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Earth Observation in Support of EU Policies for Biodiversity

A deep-dive assessment of the Knowledge Centre on Earth Observation

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Contents

Abstract

This report describes the results from a deep dive assessment of the Knowledge Centre on Earth Observation (KCEO) exploring the use of Earth Observation (EO) products and services to support EU biodiversity policies.

EU policy needs in the biodiversity domain are analysed with the ambition to verify how and to what extent existing EO products and services meet these needs, highlight existing gaps and provide recommendations on future evolution.

The spatial resolution of Copernicus products in most cases matches the user requirements. Improvements are suggested on more regular and frequent updates of products, as well as on products latency. The length of time series and their consistency over time are considered not always adequate. Uncertainty and accuracy of EO products are key but not addressed in the deep dive.

Other areas of improvement are related to the thematic detail: existing land cover maps are not sufficient for many biodiversity applications, and this is as well applicable to land use and sea use products. There is a need to map ecosystem types further refining more aggregated land cover classes, to drive the assessment of habitats and ecosystems condition.

In this respect, although satellite EO can already offer significant and valuable datasets to support biodiversity related policies, for the full exploitation of available technology, the availability of ground-based and more broadly *in-situ* data both on land and in marine and freshwater environments, is essential and should be enhanced.

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Executive summary

The European Commission Knowledge Centre on Earth Observation (KCEO) aims to maximise the uptake of products and information from Copernicus to support EU Policies in various sectors and translate policy needs into concrete requirements for products and services. It also aims to provide a forum for dialogue with the technical implementing entities associated with Copernicus and to raise awareness of next generation Earth Observation (EO) science and associated technologies to enhance the exploitation on Copernicus throughout the policy cycle.

The deep dive assessments, focused on specific needs and use of EO in specific policy areas, are among the tools that the KCEO has put in place for enhancing the EO uptake in EU policies. The main objective of deep dives in KCEO is to analyse EU policy needs in a defined policy area, to verify whether existing EO products and services meet these needs, to highlight existing gaps and provide recommendations on future evolution of Copernicus products and services to address these needs.

This report stems from the deep dive assessment of the KCEO focused on biodiversity policies, exploring how EO (mainly ground-based and from space) products and services can be used in supporting biodiversity related policies. Being the first deep dive exercise, it also serves as a test of the deep dive methodology. In summary this deep dive analyses the needs of EU policies for biodiversity with the ambition to verify how and to what extent existing EO products and services meet them, identify existing gaps and provide recommendations on future evolution.

