracking progress towards the Aichi Biodiversity Targets

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## Abstract

Biodiversity is continuing to decline. This crisis has been recognised by the Convention on Biological Diversity (CBD), whose members have set ambitious targets to avert ongoing declines in the state of biodiversity by 2020. These so called "Aichi Biodiversity Targets" (ABTs) are organized around five strategic goals, with indicators showing the level of progress made towards each target. Currently, measurements of many ABT indicators are not available. The Essential Biodiversity Variable (EBV) framework, developed by the Group on Earth Observations Biodiversity Observation Network (GEO BON), attempts to form a coherent and harmonised set of observations of biodiversity. In this paper, we explore the potential role of Earth Observation (EO) as a tool to support biodiversity monitoring against the ABT and EBV frameworks. We show that EO-based measurements are adequate for assessing progress towards 11 out of 20 ABTs. In addition, 14 of the 22 candidate EBVs have a fully or partly remotely-sensed component and can be considered as Remote Sensing Essential Biodiversity Variables (RS-EBVs). Those with a partial EO component require further *in-situ* data and/or modelling effort to complete the EBV. While the status of biodiversity can be assessed with both fully and partly measured RS-EBVs, assessing trends is more challenging, particularly for partly measured RS-EBVs, as coincident time series of EO and supporting data are lacking. A synthetic pathway for developing generic biodiversity indicators using RS-EBVs is proposed.

## Introduction

Global biodiversity is in crisis, as evidenced by dramatic global declines in species distributions and populations, together with loss of large areas of natural habitat (e.g. Butchart et al. 2010). In response, the Convention on Biological Diversity (CBD) has set out the 'Strategic Plan for Biodiversity 2011–2020', whose vision is to restore, value and conserve biodiversity for the benefit of all people by 2050 (CBD Secretariat 2010). Embedded within this plan are 20 so called 'Aichi Biodiversity Targets' (ABTs), adopted at the CBD meeting in Nagoya in 2010 and organized under five strategic goals (Table 1). While the targets are aimed at increasing successful outcomes for biodiversity conservation at the global level, they are also a guide to regional and national-scale target setting.

To support the measurement of ABTs, parties to the CBD in 2012 proposed a suite of 98 indicators as the

**Table 1.** Adequacy of EO data products to address the Aichi Targets as evidenced by the candidate EBVs which can be remotely sensed (RS-EBVs). Examples of RS-EBVs are shown for the Targets with high and medium adequacy as well as the possible EO approach which can be used to measure the EBV. The examples shown are indicative and more than one EBV can map to a Target.

| Strategic goal | Aichi biodiversity targets | Adequacy of current EO data products | Candidate RS-EBV (where applicable) | Sample EO product or observational approach |
|---|---|---|---|---|
| A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society | 1. Awareness of biodiversity values | 🔴 | | |
| | 2. Integration of biodiversity values | 🔴 | | |
| | 3. Incentives | 🔴 | | |
| | 4. Sustainable production and consumption | 🟡 | Net primary and secondary productivity | EO-based measures of productivity (NDVI, FAPAR etc.) EO-ba |
| B: Reduce the direct pressures on biodiversity and promote sustainable use | 5. Habitat loss, fragmentation and degradation | 🟢 | Ecosystem extent and fragmentation | Land cover change |
| | 6. Sustainable exploitation of marine resources | 🟡 | Net Primary Productivity | FAPAR, ocean greenness |
| | 7. Sustainable management | 🟡 | Habitat structure | Land cover and Tree height (LiDAR or RADAR) |
| | 8. Pollution reduction | 🟢 | Nutrient Retention | EO-based observations of crop cover to infer nutrient retention over large areas, for example watershed |
| | 9. Control of invasive alien species | 🟡 | Species distribution | EO-based vegetation maps as input to species distribution model |
| | 10. Coral reefs and other vulnerable ecosystems | 🟡 | Ecosystem composition by functional type and/or habitat structure | Functional type can be inferred from RS, structure obtained by 3-D survey, for example underwater sonar or airborne LiDAR |
| C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity | 11. Protected areas | 🟢 | Ecosystem extent and fragmentation | Land cover and surrounding matrix |
| | 12. Prevented extinctions of threatened species | 🟡 | Population abundance | Tracking and remote observation of individuals through satellite telemetry |
| | 13. Genetic diversity of socio-economically and culturally species | 🔴 | | |
| D: Enhance the benefits to all from biodiversity and ecosystem services | 14. Ecosystem services safeguarded | 🟢 | Ecosystem composition by functional type Ecosystem extent and fragmentation | Plant functional traits determine the productivity of an ecosystem |
| | 15. Ecosystem resilience enhanced | 🟡 | Phenology and/or land cover change | Land surface phenology from vegetation index time series |
| | 16. Nagoya protocol enforced | 🔴 | | |
| E: Enhance implementation through participatory planning, knowledge management and capacity building | 17. Parties implement National Biodiversity Strategy and Action Plans | 🔴 | | |
| | 18. Traditional knowledge respected and protected | 🔴 | | |
| | 19. Biodiversity knowledge and technology widely used | 🔴 | | |
| | 20. Resource mobilization and finances directed towards the Strategic Plan | 🔴 | | |

