CEOS Ecosystem Extent Activity for Biodiversity: A Demonstrator Proposal based in Costa Rica Forested ecosystems

A Data-cube-based demonstrator for exploring operational ecosystem extent methodologies
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Maintaining the integrity and biodiversity of natural ecosystems is vital for achieving the EU biodiversity strategy for 2030, Sustainable Development Goals (SDGs), and Kunming-Montreal Global Biodiversity Framework. We need to develop a strategy to map ecosystems and their status. Biodiverse ecosystems are more productive and resistant to the impacts of climate change due to their high degree of integrity and diversity. Over the past decades, biodiversity continues to decline significantly. In 2019, the first global and regional biodiversity assessment, undertaken since 2004, by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), indicated that although awareness on preserving and protecting biodiversity has increased and promising steps have been taken to tackle biodiversity losses around the globe, the overall progress is still insufficient. Following the IPBES report the Parties to the CBD have defined the Kunming-Montreal biodiversity plan, aiming to stabilise biodiversity loss by 2030 and allow for the recovery of natural ecosystems in the following 20 years, thereby ensuring that by 2050 "all of the world's ecosystems are restored, resilient, and adequately protected". To achieve this goal, several biodiversity targets both at global and European scales are currently being defined. Understanding, predicting, and managing the changes in biodiversity requires understanding both long-term and abrupt changes in the ecosystems, as well as their direct and indirect drivers. Monitoring progress towards the achievement of the global biodiversity targets requires further development of the adopted monitoring framework and indicators at the global level and translating its use to the national and sub-national levels to yield accurate and regular observations over the Earth. The biodiversity indicators allow for consistent monitoring of the state of biodiversity, evaluation of the condition of the ecosystems, the services they provide and the drivers of change. The Group on EO Biodiversity Observation Network (GEO BON) has developed a framework for an integrated biodiversity monitoring system under the general concept of Essential Biodiversity Variables (EBVs), and remote sensing (RS) has been proposed as a flagship tool to monitor biodiversity through RS-based EBVs.

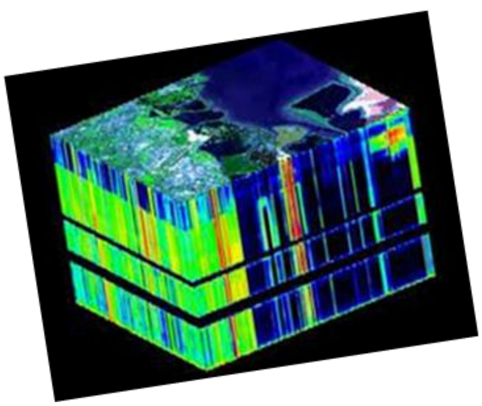
Earth System Science and EO play a prominent role in the scientific understanding of ecosystems, ecological and biophysical processes. The European Space Agency (ESA) and European Commission (EC) have launched an initiative (February 2020) to develop the next generation of biodiversity observing systems and science-based solutions through a joint Flagship Action on Biodiversity and Vulnerable Ecosystems. This addresses the main causes and drivers of biodiversity loss, improving the conservation and restoration of vulnerable ecosystems, as well as informing international community efforts of the CBD, IPBES and GEO BON on worldwide degradation and loss of biodiversity. Within this framework, the Committee on Earth Observation Satellites (CEOS) will contribute to the EC and ESA joint Flagship Action of Biodiversity and vulnerable ecosystems to advance Earth System Science and its responses to the global challenges.

CEOS Demonstrator Concept

This document constitutes a proposal for one of the "Demonstrators" within the framework of CEOS Ecosystem Extent Task Force (EETT).

One concept for the demonstrator is to assemble a development system to support experimentation with different approaches, algorithms, and data that can generate prototype products. To be practical within the timeframe of the activity such a system would need to be based on existing systems, expertise, and data. To facilitate discussion and convergence on a specific demonstrator concept, an approach is described below. This approach amalgamates suggestions provided in earlier discussions with existing capabilities and concepts.

The core of this approach is a data cube[1] that hosts a wide range of data that together captures the range of traits that characterize ecosystems and enables their delineation. It is based on the concept that every ecosystem can be classified by its physical structure, its taxonomic composition, and its functional processes along with its physical context (e.g., climate, geography, topography; see Box 1-based on the White Paper). Each of these areas can be considered a family of related traits (also called features). As such, having access to data layers that capture a range of traits and trait families will improve ecosystem discrimination. Ecosystems are also dynamic entities that evolve in space and time driven by natural or anthropogenic disturbances.