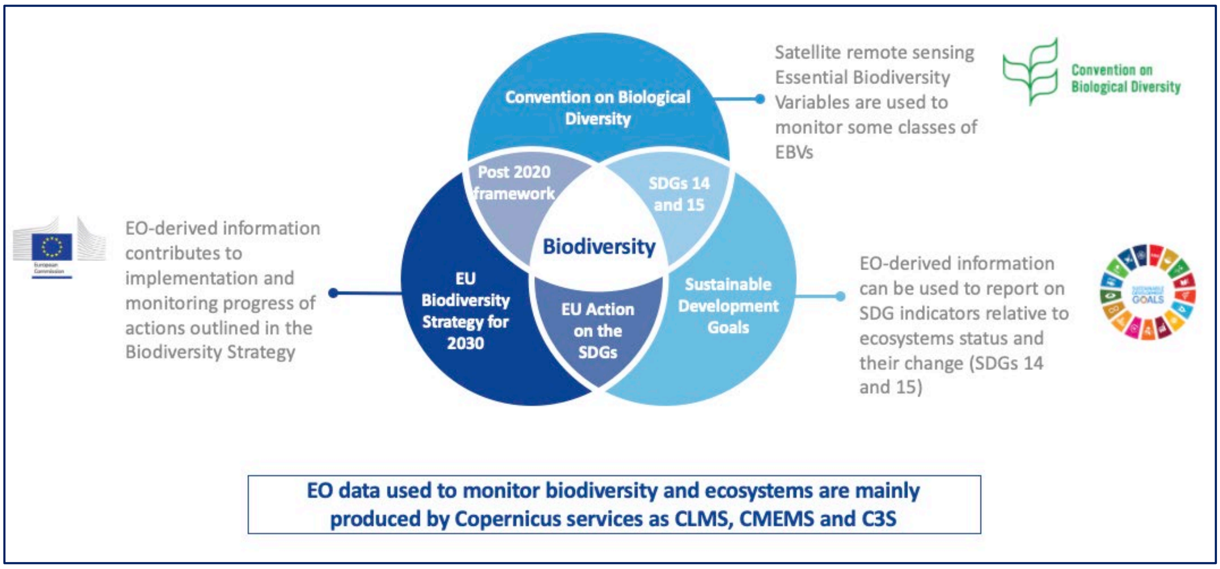
Policy context

To preserve and support the restoration of Biodiversity, the diversity of life on Earth and the variability among living organisms, the European Commission has put forward an ambitious Biodiversity Strategy for 2030[1]. The Strategy contains long-term plans and commitments to protect nature and ecosystems and it aims to set Europe's biodiversity on a path to recovery by 2030. The EU Biodiversity Strategy for 2030 will help Europe lead the way in addressing the global biodiversity crisis by promoting the adoption of a global post-2020 biodiversity framework under the Convention on Biological Diversity and the achievement of Sustainable Development Goals (SDGs) specific targets on biodiversity under SDG 14 and 15, respectively on life below water and life on land. The need to protect and restore biodiversity is also at the core of the European Green Deal, marking the EU's willingness and determination to address some of the most pressing challenges of our time.

EO and the services offered by the Copernicus programme, in particular the Land Monitoring Service (CLMS), the Climate Change Service (C3S) and the Marine Environment Monitoring Service (CMEMS) have come to play an increasingly important role in supporting biodiversity conservation and restoration. Today, products and tools offered by these services contribute to monitoring changes in ecosystems and biodiversity loss and are utilized in the context of the EU Biodiversity Strategy, the Convention on Biological Diversity and SDGs reporting.

[1] COM/2020/380

The Policy Context

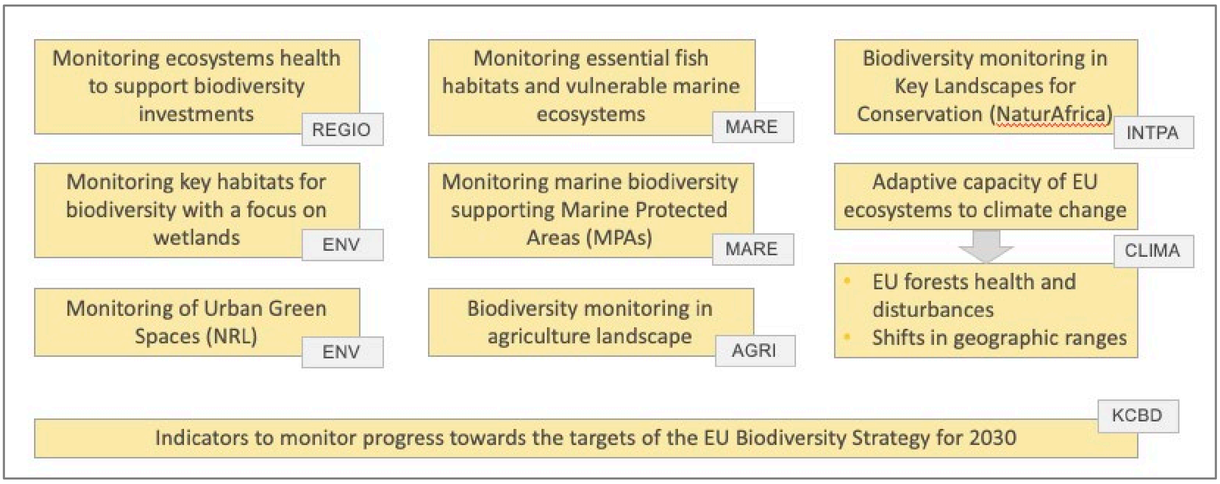


Key conclusions

The assessment has been articulated into a number of "use cases", for the different DGs having a specific interest or policy dossier related to biodiversity. The following DGs proposed use cases: DG ENV, REGIO, CLIMA, INTPA, MARE, and AGRI. A special use case on EO support to monitoring the EU Biodiversity Strategy was developed with the Knowledge Centre for Biodiversity (KCBD)[2], which is in charge of implementing the EU biodiversity monitoring system.