Low adequacy = red, medium adequacy = amber and high adequacy = green, these ratings are based on the expert consultation process of Secades et al. (2014) as discussed in section Status of Earth Observation as a tool for monitoring global conservation targets.

 

basis for reporting progress target by target (CBD COP11, Decision XI/3). In 2014, a series of 55 indicators that met pre-defined criteria were used in the Global Biodiversity Outlook (GBO4), which presents a mid-term evaluation of progress towards achieving these targets (Tittensor et al. 2014). One of the conclusions of the GBO4 was that many of the indicators that were being used were problematic due to a lack of data standardization, lack of global coverage, low spatial resolution (often countries) and lack of long-time series for measurements.

In an attempt to overcome some of these challenges and assist in the monitoring of targets in the future the 'Group on Earth Observations Biodiversity Observation Network' (GEO BON) has proposed a set of candidate 'Essential Biodiversity Variables' (EBV) (Pereira et al. 2013). The development of the EBVs was inspired by the 50 'Essential Climate Variables' which have been endorsed by the 'Global Climate Observing System' to support the work of intergovernmental interface between climate policy and climate science (i.e. the United Nations Framework Convention on Climate Change and the Intergovernmental Panel on Climate Change (IPCC); Pereira et al. 2013). It is also hoped that the EBVs will be relevant to the newly formed Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) which aims to achieve for biodiversity and ecosystem services what the IPCC has achieved for climate (Brooks et al. 2014).

The EBVs provide a distinct but complementary framework to the CBD targets and their respective indicators and occupy an intermediate conceptual level between low-level primary observations and high-level policy-relevant indicators. The list of proposed EBVs is arranged into six discrete groups or EBV classes that are thematically ordered based on the type of variables they target. The EBV classes span a range of scales from ecosystems to species to genes. For each EBV class furthermore a total of 22 individual EBVs and supporting EBV measurements are proposed. While the EBV classes are categorical groups, individual EBVs within each class are specific quantifiable variables which can be precisely measured. While understanding of how the EBV framework fits into current international policy instruments is growing, gaps for biodiversity information continue to persist within certain EBV classes such as Genetic Composition (Geijzendorffer et al. 2015). Knowledge of how they can be filled is the subject of ongoing discussion as is a complete and final set of definitive EBVs.

