Review on the use of remotely-sensed data for monitoring biodiversity change and tracking progress towards the CBD Aichi Biodiversity Targets

DRAFT FOR REVIEW

Document development

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Legal notice

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Key messages

1. **The potential of remotely sensed earth observation data to support biodiversity policy is yet to be fully realised.** Although technologies are improving and diversifying, the considerable amounts of data being generated are not being effectively used. Many of the products and demonstration initiatives provide spatial snapshots rather than temporal change analyses, limiting their utility for tracking the Aichi Targets. The lack of time series of important *in situ* biological data sets to compare against remotely sensed observations is also an important constraint.

2. **There are both constraints and opportunities presented by existing remote sensing technologies.** Key areas of development surround land cover change and water/air quality (Aichi Targets 5 and 8), although innovations in other areas offer additional opportunities including helping to fill some of the key gaps for Targets for which is has proven difficult to develop indicators using only *in situ* data (such as Aichi Target 9 and 15), and assessing effectiveness of conservation actions (Aichi Target 11). However, *in situ* data and statistical modelling are also required to create comprehensive indicators.

3. **Use of remotely sensed earth observation data is often constrained by access to data and processing capacity.** Whilst some data of appropriate spatial and temporal coverage and resolution are freely available, access to other potentially valuable and complementary data incurs a financial cost. Free and open access to all taxpayer-funded satellite remote sensing imagery would address this significant constraint. In addition, significant computational power and human resources may be required to process the data and create the kinds of analytical products suitable to inform indicators and assessments of progress towards the Aichi Targets.

4. **Remotely sensed data, when processed, packaged and communicated appropriately, can have impacts on policy and practice that yield positive biodiversity outcomes.** Current scientific understanding, computational power and web architecture create the possibility for automated products providing spatially explicit change analyses and alerts in ‘near real time’, in particular for forest cover.

5. **Creating a dialogue between data providers and users is key to realising the potential of remotely sensed data.** To date, this dialogue has been limited. A closer relationship between the earth observation community and potential users in the biodiversity policy and management communities would help to enhance understanding, align priorities, identify opportunities and overcome challenges, ensuring data products more effectively meet user needs.

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1. Introduction

1.1 Purpose

Parties to the Convention on Biological Diversity (CBD), through decision X/2, adopted a Strategic Plan for Biodiversity 2011-2020, including twenty Aichi Biodiversity Targets and committed to using these as a framework for setting national targets and to report on progress using biodiversity indicators. However, the task of monitoring elements of biodiversity and collecting the required data using traditional surveying techniques remains challenging. *In situ* measurements offer the potential of extracting precise information on the existence and distribution of species. However, monitoring often requires examining large extents of area on regular time intervals, making field measurements particularly time-consuming and cost-demanding. In addition, for certain high variable ecosystems such as wetlands or located in remote areas, field-based observation might be difficult.

Remote sensing data, derived from both airborne and satellite sensors, promise a repeatable and cost effective manner to cover spatially extended areas contributing to biodiversity monitoring. However, despite the wealth of remotely sensed data along a spectrum of sensors, wavelengths and resolutions, some of which are available free-of-charge, and examples of their potential use for biodiversity indicators at various geographic scales, there is still limited use of remote sensing data for biodiversity monitoring that can detect biodiversity change in time as well as in space. Whilst in part this may be due to data and analytical constraints, it may also in part be due to a lack of adequate connection between user needs (including the specification of standards for each indicator) and opportunities provided by remotely sensed data.

Biodiversity scientists together with the world's major space agencies are beginning to explore the challenges and opportunities for the use of satellite remote sensing for biodiversity research applications. However, explicit policy needs such as biodiversity indicators have to date received little direct attention, and functioning connections to the biodiversity policy/user community have not been made.

The present review of the use of remotely sensed data for monitoring biodiversity aims to contribute to fill this gap in the context of the CBD and the Aichi Biodiversity Targets, and it has been produced as a contribution to a developing effort to facilitate and expand the uptake of Earth Observations (EO) in the framework of the Convention. It focuses on:

1. Understand the main obstacles to, and identify opportunities for, greater use of remotely-sensed data and products in biodiversity monitoring and assessment.

2. Promote and facilitate enhanced, productive dialogue between the satellite remote sensing community and policy end users through a shared understanding of needs and opportunities.

1.2 Intended used and approach

Because the aim is to bridge the gap between the satellite remote sensing specialists (including researchers, analysts and modellers), biodiversity practitioners and managers, and policy end users, all three groups were considered both contributors and audience for this review. However, the technical level and content is directed mainly at the latter group. It is intended that the review will stimulate greater engagement of the satellite remote sensing community in the development and delivery of biodiversity indicators for the Aichi Biodiversity Targets and other policy needs by forming the basis for ongoing dialogue among the three groups.

A consultative process was conducted through a series of qualitative semi-structured surveys to compiled expert knowledge. A group of around 30 specialists consisting of appropriate representatives from the major space agencies and remote sensing scientists/analysists and indicator specialists from the international biodiversity policy community were selected to take part in the expert consultation. The results complemented a desk study review and form the basis of this review.

1.3 Organization of the review

Section 2 gives the reader a brief introduction to remote sensing methods and terminology, and compares these against traditional *in situ* measurements as a tool to monitor biodiversity. It answers common questions about what remote sensing is and how it is used.

Section 3 provides a view on the costs involved in using remotely-sensed data and analyses existing operational EO products according to their applications in biodiversity monitoring, and specifically in the framework of the CBD. Their potential for supporting the CBD Strategic Plan for Biodiversity 2011-2020 and tracking progress towards the Aichi Biodiversity Targets is discussed.

Section 4 maps remote sensing against each of the Aichi Biodiversity Targets in depth. Gaps and limitations for the use of remote sensing to develop indicators for each target are highlighted. In addition, the indicative list of indicators contained in Decision XI/3 is assessed to establish which indicators could be (partly) derived from remotely-sensed data. Information on spatial and temporal resolution suitable for global, regional and national levels, type of data and appropriate sensors required to develop the indicator is indicated. Potentially appropriate sensors for each Aichi Biodiversity Target and details on their characteristics are provided (e.g. host organization, repeat viewing frequency, availability, data products).

Section 5 summarises emerging applications of remote sensing for both marine and terrestrial environments relevant for biodiversity monitoring and exemplifies new areas of work and potential for future directions in the use of remote sensing in the context of the CBD.

Section 6 seeks to outline the key limitations that have hindered the use of remotely-sensed data in indicator development to date, and the main challenges encountered. For most of them improvements and possible solutions are suggested using practical examples.

Section 7 contains a number of case studies illustrating different approaches, methods and products used at national level to monitor diverse aspects of biodiversity, and their impact in decision-making and policy implementation. A regional example on capacity building is also featured.

Section 8 summarises the key points of the review and offers final thoughts and recommendations in the format of 'take home' messages.

1.4 Policy context: the Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets

The 10th meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD COP 10) saw the adoption of the new Strategic Plan for Biodiversity 2011-2020 (Decision X/2). This is comprised of a shared vision, a mission, five strategic goals and 20 targets, collectively known as the Aichi Biodiversity Targets. During COP11 an Indicator Framework for the Strategic Plan for Biodiversity 2011-2020 was adopted (Decision XI/3). It contains an indicative list of 98 indicators providing a flexible basis for Parties to assess progress towards the Aichi Biodiversity Targets.

Biodiversity indicators are a fundamental part of any monitoring system providing the mechanism for determining whether the policies and actions are having the desired effect. They are also designed to communicate simple and clear messages to policy and decision makers. Indicators use quantitative data to measure aspects of biodiversity, ecosystem condition, services, and drivers of change, and aim to help understand how biodiversity is changing over time and space. In the context of Aichi Biodiversity Targets, biodiversity indicators are useful if they address measures relevant to the Targets, as well as being relevant to priorities of the Strategic Goals, and can also be easily communicated.

The CBD-mandated Biodiversity Indicators Partnership (BIP) is the global initiative to promote and coordinate development and biodiversity indicators in support of the Convention. The Partnership brings together over forty organizations working internationally on indicator development to provide the most comprehensive information on biodiversity trends. Established in 2007 to support monitoring of the 2010 Biodiversity Target, its mandate was renewed during CBD COP11 (October 2012), becoming the principle vehicle for coordinating the development of biodiversity indicators at global, regional and national scales, and for delivery of indicator information for monitoring progress towards the Aichi Targets.

Finding suitable indicators is not the only obstacle for a global monitoring system. The lack of consensus about what to monitor and common sampling protocols are often a challenge. In CBD Decision XI/3, the Group on Earth Observation Biodiversity Observation Network (GEO-BON) was invited to continue its work on the identification of essential biodiversity variables (EBVs). The EBVs are being developed with the aim to help prioritize by defining a minimum set of essential measurements to capture major dimensions of biodiversity change, and facilitate data integration by providing an intermediate linkbetween primary observations and indictors (Pereira *et al*. 2013). In the context of the CBD and specifically the Aichi Targets, the EBVs could offer a way to harmonize monitoring efforts carried out by different observation communities, helping the development of a global earth observation system. A number of candidate EBVs have been proposed, but the list is still to be refined over the upcoming months. In this review we have used those EBVs from the candidate list for which remote sensing is relevant. However, as this list is periodically updated, their correlation with specific Aichi Biodiversity Targets and indicators might need to be review and updated.

2. The basics of remote sensing in biodiversity monitoring

2.1 What is remote sensing?

There are many possible definitions of the term Remote Sensing. Remote means away from or at a distance and sensing means detecting a property or characteristics. Therefore, Remote Sensing could be defined as the science of collecting and interpreting information about the Earth's surface without actually being in contact with it. In the context of environment management, United Nations (1986) states the term Remote Sensing means the sensing of the Earth's surface from ground-based, airborne or spaceborne sensors by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use and the protection of the environment.

2.2 An overview of remote sensing sources and applicability for monitoring biodiversity

2.2.1 Passive remote sensing

Remote sensing systems which measure energy that is naturally available are called passive sensors. The way to use passive sensors to examine, measure and analysis of an object is called **passive remote sensing or optical remote sensing**. Measurable energy takes the form of electromagnetic radiation from a surface, either as a reflection (reflected light) or as an emission (radiation emitted from the surface itself). For all reflected energy, this can only take place during the time when the sun is illuminating the Earth as there is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night.

Optical remote sensing is based on different areas of light's spectrum:

Visible spectrum (VIS), being this the portion of the electromagnetic spectrum from about 0.39 to 0.7 µm that is visible to the human eye. The VIS consists of three typical spectral bands: Blue band (0.45-0.515 µm) is used for atmospheric and deep water imaging, and can reach up to 50 m deep in clear water; green band (0.515-0.6 µm) is used for imaging of vegetation and deep water structures, up to 30 m in clear water; and red band (0.6-0.69 µm) is used for imaging of man-made objects, in water up to 9 m deep, soil, and vegetation

Infrared light occurs at wavelengths just below red light, hence the name, infra- (below) red. Near-infrared spectrum (NIR) ranges from about 0.7 to 1.1 µm that lies just out of the human vision, which is used primarily for imaging of vegetation. The NIR can be used to discriminate plant species. A recent study shows that the NIR has the potential to differentiate between the sex, age class, and reproductive status in the giant panda and may be applicable for surveying wild populations. Short-wave infrared (SWIR) light is typically defined as light in the 1.1 – 3.0 µm wavelength range. In the SWIR, imaging relies on the reflection of the atmospheric night sky light by the objects and it permits passive imaging during the night without starlight or moonlight illumination. One major benefit of SWIR imaging is the ability to image through haze, fog and glass. The SWIR are known to be very sensitive to leaf water content (Tucker, 1980), which therefore can enhance plant species identification. Mid-wave infrared spectrum (MWIR) ranges from about 3.0 to 5.5 µm and thermal infrared (TIR) ranges from 8 to 14 µm. Both MWIR and TIR imaging can capture the intrinsic heat radiated by objects (i.e., the objects' thermal emission): warm objects stand out well against cooler backgrounds. Warm-blooded animals become easily visible against the environment, day or night. The SWIR is perfectly suited to use this nightglow phenomenon to "see" objects even when it is pitch dark, which is a good compliment to thermal imaging. While TIR imaging can detect the presence of a warm object against a cool background, the SWIR imaging can actually identify what that object is. A latest study has found that the emissivity spectra of MWIR and TIR can be used to accurately identify the plant species (Ullah *et al*. 2012).

There are two methods to collect data using passive sensors:

Multispectral

Multispectral remote sensing collect data in few (more than 3 but less than 20) and relatively wide and noncontiguous spectral bands, typically measured in micrometers or tenths of micrometers, for example visible, near infrared, and short-wave infrared images in several broad wavelength bands. These spectral bands are selected to collect radiation in specifically defined parts of the spectrum and optimized for certain categories of information most evident in those bands. Due to that we can use the fact that different types of surfaces reflect the light of different wavelengths with various intensities. Different spectral behavior is leading to detailed classification of specific types of land surfaces (depending on the spatial, spectral and radiometric resolution of the used sensor). The remotely sensed spectral heterogeneity information provides a crucial baseline for rapid estimation or prediction of biodiversity attributes and hotspots in space and time.

Hyperspectral

Hyperspectral sensors measure energy in narrower and more numerous bands than multispectral sensors. Hyperspectral images can contain as many as 200 (or more) contiguous spectral bands. A reasonable criterion, to be considered in a rather flexible way, is that the hyperspectral remote sensing collects at least 100 spectral bands of 10-20 nm width. The numerous narrow bands of hyperspectral sensors provide a continuous spectral measurement across the entire electromagnetic spectrum and therefore are more sensitive to subtle variations in reflected energy. Images produced from hyperspectral sensors contain much more data than images from multispectral sensors and have a greater potential to detect differences among land and water features. For example, multispectral imagery can be used to map forested areas, while hyperspectral imagery can be used to map tree species within the forest.

2.2.2 Active remote sensing

Active sensors, on the other hand, provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. The way to use active sensors to examine, measure and analysis of an object is called active remote sensing. Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets.

Radar

Radar is an acronym for “radio detection and ranging”, which essentially characterizes the function and operation of a Radar sensor. Radar works by sending out microwave (radio) signals towards the target and detects the backscattered portion of the signal. By measuring the amount of time it takes for the signals to return, it is possible to detect the location, speed, direction and altitude of an object.

Radar technology allows us to experience the mystique of bird migration at night. It also serves as a useful tool for the study of bird migration patterns and behaviors, as well as alerting us to any changes in those patterns and behaviors (Liechti *et al*. 1995; Hilgerioh 2001; Ruth *et al*. 2005; Ruth 2007; Gudmundsson 2008). An important advantage to using Radar is that it can penetrate thick clouds and moisture, which would not be possible using optical remote sensing. This allows scientists to accurately map areas such as rain forests that are otherwise too obscured by clouds and rain. The high resolution Radar monitoring system is perfectly suitable in support of mapping and monitoring wildlife habitat. The system can provide regular information on the location of changes, such as changes in the forest canopy through logging or landslides, (illegal) clearing of areas (for agriculture, mining, oil palm plantation) and encroachment patterns, expansion of road networks, fire impacts and vegetation development (Bergen *et al*. 2009; Swatantran *et al*. 2012).

LIDAR

LIDAR stands for “light detection and ranging” and is very similar to the better known Radar. Basically, a laser pulse is sent out of a transmitter and the light particles (photons) are scattered back to the receiver. The photons that come back to the receiver are collected with a telescope and counted as a function of time. Using the speed of light we can then calculate how far the photons have traveled round trip. Lidar is a remote sensing technology that is now becoming more widespread in ecological research. The metrics derived from Lidar measurements can be used to infer forest canopy height and/or canopy structure complexity. Its ability to accurately characterize vertical structure makes Lidar a valuable and cost-effective approach for estimating forest attributes that are related to important ecological characteristics. In this regard, an attribute of particular interest is 3-dimensional habitat heterogeneity, which reflects the variability in both horizontal and vertical forest structure (e.g. stem, branch and foliage density and distribution). This structural variability is related to species richness and abundance, which are central components to understanding, modeling and mapping patterns of biodiversity (Vierling *et al*. 2008; Bergen *et al*. 2009; Goetz *et al*. 2010).

Sonar

Sonar – short for “sound navigation and ranging” - is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect objects on or under the surface of the water. Sonar works in a similar manner as Radar. However, instead of sending out radio waves, Sonar sensors send out sound waves. By measuring the time it takes for these sound waves to travel towards an object, bounce off of it, and then return, it is possible to calculate distances. Two types of technology share the name "Sonar": passive Sonar is essentially listening for the sound made by vessels; active Sonar is emitting pulses of sounds and listening for echoes. Sonar sensing may be used as a means of acoustic location and of measurement of the echo characteristics of "targets" in the water. Active Sonar allows scientists to accurately map the two thirds of the Earth that is under water. Active Sonar has been used to investigate the population dynamics of both deep and shallow water fish populations. Passive Sonar sensors that receive underwater sounds help overcome many of the limitations experienced with visual surveys. They have been incorporated into survey methods to improve animal abundance estimates, especially for cetacean surveys. For example, passive Sonar sensors have successfully been used in abundance estimates for several cetacean species including right whales, beaked whales, sperm whales, humpback dolphins, and finless porpoises (Akamatsu *et al*. 2001; Van Parijs *et al*. 2002; Barlow *et al*. 2005; Wade *et al*. 2006; Mellinger *et al*. 2007; Clark *et al*. 2010). The use of passive Sonar sensors may allow for more animal detections across larger ranges than would be obtained from visual methods alone, and facilitate the detection of animals that spend a large amount of time under water.

2.2.3 Levels

In addition, remote sensing can be classified according to the vehicle or carrier (called platform) by which remotes sensors are borne. According to the height of platforms, the remote sensing can be classified into three levels:

Table 2.1. Remote sensing classification according to the height of sensor-borne platforms

Level	Operational range	Height	Pros	
Ground	Short range	50-100 m	-Panoramic mapping -Millimeter accuracies -High definition surveying	
	Medium range	150-250m		
	Long range	Up to 1km		
Airborne	Balloon based	22-40km	- Unique way of covering a broad range of altitudes for in-situ or remote sensing measurements in the stratosphere - Opportunity for additional, correlative data for satellite based measurements, including both validation and complementary data - Important and inexpensive venue for testing instruments under development.	- Relative low cost - Flexibility in the frequency and time of data acquisition - Ability to record spatial details finer than current satellite technology can
	Aircraft		- Last minutes timing changes can be made to adjust for illumination from the sun, the location of the area to be visited and additional revisits to that location. - Sensor maintenance, repair and configuration changes are easily made to aircraft platforms. Aircraft flight paths know no boundaries except political boundaries	
Spaceborne	Space shuttle	250-300km	- Large area coverage - Frequent and repetitive coverage of an area of interest - Quantitative measurement of ground features using radiometrically calibrated sensors - Semi-automated computerized processing and analysis	
	Space stations	300-400 km		
	Low level satellites	700-1500 km		
	High level satellites	36000 km		

Aircraft based airborne remote sensing can be further categorized to manned aerial vehicle remote sensing and unmanned aerial vehicle (UAV) remote sensing according to the platform. The name UAV covers all vehicles which are flying in the air with no person onboard with the capability of controlling the aircraft. Thanks to GPS and communication technology, UAVs can be remotely controlled or flown autonomously based on pre-programmed flight plans or more complex dynamic automation systems. The benefits of UAVs mainly lie in the ease, rapidity and cost of flexibility of deployment that lends itself to many land surface measurement and monitoring applications. Although conventional airborne remote sensing has some drawbacks, such as altitude, endurance, attitude control, all-weather operations, and monitoring of the dynamics, it is still an important technique of studying and exploring the Earth's resources and environment.

2.3 How to use remote sensing to monitor biodiversity?

There are several approaches possible to use remote sensing to monitor biodiversity. Which approach is most suitable depends on the environment in which biodiversity is to be monitored; the characteristics of relevant species that occur in these ecosystems and the availability of remote sensing data. Four major approaches can be distinguished:

Direct measurements of individuals and populations

Direct measurements of individuals and populations are possible when very high resolution imagery is available, such as RapidEye, WorldView, GeoEye or Ikonos. Direct measurement is constrained to situations where the animals or their traces (such as burrows) can be easily detected. This means a limited vegetation cover, or a vegetation cover that is less high than the species involved. Examples where this kind of monitoring has been successfully implemented include elephants, wildebeest and zebra in the Serengeti (Zheng 2012) or marmots in Mongolia (Velasco 2009). Already in the 1980's Wombat burrows were identified from coarser resolution Landsat MSS imagery (Löffler and Margules 1980). The breeding distribution of the Emperor penguin in Antarctica has been mapped by spectral characterisation of breeding colonies on snow in Landsat imagery (Fretwell & Trathan, 2009).

Indirect proxies of biodiversity

Indirect proxies involve approaches where derived information from the reflectance values that are recorded by satellite sensors is used to infer information about biodiversity on the surface that was monitored. Such proxies can be based on variability along three potential axes, a spatial, a temporal and a spectral axis. The sensor at hand determines to great extent which proxies can be generated. Sensors with high spatial resolution offer a possibility to look at variability in the reflectance in neighborhoods of small size, i.e. with great detail. But satellite borne sensors of this kind are normally limited in their spectral and temporal dimensions. Likewise, sensors with high temporal resolutions (e.g. NOAA AVHRR or MODIS) are limited in their spectral and spatial extent. Which combination offers the best solution to monitor biodiversity depends heavily on the ecosystem and target species to be monitored. Recent literature suggest that spectral resolution would be preferred over spatial resolution (Rocchini *et al*. 2010 and references therein). The minimal size of homogeneous units within the system determines to a large extent which pixel size is acceptable. Likewise, the difference in phenology of key species in the system determines whether variation over the temporal axes can help in identifying changes in biodiversity (Oindo and Skidmore 2002).

Ancillary data

Next to indirect proxies, ancillary data is often derived from satellite data that have direct biophysical meanings, such as altitude from digital elevation models, green biomass from Normalized Difference

Vegetation Index (NDVI) products, vegetation cover, or surface temperature. These ancillary data sometimes can have a direct link to diversity (Baldeck *et al*. 2013) and be used as a proxy value. In addition they are often used as explanatory variables in species distribution modeling (SDM), which in turn can be used for species diversity assessments, as described below. Nevertheless, diversity in ancillary data, such as altitude also provides information about species diversity at intermediate scales, because it can represent heterogeneity in available niches (Allouche *et al*. 2012).

Inputs to Species Distribution Models

Remotely sensed data can also be used as an essential input to SDMs. These models, which are often implemented to map the distribution of single species, can be aggregated to map areas with high probabilities of many species (i.e. hot spots) and few species (i.e. cold spots). Often this does not involve raw satellite reflectance signals, but further refined products such as surface temperature, rainfall data, NDVI or seasonality of NDVI. These are often important parameters for most species that try to find an optimum in a multidimensional optimization of environmental conditions.

2.4 Developing biodiversity indicators from remotely-sensed data

The development of biodiversity indicators involves a two stage process. Firstly it needs to be determined which biodiversity variables are needed to capture the status of the system. Secondly, a suitable remote sensing product has to be selected that can be linked to this variable. Many methods exist to derive information from Remote Sensing data, but depending on the system under monitoring and the required level of detail, a choice has to be made. In section 3.2 a summary of existing operational EO products and their applications in biodiversity monitoring can be found.

It is worth noting that satellite-derived information is not in a format which can be readily used as a biodiversity indicator but requires some modification in order to become an indicator (Strand *et al.*, 2007). GIS-based analysis of remotely-sensed information, supported by ground validation, is usually required before the data can become a usable indicator. This process of refining remote sensing information to the level of a biodiversity indicator is not straightforward and there are sometimes limits to the type and complexity of the indicators which can be developed. This applies to both terrestrial and marine environments which demonstrate unique challenges to indicator development (see sections 6.1 and 6.2 for further details).

2.5 Why use remote sensing to monitor biodiversity?

2.5.1 Traditional *in situ* methods

A variety of traditional *in situ* methods exist to survey (and then monitor) biodiversity. Their adequacy strongly depends on the target taxon. Common methods for sessile organisms (plants, fungi) are quadrant and transect sampling, where a square frame or rope, respectively, delineates the plot horizontally. Scientific methods to collect mobile species include canopy fogging (insects; e.g. Paarman & Stork 1987, Yanoviak *et al*. 2003), netting (birds: e.g. Dunn & Ralph 2004, Arizaga *et al*. 2011); bats: e.g. Larsen *et al*. 2007, Kalko *et al*. 2008; and fish: e.g. Lapointe *et al*. 2006, Achleitner *et al*. 2012,), pitfalls (e.g. herpetofauna: Ribeiro-Júnior *et al*. 2008, Sung *et al*. 2011), pheromones or light (insects: e.g. Baker *et al*. 2011) and camera traps (e.g. O'Brian & Kinnaird 2013). Occasionally artifacts (e.g. pellets, dung, larval pupae) serve as evidence too (Hill *et al*. 2005), and for some species, indirect measurements may suffice for identification (e.g. acoustic monitoring of bats and birds Jones *et al*. 2013).

To obtain a representative sample of the examined habitat, a number of plots are typically required. To optimally allocate sampling effort in this respect, plots may be (systematically or randomly) stratified and/or clustered. In addition, often only a (random) subset of a quadrant is sampled, and observations along transects are recorded at predefined intervals only. Temporal variability of the target habitat may be as important to survey planning as spatial heterogeneity, because seasonality, daytime, weather and irregular disturbances (e.g. fires) co-determines the presence and / or detectability of an organism. In such situations plots may require multiple sampling visits to avoid/reduce temporal bias.

Species accumulation curves (which plot sampling effort unit vs. species found) are used to assess the sufficiency of sampling effort in a given plot. Inventory results are typically summarized into various diversity indices (e.g. Simpson or Shannon-Wiener), which are calculated from the observed number of different species (richness) and their relative abundance per sample unit (evenness).

Monitoring biodiversity with traditional in situ methods often requires as much effort as compiling the initial inventory (see above), because repeat measurements should be based on (nearly) the same sampling design and methods to accurately detect changes. Some optimization is possible though using occupancy modeling and power analysis (e.g. Sewell *et al*. 2012).

Especially in case of sparsely distributed organisms, as well as difficult to detect individuals (discussed e.g. in Mazerolle *et al*. 2007), traditional in situ sampling efforts may also become prohibitively expensive before a sample size is reached with sufficient statistical power to allow for estimates of (changes in) abundance.

Inaccessibility of some habitats within a study region (e.g. steep slopes, thick mangrove) but also practical considerations (e.g. proximity to roads or observer populations) may affect the comprehensiveness of results obtained with traditional in situ methods.