Data cubes from EOS (Earth Observing System) can be applied to biodiversity research in various ways. These data cubes contain multidimensional arrays of data from satellite imagery and can be used to support biodiversity monitoring, Ecosystem mapping, habitat mapping, species distribution modelling and track changes over time among other applications. It is important to incorporate multi-sensor images through the practice of data fusion. Additionally, explore the creation of workflows aimed at generating radiometric ecosystem units as a practical illustration. It is important to note that simply incorporating additional data layers may not inherently enhance discrimination capabilities, as certain traits hold more significance in characterizing an ecosystem than others. It proves beneficial to pinpoint and prioritize these critical traits. This not only streamlines the selection of pertinent data layers but also offers valuable insights into the essence and functionality of an ecosystem.
Key objectives:

[1]Data cubes for biodiversity variables have a specific format, as they are composed of a 4D structure (geospatial location in x and y, temporal information and a species dimension).

- **Facilitating data provision (e.g., radar, hyperspectral)**

- **Sharing expertise (EO, biodiversity, data cube….)**
- **Exploring new ideas and approaches**
- **Build up synergies with monitoring programs (CBD, IPBES, GeoBON, EuropaBon,…)**

The test site

The site selected for this demonstrator is the forested ecosystems of Costa Rica, where we have sufficient field data to validate the approach (e.g. forest inventories, botanical inventories, etc.).

Costa Rica has exceptional flora and fauna, representing 6% of the world's biodiversity. Historically, Costa Rica was one of the most deforested countries in the world. Today it is a pioneer in reforestation, forest management and forest conservation policies. This exceptional biodiversity is due to Costa Rica's geographical location. In fact, the oceanic influence of the Pacific and Caribbean Oceans and the diversity of relief create particular climates that generate biodiversity. Three climatic zones can be distinguished: the Caribbean coast, humid and semi-swampy; the Pacific coast, relatively dry; and the central zone, with its high relief and dry vegetation.

Furthermore, Costa Rica provides the desired range of data types available, and a range of ecosystems to run tests and calibration. We do have a strong local partnership that provided already NFI data and botanical data at the country level. These data are essential for calibration and validation of the approaches. We have an ongoing PhD thesis working with field data from Costa Rica on forest transitions and ecosystem condition of secondary forests.

- **Very good existing & local partners**
    - Training data
    - In situ data
    - Local expertise

- **Focus on tropical forest ecosystems & transitional forests**
    - ➞ Integration classical ecology & remote sensing: structure, composition, function
    - ➞ Using a diversity of sensors (incl. Radar, Lidar, optical data , hyperspectral data…)
    - ➞ Deriving textural indices and indicators for other characteristics (see Box 1)
    - ➞ Calculating diversity metrics (i.e. spectral variation)

Figure 1 Land Use & in situ observation points (SINAC 2021)

An ongoing PhD project, as an added value, helps to strengthen the contact and synergies with key national stakeholders and institutions (i.e. CATIE, SINAC, OEFO), involved in biodiversity monitoring. The participation of local stakeholders supports also a strong collaboration with related national projects. It is essential to ensure the coherence and complementarity of the CEOS ambition and its results, with national efforts to monitor forest biodiversity. This could ensure the long-term application and enhancement of the results within larger conservation efforts.

Box 1

Characteristic Category	**Examples**
Structure	Height, complexity/heterogeneity (vertical and horizontal), textural indices, shape,size
Composition	Taxonomic (at any level); lifeform, traits
Function	Primary productivity, temporal dynamics NDVI, Spectral bands, indices
Climate	Temperature, precipitation, extremes…
Geography	Latitude, longitude
Topographic	Elevation, slope, aspect