The different experiences of the DGs in the use of EO in their respective policy areas and the variety of specific needs put forward have resulted in an interesting mix of use cases that requested dedicated assessments.

Overview of the Use Cases



A key conclusion is that, for an efficient uptake of EO technology in support of EU policy makers, sustained assistance to cover the "last mile" to precisely tailor the products or applications to the specific request, is unavoidable.

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[2] https://knowledge4policy.ec.europa.eu/biodiversity_en

There is certainly potential to streamline EO applications that involve spatial environments of cross-policy relevance, such as for example urban areas, where the cost of very high-resolution imagery could be shared between different policy DGs. Regarding the capacity to monitor the impacts of EU biodiversity policies using available EO products, a key role could be played by the KCBD and the biodiversity monitoring system under construction. Biodiversity monitoring requires long term efforts to establish trends, it is complex because it is about multi-scalar and multi-temporal structures and processes. EO can help in this regard, but in many cases alternative ways to gather data to build indicators have to be explored. Furthermore, the role of spatial resolution and the impact it has on biodiversity metrics should also be considered.

The analysis of technical requirements identified in the biodiversity deep dive revealed that policy makers in this field consider spatial resolution and thematic detail more important than high temporal frequency. However, considering to what extent existing products match specific requirements, the spatial resolution of relevant recent Copernicus products is considered appropriate in most cases. Improvements are suggested to focus on more regular and frequent updates of available products, as well as on products latency (i.e., the total time elapsed between when a sensor acquires data and when a product is made available to the users). In addition, the length of time series and their consistency over time are considered generally important although not always adequate. Other areas of improvement are related to the thematic detail of EO products; typical land cover maps are not considered sufficient for many biodiversity applications, and this is as well applicable to land use and sea use products. There is a need to apply reference ecosystem typologies further refining more aggregated land cover classes, to drive the assessment and mapping of health/condition of habitats and ecosystems. In the marine and freshwater environments, key *in-situ* data are still lacking or too heterogeneous to be efficiently exploited.

In this respect, although satellite EO can already offer significant and valuable datasets to support biodiversity related policies, for advanced products and applications and the full exploitation of available technology, the integration of ground-based and more broadly *in-situ* data is key but unfortunately difficult to implement operationally in many cases. This would require a concurrent investment in building spatially referenced *in-situ* datasets as ground truth for validation and interpretation, both on land and even more in the marine environment, where additional challenges to monitor biodiversity are encountered.

The assessment of available EO products has been focused on technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products could not be considered and no recommendations could be made in this respect. However, it was recalled that publishing training and reference data used for the accuracy assessment of Copernicus products should always be ensured, to openly reporting on the quality of the products and enhance transparency and reproducibility.

As a final remark and recommendation resulting from the deep dive on biodiversity, the efficient use of EO products and services appears to be partly hampered by the difficulty in navigating the vast amount of existing resources and in using the variety of available interfaces to access them. This has been recognised as a limiting factor for their full exploitation in EU policy making.

Related and future JRC work

Following the biodiversity deep dive, the use case on monitoring key habitats with a focus on wetlands has been chosen by the JRC to develop a pilot downstream application in order to concretely explore EO solutions proposed and apply them in selected study areas.

Furthermore, the on-going development of the EU biodiversity monitoring system by the KCBD will also be in a position of taking advantage of the outcome of the deep dive.

The deep dive on biodiversity was the first, pilot of a series of thematic assessments started in 2022. Other deep dives will follow according to a roadmap agreed with the Steering Group of the KCEO. Next policy areas addressed in 2023 will be Climate adaptation, with specific focus on urban areas, and Compliance assurance.