All sample site allocation schemes require a priori knowledge of the spatial (habitat) heterogeneity, which may be insufficient – especially at finer scales. Consequently some biodiversity values within the study region may remain undetected.

Insufficiently standardized sampling protocols may reduce the reproducibility of the initial inventory and thus inflate uncertainty of subsequent monitoring results (e.g. Braga-Neto *et al*. 2013).

Results cannot be extrapolated to the surrounding landscape or different temporal periods. At most, using expert knowledge and some generalized habitat maps, observed species-habitat relationships can be used to infer biodiversity in similar settings. The common practice however is to depict results of traditional in situ methods either as atlas grid cells or homogeneously for an entire examined area or strata.

2.5.2 Remote sensing

Remote sensing cannot replace traditional in situ methods for compiling initial inventories of species, except in case of very large species identifiable on airborne images. However, remote sensing is a valuable large scale biodiversity monitoring tool at the level above species if coupled with quality ground data and likely to grow in value if embedded in a global, harmonized observation network (Pereira *et al*. 2013).

Remote sensing can be very useful for both planning surveys (and delineating strata in which initial surveys take place) as well as most importantly monitoring biodiversity changes thereafter. For example, remotely sensed imagery allows delineation of (spatial-temporal) habitat classes and strata within a study area, which is crucial for optimal sample site allocation. Remote sensing can also be used to identify habitat in space and time, which has not been examined yet with traditional in situ methods, and may harbor overlooked or yet unknown species. To meet the requirement of carrying out repeat measurements under spatiotemporal conditions similar to the initial inventory, remote sensing is extremely useful in identifying when and where to monitor.

If a robust relationship between ground truth observations and multivariate remote sensing data can be established, biodiversity conditions may be estimated for similar settings outside the study area – at species level by means of aggregated Species Distribution Models (SDMs) (e.g. Raes *et al*. 2009, Dubuis *et al*. 2011) or at ecosystem level (e.g. Duro *et al*. 2007, Roccini *et al*. 2010). Using SDM techniques, remote sensing represents an efficient and cost-effective monitoring tool. To identify and calibrate reliable biodiversity proxies and indicators (see section 2.4 for further), permanent monitoring plots and standardized survey protocols are essential (e.g. Jürgens *et al*. 2012, Chawla *et al*. 2012, and Braga-Neto *et al*. 2013).

Table 2.2. Advantages and disadvantages of remote sensing compared to traditional *in situ* methods

Advantages	Disadvantages
Provide a continuous, repetitive, large-scale synoptic view relative to traditional point-based field measurements	Remote sensing instruments are expensive to build and operate
Practical way to obtain data from dangerous or inaccessible areas	Remote sensing data are not direct samples of the phenomenon and it must be calibrated against reality. The measurement uncertainty can be large
Relatively cheap and rapid method of acquiring up-to-date information over a large geographical area	Remote sensing data must be corrected geometrically and georeferenced in order to be useful as maps, not only as pictures. This can be easy or complicated
Easy to manipulate with the computer, and combine with other geographic coverage in the GIS.	Remote sensing data interpretation can be difficult, which usually need to understand theoretically how the instruments is making the measurements, need to understand measurement uncertainties, and need to have some knowledge of the phenomena you are sampling.

3. Earth Observation products and costs for biodiversity monitoring

3.1 Relative costs of using remote sensing for biodiversity monitoring

3.1.1. Data production

Data can be produced by public institutions, such as space agencies and national geo-spatial agencies, or via commercial companies. Many spaces agencies have adopted an open access data policy, offering free data to virtually all users. Nonetheless, a full and open access data policy does not necessarily mean easy and fast data access, and sometimes distribution of imagery can be subject of a fee depending on the type of user agreement in place. For more details see section 6.1.2.

High resolution imagery is usually available via commercial companies and costs vary depending on the remote sense technology used, amount of imagery requested, and specific agreement with the data provider.

Costs of the most common and popular satellite products are summarized in table 3.1. Prices are in USA dollars ($) as estimated in mid-2013.

Table 3.1. Costs of the most common and popular satellite products as of mid-2013

Satellite (sensor)	Pixel size (m)	Minimum order area (sq. km)	Approx. cost ($)
NOAA (AVHRR)	1100	Free	No cost
EOS (MODIS)	250, 500, 1000	Free	No cost
SPOT-VGT	1000	Free	No cost
LANDSAT	15, 30, 60, 100, 120	Free	No cost
ENVISAT (MERIS)	300	Free	No cost
ENVISAT (ASAR)	150	Free	No cost
SRTM (DEM)	90	Free	No cost
EO-1 (Hyperion)	30	Free	No cost
EOS (ASTER)	15, 30, 90	3600	100
SPOT-4	10, 20	3600	1,600 - 2,500
SPOT-5	2.5, 5, 10	400	1,300 – 4,000
SPOT-6	1.5, 6.0	500	1,000 – 3,000
RapidEye	5	500	700
IKONOS	1, 4	100	1,000 - 2,000
QuickBird	0.6, 2.4	100	2,500
GeoEye	0.25, 1.65	100	2,000 – 4,000
WorldView	0.5, 2, 4	100	2,600 – 7,400

Source. IKONOS, QuickBird, GeoEye, WorldView and RapidEye: Landinfo. SPOT 4 & 5: Astrium EADS. Aster: GeoVAR. SRTM DEM, Landsat, Hyperion, MERIS, ASAR, AVHRR, SPOT-VGT and MODIS: NASA, ESA and Land Cover Facility

3.1.2. Data analysis

Data can be analysed either *in house* or be outsourced. Space Agencies most often analyse their own data as they have the required expertise. Agencies at the national, provincial and local level might outsource the process to commercial companies offering the service, which they cost according to the amount of work and level of complexity.

3.1.3. Data validation

Companies or institutions creating the data would verify it as part of the creation process, but verification and updating may also be done by those experts who have knowledge of the specific area. The cost are usually incurred at the point of data editing, or in the case of the expert being requested for their input the cost incurred could be equal to that of their hourly rate.

3.1.4. Other costs

Besides the above costs, there are a number of other costs associated with the use of Earth Observation for biodiversity mapping and monitoring that need to be taken into account. The key categories to consider are:

- Hardware and software costs
- Training and support costs
- Age and frequency of the EO data required
- Type of EO product to purchase

The following examples illustrate the broad costs for each of the above categories in USA dollars ($), as estimated in mid-2013. However, it is an estimate, and advice from suppliers of services and products should be foreseen to refine the estimates. The estimates provided below reflect the basic versions of commercial products which could be used to support the various image processing and analysis requirements.

3.1.4.1. Hardware and software costs

Hardware requirements can/should include:

- Production based computer: $2,000 - $4,000
- Plotter (or large format color printer) – $4,500 – $13,500

Software requirements can include:

- Image processing package
    - ERDAS Imagine Professional - $13,500 for 1 license
    - Exelis ENVI (no versioning) – $4,500 for 1 license
- Desktop GIS package to allow integration of datasets, GIS analysis functions
    - ArcGIS 10 – $3,000
    - MapInfo – $2,000
- Integrated GIS and Remote Sensing software
    - ILWIS 3.8 – Open source and free of charge, http://52north.org/

3.1.4.2 Training and support costs

Depending on the complexity of the earth observation monitoring using remote sensed data with support of field data should be 2-4 person weeks of effort (also depending on size of area). In addition:

- GIS and Remote Sensing expertise would be required
- Training can be provided, or personnel can be hired

A key factor influencing the decision to hire specialists or to invest in-house is whether the inventory and future monitoring is going to be done frequently or not. For short duration work perhaps only performed every three years, it is likely that consistent product quality will not be possible using in-house personnel that are infrequently using their skills. Instead, hiring external services and working with them closely to ensure the quality will yield the best results.

3.1.4.3. Age and frequency of the EO data required

Data costs are affected by:

- Urgency - emergency services - the faster you need it, the higher the cost.
- Age of the data - the older the data, the less expensive it is.
- Spatial resolution - the higher the spatial resolution, the higher the cost.
- Level of the product – the higher level image processing, the higher the cost.

3.2 Operational Earth Observation products used to monitor biodiversity

The field of remote sensing is a discipline in fast and constant evolution, with an increasing number of operational Earth Observation (EO) products that can be used for biodiversity monitoring. The choice of product can be daunting due to this fast pace, as it is difficult to keep up-to-date with the latest developments and improvements in the different areas. Nonetheless, the choice of product is in first instance determined by what is to be monitored.

On the following pages existing operational EO products are summarized according to their applications in biodiversity monitoring and their potential to support the Convention. To this purpose they have been mapped against the key Aichi Targets they have the potential to help tracking progress towards and the CBD operational indicators. In addition, candidate EBVs they could contribute to have been identified. Databases mentioned can be found in the Annex (Tables 10.1 and 10.2). In addition, a more detailed mapping including secondary Aichi Biodiversity Targets these products could support, key features, summary of key features and available datasets can be found in the Annex to this review (Table 10.3).

3.2.1. Operational land-based EO products

Land cover and Land cover change

Land cover is the visible features of the Earth surface including vegetation cover as well as natural and manmade features which cover the surface of the Earth (Campbell, 2006). These are physical features of the Earth surface in contrast to land use which is an implied use of the feature, e.g. a field for agriculture. Physical features of the Earth's surface reflect solar radiation in different ways and therefore demonstrate unique spectral characteristics. The spectral characterization of different land cover types allows land cover to be mapped over broad areas from EO satellite sensors. Land cover can be mapped at a range of spatial scales. At the local-scale ground surveys are often employed while aerial and satellite images are more commonly employed from regional to national scales.

Land cover maps are frequently used as a means of visually assessing broad-scale patterns in land cover across regions, countries or continents and relating these with species distributions or species richness (Cardillo *et al.*, 1999) and identifying likely biodiversity hotspots through 'gap analysis' (Scott and Jennings, 1998). Such maps can also be useful to identify land cover change in and around protected areas and can contribute to improved management of existing protected areas (Jones *et al.*, 2009). Land cover can be used as a variable to parameterise land use, agro-meteorological, habitat and climate models and as inputs to more complex EO-based products such as the MODIS LAI and FAPAR (Myneni *et al.*, 2002).

Examples of operational land cover maps and some land cover data distributing centers are listed in the annex to this section. While these are open-access land cover maps, they have been created using different methodologies and classification systems which have been designed to satisfy different end user requirements and institutional needs. This makes integration of land cover maps very difficult. Furthermore, these tend to be static maps giving a snapshot of land cover in time although some have periodic updates, e.g. CORINE Land Cover (CLC) 1990, 2000 and 2006. The biodiversity community could benefit from an assessment of needs in relation to land cover mapping. This could help to focus efforts to produce a set of land-cover/use products that meet the needs of the biodiversity community.

Land cover and land cover change is most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in extent of selected biomes, ecosystems and habitats (decisions VII/30 and VIII/15)
  - ✓ Trends in the proportion of natural habitats converted
- GEO BON EBVs
  - ✓ Ecosystem extent and fragmentation
  - ✓ Habitat disturbance

Fire

The thermal radiation emitted by surface fires is detectable from EO sensors (Dozier, 1981). For example, the Along Track Scanning Radiometer (ATSR) sensor produces monthly fire maps based on land surface temperature data. The ATSR World Fire Atlas shows the spatial extent of burnt areas and the locations of active fire fronts (Arino *et al.*, 2005). However, spectral information in range of wavelengths, from the visible to infrared, can be potentially be used to detect active fires and separate them from non-burned areas, as has been done with MODIS (Roy *et al.*, 2007). Forest fire can rapidly alter ecosystem structure and change the nature of surface materials from living vegetation to charred organic matter and ash (Kokaly *et al.*, 2007).

Regularly-acquired fire data can contribute to understanding the temporal cycle of fire activity on a seasonal and annual basis and its impact on greenhouse gas emissions, in particular carbon dioxide (Zhang *et al.*, 2003). Operational fire products are produced at continental to global scales and updated in near real-time. The International Strategy for Disaster Reduction provides a comprehensive list of EO-based fire products. Fire products from 1999 to present are open access from the Global Land Service portal using SPOT/VGT data and MODIS products from the Land Processes Distributed

Active Archive Centre (LP-DAACs). The MODIS Rapid Response System provides near real-time fire monitoring from a variety of EO sensors. The European Space Agency ATSR World Fire Atlas has monthly global fire maps from 1995 to present. While these data sources provide information on the spatial distribution of fires and their timing, understanding the cause of fires is important for conservation planning.

Fire products are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced

- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in extent of selected biomes, ecosystems and habitats (decisions VII/30 and VIII/15)

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced

- GEO BON EBVs
  - ✓ Disturbance regime

Biophysical vegetation parameters

There are two operationally-produced biophysical vegetation parameters, Leaf Area index (LAI) and the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) which are important in several surface processes, including photosynthesis, respiration and transpiration (Baret *et al*., 2013).

LAI is defined as the area of leaf surface per unit area of soil surface (Campbell, 2006) and is an important variable for surface-atmosphere interactions such as water interception, photosynthesis and evapotranspiration and respiration. FAPAR acts like a battery for the plant photosynthetic process measuring the plants ability to assimilate Photosynthetically Active Radiation (PAR) and generate green leaf biomass (Gobron *et al*., 2006). Both of these parameters are related as LAI is the biomass equivalent of FAPAR and both play a role in driving ecosystem process models. For example, FAPAR is an essential variable in light use efficiency models (McCallum *et al*., 2009).

LAI can be measured in-situ by measuring leaf area directly or through hemispherical photography while FAPAR can be inferred from measurements of incoming and outgoing solar radiation. However, both of these methods are labour intensive. Remotely-sensed LAI and FAPAR products are generated at regional and global scale and produced operationally form sensors such as Envisat EMRIS (non-operational since 2012) and Terra MODIS. However, gaps due to cloud cover necessitate compositing daily data into regular intervals typically from 8 to 16 days. Time series of LAI and FAPAR can be used to monitor seasonal vegetation dynamics such as crop cycles and land surface phenology. For example, a global greening trend has been detected using a multi-decadal time series of LAI (Siliang *et al*., 2010).

The biophysical vegetation parameters are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
  - ✓ Target 10. By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.
  - ✓ Target 14. By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Status and Trends in extent and condition of habitats that provide carbon storage
  - ✓ Trends in primary productivity

- GEO BON EBVs
  - ✓ Net Primary Productivity (NPP)
  - ✓ Phenology

Vegetation Productivity Spectral Indices

A spectral index such as the Normalised Difference Vegetation Index (NDVI) is generic to any sensor recording electromagnetic radiation in the red and near infrared spectral bands. However, the shortcomings of NDVI, in relation to the influence of atmosphere and sensor-specific variation, have already been documented (Pinty and Verstraete, 1992). Other spectral indices such as the MODIS Enhanced Vegetation Index (EVI) have been designed for specific sensors however. While the NDVI solely employs spectral information, indices such as the EVI are built on spectral information parameterised for sensitivity to green biomass and are therefore less likely to saturate in areas of dense biomass such as rainforest (Huete *et al*., 2002). The NDVI is a general indicator of vegetation presence or absence but is less stable than the EVI, particularly in time series analysis. However, both indices can show variation in vegetation productivity and condition when mapped spatially. These spectral indices can be used at any scale from local to global, particularly the NDVI as any sensor measuring radiation in the red and near infrared spectral bands is all that is required. However, there is a need for awareness of the strengths and weakness of these indices and caution in applying them to strictly quantitative rather than qualitative analyses (Campbell, 2006). The biophysical variables are best used in quantitative analysis of vegetation variables. These indices are best used as general indicators of the vegetation state and are useful to detect relative change in vegetation condition, in particular to detect where habitat disturbances are occurring and causes a reduction in the spatial extent of vegetated areas.

The Vegetation Condition Index (VCI) and the Vegetation Productivity Index (VPI) are operational global products based on NDVI. These products compare contemporary NDVI data with historic trends to identify vegetation growth anomalies, e.g. drought, and so are useful to monitor temporal change in vegetation condition. The VCI and VPI can be obtained from the Copernicus Global Land Service.

The biophysical vegetation parameters are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in condition and vulnerability of ecosystems
  - ✓ Trends in primary productivity
- GEO BON EBVs
  - ✓ Ecosystem extent and fragmentation
  - ✓ Habitat disturbance.

Vegetation Cover and Density

Vegetation Continuous Fields (VCF) and Fraction of vegetation Cover (fCover) are designed to measure the relative spatial coverage of vegetation in an image pixel. While the VCF estimate the relative proportions of vegetative cover types per pixel: woody vegetation, herbaceous vegetation, and bare ground (de Fries *et al*., 1999, Hansen *et al*., 2003), the fCover is a relative measure of the gap fraction in green vegetation (Baret *et al*., 2007). However, fCover has also been used as an input to climate models in separating the contribution of soil from vegetation (Baret *et al*., 2013).

They are also important components of land cover. For example, the continuous classification scheme of the VCF product may be more effective in characterising areas of heterogeneous land cover better than discrete classification. Regularly updating static land cover maps with measures of fCover can incorporate disturbance as a land cover variable producing more adaptable land cover products. Annual and global VCF data from Terra-MODIS (NASA) imagery are distributed by the Global Land Cover Facility (GLCF). The fCover product is accessible from the Copernicus Global Land Service.

Vegetation Continuous Field and fraction of green cover are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in proportion of degraded/threatened habitats
  - ✓ Trends in fragmentation of natural habitats
- GEO BON EBVs
  - ✓ Ecosystem extent and fragmentation
  - ✓ Habitat disturbance.

Biomass

Biomass is quantified in terms of the overall mass of plant material (Campbell, 2006). EO-based measures of biomass are calibrated and validated using local-scale in-situ measures of above-ground biomass (Saatchi *et al*., 2007), while below-ground biomass is a more challenging parameter for EO-based technology (Cairns *et al*., 1997). However, the total combined above-ground and below-ground biomass has been estimated from a synthesis of EO and airborne sensor data, as well as ground measurements, across Latin America, sub-Saharan Africa, and Southeast Asia (Saatchi *et al*., 2011). As there is currently no EO sensor directly monitoring biomass, remotely-sensed methods of biomass estimation are indirect and inferred from estimates of vegetation canopy volume. Therefore canopy height estimation from airborne or satellite LIDAR is an important first step in biomass calculations which are then extrapolated over large areas using a model based on coarser resolution satellite imagery (Saatchi *et al*., 2011).

As most of the global biomass is held in woody trees (Groombridge and Jenkins, 2002), biomass is frequently used as preliminary variable to assess forest carbon stocks. Satellite-derived estimates of above-ground woody biomass provide reliable indications of terrestrial carbon pools (Dong *et al*., 2003). Therefore, remote sensing of deforestation, land use change and global forest fires can contribute to improved models of the global carbon cycle. Changes in biomass are also likely to result in changes in biodiversity.

As biomass estimation methods are labour intensive and indirect, EO-based biomass products are not yet operational. However, Dry Matter Productivity (DMP) is produced operationally and can be accessed from the Global Land Service, GEONET Cast and DevCoCoast. DMP represents the daily growth of standing biomass (equivalent to the Net Primary Productivity) and is expressed in kilograms of dry matter per hectare per day. The European Space Agency mission, BIOMASS, due in 2020 and based on radar technology, will provide global measurements of forest biomass (Le Toan *et al*., 2011).

Biomass is most relevant to

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
  - ✓ Target 15. By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.

- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in primary productivity
  - ✓ Status and trends in extent and condition of habitats that provide carbon storage

- GEO BON EBVs
  - ✓ Habitat Structure
  - ✓ Net Primary Productivity (NPP)

3.2.2. Operational marine EO products

Ocean-based EO products differ in their method of retrieval and their spatial and temporal coverage from land-based products (Campbell, 2006). This difference is predominately due to the physical reflectance characteristics of land surfaces and water bodies. Water reflectance is determined by the state of the water surface, the amount and type of suspended material in the water column and the bottom substrate in areas of shallow water (Lillesand *et al*., 2008). Furthermore, dynamic ocean variables such as eddies and currents change at a more rapid rate than polar-orbiting sensors can sufficiently monitor (Campbell, 2006).

Nevertheless, satellite sensors (e.g. SeaWiFs, Envisat MERIS and NOAA AVHRR) have been optimised to retrieve ocean variables such as ocean colour (chlorophyll-a concentration in mg/m3) (Brewin *et al*., 2011), ocean Primary Productivity (Antoine *et al*., 1996), suspended sediment , sea surface wind speed (m/s), sea surface temperature (°C) , sea surface salinity and sea surface state (Campbell, 2006). While these are important state variables of the oceans and routinely monitored to track climate change, they are also habitat parameters in themselves. For instance, oceanic variables can be correlated with sea bird density and species compositions (Hyrenbach *et al*., 2007), cetacean species ranges (Tynan *et al*., 2005), as well as the distribution of pelagic species and near shore fishes (Johnson *et al*., 2011). Measures of ocean colour can be related to the abundance and type of phytoplankton which has important implications for the marine food chain (Brewin *et al*., 2011). For climate change monitoring in the marine envrionment, satellite remote sensing has been used to track Arctic sea ice extent, sea level rise, tropical cyclone activity and sea surface temperature (IPCC, 2007). This application of satellite remote sensing is discussed further in relation to Aichi target 15 in section 4.Global ocean colour, sea surface temperature and salinity are operationally produced and available for download from the NASA Ocean Colour website or from the GMES My Ocean website. ESA have an operational data portal for Ocean colour products called Globcolour. The NOAA Ocean Surface and Current Analysis (OSCAR) provide near-real time global ocean surface currents maps derived from satellite altimeter and scatterometer data.

The marine EO products are ocean colour (chlorophyll-a concentration in mg/m^3), ocean Net Primary Productivity (NPP), suspended sediment, sea surface wind speed (m/s), sea Surface temperature (°C), sea surface salinity and sea surface state. They are most relevant to:

- CBD Aichi Biodiversity Target
    - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
    - ✓ Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
    - ✓ Trends in condition and vulnerability of ecosystems
    - ✓ Trends in sediment transfer rates storage

- GEO BON EBVs
    - ✓ Ecosystem extent and fragmentation
    - ✓ Habitat disturbance
    - ✓ Net Primary Productivity (NPP)

3.3.3 EO products for pollution monitoring

Remote sensing has considerable potential in monitoring the spatial extent of polluting material both in the upper atmosphere, on the land surface and in the marine environment. Though this is a relatively new application of earth observation satellite technology, it is a promising field of development and potentially impacts on a number of EBV categories and in helping to chart the progress towards achieving the 2020 Aichi targets. The EO products related to pollution are not strictly operational in that these products are mostly in development or form part of larger data dissemination and early warning systems. Nevertheless, examples of EO-based information systems which are currently in use for monitoring and forecasting pollution events are listed below.

Atmospheric pollution and greenhouse gas emissions

Some atmospheric pollutants contribute to the greenhouse effect while others are directly harmful to life and can contribute to habitat degradation and biodiversity loss. The main greenhouse gases are carbon dioxide, methane and nitrous oxide (N2O). Further information on these gases and their implication for climate change can be found online (Greenhouse Gas Online, 2013).

The European Infrared Atmospheric Sounding Interferometer (IASI) measures the total column content of the main greenhouse gases, i.e., ozone, methane, nitrous oxide and carbon monoxide. These measurements contribute to an understanding of climate processes though their assimilation into global climate models. Products can be obtained from the IASI or associated sensors such as the EUMetsat Polar System (EPS). These products relate to temperature, humidity, ozone content and trace gas constituents of the atmosphere.

The NASA Microwave Limb Sounder (MLS) instrument measures passive microwave radiation from the upper atmosphere and derives estimates of atmospheric gases, temperature, pressure, and cloud ice. The MLS instrument is unique in its measurements of pollution in the upper troposphere as it can see through ice clouds that previously prevented such high altitude measurements. Such data can provide insights into the long-range transport of pollution and its possible effects on global climate. Near real time MLS products such as temperature, water vapor, ozone, carbon monoxide, water vapor, nitrous oxide, nitric acid and sulphur dioxide can be viewed online.

Nitrogen dioxide (NO2) is a mainly man-made gas which forms nitric acid when oxidised creating acid rain. Acid rain has adverse impacts on soil, vegetation and can contribute to ocean acidification. Nitrogen oxides such as NO2 are produced by emissions from power plants, heavy industry and road transport, along with biomass burning. NO2 is important in atmospheric chemistry as it is responsible for the overproduction of tropospheric ozone, i.e. in the lower part of the atmosphere. A global NO2 pollution map was produced by the ESA Envisat Sciamachy satellite in 2004 although this sensor was decommissioned in 2012. However, a variety of Sciamachy-based atmospheric products from 2002 to 2012 are available though registration with ESA on their data user portal. Upper atmosphere, stratospheric N2O is inferred from measurements by sensors on board the US AURA and European MetOp satellite series.

The atmospheric EO products that relate to NO_2 and ozone are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in nitrogen footprint of consumption activities
  - ✓ Trends in ozone levels in natural ecosystems
- GEO BON EBVs
  - ✓ Habitat disturbance

Ocean pollution

Oil spills such as the Prestige disaster of 2002, the Exxon Valdez in 1989 or the Deepwater Horizon oil rig of 2010 are a reminder of the threat posed to the marine environment of oil spills. Fortunately, large-scale surveillance of oil spills in the marine environment can now be readily achieved by satellite and airborne remote sensing (Leifer *et al.*, 2012). Accidental, high-impact oil spills, and non-accidental incidental spills from marine vessels can be tracked in spatial extent and flow direction (Engelhardt, 1999). Remote sensing is also used to localise point sources of oil slicks and for tactical assistance in emergency remediation.

Synthetic Aperture Radar (SAR) is the most frequently used satellite-based tool since it operates at night time. It penetrates cloud cover and is sensitive to surface roughness (Bern *et al.*, 1993; Campbell, 2006). The smooth oil slick contrasts with the surrounding surface water and appears as a dark patch on the SAR image.

CleanSeaNet is an example of an operation oil spill monitoring service based on EO technology which consists of oil slick imaging systems which also provide real-time sea state and weather information. This information is essential to track the rate and direction of slick movement. CleanSeaNet, which is operationally employed by marine authorities in EU member states, is part of the Global Monitoring for Environment and Security (GMES) initiative. Pollution alerts and related information is relayed to the relevant authorities 30 minutes after image acquisition for timely response. Currently, there are no operational open access products on ocean pollution events as they are relayed to relevant users as they occur and therefore need rapid delivery through formalised systems.