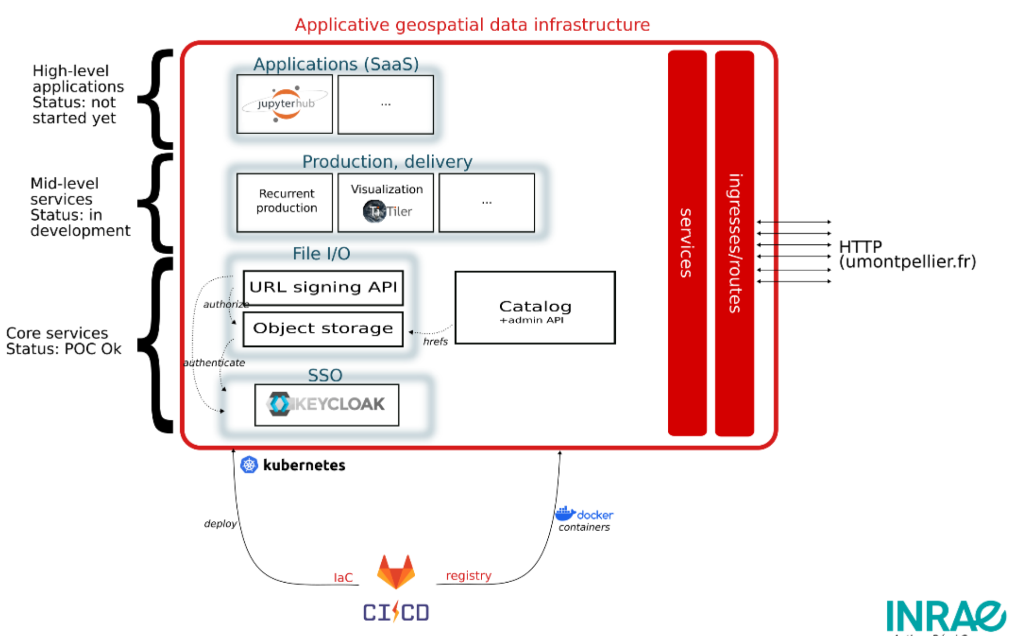
Approach

Current data show that the tropics lost 11.1 million hectares of tree cover in 2021 (University of Maryland and available on Global Forest Watch 2022). In particular, 3.75 million hectares were lost in tropical primary rainforests - areas of critical importance for carbon storage and biodiversity. We need operational solutions to address biodiversity challenges (Luque et al 2018; Alleaume et al 2018). Given the multidimensional nature of biodiversity, there is no single indicator to describe and/or monitor forest biodiversity. In this context, ***the aim and main objective of our proposal is to monitor the extent of forest ecosystems and predict changes in***

forest biodiversity and its direct and indirect drivers by integrating state-of-the-art multi-sensor Earth Observation (EO) data, comprehensive in-situ data and products, together with next-generation ecological models that account for uncertainty. We also aim to improve the availability of data on biodiversity change to decision-makers and scientists in support of forest policy. This goal goes well beyond the current state of the art in combining different data sources, advanced modelling and uncertainty assessment. The approach also supports the integrated efforts needed to consolidate data from current and future in-situ and remote sensing missions. The concept of Essential Biodiversity Variables (EBVs) is currently gaining momentum, where we are working as part of the GEOBON network on the development and testing of RS-EBVs (Remote sensing enable EBVs). To meet these research and operational needs, it is essential to prioritise, integrate and consolidate biodiversity observations and monitoring programmes worldwide. However, the complexity of the data required to actually achieve the development and implementation of the key indicators endorsed at COP 15 (CBD-GBF) requires new ways and technological advances.
The core of this approach is a data cube that hosts a wide range of data that together captures the range of forests traits that characterize ecosystems and enables their delineation trough RS-EBV's.

Working Objective: Develop an operational approach for improved standards for biodiversity mapping and monitoring (i.e. Ecosystems), using remotely sensed data. Contribute to the identification of relevant RS-EBV's for mapping ecosystems.

1[st] **Phase Year 1** (2024): Develop and populate the Data Cube
Stage 1: Development of an operational geospatial data structure within a logic of data flow; following the simplified figure 2 bellow:



The logical flow is in the same vein of the Swiss Data Cube (Chatenoux et al 2021), and similar to the "Americas Data Cube" under development, Chilean Data Cube and other related initiatives, with whom exchange is taking place.

Stage 2: Inclusion and treatment of Sentinel-2 time-series & production of dynamic vegetation indices and diversity indices (Rocchini et al 2018; Chraibi et al 2021)
Stage 3: compute a selection of α- and β-diversity indicators from optical imagery, based on spectral variation hypothesis (Féret and Asner 2014; Rocchini et al 2018). Implementing in the Data Cube and using biodivMapR package (Féret and de Boissieu 2020), that builds upon previous work on biodiversity mapping using airborne imaging spectroscopy, and has been adapted in order to process broader range of data sources, including Sentinel-2 satellite images.

Use of additional functions of biodivMapR package to compute diversity indicators directly from field plots to compare results using ground data for validation. Cross validation of approaches derived from spectral information vs species data modelling (PhD student Maïrì Souza-Oliveira).

Stage 4: labelling forested ecosystems derived from the aforementioned processes working with local experts

2nd Phase year 2 (2025 depending of funding) **-** Consider inclusion of forest structural data – including available GEDI L2 data; inclusion of Radar data: ALOS-2/Sentinel-1 SAR backscatter. (Additional experts: Sylvie Durrieu (Lidar); Nicolas Baghdadi (Radar))

Further development of RS-EBV's considering the addition of structure
Develop machine learning models for predicting vegetation types from multi-spectral imagery and field data.

Overall Challenge: Consider pathways for other members of the EETT to get involved and contribute – develop synergies with existing networks working on Biodiversity data cubes.

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