Earth Observation is an all-encompassing description of both direct and indirect observations of the Earth's surface via active or passive sensors on space-based, airborne, ground-based, ship-borne or underwater systems (Andrefouet et al. 2008). Although non-space forms of EO can provide multi-dimensional data on ecosystems, climate and atmosphere-biosphere at local to regional scales in support of biodiversity conservation and management (Turner 2014; Corbane et al. 2015), satellite-based Earth Observation (EO) is the only truly global monitoring tool adequate for the large and complicated task of assessing the status and trends of global biodiversity. Therefore, the goal of this study was to link satellite EO data products with indicators for the ABTs and the emerging EBVs, using a harmonized framework which summarizes biodiversity status and trends. The specific objectives of this study are:

1 To summarize the role of EO as a tool to track progress towards the 2020 Aichi Biodiversity Targets by quantifying the number of indicators which could be partly or wholly measured with satellite data products.
2 To further develop the emerging EBV concepts through the medium of EO by refining a subset of the candidate list of EBVs proposed by Pereira et al. (2013) referred to here as Remote Sensing – Essential Biodiversity Variables (RS-EBVs).

To achieve this goal we review the ABTs and EBVs against direct and indirect, operational and emerging, EO data products. The review was conducted by consulting expert opinion and categorically rating the Targets based on the adequacy of currently available EO technology to build indicators per target. The potential RS-EBVs were also matched with their respective EO data products. To summarize this information a monitoring framework is proposed where RS-EBVs are used to harmonize observations prior to the indicator stage. Potential obstacles to implementing this framework and challenges to its adoption by the wider science and policy community are discussed. Finally, upcoming satellite missions which could offer potential for assessing global biodiversity status and trends beyond the 2020 timeframe of the CBD's current Strategic Plan for Biodiversity are discussed.

## Status of Earth Observation as a Tool for Monitoring Global Conservation Targets

The benefits of satellite-based EO as a measurement tool for global biodiversity indicators are listed below:

1 Synoptic view of the Earth's surface; polar-orbiting, sun synchronous EO sensors observe wide swaths of the Earth in one pass, acquiring and storing large amounts of Earth surface imagery under constant conditions of solar illumination
2 Regular and repeatable observations; polar-orbiting EO satellites orbit the Earth several times per day allowing consistent and systematic surface observations of the entire Earth surface (with the exception of the extreme poles)

3 Multi-annual time series of observations; since the 1970s the average operational lifetime of an EO mission has almost tripled to today's average mission lifetime of 8.6 years (Belward and Skøien 2015) enabling more stable and continuous observations from the same sensor over several years or more
4 Cost-effective for monitoring remote and inaccessible areas; EO satellites are designed to observe any location on the Earth's surface at some time in their orbit, albeit with some constraints around polar regions, permitting observation of areas otherwise inaccessible for ground-based surveys

These benefits are enhanced when combined with near-Earth and sub-surface forms of EO such as acoustic devices, airborne sensors and Unmanned Airborne Vehicles (UAVs). This multi-scale combination provides a powerful measuring and monitoring tool for biodiversity conservation as has been shown across different scales (Kerr and Ostrovsky 2003) and thematic applications ranging from tracking the impact of climate change on ecosystems to evaluating the effectiveness of conservation measures (Rose et al. 2015). The potential of satellite-based EO in building global environmental indicators has been demonstrated for ambient air pollution, coastal eutrophication and biomass burning (De Sherbinin et al. 2014).

Here, we aim to highlight the state of this potential for monitoring progress towards the ABTs and the emerging EBVs by summarizing information collated by an external review conducted by Secades et al. (2014). The approach taken was firstly to map EO products against ABTs using expert opinion from 19 specialists (see Appendix) and then to rate their responses on a qualitative scale of adequacy; with the scale ranging from not observable (red rating), to partially observable (amber rating), and totally observable from EO data products (green). Each of the 98 indicators contained in the indicative list of indicators (CBD Decision XI/3) was matched to their respective ABT and then assessed in terms of being measurable by EO (yes or no). Second, all those EBVs that could be measured by EO were determined by expert review from the list of 22 candidate EBVs.