The impact of spills on biodiversity can be accessed through the integration of remote sensing imagery with other geographical layers such as marine and coastal protected areas and marine species ranges (Engelhardt, 1999). For example, the NOAA Office of Rapid Response and Restoration has produced an open-access Environmental Sensitivity Index (ESI) system, based on multiple data layers on biological and human land use of shorelines, for the U.S. This index is used to rank shorelines according to their sensitivity to an oil spill. The system is useful to planners for contingency planning before an oil spill occurs and for rapid response once it has occurred in order to direct resources to where they are most needed.

The oceanic EO products that relate to oil spill detection and shoreline sensitivity are most relevant to

- CBD Aichi Biodiversity Target
  - ✓ Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in emission to the environment of pollutants relevant for biodiversity

- GEO BON EBVs
  - ✓ Habitat disturbance

4. Mapping of indicators to track progress towards the Aichi Biodiversity Targets and EO products

In Decision XI/3, Parties to the CBD adopted an Indicator Framework for assessing progress towards the goals of the Strategic Plan for Biodiversity 2011-2020. It contains an indicative list of 98 indicators that provides a flexible basis for Parties to assess progress towards the Aichi Biodiversity Targets which can be adapted taking into account different national circumstances and capabilities.

In the same decision Parties were invited to use this flexible framework and the indicative list of indicators and to prioritize the application at national level of those indicators that are ready for use at global level to track country progress towards the Aichi Targets. In addition, the Executive Secretary in collaboration with the BIP and GEO-BON among other partners was requested to develop practical information on the indicators, including information on data sources and methodologies to assist in the application of each of the indicators.

In order to support Parties to monitor the Aichi Biodiversity Targets and answering the request of the CBD, this section analyses the potential use of remote sensing for each Aichi Biodiversity Target in depth. A full mapping of each of the 98 indicators included in the indicative list of indicators has been undertaken to establish which could be (partly) derived from remotely-sensed data. Information on spatial and temporal resolution suitable for global, regional and national levels, type of data and appropriate sensors required to develop the indicator can be found in the Annex of this review (Tables 10.4A, 10.4B, 10.4C, 10.4D and 10.4E). It should be noted this mapping does not mean to be absolute. It should be regarded as a guideline, and therefore it is subject to review and refinement.

The adequacy of remotely-sensed data to monitor progress towards the Aichi Biodiversity Targets varies greatly. Potential applications for Strategic Goal A and E are limited; opportunities to contribution to Strategic Goal B have already proven to be extensive; and recent developments hold promising options for Strategic Goal C and D. A summary of Aichi Target Biodiversity Targets and operational indicators which remote sensing has the potential to contribute to, can be found in Table 4.1. In addition a mapping of existing remote sensing sensors and their potential use for each Aichi Biodiversity Target can be also be found in the Annex (Table 10.5).

Table 4.1. Aichi Targets, headline indicators and operational indicators which could be (partially) delivered from remotely-sensed data. Targets for which remote sensing has greatest potential to contribute to are highlighted in grey.

Aichi Target	Headline indicator	Operational indicator	Potential contribution of remote sensing
4	Trends in pressures from unsustainable agriculture, forestry, fisheries and aquaculture	Trends in population and extinction risk of utilized species, including species in trade (A) (also used by CITES)	Remote sensing derived terrestrial and marine carbon estimates, atmospheric GHG emissions and terrestrial vegetation parameters can contribute to understanding sustainable production through better carbon budget calculations.
		Trends in ecological footprint and/or related concepts (C) (decision VIII/15)	
		Ecological limits assessed in terms of sustainable production and consumption (C)	
	Trends in pressures from habitat conversion, pollution, invasive species, climate change, overexploitation and underlying drivers	Trends in biodiversity of cities (C) (Decision X/22)	
5	Trends in extent, condition and vulnerability of ecosystems, biomes and habitats	Extinction risk trends of habitat dependent species in each major habitat type (A)	Marine habitats monitored indirectly by tracking spatiotemporal patterns in primary productivity, sea surface state, temperature and salinity. Terrestrial habitats require landcover as a surrogate for habitat.
		Trends in extent of selected biomes, ecosystems and habitats (A) (Decision VII/30 and VIII/15)	
		Trends in proportion of degraded/threatened habitats (B)	
		Trends in fragmentation of natural habitats (B) (Decision VII/30 and VIII/15)	
		Trends in condition and vulnerability of ecosystems (C)	
		Trends in the proportion of natural habitats converted	

		(C)	
	Trends in pressures from unsustainable agriculture, forestry, fisheries and aquaculture	Trends in primary productivity (C)	
		Trends in proportion of land affected by desertification (C)	
	Trends in pressures from habitat conversion, pollution, invasive species, climate change, overexploitation and underlying drivers	Population trends of habitat dependent species in each major habitat type (A)	
6	Trends in pressures from unsustainable agriculture, forestry, fisheries and aquaculture	Trends in extinction risk of target and bycatch aquatic species (A)	Optical and LiDAR technology harnessed for tracking sea surface parameters while Radar and optical imagery combined can monitor marine pollution and track fishing vessels
		Trends in fishing effort capacity (C)	
7	Trends in pressures from unsustainable agriculture, forestry, fisheries and aquaculture	Trends in population of forest and agriculture dependent species in production systems (B)	Remote sensing based methods for mapping land use, monitoring habitat and predicting species distribution and richness are widespread but agriculture and biodiversity are not yet explicitly linked via remote sensing. Local-scale studies, using UAVs, for example, could show how biodiversity and agricultural practices are linked at the field level.
		Trends in production per input (B)	
		Trends in proportion of products derived from sustainable sources (C) (decision VII/30 and VIII/15)	
	Trends in integration of biodiversity, ecosystem services and benefits sharing into planning, policy formulation and implementation and incentives	Trends in area of forest, agricultural and aquaculture ecosystems under sustainable management (B) (decision VII/30 and VIII/15)	
8	Trends in pressures from habitat conversion, pollution, invasive species, climate change, overexploitation and underlying drivers	Trends in incidence of hypoxic zones and algal blooms (A)	Atmospheric pollution can be tracked by inputs of NO_2.Coastal algal blooms can be monitored by optical sensors. Radar is invaluable for oil spill detection. More research to be done on monitoring pathways of pollution from terrestrial to marine environments.
		Trends in water quality in aquatic ecosystems (A) (decision VII/30 and VIII/15)	
		Trends in pollution deposition rate (B) (decision VII/30 and VIII/15)	

		Trend in emission to the environment of pollutants relevant for biodiversity (C)	
		Trends in ozone levels in natural ecosystems (C)	
		Trends in UV-radiation levels (C)	
9	Trends in pressures from habitat conversion, pollution, invasive species, climate change, overexploitation and underlying drivers	Trends in the impact of invasive alien species on extinction risk trends (A)	Hyperspectral remote sensing shows promise in monitoring invasive alien species but outputs can be improved by integrating model and ground-based observations of species distributions
		Trends in the economic impacts of selected invasive alien species (B)	
		Trends in number of invasive alien species (B) (decision VII/30 and VIII/15)	
	Trends in integration of biodiversity, ecosystem services and benefits sharing into planning, policy formulation and implementation and incentives	Trends in invasive alien species pathways management (C)	
10	Trends in pressures from habitat conversion, pollution, invasive species, climate change, overexploitation and underlying drivers	Extinction risk trends of coral and reef fish (A)	LiDAR can penetrate shallow water to map coral reef at coarse resolutions. RS-derived SST has been successfully correlated with coral bleaching.
		Trends in climate change impacts on extinction risk (B)	
		Trends in coral reef condition (B)	
		Trends in extent, and rate of shifts of boundaries, of vulnerable ecosystems (B)	
		Trends in climatic impacts on community composition (C)	
		Trends in climatic impacts on population trends (C)	
11	Trends in coverage, condition, representativeness and effectiveness of protected areas and other area-based	Trends in coverage of protected areas (A) (decision VII/30 and VIII/15)	

	approaches	Trends in extent of marine protected areas, coverage of key biodiversity areas and management effectiveness (A) Trends in protected area condition and/or management effectiveness including more equitable management (A) (decision X/31) Trends in representative coverage of protected areas and other area based approaches, including sites of particular importance for biodiversity, and of terrestrial, marine and inland water systems (A) Trends in the connectivity of protected areas and other area based approaches integrated into landscapes and seascapes (B) (decision VII/30 and VIII/15) Trends in the delivery of ecosystem services and equitable benefits from protected areas (C)	Hyperspectral, hyperspatial, optical, radar and LiDAR remote sensing can all be used. Finding a reliable indicator of PA effectiveness is a challenge.
12	Trends in abundance, distribution and extinction risk of species	Trends in abundance of selected species (A) (decision VII/30 and VIII/15) (UNCCD indicator) Trends in extinction risk of species (A) (decision VII/30 and VIII/15) (MDG indicator 7.7) (also used by CMS) Trends in distribution of selected species (B) (decision VII/30 and VIII/15) (also used by UNCCD)	Direct observation of mega fauna individuals can be achieved with very high resolution sensors. Precision measurements from LiDAR can track threatened tree species. Modelling and field information can greatly help.
14	Trends in distribution, condition and sustainability of ecosystem services for equitable human well-being	Trends in benefits that humans derive from selected ecosystem services (A) Trends in delivery of multiple ecosystem services (B) Trends in economic and non-economic values of	

		selected ecosystem services (B)	Water and carbon-based ecosystem service models intake remotely sensing derived parameters. Landcover plays a key role in most ecosystem services models.
		Trends in human and economic losses due to water or natural resource related disasters (B)	
		Trends in nutritional contribution of biodiversity: Food composition (B) (decision VII/30 and VIII/15)	
		Trends in incidence of emerging zoonotic diseases (C)	
		Trends in inclusive wealth (C)	
		Trends in nutritional contribution of biodiversity: Food consumption (C) (decision VII/30 and VIII/15)	
		Trends in natural resource conflicts (C)	
		Trends in the condition of selected ecosystem services (C)	
	Trends in coverage, condition, representativeness and effectiveness of protected areas and other area-based approaches	Trends in area of degraded ecosystems restored or being restored (B)	
	Trends in coverage, condition, representativeness and effectiveness of protected areas and other area-based approaches	Trends in area of degraded ecosystems restored or being restored (B)	
15	Trends in distribution, condition and sustainability of ecosystem services for equitable human well-being	Status and trends in extent and condition of habitats that provide carbon storage (A)	Remote sensed derived measurements of sea level rise and sea ice extent contribute to understanding global climate change. The time series of satellite data can hamper their use for long-term climate change monitoring.
	Trends in coverage, condition, representativeness and effectiveness of protected areas and other area-based approaches	Population trends of forest-dependent species in forests under restoration (C)	
18	Trends in integration of biodiversity, ecosystem services and benefit-sharing into planning, policy formulation	Trends in land-use change and land tenure in the traditional territories of indigenous and local	Possibilities and limitations of RS similar to those in the context of targets 7, 11, 14 and 15

	and implementation and incentives	communities (B) (decision X/43) Trends in the practice of traditional occupations (B) (decision X/43)	
19	Trends in accessibility of scientific/technical/traditional knowledge and its application	Trends in coverage of comprehensive policy-relevant sub-global assessments including related capacity-building and knowledge transfer, plus trends in uptake into policy (B)	Remote sensing -based technologies can create awareness and attract attention to biodiversity and the need for conservation

A series of gaps and limitations for the use of remote sensing to develop indicators were identified for each Aichi Biodiversity Target:

Target 1. Awareness of biodiversity values

Human awareness cannot be measured directly by remote sensing as is not a measurable environmental characteristic of the Earth. While it is expected that awareness leads to positive gains for biodiversity including measurable environmental factors such as reforestation, sustainable agriculture, increased fish stocks, restored habitats and the preservation of species diversity, there is no way to directly correlate human awareness with a change in environmental conditions using remote sensing.

Target 2. Integration of biodiversity values

Green infrastructure such as ecological networks, forest corridors, viaducts, natural water flows and other realisations of the integration and implementation of biodiversity values into spatial planning are potentially possible to measure with remote sensing, if they are represented by visible features on the surface of the Earth. However it would be difficult to link the existence of these features with 'value' which is not an environmental characteristic and has no biophysical parameters to be measured by remote sensing.

Target 3. Incentives

Socio-economic condition and monetary frameworks are abstract anthropomorphic concepts that cannot be measured with remote sensing as they have no biophysical environmental characteristics.

Target 4. Sustainable production and consumption

Carbon parameters are one of the newest remote sensing metrics for monitoring sustainable production within ecological limits. Archived data levels of carbon and greenhouse gas emissions (GHGs) acquired through ground-based methods dating from the Ice Age to the Industrial Revolution to present day can be combined with satellite measurements of carbon emissions, carbon stocks and other parameters of carbon and GHGs to assess trends in a climate change focused change detection analysis. Carbon and GHG data can also be combined with other remotely-sensed derived data products, such as landuse, landcover, vegetation indices, crop monitoring and habitat degredation for a variety of research applications including identifying and measuring sustainable agriculture. At least one new sensor focused on obtaining carbon transmission and related vegetation parameters is scheduled for launch in 2014 (e.g. Orbiting Carbon Observatory) and one experimental vegetation-specific sensor was launched in 2013 (Proba-V). However, even of the existing sensors (GOSAT, Terra/Aqua and SeaWiffs) not all data products are currently available. With the exception of Terra and Aqua's MODIS instrument, many of the carbon measuring sensors focus on atmospheric monitoring rather than Earth observation. Therefore, their utility for helping to evaluate sustainable landuse in relation to biodiversity protection is yet to be proven.

Agricultural monitoring has long been a key use of remote sensing for estimating product yields, however linking agricultural and other resource production with biodiversity conservation presents a new twist on this application. Linking good data on historical crop yields with data on areas of importance for biodiversity on the Earth where remotely-sensed data is prolific (both historical and actively monitored) will be key challenges in monitoring progress toward achieving Target 4 due to gaps in both data availability and data consistency over time.

Target 5. Habitat loss, fragmentation and degradation

Using remote sensing to monitor habitats is routinely performed in terrestrial environments (Lengyel *et al*., 2008), and habitat distribution represents one of the most common pieces of information reported by Parties to the CBD. Primary productivity, sea surface parameters, currents and prevailing wind patterns are all important parameters structuring the spatiotemporal distribution of marine biodiversity and can also be used for habitat classification.

Optical sensors are the primary choices for landuse and landcover modelling as surrogates for habitat However, the majority of historical and freely available sensors are limited in their spectral resolution, unable to facilitate detailed habitat monitoring at broad scales, making it difficult to monitor habitat comprehensively and seamlessly for Target 5. Hyperspectral data has the potential to improve monitoring of habitats and species, especially related to fine-scale successional change and species diversity. However, hyperspectral data are not widely available and are technically and economically challenging to procure and process. Very High Resolution (VHR) datasets are frequently mentioned as being the ideal option for fine scale mapping of habitats with high spatial heterogeneity. However moderate-high resolution imagery such as Landsat, SPOT, ASTER and IRS are often sufficient for the purpose of habitat mapping over large areas, even in complex fine-scale habitat mosaics (Lucas *et al*., 2011). VHR and high resolution datasets can suffer from problems of shadowing objects in a scene, cloud cover and mixed pixels. VHR can also be expensive and time consuming to procure and process.

Recent VHR satellites such as WorldView-2 are beginning to open up the possibility of combining high spatial and spectral resolution in the same platform (Nagendra and Rocchini, 2008). Active remote sensing through Synthetic Arpeture Radar (SAR) and Light Detectio and Ranging also holds great potential for the mapping and identification of structurally complex habitats, especially in areas where there is high and/or frequent cloud cover.

Key gaps in data on habitat extent, fragmentation and degradation include: the condition of temperate coastal marine habitats, offshore marine breeding and spawning grounds, kelp forests, intertidal and sub-tidal ecosystems, vulnerable shelf habitats, seamounts, hot-and cold seeps, ocean surface, benthic and deep sea habitats; inland wetland and non-forested terrestrial habitats and polar habitats. Better information is also needed on small-scale habitat degradation in all habitats (GEO BON, 2011).

The different intra- and international definitions of various types of habitats under equally unsettled definitions of ‘Forest’, ‘Wetland’ and ‘Marine’ environments in general is also a limitation to monitor habitats which affects any efforts to use remote sensing to track progress toward achieving Target 5 (GEO BON, 2011). This inconsistency of definitions may undermine the effectiveness of the monitoring of the extent of ecological regions, habitat loss, fragmentation and degradation. Change detection analysis is critical to monitoring changes on the surface of the Earth, especially of habitats and will be important for successful monitoring of progress toward all Aichi Targets but is particularly notable for Target 5 when focusing on changes in habitat related to loss, fragmentation and degradation. In addition, remote sensing in all biodiversity monitoring scenarios is not a stand-alone resource and needs to be used in conjunction with other data modelling and field information. Expanded population trend and species extinction risk monitoring is needed in parallel with improvements in remote sensing to derive accurate monitoring of habitat degradation.

In summary, to advance towards meeting Target 5, the spatial, spectral and temporal resolution of datasets should be carefully considered to enable best possible assessments of changes in habitat loss, degradation and fragmentation (Nagendra *et al*. 2013).

Target 6. Sustainable exploitation of marine resources

Most remote sensing methods can only derive information from the upper layer of the ocean. Space-borne optical sensors only penetrate the water to a maximum of 27 meters under the best conditions (Rohmann and Monaco, 2005) and are naturally limited at shallow depths due to the light absorption properties of sea water. Airborne sensors such as LIDAR only penetrate up to 46 meters (Rohmann and Monaco, 2005). This focus on shallow water monitoring impedes the monitoring of many marine species, with the exception of some marine mammals and phytoplankton. As with any species, direct observation with remote sensing is not usually possible. In place of direct monitoring, biological and physical parameters that are reported to structure biodiversity patterns can be derived from remotely-sensed data. In the marine environment, primary productivity has been linked with benthic community patterns (e.g., Patagonian scallop; Bogazzi *et al*., 2005), and the distribution of highly migratory marine species (e.g., blue shark (Queiroz *et al*., 2012); bluefin tuna (Druon, 2010); whale sharks (Sequeira *et al*., 2012); and seabirds (Petersen *et al*., 2008).

Nonetheless, optical and radar sensor can also be used to detect vessels and monitor vessel movement for tracking illegal fishing (Corbane *et al*., 2010).

Target 7. Biodiversity-friendly agriculture, forestry and aquaculture

Land use change is the premiere driver of biodiversity loss in terrestrial habitats that can be measured by remote sensing. However, more work is needed to identify and define sustainable agriculture, forest and aquaculture practices that enable biodiversity conservation. Following on from that work indicators of ‘biodiversity friendly’ practices will need to be identified and the feasibility to measure those indicators by remote sensing either directly or indirectly will need to be ascertained. While there are a plethora of studies that show how remote sensing can be used to map land use, monitor habitat and predict species distribution and species richness there are no studies that link agriculture to biodiversity through remote sensing in an attempt to ascertain if the practices are ’biodiversity-friendly’. It is likely that parameters for measuring pollution reduction through remote sensing (associated with Target 8) will also be important for monitoring sustainable land use practices.

Target 8. Pollution reduction

Atmospheric monitoring of haze, smoke and smog occupy a large proportion of remote sensing studies on pollution monitoring. However remote sensing for tracking aerosols, ozone and GHGs is less well-developed as noted in the gaps and limitations section for Target 4.

Land use change impacts on both terrestrial and marine environments though less attention has been given in the remote sensing studies as to how landuse contributes to pathways of pollution from terrestrial to marine environments. For example, landuse in the form of agriculture and development leads to run-off which can have adverse effects on marine biodiversity (Boersma and Parrish, 1999). The main parameters for monitoring pollution in coastal waters include suspended particulate matter (SPM) and coloured dissolved organic matter (CDOM). SPM, like many biophysical parameters available from remote sensing serves only as an indicator for land-based pollutants that cannot be detected by remote sensing, e.g., heavy metals (Burrage *et al.*, 2002). SPM and CDOM can also be inferred from ocean colour data but only when ground calibration data is available (Oney *et al.*, 2011).

Remote sensing based methods have been critical in tracking oil spills through the use of synthetic aperture radar (SAR) or infrared sensors which can ‘see’ through clouds and hyperspectral data which are very good at discriminating hydrocarbons and minerals. Hörig *et al.*, 2001 postulates that hyperspectral remote sensing could potentially be used in the monitoring of plastic pollution as well, but this has not been tested widely. The downside of hyperspectral sensors is that they are require complex processing and computing capacity, are mostly commercially available and therefore costly to procure and process. Hyperspectral sensors are also primarily airborne, with one exception: the Hyperion sensor on the EO-1 Satellite. The utility of Hyperion data however is limited by its modest 30 meter resolution and 16 day revisit period and therefore may not be of use in emergency situations where constant monitoring is desired but may be of use in long-term, broad scale pollution.

More work is needed to identify the best parameters for tracking pollution in the open ocean, in terrestrial environments and in the atmosphere (e.g. aerosol, ozone and GHGs tracking).

Target 9. Control of invasive alien species

With relation to invasive species, remotely-sensed datasets must always be used in conjunction with modelling and field information to predict changes in specific species of interest (e.g. Asner and Martin, 2009; He *et al.*, 2011; Nagendra *et al.* 2013).

Standard multispectral remote sensing (e.g.Landsat) was found to be useful when combined with orthophotos (Somadi *et al.* 2012).

Hyperspectral imagery was found to be useful on a number of occasions, especially when timing the acquisition of high precision spectroscopy data with critical phenological stages of flowering or leaf senescence (He *et al.*, 2011; Andrew and Ustin, 2008; Lucas *et al.*, 2008, Clark *et al.*, 2005; Ramsey *et al.* 2005). However intra-species variation, mixed pixels due to high levels of heterogeneity and shadowing in the image were found to minimize success. Accurate discrimination of all top-canopy species is therefore unlikely, particularly in high density forests where there is a substantial amount of overlap between leaves and branches of different species. This problem is unlikely to disappear even if hyperspectral image resolution and noise to signal ratios improve significantly in the future (Nagendra, 2001; Fuller, 2007).

Very High Resolution imagery (e.g. Quickbird, IKONOS, GeoEye) was be found to be unsuitable for invasive species identification and monitoring because of the very small pixel sizes and lack of a short-wave infrared band, increasing the variability between different tree canopies (Nagendra 2013; Fuller 2005) in the scene.

Target 10. Coral reefs and other vulnerable ecosystems

The limitations of monitoring marine habitats and species due to shallow depth penetration of spaceborne (27 meters) and airborne sensors (47 meters) was discussed in Target 6 but is also relevant for Target 10 as it affects the ability to monitor coral reefs and other potentially vulnerable marine ecosystems in deeper waters. However monitoring coral reefs, is also suffers from the limited availability of high spatial resolution data. In-situ management often requires stratified sub-meter resolution to be useful. The best solution for bathymetric mapping and under-water habitat classification are proving to be those provided by LiDAR with its pin-point precision and high resolution; however even LiDAR falls short of capturing the complexity of coral reefs and other complex habitats (Kachelriess *et al*. 2013; Purkis and Klemas 2011). This is regrettable as it means that for the foreseeable future, mapping individual colonies or reefs will remain unfeasible with remote sensing. This limitation is less worrying for pelagic ecosystems which are influenced on broader oceanographic patterns and can therefore be monitored more readily.

Large-scale coral mortality events known as coral bleaching have been successfully studied using remote sensing, as the occurrence of these events is found to be strongly correlated to a biophysical parameter, Sea Surface Temperature (SST) (Maynard, 2008; Sheppardand Rayner, 2002). However the correlation between SST and bleaching varies by species owning to different mortality thresholds influenced by a variety of factors and therefore, global prediction of coral bleaching for a given SST anomaly is, not always a consistent or straightforward measurement (Maynard, 2008). Kachelriess *et al*. (2013) recommended that when it comes to monitoring coral bleaching, SST should only be used as an indicator for threats, and not as a way to quantify bleaching. All of these studies emphasised the need for validation of remotely-sensed data with field surveys which can often be a challenge for reasons of cost and human resource.

In terms of spectral resolution, it is very difficult to discriminate between species of coral without hyperspectral sensors (Klemas, 2011a;Purkis and Klemas, 2011; Wingfield *et al*., 2011) but as previously indicated, the majority of hyperspectral data options are not freely available and require a great deal of skill and resource to utilise .

Target 11. Protected areas

Hyperspectral, hyperspatial, optical, radar and LiDAR remote sensing can all be beneficial to monitoring biodiversity within and around protected areas. However remote sensing has yet to be used routinely and operationally by many charged with the management of protected areas.

Furthermore the limitations and challenges that apply to all other Aichi Targets will also apply to Target 11. For example, remotely-sensed habitat change is not always a suitable indicator of protected area effectiveness (Geldmann *et al*., 2013). More subtle variation in habitat condition, such as reduction in forest megafauna, cannot be inferred from remotely-sensed measures of deforestation (Redford, 1992). This problem is compounded by the fact that not all forest dwellers are correlated with the area of forest cover (Wilkie *et al*., 2011). Therefore estimating deforestation by remote sensing alone may not give a realistic interpretation of habitat condition, hence protected area effectiveness. For a realistic implementation of remote sensing to support PA management, financial and human resources will need to be taken into account. While excellent open source solutions exist for the processing and analysis of remotely-sensed data (Knudby *et al*., 2011), commercial software solutions dominate the bulk of education and training resources available. The limitations on commercial remote sensing software include reproducibility in addition to high costs (Kachelriess *et al*. 2013, Inceet *al*., 2012; Morin *et al*., 2012). The costs of remote sensing for PA management and monitoring are further expounded by the purchase of remotely-sensed data, the computing power and volumes of storage needed and the high-level of expertise required (Strant 2007). The amount of data required can quickly reach 10s of terabytes when considering the need to acquire data sets at multiple, spectrally and phonologically important seasons and often additional data is required from multiple sensors to overcome cloud cover and other atmospheric or sensor distortions that render some images unfit for purpose.

Target 12. Prevented extinction of threatened species

It is important to keep in mind that in relation to monitoring species, the direct observation of individual species is usually not possible using remotely-sensed information, with exceptions only among mega-fauna where the animals or their habitats can be easily detected. Examples where this kind of monitoring has been successful include blue shark (Queiroz *et al*., 2012); bluefin tuna (Druon, 2010); whale sharks (Sequeira *et al*., 2012); seabirds (Petersen *et al*., 2008), elephants, wildebeest and zebra (Zheng 2012); marmots (Velasco 2009), penguins and orangutans. Nonetheless, biophysicall parameters that are reported to structure biodiversity patterns can be derived from remotely-sensed data.