Quick guide

The report is structured as it follows:

Chapter 1: introduction;

Chapter 2: introductory concepts regarding biodiversity assessment and Earth Observation;

Chapter 3: synthesis of the EU and international context on biodiversity policy and monitoring;

Chapter 4: brief illustration of the methodology used to perform the deep dive;

Chapter 5: actors involved in the biodiversity deep dive;

Chapter 6: detailed description of all the use cases assessed. For each use case: policy context, description of the use case, value chain analysis and technical requirements, fitness for purpose of existing EO products and services, conclusions and recommendations;

Chapter 7: discussion and conclusions.

1 Introduction

The European Commission Knowledge Centre on Earth Observation (KCEO) aims to provide an efficient internal coordination mechanism inside the Commission to maximise the uptake of products and information from Copernicus to support EU Policies in various sectors and to establish best practices in efforts to translate policy needs into concrete requirements for products and services. It also aims to provide a forum for dialogue with the technical implementing entities associated with Copernicus to enhance the exploitation on Copernicus throughout the policy cycle.

The 2016 Space Strategy for Europe[3] mandates the Commission Copernicus Programme to encourage the uptake of Earth Observation methods for EU policy. Specifically, "The Commission will encourage the use of space services, data and applications in EU policies whenever they provide effective solutions [...] the Commission will promote the uptake of Copernicus EGNOS and Galileo solutions in EU policies, where justified and beneficial". The KCEO created in 2021 and co-chaired by JRC and DG DEFIS, responds to the necessity of a dedicated mechanism to support the uptake of EO in support of EU policy, using the Copernicus Programme to its full potential. Within the Copernicus uptake framework, a number of actors are involved:

- Member States (MS): Copernicus User Forum (in Regulation), MS needs (Core Users)
- Copernicus Entrusted Entities/Services
- EUSPA and the Cassini Space Entrepreneurship Initiative: Uptake by Other Users (private sector)
- KCEO Focus on uptake (Core Users inside the Commission, namely the policy DGs)

Among the tools the KCEO has put in place for the EO uptake in the Commission are the deep dive assessments on the specific needs and use of EO in specific policy areas. The main objective of deep dives in the KCEO is to analyse EU policy needs in a defined policy area, to verify how and to what extent existing EO products and services meet these needs, to highlight existing gaps, and to provide recommendations on future evolution of Copernicus products and services to address these needs.

To structure the deep dive assessments, EU policies were grouped according to thematic domains, also keeping in mind in a broad sense the type of EO support the different policies may entail. The result is a list of 28 policy areas (see Annex 1).

Deep dives, each addressing a specific policy area, shall follow a common methodological protocol and imply interactions mainly with relevant policy DGs, with pools of external experts, with Copernicus technical implementing entities and partners. Policy areas are selected and prioritised according to a roadmap agreed with the Steering Group of KCEO.

This report stems from the deep dive assessment of the KCEO focused on biodiversity policies, exploring how EO (mainly ground-based and from space) products and services can be used in supporting biodiversity related policies. Being the first deep dive exercise, it also serves as a test of the deep dive methodology. In summary the deep dive on biodiversity analyses EU policy needs with the ambition to verify how and to what extent existing EO products and services meet them, highlight existing gaps and provide recommendations on future evolution.

[3] COM(2016)705

2 Biodiversity assessment and Earth Observation

2.1 Defining biodiversity

Biodiversity has been described as a measure of the total difference within a biological system (Lyashevska & Farnsworth, 2012), and an expression of the variety of life on Earth (Wilson, 1988). However an unequivocal, precise, and generally accepted definition of biodiversity does not exist (Swingland, 2013) and it remains challenging to measure such a broad concept in a meaningful way (Purvis and Hector 2000). A widely accepted definition of "biological diversity" by the Convention on Biodiversity (CBD) is "*...the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*"[4]. It includes all organisms, species and populations; the genetic variation among them; and their complex assemblages of communities and ecosystems[5]. In the context of EU policies, biodiversity is defined as "*The variety of life on Earth. It refers not just to species but also to ecosystems and differences in genes within a single species*"[6]. While nearly everyone is in favour of biodiversity and its conservation, methods for its assessment vary enormously. This is not only important from a scientific point of view but also because institutions and experts active in launching initiatives and tackling the conservation of biodiversity, must be able to communicate with each other (Levè et al., 2019).