With regard to the ABTs, analysis of the 98 indicative indicators shows how 11 of 20 Aichi Targets (Targets 4-15, except Target 13) can be partly or wholly measured using EO products (Table 1). Targets within some of the CBD Goals appear to benefit more from EO than others; in particular Targets 5–10 in Strategic Goal B which all have a measurable spatial component. Indicators for Targets in Strategic Goals C and D such as the Living Planet and Red List Index (Target 12) and genetic diversity of terrestrial domesticated animals (Target 13) do not currently use EO data. It is more challenging to find a role for EO in measuring indicators in Goals C and D, with the exception of protected area management effectiveness (Target 11), for which land cover change provides an indicator (Andam et al. 2008; Joppa and Pfaff 2011; Beresford et al. 2013), as well as indicators on the provi-

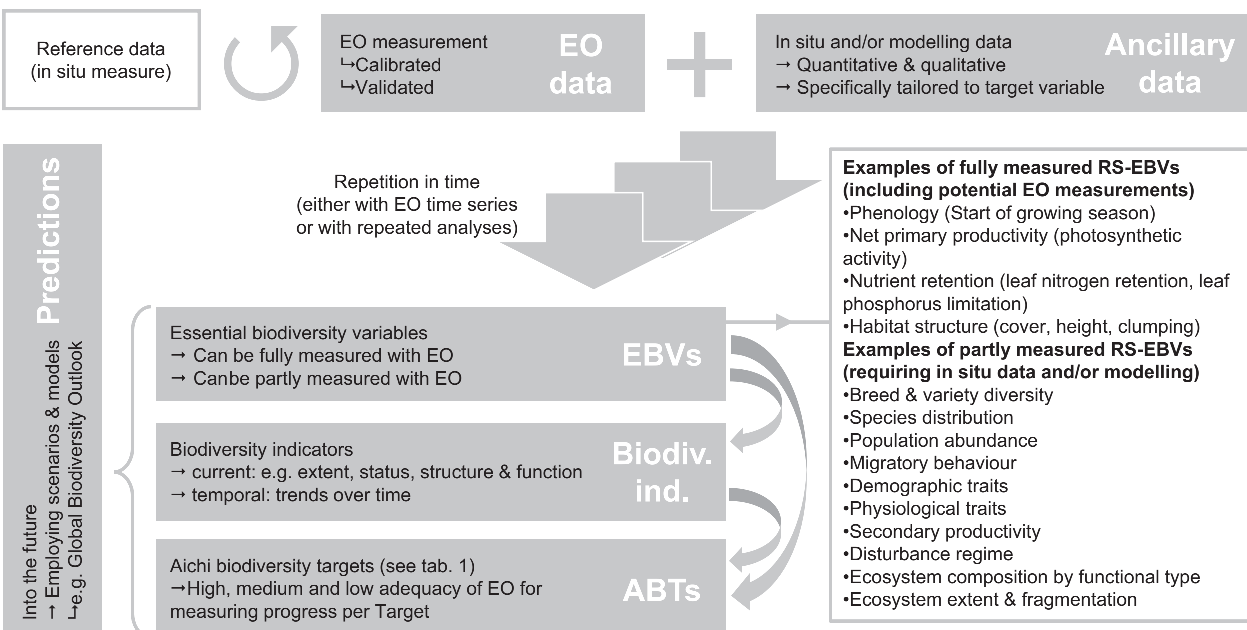


**Figure 1.** The proposed pathway from EO measurements to EBVs, biodiversity indicators and Aichi Biodiversity Targets with examples of EO measurements for fully and partly measured RS-EBVs.