The challenge of mapping individual species or species richness is also variable across ecological regions. In tropical forests where there is high taxonomic diversity within plant functional groups, optical remote sensing is met with many challenges. Atmospheric influences and a wide variety of determinants of spectral variation such as sun angle, camera viewing angle, topography, and canopy three-dimensional structure persist (Kennedy *et al*. 1997; Sandmeier *et al*. 1998; Diner *et al*. 1999). Though there are ongoing studies and technological advances to overcome these challenges they have yet to come to fruition. Asner and Martin (2009) suggest that there is a sufficient theoretical basis to link the spectral, chemical, and taxonomic diversity of tropical tree species in a way that is generic and scalable. For example, High Fidelity Imaging Spectrometers (HiFIS) which can measure a range of plant chemicals are thought to be linked with species diversity. However, rarely has the chemical information, which seemingly sets HiFIS apart from other airborne optical sensors, been used to estimate the taxonomic composition of plant canopies. This is primarily due to the interference caused by the aforementioned factors having little to do with canopy chemistry but a lot to do with other determinants of spectral variation. In their 2009 study, Asner and Martin promote using a combination of High Fidelity Imaging Spectrometers (HiFIS) and LiDAR which can precisely measure canopy height and structure in 3D in a new form of remote sensing called “spectranomics”. However, this fusion of technology is as yet untested and will at first be costly to pull-together.

Standing alone, very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is a necessary first step toward species-level measurements (Asner and Martin 2009). LiDAR also needs to progress in the usability of its intensity data – a concentrated measure of spectral reflectance. Intensity is an opportunistic by-product of LiDAR, a tag along value last in importance to precise height and location data but it has nevertheless been the focus of many new species differentiation studies. Utilising intensity successfully still requires sophisticated post-capture calibration algorithms due to a lack of sensor calibration. Additionally airborne data capture is still prohibitively expensive. For these reasons airborne remote sensing, especially that of HiFIS and LiDAR are an impossibility for many practical monitoring procedures.

Similar to Target 9, remote sensing datasets still must be used in conjunction with modelling and field information to predict changes in specific species of interest (e.g. Asner and Martin, 2009; He *et al*., 2011, Nagendra *et al*., 2013) for successful monitoring of progress toward Target 12.

Target 13. Genetic diversity of socio-economically and culturally valuable species

Genetic diversity of species cannot be detected from remote sensing.

Target 14. Ecosystem services

Ecosystems provide ecological functions that directly or indirectly translate to a variety of beneficial contributions to society, referred to as ecosystem services. The capacity of an ecosystem to deliver them depends on the status of the biodiversity it harbours. Habitat mapping is key to assess the health of a particular ecosystem and habitats in favourable conservation status tend to supply more and better ecosystem services.

Monitoring of vulnerable ecosystems, such as coral reefs, using remote sensing is limited due to the limited availability of high spatial resolution data. The longest running, most widely tested remote sensing products, such as that available from the Landsat and AVHRR series are at best limited to ecosystem monitoring capacity, where landcover can be used as a surrogate for ecosystems and must be combined with other data. Therefore without clearly defined indicators of ecosystem services and maps of ecosystem services in relation to identified beneficiaries, measuring progress toward Target 14 will be inconclusive.

It is likely that trade-offs between detailed habitat mapping (high spatial and spectral resolution) and large scale application will persist. Though radar and LiDAR data will enable high precision estimates of wood production and biomass, as discussed in section 3.2.1, they will continue to be costly forms of remote sensing to procure and process in the pursuit of mapping, measuring and monitoring ecosystem services.

Carbon sequestration has a major role in climate regulation as evidenced by initiatives such as REDD+ which aim to reduce global carbon emissions from deforestation and increase forested areas. Remote sensing of terrestrial carbon has been briefly discussed in section 3.2.1 in relation to biomass estimation as the two variables are closely correlated. However, global mapping of carbon, stored in terrestrial vegetation, is not straightforward as datasets from remotely-sensed and ground-based sources are frequently amalgamated with different methodologies employed. A number of authors have estimated regional and global biomass while publishing biomass carbon datasets (Baccini *et al.* 2008; Baccini *et al.* 2011; Ruesch and Gibbs 2008; Saatchi *et al.* 2007; Saatchi *et al.* 2011). A comparison of these datasets shows that there are major differences, not only in terms of the estimates for quantity of biomass (carbon), but also in terms of the distribution pattern of carbon they provide. For example, the Baccini *et al.* (2012) dataset has higher above-ground biomass values than the Saatchi *et al* (2011) datasets in both African and the Amazonian rainforests, whereas in the Guyana shield and in west-Central Africa (Cameroon/Gabon), the above-ground biomass values in the Saatchi *et al* (2011) datasets are higher. Minor geographic discrepancies exist elsewhere for tropical regions.

Models of water-based ecosystem services frequently use remotely-sensed measurements as inputs. Precipitation inputs can be derived from the NASA/JAXA Tropical Rainfall Measuring Mission (TRMM) which uses passive microwave instruments to detect rainfall (Mulligan, 2006; TRMM, 2013). However, in order to quantify the full hydrological balance, other parameters such as evapo-transpiration need to be calculated. Current methods of measuring evapotranspiration remotely use land surface temperature data derived from satellite sensors such as Landsat, AVHRR, MODIS and ASTER (Kalma *et al*., 2008). Groundwater provision can be measured indirectly from temporal variation in Earth's gravity field as measured by the Gravity Recovery and Climate Experiment (GRACE) mission (Rodell *et al*. 2009). Landcover plays a central role in predicting future changes in the provision of many ecosystem services so is a central variable in most ecosystem models (Swetnam *et al*., 2011).

Target 15. Climate change and resilience

Remotely-sensed information on the parameters required for measuring progress toward target 15 are not globally comprehensive and do not stand alone in this regard but are derived from associated parameters such as NDVI and FAPAR and would need to be combined with other remote sensing data on carbon and other GHG emissions to meaningfully monitor changes in these parameters. It would then be prudent to use only those remotely-sensed data products for which change detection analyses can be conducted to ascertain resilience to climate change. Utilising seasonal data timed with peak phenological and physiological changes can be useful for early identification of climate change impacts. However, the ability to do this requires a high degree of proficiency in imagery analysis and interpretation as well as the ability to procure hyperspectral imagery at the right time and appropriate software and storage capacity to maintain monitoring regimes based on remote sensing. Such regimes can become prohibitively expensive if using high quality radar or hyperspectral data, alternatively it can become arduous if sorting through freely available historical archives to find images unobstructed by atmospheric influences (e.g. cloud, haze, etc) or sensor distortions.

Remotely-sensed climate change variables have been instrumental in informing the findings of the IPCC Working Group 1 on climate change in the oceans. For example, passive microwave techniques have revealed that annual average arctic sea ice extent has shrunk by 2.7 % per decade since 1978 (IPCC, 2007). Ocean sea level rise can be measured remotely in two ways. SST measurements can be used to estimate the contribution of thermal expansion, caused by rising ocean temperatures, to sea level rise; while satellite altimetry can measure the surface height directly. Global sea level rise has been estimated by satellite measurements at 3.1 ± 0.7 mm/year for the period 1993-2003 (IPCC, 2007). A reduction in global ocean primary production from the early 1980s to late 1990s has been observed, based on satellite-derived chlorophyll estimates. Comparable estimates of terrestrial climate change have also been derived using satellite remote sensing techniques.

Target 16. Access and benefit sharing (ABS)

While access to natural resources can be mapped with remote sensing, benefit sharing cannot as it reflects anthropomorphic concepts and pathways that cannot be deduced from environmental responses.

Target 17. National strategies and action plans

Indirectly, the achievable monitoring of other Aichi Targets over time and within national contexts could potentially indicate whether a country is succeeding at implementing its NBSAPs; however this would require a long-term monitoring programme with consistent remote sensing techniques for monitoring other Aichi targets of interest. Furthermore, the impacts of implementation in the biophysical environment would not likely influence measurable changes for decades and it would be difficult to link any environmental changes to the achievement of Target 17 (or lack thereof) versus any other outside factors such as other environmental variables or the activities of neighbouring countries.

Target 18. Traditional knowledge and customary use

The nuances of Target 18 including respecting the traditional knowledge of communities and indigenous peoples and implementing that knowledge into the Convention are not parameters that can be measured by remote sensing. Traditional use of natural resources however can potentially be monitored in a variety of ways, similar to monitoring in the context of targets 7, 11, 14 and 15, the limitations of which would also apply here.

Target 19. Biodiversity knowledge improvement and transfer

Similar to Target 17 and 18, Target 19 cannot be measured with remote sensing as it refers to human constructs (knowledge and technology) rather than environmental parameters. However if knowledge and technology in the use of remote sensing to monitor other measurable Aichi Targets is improved as suggested herein, is widely available and in practice by 2020, it would go a long way toward meeting this target.

Target 20. Resources in support of the Convention

Even though the long-term expectation of successful implementation of the Strategic Plan is a measurable achievement of Aichi Targets in terms of tangible, positive environmental changes, resource mobilization itself and the achievement of the Strategic Plan itself cannot be measured by remote sensing directly.

5. Emerging applications of remote sensing in the context of the Convention

Most of the work done to date to use remotely-sensed data for biodiversity monitoring has been focused on the status and trends of selected habitats and species, and on ecosystem integrity, through the use of land cover and land use. However, research is continuously evolving and opening new possibilities. This section summarises emerging applications of remote sensing for both marine and terrestrial environments relevant for tracking progress towards the Aichi Biodiversity Targets, setting the basis for discussing on future directions.

5.1 Near real-time remote sensing for surveillance

Operational near real-time imagery has a great potential as tool for surveillance and monitoring implementation of law and policies, which has been underused to date. Satellite imagery and derived products can have a short ‘shelf-life ‘when it comes to such applications as crop monitoring, deforestation monitoring or disaster response. The images are made available after an event or a potential hazard has occurred limiting their utility in disaster response and hazard mitigation. Operational near real-time availability of imagery is needed in such cases.

An example of this applicability is the monitoring of illegal deforestation in the Brazilian Amazonia. The Disaster Monitoring Constellation International Imaging Ltd (DMCii) is now providing imagery to the DETER service of the INPE in Brazil which uses regularly acquired MODIS satellite images to detect forest clearance (Hansen and Loveland, 2012). The DMCii imagery will provide INPE with high resolution (<30m) monitoring capabilities to overcome the ability of illegal loggers to go undetected at the 250m spatial resolution of the MODIS pixel. Further details can be found in section 7.4.

Fire surveillance also adopts near real-time monitoring systems based on EO data. For example, the Geoscience Australia Sentinel system uses daily MODIS imagery to monitor fires as they occur across the Australian continent (see section 7.1 for further details). This approach has also been adopted in different African countries.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- ✓ Aichi Target 7. By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity

5.2 Pollution and its impact on biodiversity

The role of remote sensing in monitoring atmospheric gases in the context of climate change was discussed in section 3.3.3. However, there are considerable negative impacts of increased atmospheric nitrogen on biodiversity, in particular floristic diversity and plant health (Phoenix, *et al.*, 2006). Although there are currently no direct ways to monitor the biodiversity impact of atmospheric nitrogen deposition using remote sensing, its impacts on plant vigour can be monitored using the vegetation products discussed in section 3.2.1.

Eutrophication of water bodies occurs with overload of plant nutrients, closely linked to land use/ land cover changes, and frequently result in 'algal blooms'. The reflectance of water changes with chlorophyll concentration as water with high chlorophyll concentration is usually typified by high green reflectance and absorption in the blue and red spectral regions (Lillesand *et al.*, 2008). Quantitative methods of algal bloom monitoring from aerial and spaceborne sensors use these reflectance properties to map and monitor their occurrence. Due to the spectral similarities between blue-green and green algae, narrow band sensors such as hyperspectral imagery or filtered airborne cameras are frequently used. More advanced methods relying on hydrodynamic–biogeochemical models which assimilate bio-optical measurements from ocean-observing satellites are being used for more accurate EO-based products for eutrophication assessment (Banks *et al.*, 2012).

Ocean acidification has wide-ranging implications in marine ecosystems and has stimulated studies in areas ranging from biochemistry of calcareous shell-forming processes to the socio-economic impacts on marine fisheries, aquaculture, and other ecosystem services (Doney *et al.*, 2009). Acidification happens when changes in seawater chemistry result from the oceanic uptake of anthropogenic CO_2. The change in pH levels has detrimental impacts for calcareous shell-building organisms such as foraminifera and pteropod molluscs (Fabry *et al.*, 2008). Coral reefs are also at risk as the rate of coral reef calcification is projected to decrease by 40% by 2065 based on increased abundance of oceanic CO_2 (Langdon *et al.*, 2000). Satellite remote sensing can play a role in monitoring this phenomenon, e.g. by measuring reflectance from calcium carbonate, also known as Particulate Inorganic Carbon (PIC), as measured by MODIS (Balch *et al.*, 2005).

The NOAA Experimental Ocean Acidification Product Suite (OAPS) synthesises satellite and modelled environmental data sets to provide a synoptic estimate of sea surface carbonate chemistry which is updated monthly (OAPS, 2013) . Satellite - based estimates of sea surface temperature based on the NOAA-AVHRR satellite are one of many parameters which contribute to the OAPS (Gledhill *et al.*, 2009). Modelling of surface-ocean carbonate chemistry, using remote sensing as a tool, allows regional to basin wide trends in ocean acidification to be explored on seasonal to interannual time scales. This is very important for monitoring ocean-wide marine biodiversity impacts since ship-based measurement are limited in spatial scope and frequency of measurement.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.
- ✓ Aichi Target 10. By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

5.3 Monitoring the spread of invasive plant species

Spatial mapping of the spread of invasive alien plant species is a high priority for the conservation community and an area where a remote sensing-based approach could make a substantial contribution. There have been considerable advances in using remote sensing to map species that dominate forest canopies using remote sensing imagery. However, a large proportion of invasive plants in native forests occur in the understory where they are often obscured by the canopy. In addition, plant communities are often present in the form of mixed-species mosaics which can be difficult to separate using spectral data alone (Zhang *et al.*, 2006). Indirect methods of mapping including the use of GIS data layers and modeling have been used in these cases. Besides passive sensor data, lidar has proved useful.

The key challenge the conservation community faces when monitoring invasive alien plant species is that species-level plant discrimination is not possible using current operational EO-based land cover or habitat products. Nevertheless, hyperspectral imagery has potential to provide species-level discrimination at the ecosystem level (Hestir *et al.*, 2008). However hyper-spectral-based products are not operational and hyperspectral remote sensing is frequently limited to local-scale studies employing airborne hyper spectral sensors, e.g. the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) operated by NASA/JPL. Spaceborne hyper spectral sensors are the Hyperion sensor onboard EO-1 spacecraft and the Compact High Resolution Imaging Spectrometer (CHRIS) of ESA’s Proba-1 instrument.

Further exploration and operational development of hyperspectral-based products from these sensors is a necessity for future site-level plant species mapping which will highly benefit monitoring the spread of invasive alien plant species.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 9. By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

5.4 Assessment of management effectiveness and establishment of ecologically effective Protected Areas networks

Land use change around protected areas has been recognised as an important determinant of forest reserve health in tropical regions (Laurance *et al*., 2012). As observed from MODIS VCF data, up to 68% of protected areas in a wide-ranging, global sample of highly protected tropical forests had their cover reduced within a 50-km periphery of their administrative boundaries. Far fewer of those protected areas experienced loss of forest habitat within their administrative boundaries (De Fries *et al*., 2005). Such studies demonstrate the importance of considering land use dynamics at or beyond the boundaries of protected areas for more effective protected area management strategies.

Currently, large area monitoring of land cover change using high spatial resolution imagery predominately uses Landsat data due to the availability of a multi-decadal time series (Hansen and Loveland, 2012). Assessing protected area effectiveness requires change analysis methods which are consistent and repeatable over time. Change mapping methods are therefore set to change from analyst interactions with individual scenes to automated processing chains which harness powerful computing to process large data volumes (Hansen and Loveland, 2012). Ideally, this would be combined with near-real time alert systems which are triggered by sudden change, as proposed by Verbesselt *et al*. (2012). This approach would increase sensitivity of alert systems to natural and anthropogenic disturbance events such as illegal logging and drought.

In Canada, candidate areas for protection status and existing protected area networks are being monitored through remotely-sensed indicators on land cover, fragmentation, disturbance and snow cover. Areas sharing common environmental conditions using this approach can be used to assess the effectiveness of Canada's network of parks and identify sites requiring protection. More details of this approach can be found in section 7.3.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 11. By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

5.5 The use of terrestrial and marine mammals as sensor platforms

Technological advances in the last few decades have made it possible to use animals as platforms to carry remote-sensing devices in a growing discipline known as animal telemetry. However, there has been more limited use of terrestrial animals as sensor platforms in comparison to marine ecosystems. Commonly used methods for tracking animals in the terrestrial environment using individual tags are Global positioning system (GPS), Argos Doppler tags, very high frequency radio tags, light-level geolocator and banding or rings. However, not all of these rely on satellite sensor technology as acoustic devices are based on radio signals (Movebank, 2013).

The U.S. Integrated Ocean Observing System (IOOS) is making efforts to use data from electronic tags attached to marine animals to enhance understanding of the marine environment (IOOS, 2013). For example, movement of the hawksbill turtle in the Caribbean Sea has been characterized using telemetry, showing that they are more abundant in protected areas than previously thought (Scales *et al.*, 2011). Animal-based tags are so useful because sensors can track individuals over long distances for multiple years, collecting sub-surface data from remote and difficult to reach environments. Conventional earth observation techniques are technically or economically unfeasible for monitoring movement and environmental conditions at the individual level.

Main CBD Aichi Biodiversity Target it supports:

✓ Aichi Target 12. By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.

5.6 Ecosystem services: carbon storage and climate change

Remote sensing-based assessment of carbon stocks in terrestrial habitats is a major field of research and relies heavily on remote sensing for quantitative spatial data on vegetation biomass, among other variables such as Gross Primary Production (GPP). Remotely-sensed surrogates of tree species diversity, such as the NDVI-based eco-climatic distance measure, have been related to carbon storage and sequestration in forests as well. This measurement demonstrates a strong relationship with tree-density, LAI and degree of deciduousness. Therefore continuous measurements over broad spatial scale can detect broad scale patterns of bio-diversity in forested landscapes and ecosystem services that can be used in conservation planning (Krishnaswamy *et al.*, 2009).

The relation between biomass and carbon storage has already been discussed in section 3.2.1. In order to quantify above ground carbon content in forests, LiDAR is a frequently used tool, but is mostly used at a local scale owing to the small footprint of LiDAR instruments. In heteregenous forests, LiDAR-has been proven to be a more effective tool than ground-based methods in quantifying above ground carbon content (Patenaude *et al.*, 2004). The forest carbon stock of areas the size of the Peruvian Amazon can be quantified at high resolution (0.1-ha) based on the integration of LiDAR, Landsat imagery and field plots (Asner *et al.*, 2010). Landsat-derived NDVI is well correlated to carbon storage in urban forestry, based on field measurements, providing the potential for cost-effective and efficient regional forest carbon mapping (Myeong *et al.*, 2006).

However, there are few studies of carbon stocks in ecosystems other than forest. Efforts to model the land-atmosphere exchange of CO_2 from high latitude, northern hemisphere peat lands using satellite remote sensing inputs are already well established (Schubert *et al.*, 2010). Similar methods are employed to monitor grassland gross primary production and CO_2 uptake, but using in-situ spectral measurements of vegetation phenology combined with an estimation of radiation use efficiency (Migliavacca *et al*., 2011). The conservation community would find it especially useful to assess carbon stocks for grasslands and peat lands (Green *et al*., 2011). This would represent a worthwhile avenue for research in future carbon assessments based on EO data.

The role of remote sensing in monitoring the impact of climate change on ecosystems can be shared between observation data on primary and secondary indicators. Primary indicators include temperature, precipitation and FAPAR. A secondary indicator, vegetation phenology, is an essential component of ecosystem functioning (Thackeray *et al*., 2010), an important climate change indicator (van Vliet, Overeem *et al*. 2002, Butterfield and Malström, 2009), and has been widely observed for several decades.

Remote sensing of land surface phenology is now a well established field of research providing an objective and repeatable method of phenological observation that can contribute to climate change studies. However, remotely sensed phenological patterns are observed from multiple vegetation ecosystems and not a single plant or tree species and are limited in time series as compared to ground-based observations. Finer-scale ecosystem level observation are now possible using fixed-position, digital-camera based sensors, e.g. the Phenocam in selected forests in the U.S.A. (Sonnentag *et al*., 2012) or the Phenological Eyes Network in Japan (Nagai *et al*., 2013). As mentioned in section 4.3, canopy-level monitoring of phenology has important implications for estimation of gross primary production of forested or grassland ecosystems. Therefore, phenological information gathered by in-situ sensors such as digital cameras, can be used in estimating local carbon sinks and sources.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 15. By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.

5.7 Ecosystem-level monitoring using Unmanned Airborne Vehicles (UAVs)

Unmanned Airborne Vehicles (UAVs) are remotely-operated light aircraft that carry sensors or cameras. Their use for remote sensing has become more widespread due to recent technical advances in miniaturisation, communication, the strength of lightweight materials and power supplies (Campbell, 2006). They offer near-surface observations in order to record complementary environmental information such as temperature, CO_2 and humidity. Their rapid deployment allows greater flexibility for use in a range of environments and weather conditions. As they operate below the cloud line, cloud-free observations are guaranteed and atmospheric correction of imagery is not required. UAVs can be considered as flexible sensor platforms as different sensors can be mounted giving them adaptability in different applications including aerial photography, optical, thermal and hyperspectral analysis. They are limited in spatial scope however and are frequently employed in site-level monitoring for which satellite or airborne sensors are too coarse in resolution or too infrequent in revisit time. Therefore UAVs are effective tools for modeling and monitoring biodiversity-related variables at a local scale.

UAV flights can be flown at the same time as satellite or other airborne sensors for coincident measurements (Campbell, 2006). Applications include precision agriculture, to detect water stress and irrigation effectiveness in orchards (Stagakis *et al.*, 2012, Zarco-Tejada *et al.*, 2012) and to measure temperature at the plant canopy level using thermal remote sensing (Berni *et al.*,2009). UAVs are also used in the coastal zone (Malthus and Mumby, 2003) and in riparian habitats (Dunford *et al.*, 2009). However, combining multiple images from different flight lines and dates can be problematic due to variability in solar illumination and sensor movement (Dunford *et al.*, 2009).

6. Limitations and challenges

6.1 What has limited the use of remote sensing in developing indicators?

The selection of an EO product for indicator development requires a trade-off between available data, spatial resolution and coverage, spectral characteristics of the sensor, timing of image acquisition, degree of cloud cover, practicality of ground validation and subsequent analysis, combined with the overall cost of the imagery and analytical effort . Any of these criteria can potentially limit the use of RS data for developing indicators either.

6.1.1 Type of available data

More user-friendly and intuitive data portals for accessing EO-based data are a requirement for the biodiversity community (Leidner *et al.*, 2012). The type of data that can be accessed through these portals can limit the level of indicator development. For example, pre-processing steps, i.e. georeferenced, orthorectified and atmospherically corrected data, should be done centrally and systematically, so as to produce a consistent set of EO products which are ready to use. More standardisation of approaches can be achieved under initiatives such as the GMES fast-track service, making EO-based analysis more cost effective and efficient to the end-user community (Infoterra, 2007).

The lack of suitable product documentation and metadata has also been cited as a limitation associated with EO-based products. Operational products provided through Copernicus or NASA are accompanied by technical documentation which can assist users in understanding the content of a product, its limitations and strengths and its application. These are commonly in the form of an Algorithm Theoretical Basis Document (ATBD).

Finally, the level of product development is also an important concern. Frequently, derived geophysical fields, such as vegetation indices, are more useful than raw remote sensing data to non-specialists (Leidner *et al.*, 2012). The Copernicus Global Land service and similar systems in use by NASA, e.g. the Distributed Active Archive Centers (DAACs), enhance end-user capabilities by providing ready to use free EO products. However, limitations on bandwidth and internet access speed in developing countries can be a constraint on data access and limit the use of EO data (Roy *et al.*, 2010).

6.1.2 Cost of data acquisition and data access policy

Access to EO data is frequently highlighted as a key limitation by many biodiversity stakeholders. Many space agencies and some countries are now offering free and open data access to their satellite data. Thus, some Earth Observation data products are freely available to the community but some are not, especially high spatial resolution imagery (Leidner *et al.*, 2012).To date, this has limited the development of EO-based products in the biodiversity community to Landsat and MODIS which are typically free and suited for high (≤30m) to medium (≤300m) resolution applications. The launch of NASA Landsat 8 and ESA Copernicus Sentinels will offer more access to high resolution data.

However, the open access policy to remote sensing data is sometimes conditional on the type of user, whether it is a research organization, private sector or academic department. In addition, a full and open access data policy does not necessarily mean easy and fast data access. For example, ESA Copernicus Sentinels data policy will allow a free and open data access but it is still yet clear how easy the data will be accessible especially outside ESA Member States.

Larger mapping scales are now possible with the advent of private sector, airborne and spaceborne sensors with spatial resolutions appropriate for local to site-level land cover mapping (Infoterra, 2007). However, the financial cost is proving a challenge to most biodiversity researchers and conservation practitioners as very high resolution data are expensive to acquire (Leidner *et al.*, 2012).

One possibility to overcome this limitation is the involvement of government agencies in public-private sector partnerships to enable researchers to access high resolution data at low cost. For example, several federal agencies of the U.S. government, have established data purchase programs with commercial image providers in order to access new commercial remote sensing products which meet research and operational requirements (Birk *et al.*, 2003). This requires initiative on the part of government bodies to recognise the duty that central Government plays in providing mapping and monitoring information to meet the needs of its citizens. An agreement between NASA Earth Science Enterprise (ESE) and the Space Imaging IKONOS system has been a good example of cooperation between industry, government and end users (Goward *et al.*, 2003). However, the organisational and legal aspect of the partnership is more of an important determinant of success than any technical factors (Goward *et al.*, 2003).

6.1.3 Internet access and data access

Linked to the above limitations is the issue of internet access in particular regions. For example, access to the USGS Landsat archive is considerably constrained by a limited bandwidth in African countries, the majority of which have little internet capability (Roy *et al.*, 2010). However, while the situation is improving, with new fibre-optic cables opening up access to broadband connectivity, there are still problems of establishing networks within countries. African government regulation may also continue to restrict Internet access across the continent (Roy *et al.*, 2010).