2.2 Measuring and assessing biodiversity

Any attempt to define a set of variables for monitoring biodiversity change should indeed ensure that information on all components and dimensions of biodiversity are being captured (Pettorelli et al., 2016). Each of the different components of biodiversity (genetic, population/species, community/ ecosystem; Davies et al. 2013) possesses compositional, structural and functional attributes, which are often considered to be the 'three dimensions' of biodiversity (Noss 1990). Given the fundamental multidimensional nature of biodiversity (Lyashevska and Farnsworth 2012) and the inherent complexity of natural systems, comprehensive monitoring to capture all of its elements is challenging (Davies et al. 2013).

The Essential Biodiversity Variables (EBVs), defined as the derived measurements required to study, report, and manage biodiversity change[7], have been introduced to capture the different elements of biodiversity. EBVs constitute the emerging framework for measuring biodiversity using ground-based observations (Pereira et al. 2013), and there has been much progress in coupling EBVs with satellite Earth Observation (EO). Remote sensing biodiversity related products can produce information at various spatial resolution (10 m to 1 km), when needed (10 days to 1 year) and at a continental level (EU-wide), in terrestrial (Kissling et al. 2018; Pettorelli et al. 2016; Skidmore et al. 2021; Skidmore et al. 2015) and in marine (Muller-Karger et al., 2018, Miloslavich et al., 2019) ecosystems.

4 https://www.cbd.int/convention/articles/?a=cbd-02

5 The term ecosystem refers to a community of living organisms in a particular environment, including the interactions between them and their physical surroundings

6 http://ec.europa.eu/environment/nature/biodiversity/intro/index_en.htm

7 https://geobon.org/ebvs/what-are-ebvs/

2.3 The role of satellite EO in biodiversity assessment

Basic concepts of Satellite Earth Observation

Remote sensing is the process of using sensors to observe Earth's surface or atmosphere from a distance without being in direct contact, with the instruments mounted on aircraft, satellites, and other platforms (Campbell et al., 2022).

Earth Observation and Remote Sensing are often used interchangeably, however in this report Earth Observation (EO) is intended in its widest sense and includes ground-based measurements, sea-, air- and spaceborne observations. To specifically refer to spaceborne observations the expression "satellite EO" will be used. EO from airborne platforms is often used for biodiversity assessments. For example, it has been successfully applied to plant species composition mapping (Hill and Thompson 2005, Korpela et al. 2010, Simonson et al. 2012) or for detailed habitat mapping (Melin et al. 2013, Vihervaara et al. 2015). This report is focused on satellite EO; for this reason, further examples of airborne EO will be recalled only marginally.

Another source of potential ambiguity is the expression "*in-situ*" which can be used with different meanings. In Copernicus *in-situ* covers all measurements not collected from space, whereas in environmental sciences the expression strictly refers to data collected adjacent to the measuring instrument. To avoid ambiguity, in this report the expression "ground-based data" will be used to refer to data collected on the ground or at sea level, "*in-situ*" will refer to all non-space-based data.

Active remote sensing involves the use of sensors that emit energy, such as radar or lasers, to measure the reflection or scattering of that energy by the Earth's surface. Active remote sensing systems can operate in a variety of wavelengths, but the two most common operational technologies are radar (operating in the microwave) and laser (most commonly operating in the visible and near infrared range). Active remote sensing systems are typically used to measure the distance, shape, and texture of objects on the Earth's surface, and for biodiversity, LiDAR (Light Detection and Ranging) is used to measure ecosystem structural properties.