 

sion of ecosystem services (Target 14) such as carbon sequestration and water cycling which have spatially explicit biophysical components (Tallis et al. 2012). Hyperspectral-based monitoring is in the research and development stage for other targets in Strategic Goals C and D, for example spectral heterogeneity as a proxy for species diversity (Target 13) (Oindo et al. 2003; Rocchini et al. 2010). These experimental approaches require more work to prove their operational readiness and utility as indicators at a global scale. EO has the most limited role in indicators for targets in Strategic Goals A and E which address human knowledge, perception, awareness and values related to biodiversity and its conservation. However, creating awareness of biodiversity values through the dissemination of knowledge generated through EO technology can and should be quantified as an indicator for Target 1. Similarly, the number of education, training and public outreach activities which combine biodiversity-related knowledge with EO could form an indicator for Target 19. These examples show a more indirect but nevertheless important contribution of EO as a supporting technology for the ABT indicators.

The 22 candidate EBVs were also matched against satellite-based EO data products, using the same expert opinion described showing that 14 of 22 EBVs have been identified as either fully or partly measurable from EO data, comprising 4 of the 5 EBV classes. The classes of variables at a level of biological organization commensurate with the scale of spaceborne EO measurements such as Ecosystem structure and Ecosystem function are less challenging to match with EO data products than those at the level of species and genes such as Species traits and Community composition. In these latter cases, non-EO-based measurements of species, individuals and their genetic diversity are required and therefore could not be described as RS-EBVs. However, species traits such as phenology, can be approximated over broad areas through time series analysis of EO data (USGS 2014b).

In Table 1, an EO-based approach to measure an example RS-EBV is suggested next to each ABT that has a 'green' or 'amber' rating. Some RS-EBVs are listed twice as they could potentially produce relevant indicators for two or more ABTs, for example ecosystem extent and fragmentation for Target 11 and 14.

## Towards Integrated Biodiversity Monitoring that Informs Policy

In Figure 1 we propose a workflow structure whereby the RS-EBVs can be used to harmonize observations for biodiversity indicators. The first step of this workflow is the conversion of the physical EO at-sensor signal into biophysical measurements of the Earth's surface through calibration and validation with in -situ measurements. The next step is to turn these measurements into fully or partly measurable RS-EBVs using ancillary data that can be in the form of qualitative (categories or nominal labels) or quantitative (proportions) measurements derived from real world (in situ), simulated (modelled) or by other EO measurements (e.g. climatological and topographical observations). These ancillary data provide an independent means of assessing the extent or biophysical condition of the target variable of interest. Phenology presents an example of a fully measurable RS-EBV that can be directly retrieved from time series of vegetation index data while yielding usable indicators of ecosystem condition and health such as when the growing seasons starts. For example nine phenology indicator variables at 250 m and 1000 m resolution for the contiguous US are annually produced by the United States Geological Survey remote sensing of land surface phenology programme (USGS 2014b). The fully measurable RS-EBVs are totally dependent on the operational production of their respective EO measurements and the maintenance of consistent global coverage over time. The partly measured RS-EBVs on the other hand require extra ancillary data and/or modelling in addition to EO measurements to transform them into usable biodiversity indicators, for example in estimating a species range, species distribution models require remotely sensed observations of climate, topography and other biophysical data to generate indicators of where and when a species is likely to occur. A potential limitation of the partly measurable EBV is their dependency on coincident in situ and EO time series data, which cannot always be guaranteed thereby reducing their use in assessing trends.

## Challenges to Integrated Biodiversity Monitoring

A number of potential obstacles pose a challenge to the further development and deployment of EO for biodiversity conservation such as data continuity, data affordability and data access (Turner et al. 2015). Some of these as well as newer challenges are described below in the context of the ABTs while summarized and supported by examples in Table 2. The challenges can be summarized into four main themes some of which are overlapping; (1) The need for standardization, (2) Opportunities for inter-disciplinary collaboration, (3) Establishing priorities, (4) Designating leadership and institutional oversight.