6.1.4 Capacity to use EO-based data in indicator development

A lack of capacity among biodiversity experts is frequently cited as a limitation on using remote sensing for monitoring biodiversity indicators (Leidner *et al.*, 2012). A greater understanding of how to use remotely-sensed information is sought over more computing power or more advanced EO products. For example, there have been calls for more access to open-source software and more online resources and guidebooks for the conservation community (Leidner *et al.*, 2012).

Generally, indicator development from raw remote sensing data requires capacity and expertise in numerical data processing, which conservationists may not always possess. This is a common limitation to both developed and developing nations. Centres of expertise for remote sensing should be set up to address user needs at a regional or national level as has been done with the Canada Centre for Remote Sensing (CCRS) for example.

6.1.5 Effective data validation strategy

The lack of a sufficient validation strategy has limited the use of remote sensing data by biodiversity practitioners. The U.K. Department of Environment, Food and Rural Affairs (Defra) Science Directorate has already addressed some of the limitations in the use of EO data for biodiversity monitoring in the UK. More in-situ measurements are required for the calibration and validation of terrestrial EO products if they are to be used with confidence by biodiversity practitioners (Infoterra, 2007). Space agencies should also be concerned with in situ data for validation EO products. EO-based products are less likely to be used with confidence due to the absence of data validation (Green *et al.*, 2011). However, there are efforts to address this issue. For example, the CEOS Land Product Validation (LPV) subgroup has eight thematic areas where it is actively pushing efforts to globally validate EO-based products using in-situ measures. The themes are diverse and vary from validation of phenology products to snow cover, fire/burn area and land cover products (CEOS LPV, 2013).

Land cover is a thematic area that needs advanced ground validation strategies especially if land cover change is to be monitored with reliability (Green *et al.*, 2011; Hansen and Loveland, 2012). The most frequent reason for the absence of accuracy assessment is the lack of contemporary ground data with sufficient spatial coverage (Infoterra, 2007). Field campaigns are generally costly, labour intensive and sometimes difficult to synchronise with satellite image acquisition. However, an effective validation strategy is critical if the EO-based approach to landcover and habitat mapping is to be proposed as a cost-effective alternative to field-based methods (Vanden Borre *et al.*, 2011).

6.1.6 Insufficient spatial resolution and spatial scale

The issue of spatial scale is often cited as a limitation to indicator development as operational remote sensing products are provided at spatial resolutions which are often coarser than needed for operational monitoring. For example, tackling conservation issues, such as loss of habitat, at the level of protected area, requires an indicator which is sensitive to that scale of change. Land cover, for example, is a particularly sensitive parameter to scale. A global or continental scale landcover product such as GLC 2000 or Globcover might not be appropriate to address change at the protected area level. However, a product developed to meet the needs of protected area level monitoring is unlikely to be generated globally, on a routine basis, due to sensor limitations.

There is a demand among the biodiversity community for land cover products at the Landsat spatial scale (≤30m) and MODIS/AVHRR scales (250-1000m) (Leidner *et al.*, 2012). However, very high resolution land cover (≤5m) information can also be very beneficial for monitoring site -specific variation at the plant community level or to map surface objects such as tree crowns and hedgerows. Two European GMES projects, Biodiversity Multi-Source Monitoring System: From Space to Species (BIOSOS) and MS MONINA, are researching EO-based tools and models for monitoring NATURA 2000 sites and their surroundings incorporating high or very high resolution satellite imagery. Indicator development at the local level, using airborne or higher resolution satellite sensors, can be a potential solution to address site-specific conservation needs but is still in research and development level and not yet operational.

6.1.7 Long temporal repeat cycle and short time series for trend analysis

The temporal rate of change in surface processes is inconsistent with the repeat cycle of some EO satellites and therefore limits the sensitivity of the product to detect surface changes. For example, the 16-day repeat cycle of Landsat is further limited by seasonality and cloud cover, especially in tropical areas; reducing the effectiveness of annual land cover updates (Hansen and Loveland, 2012). However, the INPE in Brazil have developed the DETER product (see section 7.4 for further details), which uses daily MODIS data to provide a near-real time alert system to relevant authorities to monitor Amazon deforestation (Hansen and Loveland, 2012).

The low revisit time can limit the applicability of Landsat to indicator development, especially where surface change is on a daily to weekly time scale. Furthermore, time composited satellite products, e.g. 8-day MODIS, are insensitive to some natural phenomena, e.g. phenological changes in terrestrial vegetation, which occur on finer time scales (Cleland *et al.*, 2007). A high revisit time is required for optimal change monitoring for example. However, this needs to be balanced by the need for higher spatial resolution and sufficient spatial coverage of satellite sensors.

The length of remote sensing time series can be limiting on efforts to monitor long-term change in ecosystems. Decadal-scale time series are only available for certain sensors, e.g. Landsat and AVHRR while MODIS and MERIS time series are limited to a decade approximately. This is a particular problem for land cover products which tend to be a static representation of one point in time with only a few periodic updates, e.g. CORINE 1990, 2000 and 2006 for Europe. However, there is a need to characterise decadal-scale land cover change and at a global level with landcover classes which can be related to the ecosystem level (Leidner *et al.*, 2012).

6.1.8 Harmonisation of methodologies and data collection at national and international level

Greater coordination of methods in data collection and processing is required for harmonised EO products. This is one of the aims of the GMES initiative (Infoterra, 2007). For example, there are calls for a consistent pan-European habitat typology to reduce the uncertainty surrounding the inter comparison of national-level habitat classification systems (Vanden Borre *et al.*, 2011). A harmonised habitat monitoring methodology, devised by both EO and biodiversity researchers, could permit consistent European-wide habitat type products (Vanden Borre *et al.*, 2011). However, the kind of habitat parameters which can be retrieved is highly dependent on pixel size and sensitive to scale (Nagendra, 2001). Therefore, any harmonisation of efforts across national systems must take into account the availability of appropriate imagery. The Group on Earth Observations Biodiversity Observation Network (GEO BON) has been set up to focus efforts among different agencies in linking observing system for an integrated biodiversity monitoring system (Scholes *et al.*, 2012).

6.1.9 Cloud clover

Cloud cover is a significant limitation to optical remote sensing. This has forced end users to accept a ‘use what you can get’ approach that has made it difficult to streamline EO-based working procedures (Infoterra, 2007). However, there has been progress in automating the process of cloud removal and atmospheric correction through a harmonised approach to pre-processing methodologies. For example, the Landsat Ecosystem Disturbance Adaptive Processing (LEDAPS) system has applied cloud and cloud shadow removal, as well as automatic atmospheric correction, to a collection of Landsat 5 and Landsat 7 scenes. This harmonisation of cloud screening and atmospheric correction methods results in a consistent set of pre-processed Landsat imagery. These scenes are available through the USGS Earth Explorer site under the Landsat CDR option in the Datasets list. On demand pre-processing of any Landsat scene is now possible through the LEDAPS system.

In addition to the above, due to their specific characteristics, terrestrial, marine and intertidal environments posse unique limitations to indicator development using remotely-sensed data.

6.1.10 Specific limitations of remote sensing in terrestrial ecosystems

The terrestrial domain has not yet developed a joined up approach, involving multiple disciplines, to gain a greater understanding of the global terrestrial system, as has been done in the marine environment (Infoterra, 2007). For example, The World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO have developed a joint working group for a global met-ocean observing network in which remote sensing observations play a crucial role (JCOMM, 2013). One reason cited for this has been the socio-economic implications of protecting terrestrial biodiversity. Policy has taken precedent over science in determining the direction of terrestrial biodiversity monitoring. This has hindered the development of simulation/prediction models which have been more widespread in the marine and atmospheric domains (Infoterra, 2007). Terrestrial ecosystem variables derived from remote sensing can play a key role in model development. Typical terrestrial habitat variables include tree, shrub or grass species composition, canopy cover, tree size distribution, density of dead trees, three-dimensional forest structure, understory characteristics, vegetation architecture and the timing and duration snow and ice cover (Green *et al*, 2011). The benefits of UAVs in mapping and monitoring these variables at close range have been discussed in section 5. However, their use in terrestrial environmental applications to date has been limited by restrictions imposed by civil aviation authorities. UAV technology is easier to apply to marine applications, whereas airspace management over land is more complex (Infoterra, 2007).

Field-based mapping can be very subjective and lacking in geographic precision, e.g. lower GPS accuracy. Therefore, the accuracy of in-situ observations is difficult to assess. Furthermore, the scale of field observation may not be compatible with the EO imagery, and ancillary data is often interpolated or modeled and lacking in information on error and uncertainty (Infoterra, 2007).

Understanding how EO products translate across different scales has been noted as a limitation in the terrestrial system (Infoterra, 2007). For example, LAI, FAPAR and fCover all demonstrate variable sensitivity to scale (Weiss *et al*., 2000). For example, LAI is scale dependent, while fCover is not (Baret *et al*., 2011).

6.1.11 Specific limitations of remote sensing in aquatic ecosystems

Remote sensing and spatial analysis techniques used to study aquatic ecosystems differ from those used in terrestrial systems (Strand *et al*., 2007). This is largely due to the nature of reflectance from water bodies which reflect sunlight in different wavelengths to those from terrestrial surfaces, e.g. water bodies appear very dark in satellite images due to almost total absorption of near infrared radiation (Campbell, 2006).

The typical satellite sensor used in marine environments is therefore different in design and instrumentation to that used in terrestrial areas. For example, Synthetic Aperture Radar (SAR) systems such as Radarsat-1, Envisat ASAR and ALOS PALSAR, are mainly intended for marine applications such as oil-spill monitoring, ship detection, shallow-water bathymetry mapping, sea-ice monitoring and sea surface state (Infoterra, 2007, Kerbaol and Collard, 2005). Other satellite sensors such as the NOAA AVHRR and METEOSAT are dedicated to marine meteorology and tracking extreme events such as hurricanes.

Within the marine community, the use of EO data for monitoring biodiversity is relatively widespread and there is a core set of global and regional products to serve user needs (Infoterra, 2007). Such products are underpinned by a good scientific understanding of many of the processes in the marine environment. This has led to well established fields of research such as remote sensing for monitoring individual marine species, using telemetry (e.g., Blumenthal *et al*. 2006), or factors controlling their distribution, such as algal blooms (e.g., Burtenshaw *et al*. 2004).

For aquatic environments, key environmental parameters required by the conservation community have been listed as "'biological productivity of marine areas (critical for all marine spatial distribution models), sea surface temperature, frequency of marine and freshwater algal blooms, plankton density, seasonality of extent of sea ice cover, including polynas, sediment type of intertidal zones, bathymetry of intertidal zones (and hence the duration of tidal coverage), the mobility of intertidal mud and sand flats, volume and seasonal pattern of river flows and species identity of emergent marsh vegetation" (Green *et al*., 2011).

However, not all of these variables are routinely monitored by satellite sensors. For example, more data are needed on carbon storage and sequestration value in oceans – similar to those which are used to generate maps of terrestrial carbon (Green *et al*, 2011). There is less understood on habitat fragmentation and connectivity in marine habitats than for terrestrial ecosystems (Strand *et al*., 2007). Ship borne sonar devices can sense sub-surface features and are useful in benthic habitat mapping, although airborne LiDAR has been shown to be more cost effective than ship-based methods in shallow water coral reef mapping (Costa *et al*., 2009). Remote sensing is more typically used in mapping tropical rather than temperate marine areas as the visibility through the water column is generally better due to lower a lower volume of suspended sediment (Strand *et al*., 2007).

6.1.12 Specific limitations of remote sensing in the intertidal zone

Intertidal habitats such as mangroves, sea grasses and salt marshes exhibit both terrestrial and marine characteristics. However, satellite and airborne mapping methods for these habitats are less developed than those for terrestrial or marine habitats (Green *et al.*, 2011). This is largely due to the poor suitability of airborne and spaceborne sensors to mapping and monitoring of the intertidal zone. A balance must be achieved between tidal regime, cloud cover, vegetation seasonality, timing with field visits and the need for very high spatial resolution imagery (Murphy *et al*., 2008). Furthermore, airborne surveys tend to be expensive and logistically challenging and therefore not suitable for operational monitoring. Field-based methods such as diver survey, underwater videography and acoustic techniques such as sonar can be used in a complimentary fashion in mapping shallow coastal habitats but suffer from error in interpolation of mostly point measurements (Dekker *et al*., 2005). A nested approach, employing observations at multiple scales, combining in-situ and airborne mapping methods, appears to be the future for high resolution mapping of intertidal zones.

6.2 Key challenges in the use of remote sensing for indicator development

6.2.1 Knowledge transfer and capacity building

Knowledge transfer in remote sensing education is a particular challenge for the developing world as traditional expertise in the topic is located in western institutions. Although the World Wide Web (WWW) has a significant contribution to make in education in remote sensing (Stubkjær,1997), internet access can be a constraint in certain regions, most notably in African countries as discussed in section 6.1.3. Despite this limitation, the benefits of internet access for knowledge exchange in the field of remote sensing are numerous. Firstly, access to geospatial data is almost on demand, secondly, access to a network of scientists and practitioners who can assist each other remotely, and thirdly, development of EO-based data sets that are coordinated locally, e.g. in citizen science initiatives (Global Marketing Insights, 2009).

In addition, a lack of capacity building is of particular importance in developing countries where there is rarely access to commercial software, appropriate educational material or university - based education in remote sensing. North-South knowledge transfer is been promote with approaches such as the adopted by ESA, which EO projects have a strong capacity building component, covering both basic education on remote sensing theory and training courses on particular EO products. South-South cooperation will also be key to improve capacity at national level. On this regard, Brazil, through the National Institute for Space Research (INPE), has led the way in making remote sensing courses available to professionals in Latin America since the mid 1980s (Sausen, 2000).

6.2.2 Products accuracy

Accuracy of EO data is an issue in several themes of the discipline, e.g. in landcover mapping and land cover change detection, and in recording position-accurate geospatial data in the field and accurate EO-derived inputs for modeling work (Infoterra, 2007). As EO data are prone to error, uncorrected data are limited in their utility for ecological applications (Kerr and Ostrovsky, 2003). In a survey of nature agencies involved in management and monitoring of NATURA 2000 sites, it was found that thematic accuracy of EO-based habitat maps is seen as the most important measure of quality (Vanden Borre *et al.*, 2011). According to the Committee on Earth Observation Satellites (CEOS) Societal Benefit Area on Biodiversity, a critical drawback of EO data is spatial accuracy and alignment (Leidner *et al.*, 2012). Therefore, an EO-based approach to indicator development will be hindered by issues of reliability unless steps are taken to address error and uncertainty in input data.

The abstraction of remote sensing data in geographical information systems from lower to higher levels tends to propagate error and accumulate uncertainty (Gahegan and Ehlers, 2000). The challenge of product accuracy might be addressed on two fronts, firstly by promoting methods which produce the least error (harmonization of methodologies will play a key role in this) and by limiting the number of processing steps performed on raw EO data (quantifying error at every transformation step can help calculate overall error). Thorough documentation of error and highlighting the limitations of EO-based products must become mandatory if EO-based biodiversity indicators are to be used with confidence.

6.2.3 Uncertainty in long-term continuity

Ensured long-term (decadal) continuity of earth observations is a key element for user organizations in order to adopt this source of information in working practices. Therefore, uncertainty in the long-term continuity is a key challenge to increase the use of remote sensing in monitoring biodiversity as it restrains some organizations to invest in EO projects and development. Initiatives such as ESA Copernicus Sentinel missions that are envisage to guarantee a long term continuity of earth observations for future decades (+25 years) will be very beneficial.

6.2.4 Dialogue between EO community, biodiversity practitioners and decision makers

Greater dialogue between the remote sensing community, biodiversity practitioners and decision makers has been called for in many fora. Within the scientific community, dialogue between earth observation and biodiversity experts have significantly improved over the last years, as demonstrated by the substantial increase of publications of biodiversity related EO papers. The major gap seems to be a clearly insufficient dialogue with decision makers. Improved dialogue can have many positive results. For example, clearer conservation goals can be expressed, data and options for image processing can be thoroughly evaluated, unrealistic expectations can be moderated or refined, and the cost effectiveness of different options discussed take place (Kennedy *et al*., 2009).

More situations should be created to allow the different groups meet face to face and engage in practical discussions. These should offer the opportunity to understand what are the necessities, priorities and challenges of each group while giving context to the different groups' realities. Working groups which promote interaction and collaboration between biodiversity conservations scientists, space agencies and national agencies have a considerable role to play in the process of bridging the gap. The CEOS Group on Remote Sensing for Biodiversity and Conservation is an example of such an initiative as well as the Land Product Validation (LPV) sub-group of the CEOS Working Group on Calibration and Validation. The latter initiative is particularly important as it requires validation of the spatial and temporal consistency of EO products using in-situ data gathered by field experts.

6.2.5 Mapping a pathway to indicators from remote sensing derived primary variables: linking indicators, EBVs and Aichi targets

EBVs fill a gap in current global observation initiatives looking at environmental pressures as they are flexible, in addressing multiple facets of ecosystems, and respond to data requirements for indicator development (Pereira *et al*., 2013). They play an important role in the development of indicators from primary observations, acting as an intermediate between in-situ and/or remote sensing measures and high-level indicators. They are independent of the method of measurement at the observation level and to the changing approaches at the indicator level (Pereira *et al*., 2013).

Despite the solid basis and rationale for the development of EBVs, the link between remote sensing-derived measures and the development of high-level indicators is still not fully developed. A conceptual framework is needed to map the pathway between remote sensing-derived variables, EBVs and indicators in order to track progress towards achieving the Aichi targets. However, there are challenges to this process. An indicator only as good as the data which it is built on and current limitations on remote sensing products, related to scale, resolution and accuracy, may constrain their use in robust operational indicators. Operational indicators are feasible only if the data used to generate them can be realistically obtained whether from a remote sensing platform or other means. Nevertheless, remote sensing is having many positive and practical consequences for ecological research and there are further opportunities for development (Kerr and Ostrovsky, 2003). Having a clear EBV-based pathway for the generation of operational indicators form a remote sensing variable would greatly help in the process.

In addition, in the same way as with limitations, due to their specific characteristics, terrestrial and aquatic ecosystems present unique challenges to indicator development using remotely-sensed data.

6.2.6 Specific challenges in terrestrial ecosystems

A challenging area for EO is to supply adaptable landcover products which can answer specific biodiversity and conservation research questions at a suitable spatial resolution, with sufficient spatial coverage, accuracy that can be updated when and where change occurs.

Global land cover mapping at coarse resolution is challenging and has not always produced comparable results. For example, there are inconsistent cover estimates between GLC-2000, MODIS and GlobCover, especially for cropland, which introduces uncertainty in end user applications. Ways to overcome these challenges in future global landcover products include increasing data sharing efforts and the provision of more in situ data for training, calibration and validation (Fritz *et al*., 2011).

It is challenging to translate landcover to habitat type, though it is often used as a proxy for habitat, the assumption that they are equivalent is questionable. However, mapping habitat directly from remote sensing imagery has been achieved using high resolution (15-20m) satellite imagery, in the Phase 1, national-scale habitat map of Wales for example (Lucas *et al*., 2011). The method was based on object-oriented, rule-based classification coupled with multi-temporal, multi-sensor imagery and shows considerable promise in providing habitat-specific change updates. Such continual monitoring of habitat change, at the national scale, is not possible with current static landcover maps.

Landcover is not the only EO variable in use to infer habitat characteristics. Habitat variables such as species diversity and species richness can be estimated from spectral information alone (Rocchini *et al*. 2010, 2004). Variables such as VCF and fCover, as discussed in section 2.4.1.5, offer an alternative approach to global landcover mapping. Instead of considering discrete borders between landcover types, the VCF product estimates a continuous field of woody vegetation cover. This is a more realistic interpretation of gradients in spatial landcover variability (DeFries *et al*., 1999). Products such as fCover and VCF could potentially be one of several layers in an adaptable landcover map that could be routinely updated. Nevertheless, generating continuous-field land cover datasets at Landsat-resolution and on a global level is challenged by the difficulty of acquiring suitable reference data for validation. Local LiDAR measurements of tree height could be a potential solution to bolstering ground-based validation efforts (Sexton *et al*., 2013).

6.2. 7 Specific challenges in aquatic ecosystems

The two great benefit of EO-based monitoring of oceans and water bodies is the synoptic view of the spaceborne sensors and their regular repeat cycles which allow dynamic processes to be monitored on a regular and repeatable basis (Campbell, 2006). The aquatic environment and the wider hydrological cycle demonstrate unique challenges to EO-based monitoring however. For example, ocean colour monitoring sensors such as SeaWiFS and Envisat MERIS measure slight changes in colour which are easily attenuated by atmospheric interference. Highly dynamic surface features such as ocean currents and the movement of suspended sediment can occur at a rate not measurable by polar orbiting sensors. The recently launched Geostationary Ocean Color Imager (GOCI) has been designed to monitor short-term and regional oceanic phenomena in order to address this problem (He *et al*., 2013).

As already discussed, more data are needed on carbon storage and sequestration value in oceans. However, there are currently large discrepancies between satellite-based and model-based estimates. Furthermore, satellite-based estimates tend to suffer from wide error margins. For example, the Southern Ocean CO_2 sink in 1997/1998 was estimated at −0.08 GtC yr−1 with an error of 0.03 GtC yr−1 (Rangama *et al*. 2005) which was approximately 38% smaller than that based on in-situ measurements and climatological data of the same area (Takahashi *et al*., 2002). Some of this uncertainty can be explained by the weak correlation between in-situ and RS-derived measures of the same surface variable, e.g. chlorophyll-a, which are used in the estimation of CO2 flux (Chen *et al*., 2011).

Habitat fragmentation and connectivity in marine habitats is poorly understood (Strand *et al*., 2007). High-resolution measurements based on LiDAR can offer spatial, structural as well as thematic information on localised coastal habitats (Collin *et al*., 2012), while offshore benthic habitat mapping can be achieved with a combination of ship-based sonar devices and LiDAR (Costa *et al*., 2009). However, it is challenging to acquire the same level of information on a broader scale due to logistical constraints and financial cost. Therefore, mapping the connectivity of the marine habitat is not straight forward as different remote sensing platforms are employed and are not always compatible in producing seamless habitat maps.

7. Lessons learnt from national level experiences

Over the last years, countries have adopted different approaches to the use of remote sensing to monitor biodiversity at a national level, according to their particular needs, capacities and circumstances. The following case studies provide an insight into the application of different methods and products at national and subnational level, and their impact on decision-making and policy implementation. They also offer examples of how particular limitations and challenges have been overcome, providing valuable lessons learnt to countries in similar situation.

7.1 Remote sensing as a surveillance tool: fire monitoring in Australia.

Due to the low population base and large size of Australia's land-mass (7.5 million km^2), remote sensing technologies have been used for wildfire ("bushfire") monitoring, fire-scar mapping and general environmental monitoring ever since the first earth observation satellites were launched in the 1970's. For Australia, satellite technologies have proven to be one of the most appropriate technologies for use in wide-area fire detection and tracking, as well as general environmental monitoring, fuel-load mapping and fuel dryness monitoring.

In 2003, the CSIRO (Commonwealth Scientific and Industrial Research Organisation), together with the department of Defense and Geoscience Australia, developed the "Sentinel Hotspots" bushfire tracking system and associated webGIS portal, which used the Moderate Resolution Imaging Spectrometer Sensor (MODIS) onboard NASA's Aqua and Terra satellites. Through the use of these two satellites, a full continental coverage is achieved up to four times every 24 hours, at a spatial resolution of about 1 km, and a time-latency from satellite overpass to visualization of the hotspot location on the webGIS system of approximately 45 minutes, making this a suitable synoptic near real-time fire monitoring system. Today, the Sentinel system is housed at Geoscience Australia (http://sentinel.ga.gov.au/) , and continues to be used on a 24/7 basis by federal and state fire management agencies, natural resource managers, ecologists and the general public as fire conditions develop across the country.

Other state-based or regional systems such as “FireWatch” in Western Australia and the NAFI (Northern Australia Fire Information) system in the Northern Territory, use similar approaches.

This operational concept was also adopted in 2006 by the Asia Pacific Regional Space Agencies Forum (APRSAF), as it established the “Sentinel Asia” disaster monitoring system, which now has over 15 regional member governments and relevant agencies supplying and using the information, to help countries in the Asia Pacific monitor the progression of impending disasters, and asses the impacts of floods, rainfall, landslides, earthquakes and other natural disasters.

In parallel, these remote sensing technologies have also been used in Australia to map the burnt area and burn-scars, grass-curing and other fire-related variables associated to bushfires around Australia. The “AusCover” remote sensing data facility (www.auscover.org.au) of the Terrestrial Ecosystem Research Network (TERN – www.tern.org.au) of Australia, has since 2009 been providing free and open satellite-derived information, at regional and continental scales, for use in fire ecology studies, assessment of fire impacts on protected areas and for estimation of greenhouse gas emissions, to name a few uses. A key satellite-derived product called the “fire-severity index”, developed and produced for AusCover by Dr. Stefan Maier at the Charles Darwin University in Darwin, allows local land managers and ecologists to monitor the effect of often unplanned fires and strategically implement controlled burns during less damaging times of year. Similarly the “grass curing index” produced by another partner, the Bureau of Meteorology, provides a way to evaluate the dynamics of grass drying and fire-risk, as dry seasons and summers progress across the continent. Such derived datasets provide ecosystem researchers and conservation managers with greater information about the effects of fires on ecological communities, and improve estimates of carbon emissions resulting from fires in different types of ecosystems.

7.2 Use of remote sensing in data creation for use in biodiversity indicators in South Africa

Remotely sensed data has formed the part of the base data for many of the South African indicators used in by the South African National Biodiversity Institute (SANBI) both the National Spatial Biodiversity Assessment (NSBA), 2004 and the National Biodiversity Assessment (NBA), 2011 with a total of 16 indicators derived (totally or partially) from remotely-sensed data.

Although the remotely sensed data is widely used in indicators, there are only two core data layers that have been created from a direct analysis of remotely sensed data, the National land cover datasets dated 2000 and 1994. The next national land cover dataset is only expected to be finalized in 2017 (Parker, 2013). In the interim SANBI has updated the National land cover 2000 dataset with updated provincial land cover data and various other vector data sources (SANBI, 2009). This has provided the base data for the NBA 2011 indicators. The following biodiversity indicators have made use of the land cover as a base data set:

- Terrestrial ecosystem threat status
- Climate change stability in Biomes
- Biodiversity priority areas

The following indicators in the NBA 2011 were created using either satellite or aerial photography:

- **River**: River ecosystem threat status; River ecosystem protection levels; Freshwater ecosystem protection areas; and, Flagship free flowing rivers
- **Wetland**: Wetland ecosystem threat status; and Wetland ecosystem protection levels
- **Estuarine:** Estuarine ecosystem threat status; Estuarine ecosystem protection levels; and, Priority estuaries
- **Marine and coastal**: Marine and coastal ecosystem threat status; and, Marine and coastal ecosystem protection levels
- **Species of special concern** (specifically medicinal plants and threatened freshwater fish)
- **Invasive alien species** (specifically woody invasives)

7.2.1 Limitations

The following limitations have been experienced in using remotely sensed data. In most cases these limitations have resulted in the decision not to use remotely sensed data for indicator generation.