Passive remote sensing, on the other hand, involves the use of sensors that detect natural energy reflected or emitted from the Earth's surface and the atmosphere, in the UV, visible and infrared regions of the electromagnetic spectrum. Passive remote sensing systems are used to measure the spectral reflectance, temperature, or emission characteristics of the Earth's surface, which can be used to identify the state variables of the specific land covers, ecosystem function, ecosystem structure, community composition and species populations in terrestrial applications, as well as water characteristic in marine and freshwater environments. A particular case of passive remote sensing is the hyperspectral remote sensing, also known as imaging spectroscopy, based on the analysis of the radiation detected by a high number of narrow and contiguous spectral bands continuously covering a broad wavelength range. The detailed spectral characterization provided by imaging spectrometers enables to use quantitative spectroscopic algorithms for the retrieval of bio- and geochemical information, particularly relevant for biodiversity (Lillesand, et. al., 2015).

Since NASA launched the first EO satellite (Landsat 1) in 1972, a large number of satellite missions have been operated providing an enormous collection of multispectral imagery. According to the United Nations Office for Outer Space Affairs (UNOOSA), more than 8,260 Earth Observation satellites are currently in orbit around our planet – operated by various countries and private companies, to fulfil different tasks.

The advances of computer technology have dramatically changed the way we produce information on the basis of satellite EO data for monitoring biodiversity. Cloud computing is nowadays widely used for processing the vast amount of raw data acquired by multi-platform remote sensing sensors. Most data produced by EU and US space programs are available with open access policies, while national programs differ in terms of data access policies and commercial satellite operators usually charge for data, although some may provide free imagery e.g., for research and development.

Following a process interrelated to the development of Essential Climate Variables[8] (ECVs) of the Global Climate Observing System (GCOS), by Parties to the UN Framework Convention on Climate Change (UNFCCC),

[8] https://gcos.wmo.int/en/essential-climate-variables

the Group on Earth Observations Biodiversity Observation Network (GEOBON) has developed the concept of Essential Biodiversity Variables (EBVs) for monitoring biodiversity. The EBVs (Figure 1) form a core set of complementary biological measurements for capturing biodiversity change and can be produced by integrating primary observations from ground-based monitoring with satellite EO (Pereira et al., 2013). In this context, satellite EO technologies provide excellent resources to support spatially explicit monitoring of EBVs, in a globally consistent and repeatable way (Valbuena et al., 2020). The EBVs are grouped into six classes (Figure 1).

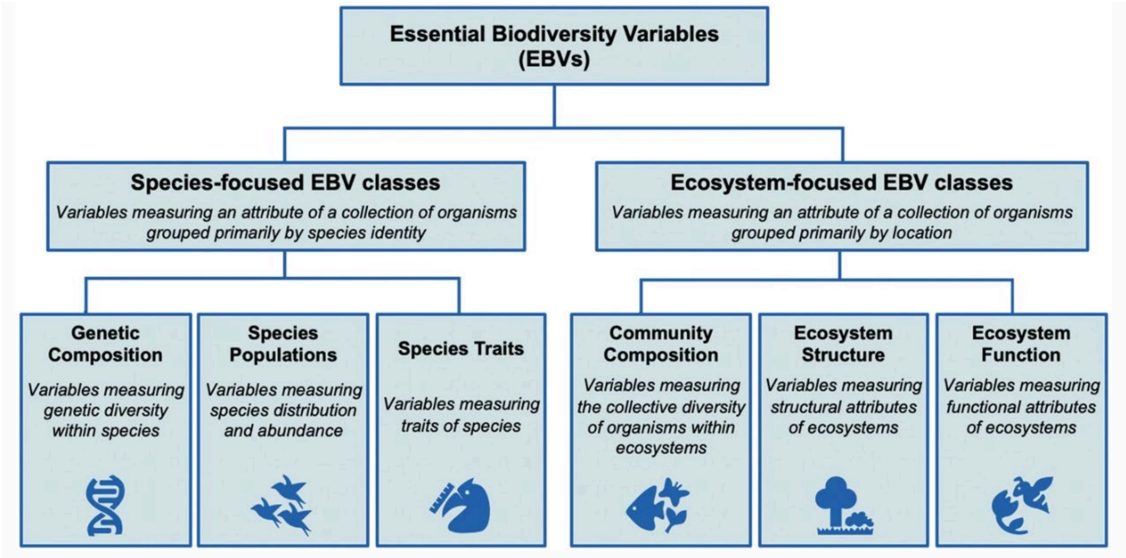

Figure 1. EBVs classes (from Fernández et al. 2020).