### Challenge 1: Standardization in EO data and products

A major challenge to trend analysis in biodiversity is the lack of long-term (multi-decadal) and global EO time ser-

 

**Table 2.** The key challenges preventing the use of Earth Observation (EO) in the development of biodiversity indicators with proposed solutions, examples of solution implementation and a reference source.

| Challenge | Description | Scale of challenge | Potential solutions | Example solution | Reference |
|---|---|---|---|---|---|
| 1: Standardization in EO data and products | No back-calibration of data archives for coherent time series compounded by changing methodologies | International – harmonization of data sources and methodologies among lead agencies producing EO data products | Interoperable satellite systems with back-calibration of archival datasets and harmonization of processing algorithms | Landsat archive and Landsat-8 continuity mission with ESA Sentinel-2 satellites | Sexton et al. (2013) |
| 2: Providing more opportunities for inter-disciplinary collaboration | Experts in EO data processing not trained in applied biodiversity concepts – EO data products are not fit for purpose | International -Developed and Developing world countries | Knowledge of established EO data providers must be matched with that of biodiversity conservation policy specialists to enable knowledge transfer | Employment of mixed specialist teams in recognized institutes, developing internship programmes for students with multi-disciplinary skills | Global Forest Watch (2014) DETER (Brazilian Government) |
| 3: Establishing priorities for EO in biodiversity conservation | A lack of funding and scientific interest in change detection from EO data archives, for example for land cover change | Institutional – aligning priorities of policy fora such as the CBD and IPBES and the major remote sensing institutes | Inter-calibration of the EO data record to generate global, medium resolution land cover data over multiple decades | GlobeLand 30, ESA Climate Change Initiative (global land cover 2000, 2005 and 2010) | Jun et al. (2014); Defourny et al. (2014) |
| 4: Designating leadership and institutional oversight | No overseeing authority ensuring EO-based biodiversity observations are in line with user needs | International – An inter-governmental body needed to provide leadership in this area | GEO BON network for facilitating inter-disciplinary dialogue and IPBES for achieving consensus on what biodiversity and ecosystem services need from EO | GEO BON workshops on Remote Sensing for EBVs | Wulder and Coops (2014) |

ies of measurements (relevant to biodiversity) which has been thoroughly inter-calibrated and validated. While inter-calibration has largely been achieved between families of sensors such as Landsat, MODIS and NOAA AVHRR, giving access to multi-decadal time series in the case of Landsat, cross-calibration is still an unresolved issue. The Landsat Continuity Mission (Landsat 8) offers comparability with the ESA Sentinel-2 satellite and should combine the high revisit time and high spatial resolution of both satellite series into a continuous data record. However, the problem of calibration is compounded by the lack of standards at the validation phase where pre-processing methods turning EO data into an EO measurement differ between image providers sometimes rendering the same data products incomparable. Secondary to this obstacle is the unfulfilled need for consistent high level data products such as the climate data record (CDR) of the USGS which allow valid change detection through the provision of consistent surface reflectance products for example (USGS 2014a).

## Challenge 2: Providing more long-term opportunities for inter-disciplinary collaboration

The diverse but not mutually exclusive expertise of remote sensing and biodiversity conservation scientists have been separated, most notably in different university departments, preventing cross -fertilization of ideas and interests (Pettorelli et al. 2014). Therefore, the expertise and capacity needed to transform EO measurements into RS-EBVs and harmonize observations for biodiversity monitoring are disparate and fragmented. As a result, EO-based indicators that are used internationally for global reporting on status and trends can struggle to have policy relevance and wider acceptance by the biodiversity community, for example as evidenced by recent criticism of the Hansen et al. (2013) effort to monitor global forest change from 12 years of Landsat data based on different interpretations of what constitutes deforestation versus tree cover loss (Tropek et al. 2014). More dialogue between the conservation and remote sensing community could reduce future misunderstandings and help manage expectations of what EO can and cannot deliver.