Raw data cost vs. spatial resolution

The South African National Space Agency (SANSA) provide Level 3A and 3B SPOT 5 imagery (with a spatial resolution of 2.5m and 10m) to the provinces, the Presidency, government departments and government agencies such as SANBI (SANSA, 2012). The first Spot 5 mosaic of the country was compiled in 2006 (Campbell, 2012). Cape Nature used SPOT 2005 imagery in the CAPE Fine scale analysis (SANBI, 2007); SANBI does not currently pay to access this imagery. Landsat imagery has been obtained via download from United States Geological Survey (USGS) (U.S. Geological Survey, 2012) and Landsat 5 imagery was used in the SANBI vegetation (Mucina & Rutherford, 2006, p. 19).

However certain biodiversity features, such as wetlands, bush encroachment, streams, etc. cannot be identified on Landsat or SPOT. Unfortunately imagery generated by GeoEye and QuickBird are not available to SANBI free of charge and the cost of purchasing all the tiles for South Africa are excessive. This limits the use of remotely sensed data to areas where there are biodiversity features that cover areas in excess of 2.5 m^2.

Analysis of various vegetation types

The differing Biomes in South Africa require different remote sensing approaches to identify the vegetation types within them. In the Fynbos biome it is problematic to identify vegetation using remote sensing, because veld age seems to be an overriding signature in the vegetation and skews the interpretation (Mucina & Rutherford, 2006, p. 22) . This limitation has been mitigated by making use of vector vegetation distribution data. Certain invasive species such as Acacia are also misidentified as Fynbos. This limitation cannot be mitigated due to a lack of invasive distribution data.

In the Grassland Biome remote sensing faces other challenges. Fallow agricultural fields are identified as natural grassland, whereas in reality they contain only a small number of the grass species that pristine Grasslands should contain. This limitation is mitigated through the introduction of a vector layer of cultivated fields (SANBI, 2009).

Differing mandates and the cost of going commercial

In South Africa there are very limited numbers of remote sensing experts. National Geo-spatial Information, a component of the national Department of rural development and land reform, is responsible for creating and maintaining the National land cover and land use datasets. Unfortunately the process has not yielded a complete dataset since 2000 (released in 2005) and plans to complete the classification and change detection for the entire country only in 2017 (images captured in 2012 – 2014), with a pixel size of 10 m and a minimum mapping unit of 1 hectare (Parker, 2013). To mitigate this limitation the provinces have turned to commercial experts to provide land cover data at a high cost. Three provinces out of a total of nine have developed their own provincial land covers (SANBI, 2008), while a further three provinces have partial land covers. SANBI has mitigated this issue by generating an updated land cover of sorts through the intersection of provincial land covers and various other updated vector layers. This Updated national land cover has been generated for 2009 (SANBI, 2009) and will now be updated again for 2013, this layer is the primarily used for the generation of other data layers and biodiversity indicators (Driver, *et al*., 2011).

Ground truthing

The ground truthing of land cover data is a limitation for remote sensing in South Africa, since the country is vast and diverse in its land cover, commercial entities have mitigated this by making use of aerial or high resolution satellite imagery to undertake random ground truthing (SANBI, 2008). The Fine scale planning project made use of expert workshops (SANBI, 2007) to review the newly generated land cover and determine if it was accurate.

Lack of experience

SANBI has as yet not been able to create a full national land cover due to all the limitations mentioned above along with an additional limitation of a lack of skilled staff, software and hardware. Recently SANBI has had one staff member trained in the use of ENVI and has acquired licenses for both ENVI and ERDAS, however the staff required to advise on the science underlying this work are still lacking.

7.2.2. Spatial and termporal resolution

National monitoring requires the highest spatial and radiometric resolution possible, so that mapping and analysis can occur at regional as well as national scale. The ideal model of data capture and analysis for monitoring in South Africa is that much of the work happens at the regional (municipal and provincial) scale, this data is merged and gaps are filled to produce the national scale data. However in undertaking this approach it is imperative that the results reflected in the national and regional analyses do not differ, it is thus impossible to make use of SPOT imagery regionally and then Landsat imagery nationally.

The requirements for temporal resolution vary between one and five years. Although five years is an acceptable time lapse between land cover data sets, it is also desirable to be able to monitor large land cover changes that happen in much shorter time spans. Considering that it takes approximately one year to collect, classify, check and create a land cover change map, it would be prudent to suggest that the temporal resolution be a minimum of two years and a maximum of four years. In addition when mapping biodiversity features it is imperative to obtain imagery for the wet and dry seasons, in South Africa this would mean a minimum of a December and a June image.

7.2.3 Complementary information to develop an indicator

Two key data types are used to complement remote sensing data.

- Existing vector and raster data: This data informs the data creation by revealing what is known to be in that location already, for example a portion of land cannot revert back to a natural classification if it has been cultivated, it is most likely fallow instead.

- Expert opinion: Expert opinion in vegetation mapping is crucial. The group of experts, constituting the South African Vegetation Map committee, still meets on a regular basis to discuss changes to the National vegetation map (Mucina & Rutherford, 2006). These changes may be as a result of new species classifications or new field work.

7.2.4 Priorities for the future

South Africa is in urgently in need of a series of regularly updated land cover datasets that allow for the assessment of the condition of terrestrial ecosystems, rivers, wetlands and estuaries (Driver, *et al.*, 2011, p. 170). This task would benefit from well-defined leadership and international exposure to best practices in land cover creation, specifically in a biodiversity context.

7.3 Using remote sensing for Protected Area planning in Canada

Canada is the second largest country in the world by land area, at nearly 10 million km^2 in size. Monitoring biodiversity and associated ecosystems for a nation the size of Canada requires approaches that enable broad scale national assessments. Over the past five years the Universities of British Columbia (UBC) and Victoria (UVic) with the Canadian Forest Service (CFS) of Natural Resources Canada (NRCan), have investigated the role remote sensing can play in the assessment of biodiversity across Canada

This research includes the national level application of indices which capture different aspects of species habitats, and the production of regionalizations or environmental domains which allows for the assessment of , for example, the representation of park networks.

Application of a Dynamic Habitat Index (DHI) across Canada

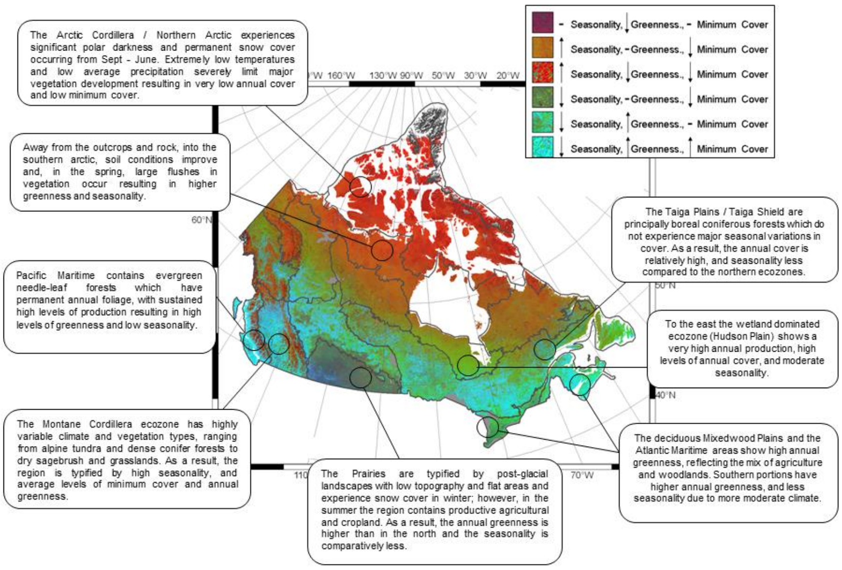
Vegetation productivity is the most widely supported predictor of broad scale biodiversity patterns. In general, regions with higher productivity support higher levels of species richness. Productivity is easily amenable to rapid, repeatable monitoring with remote sensing data. A dynamic habitat index (DHI) has been applied across Canada, a tripartite measure of vegetative productivity, to monitor habitat condition repeatedly and over large extents. The DHI is computed from satellite estimates of the fraction of Photosynetheically Active Radiation (fPAR), an index which provides an indicator of vegetation growth capacity. The three components are:

1. Annual average landscape greenness which integrates the productive capacity of a landscape across a year and has long been recognized as a strong predictor of species richness.

2. Annual minimum greenness which relates the potential of a given landscape to support permanent resident species throughout the year. Locations without significant snow cover at the end of the summer will often maintain greenness into winter, and vegetation fPAR remaining above 0. In areas where snow covers the vegetation, fPAR approaches 0.

3. Seasonal variation in greenness is an integrated measure of climate, topography, and land use. For example, forests and grasslands in the mountainous and interior regions of continents display a much shorter growing season than those in the more maritime ecoregions. High seasonality values signify seasonal extremes in climatic conditions or limited periods with agricultural production. Sites with low values typically represent irrigated pasture, barren land, or evergreen forests.

These three components of the DHI make it a prime candidate to test hypothesis related to diversity-productivity relationships and its dynamic nature, which is tailored to ecological theory, makes it more informative than single remote-sensing metrics (Figure 7.1).



The Arctic Cordillera / Northern Arctic experiences significant polar darkness and permanent snow cover occurring from Sept - June. Extremely low temperatures and low average precipitation severely limit major vegetation development resulting in very low annual cover and low minimum cover.

Away from the outcrops and rock, into the southern arctic, soil conditions improve and, in the spring, large flushes in vegetation occur resulting in higher greenness and seasonality.

Pacific Maritime contains evergreen needle-leaf forests which have permanent annual foliage, with sustained high levels of production resulting in high levels of greenness and low seasonality.

The Montane Cordillera ecozone has highly variable climate and vegetation types, ranging from alpine tundra and dense conifer forests to dry sagebrush and grasslands. As a result, the region is typified by high seasonality, and average levels of minimum cover and annual greenness.

The Prairies are typified by post-glacial landscapes with low topography and flat areas and experience snow cover in winter; however, in the summer the region contains productive agricultural and cropland. As a result, the annual greenness is higher than in the north and the seasonality is comparatively less.

The Taiga Plains / Taiga Shield are principally boreal coniferous forests which do not experience major seasonal variations in cover. As a result, the annual cover is relatively high, and seasonality less compared to the northern ecozones.

To the east the wetland dominated ecozone (Hudson Plain) shows a very high annual production, high levels of annual cover, and moderate seasonality.

The deciduous Mixedwood Plains and the Atlantic Maritime areas show high annual greenness, reflecting the mix of agriculture and woodlands. Southern portions have higher annual greenness, and less seasonality due to more moderate climate.

Figure 7.1. The Dynamic Habitat Index of Canada. Different ecological zones throughout the country exhibit different DHI components of productivity, seasonality and minimum cover. As a result spatial differences across the country are apparent as changes in color

The DHI has been derived from MODIS (NASA 2000 onwards) or AVHRR (Advanced Very High Resolution Radiometer (1986 onwards) and is freely available to researchers. The DHI has also been applied across North America and a global DHI product is underway.

Environmental Domains and Conservation Representativeness

Another approach for the use of remotely sensed derived indicators of biodiversity is to provide information for the characterization of the landbase. The DHI has been used together with other remotely sensed datasets, such as information on land cover, fragmentation, disturbance, snow cover to develop clusters (pixels) into environmental domains, or areas sharing common environmental conditions. Such domains are analogous to traditional ecoregions, however unlike ecoregions, which are forced to include atypical areas by the requirement of spatial contiguity, environmental domains are not spatially discrete and, therefore, allow a more consistent classification of homogenous units. These environmental domains can then be used to assess, for example, Canada's network of parks and protected areas and systematic conservation planning of future reserves.

Work in Canada has focused on its Boreal forest where currently, ~8.1 % (448 178 km^2) is under some form of protection, with many of these areas in low productivity environments located in the far north or at higher elevations. However, because of its remoteness and inaccessibility, ~80% of the boreal already functions as though protected; thus, there exists a vast potential for conservation investment in the region. Methods which utilized 15 remotely sensed clusters and species at risk data to assess a variety of hypothetical reserve network scenarios were applied, with (i) varied levels of conservation targets and reserve compactness and (ii) the preferential prioritization of remote or intact wilderness areas (Figure 7.2).

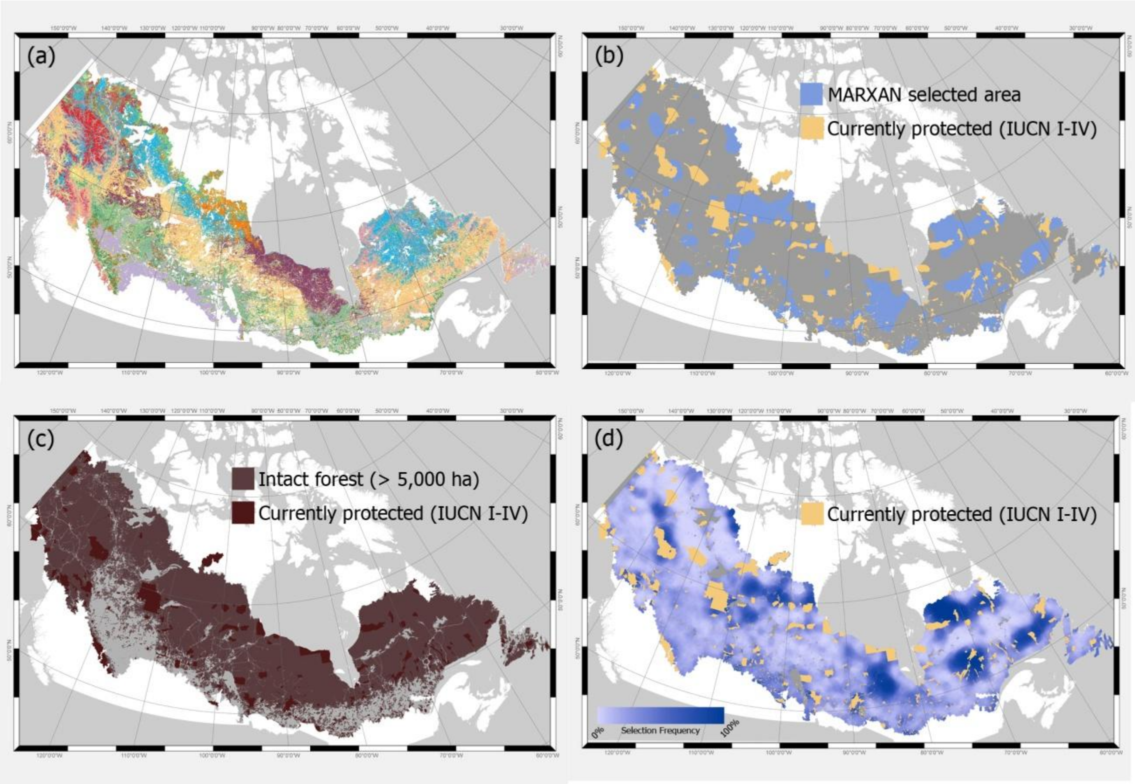


Figure 7.2. (a) Spatial distribution of 15 environmental domains (Powers *et al*., 2013). (b) A best or near optimal MARXAN reserve design solution for a scenario that preferentially prioritizes remote areas away from human presence using an accessibility cost layer. (c) Global Forest Watch Canada (GFWC) intact forest landscape and current protected areas (IUCN I-IV). (d) The sum of all MARXAN solutions for 500 runs (iterations) of the same scenario. It is used to determine the selection frequency of each planning unit (0-100%), and provides an indication of how important the planning unit is for an efficient reserve design.

Results suggest that reserve compactness greatly influences the reserve area and cost and that restricting conservation to only intact wilderness areas also reduces flexibility and reserve cost efficiency. However, preferentially prioritizing remote portions of the boreal or areas with low human accessibility was able to provide the reserve design flexibility needed to me*et al*l scenario targets and demonstrates that this approach is for aiding in biodiversity conservation efforts. Results show that the indirect indicators of biodiversity, which are available from remote sensing, are effective tools for modeling and monitoring biodiversity at national and continental scales and provide valuable insights into basic and applied ecological research.

In order to ensure the preservation of species and habitat diversity and current and anticipated future conditions, all environmental domains should be adequately represented in a comprehensive conservation network. The clustering analysis used to identify domains has also identified environmental conditions that are unique, and thus may be the most deserving of conservation attention. Spatial conservation planning tools such as MARXAN can be used to help determine where (spatially) conservation investment should be prioritized. This method works by finding cost-effective solutions to conservation problems by achieving conservation targets for the least cost, which can include a variety of factors such as area or economic costs associated with land acquisition, management, human accessibility and forgone activity.

7.4 The effectiveness of free open access data. The Brazilian example

As Brazil is large geographically—more than 8.5 million km^2—and has high biodiversity, special ecosystems such as the Amazonian and Pantanal regions, an ever-growing agriculture, a fast-changing land use and land cover, and a long coastline, it is especially suited for space-based remote sensing technologies. Therefore, Brazil has been at the forefront of remote sensing research and application since 1973 when was among the first countries to build and operate it own ground station to receive Landsat-1 data.

At the end of the 1980's, Brazil began the development of a civilian remotes sensing satellite program with China called China-Brazil Earth Resources Satellite (CBRES), becoming part of one of the first programs in the world involving two developing countries collaborating to develop and launch remote sensing satellites. To date, a constellation of three satellites has been launched (CBERS-1 in 1999, CBERS-2 in 2003, CBERS-2B in 2007 and CBERS-3 in 2012), and two more satellites are in their way (CBERS-3 planned for 2013, and CBERS-4 planned for 2104).

One of the main aspects of the CBERS Program is the data policy adopted after the CBERS-2 launch. Brazil adopted the free-of-charge CBERS data distribution policy when data are requested in electronic format, opening the field of remote sensing to new users, applications and business. Initially adopted for Brazilian users, it was extended for neighboring countries, and then to the world. Currently, all CBERS data gathered at Cuiaba, the Brazilian ground station, is distributed free of charge to everyone1

Since the adoption of this open-access data policy, more than 100,000 scenes have been distributed each year inside Brazil to thousands of users and institutions. The processing system is very fast and it takes only a few minutes for the user to have his request for a full-resolution scene fulfilled. This kind of data policy and easy distribution system promoted a strong increase in the number of users and applications. As a result, there is no organization related to agriculture, environment, geology, or hydrology in the country that is not a CBERS user. Hundreds of businesses in remote sensing were opened after the adoption of the current data policy. The environmental control by the society was also increased.

Brazilian legislation requires that each farmer identify and notify the environmental agency about areas to be protected on each farm. This procedure is called environmental licensing and has been adopted in many states around the country. Currently, most of this procedure is done based on CBERS

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1 www.dgi.inpe.br/CDSR

images and has opened hundreds of small businesses specializing in this kind of service. An interesting application of CBERS images is in tax enforcement. Some states use CBERS to help them to monitor farms to assure that all declarations made by farmers are in accordance with the tax law.

Another important application of the fast and free access to CBERS data is to map and measure deforested areas. It is often the case that governmental institutions have difficulty in acquiring up-to-date remote sensing data, especially in developing countries. In Brazil the deforestation in the Amazon region is a main environmental problem. Actions from the governmental environmental protection agency depend on monitoring. Monitoring in the Amazon region on an annual basis used to be based on NASA owned Landsat data, but with the launch of CBERS, the Brazilian capacity to monitor the Amazonia experienced a major increase. In addition, CBERS data is also used, together with MODIS data, in a permanent monitoring system for the Amazonia under a project called Detection of Deforestation in Near Real Time (DETER). It allows detecting early signs of deforestation, and alerting the environmental agency in time to take action.

8. Discussion

- Remotely sensed data and derived-measures, combined with appropriate validation and modeling, has improved insights into the ecological processes and anthropogenic disturbances that influence biological diversity, and have shown potential to fill gaps in the suite of indicators that could be used to track the implementation of the Strategic Plan for Biodiversity 2011-2020 and the achievement of the Aichi Biodiversity Targets. With a large number of examples to demonstrate this potential, remote sensing and biodiversity experts are beginning to explore these opportunities. However, caution should be taken not to oversell the promise of remote sensing for monitoring biodiversity. It is **not a fit-for all solution***,* and despite the important contribution it has the potential to provide to any biodiversity monitoring system, validating the remotely sensed data with ground truth data and traditional methods of inventorying and assessing biodiversity will still be required.

- As explored throughout this review, there are potentially many areas for **future development** of remote sensing products experts could focus on. However, human and financial resources are limited and therefore priorities must be established. As part as an enhanced dialogue between the different stakeholders, priorities should be driven by end users needs. A significant requirement of the conservation community is for **long-term Land Cover Change (LCC) products**. Current global landcover products are too coarse in resolution, single-date or infrequently updated. Consistent and repeatable land cover products over time, adopting a standardised hierarchal classification scheme, e.g. the Land Cover Classification System (LCCS), can address this need. As landcover changes such as agricultural expansion have been identified as major drivers of biodiversity loss, monitoring landcover change over time can identify where the pressures are occurring and how likely they are to impact the current status and future trends in global biodiversity. The success of conservation interventions can also be measured by assessing landcover change in and around protected areas. However, it is vital that the spatial resolution of such products are commensurate with the scale of conservation units used in conservation e.g. ecoregions and units smaller than these.

- Monitoring forest cover change has been the area of most intense research in global analyses of land cover change to date. There are numerous reasons for this. Firstly, forests are most easily distinguished in satellite imagery than other vegetation cover types, such as croplands or urban areas. Forest reserves are important conservation areas and are global in distribution. Monitoring forest cover change has important implications for carbon accounting, biodiversity monitoring, and other issues such as illicit logging. However, there is a need to address this bias in land cover monitoring. **Other terrestrial ecosystems such as open grasslands, savannah, peatlands and wetlands also need to be considered in land cover change studies**. They provide ecosystem services such as carbon storage, clean drinking water, fuel and shelter and are important habitat. Although marine ecosystems are not as readily monitored as terrestrial ecosystems for biodiversity purposes, inshore and intertidal ecosystems are also important landcover types.

- Remote sensing products are a useful tool **to assess the effectiveness of conservation interventions**. However, most of the work done to date has focused on forested protected areas. Further habitats types and broarder sets of data need to be included in future studies to expand the use of remote sensing in monitoring implementation of the Strategic Plan for Biodiversity 2011-2020.

- To date, dialogue between data providers and end users has been limited. There is a disconnection on the awareness of what is available, what can be done and what is expected. A **closer relationship between the earth observation community and potential users** in the biodiversity policy and management communities would help to enhance understanding, align priorities, identify opportunities and overcome challenges, ensuring data products more effectively meet user needs.

- Developing indicators to monitoring biodiversity in general, and the Aichi Biodiversity Targets in particular can be challenging and heavy data consuming. Most biodiversity indicators need a variety of data streams, from several sensors and often including non remotely-sensed sources. It can become a challenge to have all of them available at the required time, spatial coverage and time resolution. It only takes a blockage in one of the data streams to prevent execution and development of the indicator. This complexity makes even more necessary to nurture a **productive dialogue** among all data providers and end users in order to facilitate and align priorities and necessities.

- The link between remotely-sensed derived measures and the development of indicators for high-level policy making is still poorly developed. There is a lack of common standards regarding the measures required by the biodiversity community and the spectral information collected by the remote sensing community. In addition, a full harmonization of methodologies and data collection at national and international level and a delivery approach that works across different landscapes is still not in place. An agreed **set of minimum requirements and common standards** from biodiversity monitoring practitioners would help focus the efforts of the Earth Observations' experts. Initiatives such as the development of EBVs led by GEO BON could offer the necessary conceptual framework to bridge the gap between both communities and map the pathway from primary remote sensing observations to the delivery of high-level indicators. Closer collaboration between the GEO BON community work on the establishment of EBVs and the BIP work on biodiversity indicators could contribute to this.

- Bottlenecks in data access are a key limitation for the expansion of remote sensing for biodiversity monitoring. Free open access data policies have been adopted and implemented by various space agencies and national institutions to date, proving effectively for increasing the use of remote sensing in biodiversity monitoring, as well as enhancing policy implementation and law enforcement in some cases. Free open data access schemes should continue to be the international trend among data providers to support the democratization of access to remotely-sensed data. **Free and open access to all taxpayer-funded satellite remote sensing imagery** will address this significant constraint.

- However, free open access data policy does not necessarily translate into **easy and fast data access.** This might be due to limited bandwidth and internet constrains, or to be related to a hierarchical tier approach to prioritize data dissemination among different user groups. A concerted international action to secure an easy access to remotely-sensed data should be implemented, especially to ease access from developing countries.

- Enhanced access to data will only be effective if Parties have the sufficient technical and human capacity to make use of it. The international trend of including a **major capacity building** component in Space Agencies Earth Observations projects will play an important role. In addition, better mechanisms should be established to help financially the participation of Parties in Space Agencies' projects.

- Uncertainty in the long-term (decadal) continuity of Earth Observations and satellite and other remote sensing missions is a key challenge for the funding of projects as it restrains funders to invest in Earth Observation projects, affecting further research and development on remote sensing. More initiatives to **guarantee a long term continuity of Earth Observations** are needed.

- Accessing comprehensive information on Earth Observations is often difficult to Parties since it is still very scattered hosted by different organizations, space agencies and national agencies, and a wide range of projects. Therefore, missing for Parties in the context not only of the CBD but of international Conventions and MEAs is to have a unique reference they can consult on Earth Observation matters in relation to biodiversity. A reference entity, such as the BIP as main vehicle for information on biodiversity indicators, that would act as a **hub to concentrate and coordinate existing information and is easily accessible globally** could be a key component to facilitate greater use of remotely-sensed data and products in biodiversity monitoring. This hub would require significant work to constantly offer the most updated information due to the fast pace of development of the EO field.

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10.Annex

Table 10.1. Mentioned existing global databases for the main EO products used to monitor biodiversity

Variable	**Existing database**	**Institution**	**Satellite Sensors**	**Access**
Land-based	Global Land Service	Copernicus	SPOT- VGT	Open
	Distributed Active Archive Centers (DAACs)	NASA	MODIS	Open
Land, atmosphere and water based	Giovanni2	NASA Goddard Earth Sciences	Multiple	Open
Marine	Ocean Colour website	NASA	Multiple	Open
Land, atmosphere and ocean	Office of [3]satellite and product operations	NOAA	Multiple	Open
Atmospheric, ocean and land	GEONETCast website	Group on Earth Observation (GEO)	Space-based, air-borne and *in situ*	Open
Land-based (developing countries)	DevCoCast website	Global Earth Observation System of Systems (GEOSS)	Multiple	Open
Land-based (Indian sub-continent)	Biodiversity Information System (Roy and Saran, 2004)	Indian Institute of Remote Sensing	IRS-LISS II/ SPOT/Landsat	Open

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[2] The Giovanni data parameter database contains over 4,000 data parameters which are catalogued by their corresponding data product or sensor but are more restricted in terms of their spatial coverage, access rights and require more processing and user input. It has in-built analytical tools and is more of a scientific analysis tool than a download portal

[3] Spatial coverage is sometimes restricted to the United States

Table 10.2 Existing landcover databases

Variable	Existing database	Year	Institution	Scale	Sensor
Landcover (and associated variables)	National Land Cover Database (NLCD)	1992,2001,2006	USGS Earth Resources Observation and Science (EROS) Centre	U.S.A.	Landsat
Landcover	Global Land Cover (GLC) 2000	2000	Joint Research Centre (European Commission)	global	SPOT-VGT
Landcover	GlobCover Portal	2006,2009	European Space Agency (ESA)	global	MERIS
Landcover (and associated variables)	Africover database	Various	The Food and Agricultural Organisation (FAO)	National (African countries)	Various
Landcover	CORINE Land Cover (CLC)	1990,2000,2006	European Environment Agency(EEA)	Pan-European	

Table 10.3. Mapping of EBVs, Aichi targets, CBD Operational indicators and relevant EO products

Operational indicator	**Candidate EBV**	**Most relevant Aichi target**	**Other Aichi Target supported**	**EO Product**	**Acronym**	***In-situ***	**Key features**	**Variable Measured**	**Spatial scale**	**Application to conservation**	**Access**	**Existing databases**	**Temporal coverage**	**Level of product development**
Trends in climate impacts on population trends Status and Trends in extent and condition of habitats that provide carbon storage	Phenology (vegetation)	15	8,14, 10	Leaf Area Index	LAI	Measuring leaf area directly or through hemispherical photography	Important in surface-atmosphere interactions such as photosynthesis, evapotranspiration and respiration	Area of leaf surface per unit area of soil surface	Global, 10°x10° tiles, Continental tiles Global, 10°x10° tiles Africa and South America continental tiles	Input to Net Primary Productivity Models or as a correlate of other environmental variables understand vegetation-climate interactions	Open access	Global Land Service Global Land Service GEONET Cast DevCoCast website	1999-present 2009-present Near-real time only Aug 2007-present	Operational
Trends in primary productivity Status and Trends in extent and condition of habitats that provide carbon storage		5 15		Fraction of Absorbed Photosynthetically Active Radiation	FAPAR	Eddy covariance measurements	Acts like a battery for the plant photosynthetic process	FAPAR absorbed by the plant canopy instantaneous with satellite overpass	Global, 10°x10° tiles, Continental tiles	Input to Net Primary Productivity Models or as a correlate of other environmental variables	Open access	Global Land Service	1999-present	Operational
Trends in condition and vulnerability of ecosystems Trends in proportion of degraded/threatened habitats				Normalised Difference Vegetation Index	NDVI	Flux towers and digital cams	Spectral band ratio to detect differential reflectance in red and near infrared bands from green vegetation	Not a biophysical variable but an estimate of the vegetation amount	Global, 10°x10° tiles Africa and South America continental tiles	Monitor vegetation state, health and disturbance	Open access	Global Land Service GEONET Cast DevCoCast website	1999-present Near-real time only Aug 2007-present	Operational
Trends in primary productivity Status and Trends in extent and condition of habitats that provide carbon storage	Net primary productivity	5 15		Dry Matter Productivity	DMP	Not measurable	Directly related to NPP but customised for agronomic applications	Dry matter biomass increase (growth rate) expressed in kilograms of dry matter per hectare per day	Global, 10°x10° tiles Africa and South America continental tiles	Identify anomalies in vegetation productivity and to forecast crop yields	Open access	Global Land Service GEONET Cast DevCoCast website	2009-present Near-real time only Aug 2007-present	Operational
Trends in condition and vulnerability of ecosystems	Net primary productivity	5		Ocean colour	n/a	Not measurable	Phytoplankton contain chlorophyll and	Chlorophyll-a	Regional seas, major oceans, major inland water bodies	Related to phytoplankton, primary production and marine food chain	Open access	GMES My Ocean NASA Ocean Colour	Variable	Operational
Trends in condition and vulnerability of ecosystems	Net primary productivity	5		Sea Surface Temperature	SST	Marine weather buoy network	Depends on method , e.g. optical measures 'skin' temperature, radar penetrates sub-surface	Temperature of water surface		Determines the distributions of marine plant and animal species	Open access	PO DAAC (NASA) GMES My Ocean ESA CCI SST	Variable	Operational

Operational indicator	**Candidate EBV**	**Most relevant Aichi target**	**Other Aichi Target supported**	**EO Product**	**Acronym**	***In-situ***	**Key features**	**Variable Measured**	**Spatial scale**	**Application to conservation**	**Access**	**Existing databases**	**Temporal coverage**	**Level of product development**
Trends in distribution of selected species	Migratory behavior	12	5,6,10,11	Banding/ marking/ tagging and observation of individuals	International Cooperation for Animal Research Using Space (ICARUS)	Measurable	Satellite or radio tagging	Global position but also physiological characteristics	All scales	Species range and habitat, foraging behavior, migration patterns	Open access	Movebank	Variable	Operational
Trends in extent of selected biomes, ecosystems and habitats (decision VII/30 and VIII.15)	Disturbance regime	5	7,9,10,11, 14,15	Burnt Areas	n/a	Not measurable	Fire detection	Spatial extent of burnt scars	Continental, 10°x10° tiles Global	Temporal information on the fire season	Open access	Global Land Service MODIS Global Burned Area product	1999-present 2000-present	Operational
Trend in emission to the environment of pollutants relevant for biodiversity		8		Oil spill detection	Synthetic Aperture Radar (SAR)	Spatial extent not measurable	Tracking potential pollution events	oil slicks, vessels and installations at sea	Local to regional	Marine pollution represents a habitat disturbance	Open access for maritime administration in EU member states	CleanSeaNet Data Centre	2007-present	Operational
Trends in condition and vulnerability of ecosystems		5		Vegetation Condition Index	VCI	Not measurable	Compares the observed NDVI to the range of values in same period in previous years	Good or bad vegetation state as a percentage of normal range	Continental, 10°x10° tiles	Identify areas of poor or improving vegetation state on a qualitative basis	Open access	Global Land Service	2013-present	Operational
Trends in primary productivity		5		Vegetation Productivity Index	VPI	Not measurable	Compares the observed NDVI to NDVI value from previous years over the same 10-day period	Overall vegetation condition	Continental, 10°x10° tiles Africa and South America continental tiles	Useful to monitor growing season in – progress i.e. As an early warning system for anomalous change	Open access	Global Land Service GEONET Cast DevCoCast website	2013-present Near-real time only Aug 2007-present	Operational
Trends in condition and vulnerability of ecosystems		5		Sea Surface State	n/a	Offshore weather buoys	Radar Scatterometry (wind) Radar Altimetry, e.g. *Jason-2* (wave height)	Wave height, direction, length and frequency	Regional seas and major oceans	Monitoring of extreme weather events with potential for marine habitat disturbance	Open access	ESA Globwave (satellite and *in-situ* data) Aviso (altimetry products)	Variable	Operational

Table 10.4A .Mapping of the adequacy of remote sensing for development of CBD indicative list of indicators (Decision XI/3) for the Strategic Goal A.

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS	Other requirements / standards	Global			Regional			National		
								Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
1.	By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.															
	1	Trends in awareness and attitudes to biodiversity (C)	NO													
	2	Trends in public engagement with biodiversity (C)	NO													
	3	Trends in communication programmes and actions promoting social corporate responsibility (C)	NO													
2.	By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.															
	4	Trends in number of countries incorporating natural resource, biodiversity, and ecosystem service values into national accounting systems (B)	NO													
	5	Trends in number of countries that have assessed values of biodiversity, in accordance with the Convention (C)	NO													
	6	Trends in guidelines and applications of economic appraisal tools (C)	NO													
	7	Trends in integration of biodiversity and ecosystem service values into sectoral and development policies (C)	NO													
	8	Trends in policies considering biodiversity and ecosystem service in environmental impact assessment and strategic environmental assessment (C)	NO													
3.	By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.															
	9	Trends in the number and value of incentives, including subsidies, harmful to biodiversity, removed, reformed or phased out (B)	NO													
	10	Trends in identification, assessment and establishment and strengthening of incentives that reward positive contribution to biodiversity	NO													

		and ecosystem services and penalize adverse impacts (C)														
4. By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.																
	11	Trends in population and extinction risk of utilized species, including species in trade (A)	YES	intrinsic rate of increase,	daily surface water inundation fraction, surface air temperature, soil moisture, and microwave vegetation opacity	in situ weather station data								various	30d	microwave AMSR-E, Landsat
	12	Trends in ecological footprint and/or related concepts (C)	YES	natural capital consumption, area units	thematic classification		population model	low/medium	monthly/yearly	MODIS, Lansat, Sentinel 2	low/medium	monthly/yearly	MODIS, Landsat, Sentinel3	low/medium	monthly/ yearly	MODIS, Landsat, Sentinel 4
	13	Ecological limits assessed in terms of sustainable production and consumption (C)	YES	usd/ha	crop yield	ecosystem capacity	model - indirect				low/medium	6months	MODIS/ Landsat/ Sentinel2	low/ medium	6months	MODIS/ Landsat/ Sentinel3
	14	Trends in biodiversity of cities (C)	YES	green space - area unit, green infrastucture	classification		indirect							high/ medium	monthly/ yearly	ikonos, rapideye, Landsat/ sentinel2
	15	Trends in extent to which biodiversity and ecosystem service values are ncorporated into organizational accounting and reporting (B)	NO													

Table 10.4B .Mapping of the adequacy of remote sensing for development of CBD indicative list of indicators (Decision XI/3) for the Strategic Goal B.

Target	**Code**	**Operational indicator**	**Mesurable by RS**	**Metrics/Proxy**	**EO product**	**Additional non-RS data**	**Other requirements / standards**	**Global**			**Regional**			**National**		
								Spatial	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**
5	By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.															
	16	Extinction risk trends of habitat dependent species in each major habitat type (A)	YES	scenarios		indirect measurement										
	17	Trends in extent of selected biomes, ecosystems and habitats (A)	YES	surface circulation features	water surface vertical displacements			Large scale circulation features	weeks to months	radar altimeter	Large scale circulation features	weeks to months	radar altimeter			
	18	Trends in proportion of degraded/threatened habitats (B)	YES	surface circulation features	Ocean Color, water surface vertical displacements					lidar, radar altimeter			lidar, radar altimeter			lidar, radar altimeter
	19	Trends in fragmentation of natural habitats (B)	YES	area	classification, change detection map						medium/high	monthly/yearly	ikonos, rapideye, geoeye, landsat, sentinel2	medium/ high	monthly/yearly	ikonos, rapideye, geoeye, landsat, sentinel3
	20	Trends in condition and vulnerability of ecosystems (C)	YES	eco-environmental vulnerability index	spatial principle component analysis		elevation, slope, accumulated temperature, drought index, land use, vegetation, soil, water-soil erosion, and population density	low	year	modis				high	monthly	ikonos, rapideye, geoeye
	21	Trends in the proportion of natural habitats converted (C)	YES	area	classification, change detection map						medium/high	monthly/yearly	ikonos, rapideye, geoeye, landsat, sentinel2	medium/ high	monthly/yearly	ikonos, rapideye, geoeye, landsat, sentinel3
	22	Trends in primary productivity (C)	YES	NPP	fAPAR, NDVI											
	23	Trends in proportion of land affected by desertification (C)	YES	RUE	fAPAR, NDVI	precipation										
	24	Population trends of habitat dependent species in each major habitat type (A)	YES	kg/km2, mg/cu.m	echosounder echograms, fish school density, chlorophyl pigments	fish, seaweed samples	SST				m to km		Echosounder, sonar, lidar, Aerial photography	m to km	minutes to days	Echosounder, sonar, lidar, Aerial photography

6 By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.																
	25	Trends in extinction risk of target and bycatch aquatic species (A)	NO													
	26	Trends in population of target and bycatch aquatic species (A)	YES	kg/km2, mg/cu.m	echosounder echograms, fish school density, chlorophyl pigments	fish, seaweed samples	SST				m to km		Echosounder, sonar, lidar, Aerial photography	m to km	minutes to days	Echosounder, sonar, lidar, Aerial photography
	27	Trends in proportion of utilized stocks outside safe biological limits (A) (MDG indicator 7.4)														
	28	Trends in catch per unit effort (C)	NO													
	29	Trends in fishing effort capacity (C)	YES	Number of Boats	Aerial images											Airborne
	30	Trends in area, frequency, and/or intensity of destructive fishing practices (C)	NO													
	31	Trends in proportion of depleted target and bycatch species with recovery plans (B)	NO													
7 By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.																
	32	Trends in population of forest and agriculture dependent species in production systems (B)	YES	%, unit	species map									high res	year	ikonos, rapideye
	33	Trends in production per input (B)	YES	usd/unit	yield estimation									high res	year	ikonos, rapideye
	34	Trends in proportion of products derived from sustainable sources (C)	YES	%, loss of vegetation	classification, land cover change									high res	year	ikonos, rapideye
	35	Trends in area of forest, agricultural and aquaculture ecosystems under sustainable management (B)	YES	area	land cover map		land tenure	low/medium	year	MODIS/ Landsat	low/medium	year	MODIS/Landsat	low/medium	year	MODIS/Landsat
8 By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.																
	36	Trends in incidence of hypoxic zones and algal blooms (A)	YES	phytoplancton concentration (mg/m3),	Water leaving radiance, Ocean Color	algal inventory		km2	weeks-month	MODIS, Sentinel 3(OLCI)	km2	weeks-month	MODIS, Sentinel 3	km2	weeks-month	MODIS, Sentinel 3

	37	Trends in water quality in aquatic ecosystems (A)	YES	water constituents	Water leaving radiance	water samples		km2	weeks-month	MODIS, Sentinel 3(OLCI)	km2	weeks-month	MODIS, Sentinel 3	km2	weeks-month	MODIS, Sentinel 3
	38	Impact of pollution on extinction risk trends (B)	NO													
	39	Trends in pollution deposition rate (B)	YES	meters	bathymetry											airborne, bathymetric lidar
	40	Trends in sediment transfer rates (B)	NO													
	41	Trend in emission to the environment of pollutants relevant for biodiversity (C)	YES		SAR images, Ocean Color	wind speed under certain threshold	proper sun glint correction	10 cm to meters		SAR, Sentinel 1	10 cm to meters		SAR/Sentinel 1	10 cm to meters		SAR/Sentinel 1
	42	Trend in levels of contaminants in wildlife (C)	NO													
	43	Trends in nitrogen footprint of consumption activities (C)	NO													
	44	Trends in ozone levels in natural ecosystems (C)	YES	ppmv, Dobson unit	ozone concentrations				1 or 8 days	Total Ozone Mapping Spectrometer (TOMS), the Solar Backscatter Ultraviolet Spectrometer (SBUV), and the Global Ozone Monitoring Experiment (GOME).						
	45	Trends in proportion of wastewater discharged after treatment (C)	NO													
	46	Trends in UV-radiation levels (C)	YES	UV-A, UV-B	Ocean Color	use of a AERONET/OC network (CIMEL)	corection of aerosols			CIMEL sensors			CIMEL sensors			CIMEL sensors
9	By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.															
	47	Trends in the impact of invasive alien species on extinction risk trends (A)	YES	area%	time series, land cover map	population dinamics model								medium/high	year	rapideye, ikonos
	48	Trends in the economic impacts of selected invasive alien species (B)	YES	usd/output	time series, land cover map		econometric model							medium/high	year	rapideye, ikonos

	49	Trends in number of invasive alien species (B)	YES	area%	land cover, species distribution maps									medium/high	year	rapideye, ikonos
	50	Trends in incidence of wildlife diseases caused by invasive alien species (C)	NO													
	51	Trends in policy responses, legislation and management plans to control and prevent spread of invasive alien species (B)	NO													
	52	Trends in invasive alien species pathways management (C)	YES	area	land cover map									medium/high	year	rapideye, ikonos
10	By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.															
	53	Extinction risk trends of coral and reef fish (A)	YES		SST, Ocean Color			10 cm to km^2	days to months	MODIS, SAR	10 cm to km^2	days to months		10 cm to km^2	days to months	
	54	Trends in climate change impacts on extinction risk (B)	YES	Celsius, W m -2 nm -1,	SST, Ocean Color	wind speed		10 cm to km^2	days to months	MODIS, SAR	10 cm to km^2	days to months		10 cm to km^2	days to months	
	55	Trends in coral reef condition (B)	YES	Celsius, W m -2 nm -1,	SST, Ocean Color, Insolation, SAR, Ocean Surface Vector Winds	wind speed		10 cm to km^2	days to months	MODIS, SAR	10 cm to km^2	days to months		10 cm to km^2	days to months	
	56	Trends in extent, and rate of shifts of boundaries, of vulnerable ecosystems (B)	YES	area	land cover			10 cm to km^2	days to months	MODIS, SAR	10 cm to km^2	days to months		10 cm to km^2	days to months	
	57	Trends in climatic impacts on community composition (C)	NO													
	58	Trends in climatic impacts on population trends	NO													

Table 10.4C .Mapping of the adequacy of remote sensing for development of CBD indicative list of indicators (Decision XI/3) for the Strategic Goal C.

Target	**Code**	**Operational Indicator**	**Mesurable by RS**	**Metrics / Proxy**	**EO product**	**Additional non-RS data**	**Other requirements / standards**	**Global**			**Regional**			**National**		
								Spatial	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**
11	By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.															
	59	Trends in coverage of protected areas (A)	YES	area	landcover	cadastral DB		low/medium	month/year	MODIS/landsat/sentinel2	low/medium	month/year	MODIS/landsat/sentinel2	low/medium	month/year	MOIDS/landsat/sentinel3
	60	Trends in extent of marine protected areas, coverage of key biodiversity areas and management effectiveness (A)	YES	area	time series			low/medium	month/year	MODIS/landsat/sentinel3	low/medium	month/year	MODIS/landsat/sentinel3	low/medium	month/year	MODIS/landsat/sentinel4
	61	Trends in protected area condition and/or management effectiveness including more equitable management (A)	YES		soil moisture, phenology			low/medium	daily	amser-e, aviris, WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT	low/medium	daily	amser-e, aviris, WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT	low/medium	daily	amser-e, aviris, WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT
	62	Trends in representative coverage of protected areas and other area based approaches, including sites of particular importance for biodiversity, and of terrestrial, marine and inland water systems (A)	YES	area	landcover			low/medium	month/year	modis/landsat/sentines3	low/medium	month/year	MODIS/landsat/sentinel3	low/medium	month/year	MODIS/landsat/sentinel4
	63	Trends in the connectivity of protected areas and other area based approaches integrated into landscapes and seascapes (B)	YES	area	landcover			low/medium	month/year	MOIDS/landsat/sentinel3	low/medium	month/year	MODIS/landsat/sentinel3	low/medium	month/year	MODIS/landsat/sentinel4
	64	Trends in the delivery of ecosystem services and equitable benefits from protected areas (C)	YES			socio-economics	baseline data	low/medium	month/year	MODIS/landsat/sentines3	low/medium	month/year	MODIS/landsat/sentinel3	low/medium	month/year	MODIS/landsat/sentinel4
12	By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.															
	65	Trends in abundance of selected species (A)	YES	mm	landcover		rainfall							1-30m	2-16d	casi, sentinel, lidar
	66	Trends in extinction risk of species (A)	YES	mm	landcover, species composition		rainfall							1-30m	2-16d	casi, sentinel, lidar
	67	Trends in distribution of selected species (B)	YES	area	land cover		canopy structure, collard							1-30m	2-16d	slicer/elvis

13 By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.																
	68	Trends in genetic diversity of cultivated plants, and farmed and domesticated animals and their wild relatives (B)	NO													
	69	Trends in genetic diversity of selected species	NO													
	70	Trends in number of effective policy mechanisms implemented to reduce genetic erosion and safeguard genetic diversity related to plant and animal genetic resources (B)	NO													

Table 10.4D .Mapping of the adequacy of remote sensing for development of CBD indicative list of indicators (Decision XI/3) for the Strategic Goal D.

Target	Code	Operational Indicator	Measurable by RS	Metrics / Proxy	EO product	Additional non-RS data	Other requirements / standards	Global			Regional			National		
								Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
14	By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.															
	71	Trends in proportion of total freshwater resources used (A) (MDG indicator 7.5)	NO			seasonal water levels of large catchments										
	72	Trends in proportion of the population using improved water services (A) (MDG indicator 7.8 and 7.9)	NO			trends in national statistics										
	73	Trends in benefits that humans derive from selected ecosystem services (A)	YES	pollination potential	land cover/land use	species/population modeling	food provision				medium/high	30d	ikonos, rapideye Landsat Sentinel2	medium/high	30d	ikonos, rapideye, Landsat Sentinel3
	74	Population trends and extinction risk trends of species that provide ecosystem services (A)	NO													
	75	Trends in delivery of multiple ecosystem services (B)	YES	delta/rate of change	time series	socio-economics		low/medium	15,30,180,365D	MODIS Landsat Sentinel2	low/medium	15,30,180,365D	MODIS Landsat Sentinel3	low/medium	15,30,180,365D	MODIS/ Landsat/ Sentinel4
	76	Trends in economic and non-economic values of selected ecosystem services (B)	YES	npp, area, fpar, par	ground biomass, seasonal productivity and carbon sequestration			low/medium	daily	modis	low/medium	daily	MODIS	low/medium	daily	MODIS
	77	Trends in health and wellbeing of communities who depend directly on local ecosystem goods and services (B)	NO			health and socio-economic indicators, nutrition measures, food availability										
	78	Trends in human and economic losses due to water or natural resource related disasters (B)	YES	usd	Land cover	socio-economics								vhr/high	1 day	aerial/ ikonos
	79	Trends in nutritional contribution of biodiversity: Food composition (B)	YES	area	Land cover	agricultural output					medium	30d	Landsat/ Sentinel2	medium	30d	landsat/ sentinel2
	80	Trends in incidence of emerging zoonotic diseases (C)	YES	area	water bodies		malaria				medium	30d	radar			
	81	Trends in inclusive wealth (C)	YES	area, unit	urbanization map	socio-economics								high	year	ikonos, geoeye

	82	Trends in nutritional contribution of biodiversity: Food consumption (C)	YES	unit	agriculture, yield						medium	30d	Landsat Sentinel2	medium	30d	Landsat Sentinel2
	83	Trends in prevalence of underweight children under-five years of age (C) (MDG indicator 1.8)	NO			time series of national statistics on children weight measures										
	84	Trends in natural resource conflicts (C)	YES	unit, area	mining map, deforestation map									medium	year	Landsat Sentinel2
	85	Trends in the condition of selected ecosystem services (C)	YES	area	land cover, time series									medium	year	Landsat Sentinel2
	86	Trends in biocapacity (C)	NO													
	87	Trends in area of degraded ecosystems restored or being restored (B)	YES	area	land cover, time series									medium	year	Landsat Sentinel2
15	By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.															
	88	Status and trends in extent and condition of habitats that provide carbon storage (A)	YES	npp, area, fpar, par	land cover, species composition, ground biomass, seasonal productivity and carbon sequestration	carbon model		low/medium	daily	MODIS	low/medium	daily	MODIS	low/medium	daily	MODIS
	89	Population trends of forest-dependent species in forests under restoration (C)	YES	area%	time series, land cover map	population dinamics model								medium/high	year	rapideye, ikonos
16	By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.															
	90	ABS indicator to be specified through the ABS process (B)	NO													

Table 10.4E .Mapping of the adequacy of remote sensing for development of CBD indicative list of indicators (Decision XI/3) for the Strategic Goal E.