## Challenge 3. Establishing priorities for EO in biodiversity conservation

Ensuring that EO-based tools and services deliver real outcomes for biodiversity conservation is challenging not least because of a lack of consensus on what conservation really needs from EO. As it stands, a global trend towards cheaper, smaller, longer lasting and higher spatial resolution EO satellites has created a demand for newer and more innovative EO data products (Belward and Skøien 2015). This progression in technology captures the imagination of researchers and funders alike, and provides research opportunities for the next generation of doctoral students. However, there are few career rewards for generating repetitive data from old satellite sensors at lower spatial resolution, even though this would be of great utility for conservation monitoring purposes not least in the quest for a global and multi-decadal conservation-relevant land cover change product – a need highlighted by two recent unpublished surveys among the conservation community (CEOS Biodiversity 2012; Cambridge Conservation Initiative 2010). However, the challenges in relating land cover to habitat and reducing confusion between EO-based definitions of land cover and ground realities cannot be discounted. Problems also occur when extensive habitat loss has occurred prior to the availability of EO data. Defining the original state of land cover prior to change can be challenging in the absence of EO data and solutions require careful thought.

**Table 3.** Upcoming Earth Observation (EO) missions which have the potential to yield both direct and indirect observations of biodiversity.

| Satellite | Sensor(s) | Agency | Expected launch date | Key observation characteristics for terrestrial biodiversity |
|---|---|---|---|---|
| Sentinel-2 | Optical multi spectral | ESA | April – June 2015 | Global plant status and health every 5 days at 10 m spatial resolution providing continuity with Landsat and SPOT satellites |
| EnMap | Hyperspectral sensor | German Aerospace Center (DLR) | 2018 | Global biochemical and biophysical parameter retrievals and fine scale ecosystem transitions |
| HYSPIRI | Hyperspectral Infrared Imager | NASA | 2022 or later | Global assessments of vegetation canopy condition, invasive species and plant disease |
| ICESat-2 | Laser altimeter | NASA | 2017 | Global vegetation height from which biomass carbon can be inferred |
| BIOMASS 2020 | P-band radar | ESA | 2020 | Status and trends in above ground biomass of tropical forests |

### Challenge 4. Designating leadership and institutional oversight

The above challenge can only be tackled through strong leadership. Organizational leadership is currently lacking in efforts to establish an integrated biodiversity monitoring system. At present EO data and products are diverse and the linkage between their production and user needs is not always evident. In particular, there is no responsible authority ensuring that EO data are suitable and used to develop biodiversity and ecosystem service change indicators. The emerging IPBES would appear to be a prime candidate for this role, however. In that regard IPBES would function in the same way as the IPCC has in terms of defining the science/policy need, which is then addressed by the science community.

## Discussion

We have shown that current satellite-based EO data products, combined with those in research and development, have the potential to fulfil the monitoring requirements for over half of the ABTs and their respective indicators. We also show that EO can form the basis for over half of the 22 proposed EBVs, forming a subset of RS-EBVS. Four key challenges to making existing EO measurements fully useful for measuring EBVS and ABT indicators have been summarized.

Although the lack of long-term and global observations of land cover change has emerged as a major unfulfilled need of the biodiversity community new change products show promise for the future. These include but are not limited to decadal-scale forest cover change based on Landsat (Hansen et al., 2013) and a newly released land cover change product (GlobeLand30) that shows change in ten land cover types using Landsat and Chinese HJ-1 satellite images combined (Jun et al. 2014; Chen et al. 2015). There are also static products with potential for future change analysis, for example two new global urban settlement layers, the Global Human Settlement Layer (Pesaresi et al. 2013) based on optical imagery and the radar-based Global Urban Footprint (Esch et al. 2014). However, it is important that the temporal domain be prioritized over the spatial, that is that annual land cover change at moderate resolutions (300 $m^{-1}$ km) is preferable to one-off products at high spatial resolution ($\leq$30 m).

Earth Observation and the space sector, in particular, are rapidly evolving (Belward and Skøien 2015). A selection of upcoming EO missions in this decade and beyond which can yield potentially useful biodiversity observations is described in Table 3. The satellites listed have the potential to fill important data gaps, for example for spaceborne hyperspectral imagery, spaceborne laser altimetry and spaceborne estimates of biomass carbon, while there are likely to be many indirect observations as yet undiscovered which these satellite missions could provide.

These satellite sensors present new frontiers for biodiversity observations offering unprecedented global coverage at high spatial detail with sophisticated measurements of the structure, composition, biochemical and biophysical properties of the Earth's ecosystems. Yet putting this technology to good use requires knowledge sharing. Challenge 2 captures this issue and describes the need for more joined –up thinking between conservation and remote sensing scientists. More opportunities should be created for experts from both communities to combine their expertise, for example through dedicated focus groups and through practical working sessions such as the global 'EcoHack' (http://ecohack.org/). Alternatively, employment of diverse specialists in 'mixed teams', or in 'regular exchange' between recognized biodiversity and remote sensing institutes, should be encouraged on a long-term basis.

Challenge 3 calls for consensus among the biodiversity conservation community on what it really needs from EO. On the part of the EO community this entails finding the right balance between innovation and habitual, long-term products which would allow trends to be inferred and future changes to be predicted. Many of the existing CBD indicators, as well as potentially new indicators, could benefit from such a 'change product', in particular for reporting on habitat change and progress towards Aichi Target 5. This requires back-processing and reanalysis of existing temporal archives of EO data, and touches on challenge 1 dealing with standardization of EO data and products. This is crucial for time series which span multiple decades, to assess change based on pre-2010 benchmarks.

## Conclusion

Existing EO technology shows considerable potential for biodiversity indicators within the timeframe of the 2020 ABTs yet this potential have not been fully realized. Emerging EO technologies such as spaceborne LiDAR and hyperspectral imaging show promise for indicators beyond the 202 timeframe. A potential mismatch between what biodiversity conservation needs from EO in terms of building global indicators of change and what the EO community have provided appears to be a major reason for this unrealized and unused potential. Lack of standardization in EO data, lack of joined-up thinking among conservationists and remote sensing scientists, little consensus on what conservationists need and absence of institutional leadership appear to be compounded this problem. The proposal for RS-EBVs as a means to standardize EO observations for biodiversity indicators is one potential solution. This framework also calls for harmonization with non-EO data sources. Four important challenges to the adoption of this framework have been identified. The solution lies in a strategic approach and clear leadership, giving rise to more joined-up thinking between key players across the EO, biodiversity conservation and biodiversity policy sphere. Without this strategy, isolated one-off collaborative initiatives will continue and challenges will persist. There is an over-arching need for a global, conservation-relevant and multi-annual land cover change product for a number of indicators and ABTs. The biodiversity community need to contribute to the discussion on EO for biodiversity indicators and EBVs through forums like IPBES and engage with the EO community through networks such as GEO BON. Otherwise the full potential of EO remains unlocked at least until 2020 and perhaps beyond.

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## Conflict of Interest

None declared.

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**Appendix:** The following interviewees were consulted during the external phase of the review: Bob Scholes, South Africa Council for Scientific and Industrial Research (CSIR); Edward Mitchard, Edinburgh University; France Gerard, UK Centre for Ecology and Hydrology; Hervé Jeanjean, French Space Agency (CNES); Marc Paganini, European Space Agency (ESA); Gary Geller, National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory; Mark Spalding, The Nature Conservancy (TNC); Matthew Hansen, University of Maryland; Peter Fretwell, British Antarctic Survey (BAS); Rob Rose, Wildlife Conservation Society (WCS); Ruth de Fries, Columbia University; Ruth Swetnam, Stafforshire University; Colette Wabnitz, Secretariat of the Pacific Community (SPC); Susana Baena, Kew Royal Botanic Gardens; Lera Miles, UNEP-WCMC; Heather Terrapon, South Africa National Biodiversity Institute (SANBI); Ben Halpern, University of California; Jesse Ausubel, The Rockefeller University; Jorn Scharlemman, University of Sussex and Nathalie Petorelli, Zoological Society of London (ZSL).

 