Target	Code	Operational Indicator	Measurable by RS (Yes/No)	Metrics / Proxy	EO product	Additional non-RS data	Other requirements / standards	Global			Regional			National		
								Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
17	By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.															
	91	Trends in implementation of national biodiversity strategies and action plans, including development, comprehensiveness, adoption and implementation (B)	YES	area	landcover	land tenure	REDD							low/medium	1y	MODIS Landsat Sentinel2
18	By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.															
	92	Trends in land-use change and land tenure in the traditional territories of indigenous and local communities (B)	YES	area	landcover	land tenure, indigenous territories maps	REDD							low/medium	1y	MODIS Landsat Sentinel2
	93	Trends in the practice of traditional occupations (B)	YES	area	landcover	land tenure, land use change analysis, changes in proportion of population engaged in traditional occupations,	REDD							low/medium	1y	MODIS Landsat Sentinel2
	94	Trends in which traditional knowledge and practices are respected through their full integration, safeguards and the full and effective participation of indigenous and local communities in the national implementation of the Strategic Plan (B)	NO			Presence of indigenous organizations and linkages to national level decision making, number of laws protecting indigenous rights and resources at national level										
	95	Trends of linguistic diversity and numbers of speakers of indigenous languages (B)	NO			National level statistics, Number of indigenous languages included in national primary education systems										
19	By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.															
	96	Trends in coverage of comprehensive policy-relevant sub-global assessments including related capacity-building and knowledge transfer, plus trends in uptake into policy (B)	NO													
	97	Number of maintained species inventories being used to implement the Convention (C)	NO													
20	By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated															
	98	Indicators in Decision X/3	NO													

Table 10.5. Existing satellites and remote sensing sensors and their potential applications to track progress towards the Aichi Biodiversity Targets

Aichi Target	Category	Satellite	Sensors	Data Products (eg raw data or derived)	Uses specific to Aichi Targets	Sources	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
4,15	Optical/Passive Low Spatial High Temporal	Greenhouse Gas Observation SAT (GOSAT)	Thermal And Near infrared Sensor for carbon Observation - Fourier Transform Spectrometer (TANSO-FTS) Thermal And Near infrared Sensor for carbon Observation - Cloud and Aerosol Imager (TANSO-CAI)	Radiance Cloud cover Mapped CO2 & CH4 (abundance, vertical mixing, concentrations and vertical profile) CO2 flux and 3-D distribution concentration map) Normalized Difference Vegetation Index (NDVI) Global Radiance distribution Clear sky reflectance	Monitoring Impacts of use of natural resource consumption and production by combining monitoring of carbon emission and vegetation condition Measuring carbon stocks	Japanese Aerospace Exploration Agency (JAXA)	2009 (expected to last 5 years)	Global - atmospheric	3	500 - 1,500	Freely Available: At present, only one ACOS product is publicly available - ACOS_L2S. It is a Level-2 product that contains full physics retrievals of column-averaged CO2 in units of dry-air mole fraction (Xco2). Restricted: Level 1B product (with calibrated radiances and geolocation), which is the input to the ACOS Level-2 production process, is currently restricted by cooperation agreements between JAXA and NASA.	-Not all data products are available -Primary objective is on atmospheric monitoring of GHGs, not Earth Observation; -Is not a stand-alone resource for biodiversity monitoring and needs to be used in conjunction with modelling and other RS and non-RS data
4,15	Optical/Passive Medium Spatial and Temporal Resolution	Orbiting Carbon Observatory (OCO)	Three high-resolution grating spectrometers; specifics and other sensors TBA	Orbit granules of calibrated radiances Orbit granules of geolocated Xco2 Global Xco2 Global CO2 sources and sinks	Monitoring Impacts of use of natural resource consumption and production by combining monitoring of carbon emission and vegetation condition Measuring carbon stocks	National Aeronautics and Space Administration (NASA)	2014	Global - atmospheric	16	TBA - medium/moderate	Freely Available	-Initial launch failed in 2009, second launch was delayed form 2011 to 2014
5,11	Optical/Passive Medium - High Spatial and Temporal Resolution	Satellite The Sino-Brazilian Earth Observation (CBERS) 1, 2, 2b, 3, 4, &4b	(1, 2 & 3) Wide Field Imager Camera (WFI); Medium Resolution Camera (CCD); Infrared Multispectral Scanner Camera (IRMSS) (3) High Resolution Panchromatic Camera (HRC) (3 & 4) Advanced Wide Field Imager Camera (AWFI); IRMSS; Panchromatic and Multiespectral Camera (PANMUX) (4b) TBA	Multispectral Images	Broad-Fine Scale Habitat Mapping Protected Area Monitoring	Instituto Nacional de Pesquisas Espaciais (INPE) Chinese Academy of Space Technology, China National space and Brazilian Space Agency	(1) 1999-2003; (2) 2003; (2b) 2007-2010; 3 (2013); 4 (2014); 4b (2016)	Global	3, 5 , 26	(1&2) 20 (2b) 2.7 (3&4) 5 (4b) TBA	Freely Available to all Chinese and Brazilian people	-Is not a stand-alone resource for biodiversity monitoring, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze create also challenges for monitoring using optical sensor; -Very High Resolution (VHR) optical datasets have been exploited or tested to their full extent and even in cloud free images, present pixel mixing and shadowing challenges; -The lack of shortwave infrared band and provision of too much detail present noise in the data and challenges in extracting the desired metrics; -Limited availability, may be prohibitively expensive and time consuming to procure and process.

5,6,9,10,11, 12,14,15	Optical/Passive Medium-High Spatial Resolution High Temporal Resolution	Landsat 1-5, 7-8	(1-7) Multispectral Scanner (4-5)Thematic Mapper (TM) (7) Enhanced Thematic Mapper Plus(TM) (MSS)(8) Operational Land Imager (OLI); Thermal Infrared Sensor (TIRS)	Climate Data Records (CDR) such as surface reflectance, land surface temperature Essential Climate Variables (ECV): leaf area index, burned area extent, snow covered area, surface water extent Normalised Difference Vegetation Index (NDVI) (4-5, 7) Bathymetry, ocean colour, SST	Protected Area Monitoring Habitat mapping and change detection -capturing broad extent -spatial patterns of fragmentation Assessing Habitat Degredation -desertification -ocean acidification Biodiversity Assessment -Indicators of overall species richness and diversity -Tracking species distributions Ecological Monitoring -Mapping ecosystems -Assessing the effectiveness of ecosystem Landcover / Landcover change -quantifying the rate and extent of forest disturbance and re-growth Tracking pressures and threats -identifying disturbance Restoration projects	US Geological Survey (USGS)/NASA/Global Land Cover Facility (GLCF)	(1) 1972 (4) 1982–1993, (5) 1994 (7) 1999	Global	(4-7) 16 days	(4-5) 30 meter+ (8) 15 meter+	Landsat 4-5: Freely Available Landsat 5 and 7: Commercially & Freely available Landsat 8: At least 400 scenes are collected daily, and placed into the USGS archive to become available for download within 24 hours after acquisition	-The Landsat surface reflectance CDR products are considered provisional; -Less effective at capturing good imagery in hyper-arid or snow-covered regions, areas with low sun angle conditions, coastal regions where land area is small relative to adjacent water and areas with extensive cloud contamination; -Users are strongly cautioned against correcting data acquired over high latitudes (>65 degrees North or South); -Less able to provide information on changes in habitat quality, species distribution and fine-scale disturbances, than spaceborne optical sensors Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Limited ecosystem monitoring capacity, using landcover as a surrogate and must be combined with other data.
5,9,11,12	Active Medium - High Spatial and Temporal Resolution	Multi-Application Purpose Synthetic Apeture Radar (MAPSAR)	L-band synthetic aperture radar (SAR)	Cloud free multi-spectral Images	Landscape Monitoring Monitoring Landscapes and Disaster Events Resource Surveying Protected Area monitoring Landscape Monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure -Retrieving above ground biomass and structure (e.g., height, cover) -Assessing habitat condition Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures, threats and disturbance -Detecting dead standing trees -Patterns of clearing and other damage caused by fire	Instituto Nacional de Pesquisas Espaciais (INPE) & Deutsches Zentrum für Luft-un Raumfahrt eV (DLR)	TBA	Global	7	3 - 20	TBA	-Unknown at this time but is likely to have similar limitations as other SAR sensors and will not be a stand-alone product for monitoring biodiversity but will need to be combined with other data, modelling and field information; -L-band SAR is incapable of simultaneously providing high resolution and wide coverage.

5, 6, 10,11,15	Optical/Passive Course Spatial, High Temporal Resolution	Terra and Aqua	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Clouds and Earth's Radiant Energy System (CERES) Multi-angle Imaging Spectroradiometer (MISR) Moderate-resolution Imaging Spectroradiometer (MODIS) Measurements of Pollution in the Troposphere (MOPITT)	Numerous data products measuring Land, Ocean, Atmospheric, Cryospheric and Calibrationi parameters from both Terra and Aqua Sensors:	Monitoring Earth's atmosphere, lands, oceans, and radiant energy including: -measuring levels of gas in the lower atmosphere and tracking its source -monitoring ocean parameters, circulation, temperature, colour, etc. Very Broad-scale Habitat Monitoring and Degredation -Early warnings of regional ecological change and climate change (photosynthetic activity) including: -coral reef monitoring -comparing plant productivity with carbon dioxide and other important greenhouse gases, as well as global temperature trends to better enable scientists to predict how changes in the climate will impact Earth’s ecosystems. Tacking Pressures and Threats (fires and photosynthetic activity) -identifying and monitoring ocean acidification -measure how certain human activities, such as biomass burning and deforestation, may be contributing to climate change -Near real-time alerts of deforestation Protected Area Monitoring	San Diego State University (SDSU)/NASA	Terra: 1999 Aqua: 2002	Global	16	ASTER (15-90) MISR (250-275) MODIS (250-1,000) CERES (20,000) MOPITT (22,000 at nadir)	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Course resolution; -Cloud cover and haze create challenges for monitoring using optical sensors.
5,11,12	Active Moderate - High Spatial Resolution Moderate - Low Temporal Resolution	Advanced Land Observing Satellite - Phased Array type L-band Synthetic Aperture Radar (ALOS-PALSAR)	Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM); Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2); Phased Array type L-band Synthetic Aperture Radar (PALSAR)	PALSAR data are in dual Polarization, HH+HV, mode. Bands HH (red and green) and Band-HV (blue) can be used to visualize land use patterns. The backscattering coefficient or Normalized Radar Cross Section (NRCS) are also provided as gray scale images.	Monitoring Landscapes and Disaster Events Resource Surveying Protected Area monitoring Landscape Monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing	Japanese Aerospace Exploration Agency (JAXA)	Around 2007; completed 2011	Global	46	10	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with data, modelling and field information; -Incapable of simultaneously providing high resolution and wide coverage.

					trees -Patterns of clearing and other damage caused by fire						
5,10,11,12, 14, 15	Active Low Spatial and Temporal Resolution	ENVISAT	Advanced Synthetic Aperture Radar (ASAR); The Medium Resolution Imaging Spectroradiometer (MERIS)	GlobCover Bathymetry Sea Surface Height (SSH) sea colour (can be converted to chlorophyll pigment concentration, suspended sediment concentration and aero loads over marine areas) Cloud type, top height, and albedo Top and bottom indices of atmosphere vegetation Photosynthetically available radiation Surface pressure Water vapor total column content for all surfaces Aerosol load over land and sea Vegetation indices Fractional Absorbed Photosynthetically Active Radiation (FAPAR)	Protected Area monitoring Landscape Monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure -Coral reef monitoring Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire -Identifying and monitoring ocean acidification Ecosystem monitoring Disaster management -detecting oil spills -monitoring floods, landslides, volcanic eruptions -aiding forest fighting	European Space Agency (ESA)	2002/3-2012 Globcover 2005-2006; 2009	Global	35	300 meter	Commercially available from Radarsat International	- Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with data, modelling and field information; -Incapable of simultaneously providing high resolution and wide coverage (swath width).
5,10,11,12, 14,15	Active High Temporal and Spatial Resolution	Light Detection and Ranging (LiDAR) Remote Sensing	Laser scanner and photodetector/optical receiver	Point Cloud: A 3-dimensional (3D) dense assemblage of points with precise location of individual points hit by the laser, height of the object in the lasers path and intensity of the laser return (similar to optical reflectance only more concentrated and not influenced by cloud or other atmospheric	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional	Multiple	Various	Airborne	1+	0.1 - 10	Commercially and Freely Available on case-by-case basis. Sources of freely available data include USGS & university/institutional collections	-Not currently utilised widely, effectively or efficiently though it is growing in popularity around the world; -Not available at global scale; -Costly to obtain data if not already available as requires flying a plane and operating cameras, software, expertise, etc.; -Requires formatting, importing and process which can create huge transaction (computing) costs and technical challenges to process data, the larger the study area the

				disturbance to as great an extent as optical sensors are).	structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire							more time consuming, costly and otherwise prohibitive to utilize; -LIDAR data handling software packages are not keeping pace with the LiDAR technology advancements, especially in automated classification and vegetation mapping; -Intensity must be calibrated when doing the flight campaign with targets and/or utilising correction algorithms for existing data as most LiDAR sensors are not calibrated for intensity; without calibrating intensity LiDAR is less useful for habitat and species monitoring; -Is not a stand-alone resource for biodiversity monitoring; the point clouds are used to generate other geospatial products, such as digital elevation models, canopy models, building models, and contours for monitoring/predicting trends in species changes, needs be used in conjunction with modelling and field information.
5,11,12,14, 15	Active Low-High Spatial Resolution Moderate-High Temporal Resolution	Radarsat 1 & 2 Radarsat Constellation Mission (RCM)	Synthetic Aperture Radar (SAR)	Cloud free multispectral images with change detection capacity	Protected Area Monitoring Resource management -Forestry -monitoring growth and other changes Hydrology -monitoring water use/consumption Oceanography -mapping sea ice distribution -maritime surveillance - improving shipping navigation Geology Meteorology Ecosystem monitoring Disaster management -detecting oil spills -monitoring floods, landslides, volcanic eruptions -aiding forest fighting Sustainable development Fine to Broad Habitat Mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in	Government of Canada / Canadian Space Agency	(1) 1995-2012 (2) 2007 (7 year minimum duration) Constellation scheduled for 2018 launch	Global	RS-1 &-2 (24) RCM (12)	(RS-1) 8-100 meters (RS-2 & RCM) 3 -100 / 1 + in Spotlight Mode	Commercially Available	-Is not a stand-alone resource for monitoring/predicting trends in species changes, needs be used in conjunction with modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas b/c of a fundamental incapability to simultaneously providing high resolution and wide coverage VHR and high resolution datasets suffer from problems of shadowing from and within objects and mixed pixels, and can be expensive and time consuming to procure and process.

					habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire							
5,9,10,11,12	Optical/Passive High Spatial Resolution High Temporal Resolution	IKONOS	High resolution stereo imaging sensor (satellite based camera)	Images available as panchromatic (PAN) or multispectral (MS)	Protected Area monitoring Ecological monitoring Habitat mapping and change detection -Mapping successional fine scale homogeneous habitats, ecotones and mosaic areas (e.g. coral reefs) Assessing habitat degradation -Identifying fine scale degradation in forests Biodiversity assessment -Indicators of overall species richness and diversity -Delineation of tree crowns/clumps to species level Tracking pressures and threats -Detection of fine-scale disturbances -Identification and monitoring of ocean acidification	GeoEye	1999	Global	1–3	1 (PAN) - 4 (MS	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -IKONOS imagery may incur a high purchasing cost to the user; -Specialist hardware/software for utilising data may be required; -IKONOS data needed lengthy processing; -Visual interpretation of the IKONOS image necessitated fieldwork; -IKONOS images are not great for creating accuracy of vegetation classes with high spectral variance (heterogeneous) -Often insufficient for the purpose of habitat mapping over large areas; -Cloud cover and haze create challenges for monitoring using optical sensors; -Very High Resolution (VHR) and high resolution datasets have not yet been tested or exploited to their full extent and suffer from problems of shadowing and mixed pixels;

												-Can be prohibitively expensive and time consuming to procure and process.
5, 10, 11,12,15	Optical/Passive and Radar/Active High to Low Spatial Resolution Moderate Temporal Resolution	Indian Remote Sensing Satellite (IRS) System	Multiple optical and radar based sensors on 11 satellites in operation - largest civilian remote sensing satellite constellation in the world	The main data products are images in a variety of spatial, spectral and temporal resolutions utilised for a variety of applications with climate monitoring & environmental monitoring among them. The latest satellite to add to the constellation, SARAL includes biodiversity protection as a focused use case, focused on oceanographic studies.	Landscape Monitoring Protected Area Monitoring Habitat mapping and change detection -broad extent and spatial patterns Assessing habitat degradation -broad scale loss (i.e., desertification) Biodiversity assessment -Indicators of overall species richness and diversity Tracking pressures and threats -Identifying disturbances -Monitoring desertification	Indo-French collaboration built by the French National Space Agency (CNES) and the Indian Space Research Organisation (ISRO)	First satellite launched in 1988, The first of the still operational satellites in the constellation was launched in 2003 SARAL is scheduled for 2013	Global	various	various	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Limitations vary with individual satellites/sensors; SARAL will likely only benefit marine biodiversity monitoring; -Can be prohibitively expensive and time consuming to procure and process.
5,10,11,12	Active Moderate Spatial Resolution Low to High Temporal Resolution	European Remote Sensing Satellite 1 & 2	Synthetic Aperture Radar (SAR)	Radar Imagery	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure -coral reef monitoring Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire -Identifying and monitoring ocean acidification	European Space Agency (ESA)	(1) 1991–2001; (2)1995–2001	Global	3/35/336	50	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Incapable of simultaneously providing high resolution and wide coverage (swath width).

5,9,10,11,12, 14	Optical/Passive High Spatial Resolution High Temporal Resolution	QuickBird	Panchromatic (PAN) and multispectral (MS)	Three levels of imagery ranging from least processed/corrected to orthorectified, GIS ready. 1) Basic Imagery - black and white or multispectral imagery available by scenes (not georeferenced) 2) Standard Imagery - black and white, multispectral or pan sharpened imagery (is georeferenced) available by area of interest 3) Orthorectified Imagery - in addition to the Standard Imagery corrections it is terrain corrected and comes GIS ready as an Image basemap in black and white, multispectral or pan sharpened option; available by area of interest.	Protected Area monitoring Ecological monitoring Habitat mapping and change detection -Mapping successional fine scale homogeneous habitats, ecotones and mosaic areas Assessing habitat degradation -Identifying fine scale degradation in forests -rapid detection of clearing and degradation Biodiversity assessment -Indicators of overall species richness and diversity -Delineation of tree crowns/clumps to species level Tracking pressures and threats -Detection of fine-scale disturbances -identify and monitor ocean acidification	DigitalGlobe	2001	Global	4	<1 (PAN) - 2.4 -2.8 (MS)	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Often insufficient for the purpose of habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors: -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -Can be prohibitively expensive and time consuming to procure and process.
5,11,12,14, 15	Optical/Passive Medium-High Spatial Resolution High Temporal Resolution	Système Pour l'Observation de la Terre (SPOT)	Panchromatic (PAN) and multispectral (MS) , infrared and SWIR	A range of high resolution, multipspectral NIR and SWIR imagery with or without orthorectification	Protected Area Monitoring Ecological Monitoring Fine-scale Habitat Monitoring -rapid detection of habitat and degradation Biodiversity assessment -Indicators of overall species richness and diversity Tracking pressures and threats -Identifying disturbances -Monitoring droughts and desertification Agricultural monitoring -crop yields Oceanography Climatology	Astrium	SPOT 1 (1986-1990) SPOT 2 (1990-2009) SPOT 3 (1993-1997) SPOT 4 (1998-2013) SPOT 5 (2002) SPOT 6 (2012) SPOT 7 scheduled for 2014	Global	1-4 Tasking optional with 1 day revisit	SPOT 1-4 (10-20) SPOT 5 (2.5-5) SPOT 6-7 (1.5)	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -Can be prohibitively expensive and time consuming to procure and process.
5,6,10	Optical/Passive Low Spatial Resolution High Temporal Resolution	Sea-viewing Wide Field-of-view Sensor (SeaWiFS)	Optical scanner	Angstrom Exponent Aerosol Optical Thickness Chlorophyll-chromophoric dissolved organic matter (CDOM) proportion index Chlorophyll a Photosynthetically Available Radiation Particulate Inorganic/Organic Carbon concentration Sea Surface Temperature Quality Sea surface Reflectance Sea Surface Temperature	monitor coral reefs and ocean acidification	GeoEye	1997–2010	Global	1-2	1,100	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Ocean focused; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges.

5,10,11,14	Optical/Passive Low Spatial Resolution High Temporal Resolution	Advanced Very High Resolution Radiometer (1-3)	AVHRR 1 included a 4 channel radiometer AVHRR 2 include 5 channel radiometer AVHRR 3 includes a 6 channel radiometer	Imagery available in four data sets: The Global Area Coverage (GAC) data set The Local Area Coverage (LAC) data set High Resolution Picture Transmission (HRPT) is real-time downlink data Full Resolution Area Coverage (FRAC)	Very Broad-scale Habitat Monitoring and Degredation -Early warnings of regional ecological change and climate change (photosynthetic activity) -Near real-time alerts of deforestation Tacking Pressures and Threats (fires and photosynthetic activity) Protected Area Monitoring Ecological Monitoring -coral reefs and ocean acidification	National Oceanic and Atmospheric Association (NOAA)	1978-? 1981-? 1998-?	Global	6	1,100	Freely Available	-Not particularly useful for habitat mapping; -Not useful for change detection or biodiversity assessment; -Limited ecosystem monitoring capacity, using landcover as a surrogate and must be combined with other data; -Early data products suffered from difficulties with sensor calibration, orbital drift, limited spectral and directional sampling; -Is not a stand-alone resource for biodiversity monitoring needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges.
5,10, 15	Optical/Passive Low Spatial Resolution High Temporal Resolution	Aquarius	Specialised radiometer	Sea Surface Salinity (SSS)	monitor coral reefs and ocean acidification supplements observations of precipitation, evaporation, soil moisture, atmospheric water vapor, and sea ice extent	National Aeronautics and Space Administration (NASA)	2011	Global	7	150	Freely Available	-Is not a stand-alone resource for biodiversity monitoring needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Ocean focused
5,6, 10, 11	Optical/Passive Moderate Spatial Resolution High Temporal Resolution	Seawinds: Quikscat	Specialised radiometer	Surface Wind Vector (SWV)	monitor coral reefs and ocean acidification ocean response air-sea interaction mechanisms annual and semi-annual rainforest vegetation conditions daily or seasonal ice edge/ice pack movement and changes	National Oceanic and Atmospheric Association (NOAA)	1999-2009	Global	1	12.5-25	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Ocean focused
5,9,11,12	Optical/Passive - Hyperspectral High Spatial Resolution High Temporal Resolution	WorldView-2	Multispectral sensor (MS)	high resolution Panchromatic band and eight (8) Multispectral bands; four (4) standard colors (red, green, blue, and near-infrared 1) and four (4) new bands (coastal, yellow, red edge, and near-infrared 2), full-color images	Protected Area monitoring Ecological monitoring Habitat mapping and change detection -Mapping successional fine-scale homogeneous habitats, ecotones and mosaic areas Assessing habitat degradation -Identifying fine scale degradation in forests Biodiversity assessment -Indicators of overall species richness and diversity -Delineation of tree	DigitalGlobe	2009	Global	1	0.46 (PAN) 1.84 (MS)	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges;

					crowns/clumps to species level Tracking pressures and threats -Detection of fine-scale disturbances							-Can be prohibitively expensive and time consuming to procure and process.
5,9,11,12	Optical/Passive - Hyperspectral High Spatial Resolution High Temporal Resolution	Airborne	Airborne Hyperspectral imaging sensor (HyMAP)	Hyperspectral imagery spanning 126 spectral bands	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successioinal classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance	Spectronics	1999	Airborne	Airborne	5	Commercially available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.
5,9,11,12	Optical/Passive - Hyperspectral High Spatial Resolution High Temporal Resolution	Airborne	Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)	calibrated images of the upwelling spectral radiance in 224 contiguous spectral channels (bands) with wavelengths from 400 to 2500 nanometers.	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successioinal classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities	National Aeronautics and Space Administration (NASA)	First developed in 1983, updated in 2012	Airborne	Airborne	2	Freely and commercially available	- Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Only data from 2006-2013 is currently downloadable, pre 2006 data is processed on request if possible; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present

					-Mapping top canopy trees to species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance							challenges for monitoring with optical sensors; -Very High Resolution (VHR) and High Resolution optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.
5,11,12	Active Radar High - Moderate Spatial and Temporal Resolution	TerraSAR-X and Tandem-X	Synthetic Aperture Radar (SAR)	WorldDEM: a homogenous, worldwide digital elevation model data (DEM) Additional individual image products	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire	German Aerospace Center (DLR) and EADS Astrium	TerraSAR - 2007 TandemX - 2010	Global	11 (3-4 at poles) Tasking 1-3	1-18 for individual products 2-10 for WorldDEM	Commercially Available	-Often insufficient for the purpose of detailed habitat mapping over large areas; -VHR and high resolution datasets suffer from problems of shadowing from and within objects and mixed pixels; -Incapable of simultaneously providing high resolution and wide coverage (swath width); -Can be expensive and time consuming to procure and process.
5,9,11,12	Optical/Passive - Hyperspectral Moderate Spatial and Temporal Resolution	E0-1	High resolution hyperspectral imager capable of resolving 220 spectral bands (Hyperion) Advanced Land Imager (ALI) Linear Etalon Imaging Spectrometer Array (LEISA) Atmospheric Corrector (LAC)	Hyperion - High resolution hyperspectral images ALI - panchromatic and multispectral	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successioinal classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to	National Aeronautics and Space Administration (NASA)	2000	Global	16	30	Freely available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors.

					species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance							
5,11,12	Active Radar Moderate Spatial Resolution Low Temporal Resolution	JERS-1 SAR	An L-band (HH polarization) synthetic aperture radar (SAR); A nadir-pointing optical camera (OPS); A side-looking optical camera (AVNIR).	Radar and optical Imagery data available spanning seven bands from the visible region to short wave infrared band and is capable of stereoscopic data in NIR	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats Land surveys Agricultural-forestry-fisheries Disaster prevention and monitoring Coastal surveillance Locating natural resources.	Japanese Aerospace Exploration Agency (JAXA)	1992-1998	Global	44	18	Freely available	-No longer operational -Cannot easily differentiate between species in high heterogeneity habitats, shadowing and mixed pixels can present challenges for mapping detailed habitats over large areas; -Not great for change detection due to inactivity, low temporal resolution and inconsistency in classifying heterogeneous images; -May have difficulty finding complementary/supporting data sets (e.g. DEMs) in tropics; -The L-band is incapable of simultaneously providing high resolution and wide coverage.
5,9,11,12	Optical/Passive - Hyperspectral High Spatial and Temporal Resolution	Airborne	Compact Airborne Spectrographic Imager (CASI)	Multispectral imagery	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successioinal classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale	Itres Research Ltd. of Calgary, Canada	Various	Airborne	Airborne	1+	Publically Available (may not be free)	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne

					modifications due to disturbance							HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.
5,9,11,12	Optical and Chemical Passive High Spatial and Temporal Resolution	Airborne	High-fidelity Imaging Spectrometers (HiFIS)	two-dimensional image, but with a third dimension containing a detailed spectroscopic signature of plant canopies.	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successioinal classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance	Carnegie Airborne Observatory	Various	Airborne	Airborne	<1+	Publically Available (may not be free)	-Although HiFIS has come of age technologically, the theories and algorithms required to extract taxonomic information from the spectra remain in the early stages of development; -Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.
4,5,10,11, 12, 14, 15	Optical/Passive Low Spatial Resolution High Temporal Resolution	Proba V	Vegetation Instrument	multispectral images: VNIR: -Blue(438-486nm) -Red(615-696nm) -NearIR(772-914nm) SWIR(1564-1634nm)	-Land observation with focus on vegetation -Environmental & agro-climatic conditions -Effects of extreme events as drought and floods -Natural resources (soil, water, rangeland) -Crop and livestock	European Space Agency (ESA)	2013	Global	1-2	100-350	Unknown - Contact ESA's Prova-V programme	-Primarily a technology test -Expected to have s short life span of 2.5 years -Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information;

					production; -Prevalence of diseases -Desertification							-Cloud cover and haze present challenges for monitoring with optical sensors; -Can be prohibitively expensive and time consuming to procure and process.