Resolutions of satellite imagery

There are different types of 'resolution' distinguished for remotely sensed imagery.

Spatial resolution refers to the spatial ground sampling distance, determining the smallest possible object that the sensor can identify. Spatial resolution of satellite imagery is most commonly referred to as the horizontal grid spacing (although this is strictly speaking not equivalent) and is expressed in metres. Spatial resolution ranges are often qualified with attributes (e.g. high resolution). The correspondence of attributes with quantitative resolution ranges are not standardised, for the purpose of this report we will refer to the following:

Very High Resolution (VHR):	<= 4 m
High Resolution (HR):	> 4 m and <=30 m
Medium Resolution (MR):	>30 m and <=300 m
Low Resolution:	>300 m

Temporal resolution describes how often a sensor revisits the same object and is often reported in days. For example, with two Sentinel-2 satellites we have a revisit time over the same location at mid latitudes of 2-3 days.

Spectral resolution refers to the width of each wavelength channel within the electromagnetic spectrum in which a sensor records information. High spectral resolution describes a narrow wavelength range. For example, multi-spectral satellite systems detect several discrete bands at different wavelength intervals. Hyperspectral (also known as image spectroscopy) satellites typically have hundreds of bands.

Radiometric resolution is the radiation intensity the sensor is able to capture. The radiometric resolution of an imaging system describes its ability to discriminate differences in energy reflected or emitted. The better the radiometric resolution of a sensor, the more sensitive it is to detecting small differences.

It is important to assess the baseline biodiversity status, as well as to reconstruct past trends in biodiversity indicators based on the analysis of historical EO products and to model possible future temporal trends (Miranda-Castro et al. 2022). This, of course, involves integrating remote sensing imagery with ground-based observations. In the marine context, where EO observations can be useful within a partial range of the ocean domain, the integration of satellite EO products with ground-based observations and modelling initiatives is of special relevance (Piroddi et al. 2022). Temporal trends analysis can be related to several status indicators such as phenology, land cover change, distribution, or abundance and disturbances.

Hundreds of different types of products useful for monitoring biodiversity can be produced from raw satellite EO data. Skidmore et al. (2021) have reviewed 120 remote sensing products that can be used to estimate EBVs and prioritised them according to their relevance for management and policy, the feasibility of their operational production, the accuracy of the derived product, and the maturity of the operational implementation (Table 1). Remote sensing products that are relevant, feasible, accurate and mature are essential for operational implementation and tracking of the spatial and temporal trends in biodiversity.

Table 1. Prioritization criteria and ranking factors of remote sensing biodiversity products according to Skidmore et al. (2021).

Prioritization criteria	Description	Ranking = 1 (good)	Ranking = 3 (poor)
Relevance	It is known who wants the remote sensing biodiversity product, what they will do with it and how it will be used. The remote sensing biodiversity product is relevant: (1) for management questions; (2) to inform the CBD targets; (3) to inform the SDG(s); and (4) to provide data for the IPBES risk assessment processes.	Use and user fully identified.	Remote sensing biodiversity product less directly linked to science and societal questions.
Feasibility	The science community knows how to measure the remote sensing biodiversity product at such scales that measurements can realistically be made and/or observations already exist. This criterion considers the availability of remote sensing data, the ease of access to such data, the completeness of remote sensing in space and time and the ease and affordability of data integration and analysis.	Indicates maturity of the science, technology and experience needed to make the remote sensing biodiversity product.	Indicates that considerable research and development effort remains or that remote sensing biodiversity products on the scale needed are technically, logistically or financially difficult to make.
Remote sensing status: accuracy	A measure of the current activity for the accurate observation of a given remote sensing biodiversity product. This criterion considers the effectiveness of remote sensing data and techniques to achieve an accurate and precise value of the remote sensing-enabled biodiversity product.	A fully operational network or service is in place, generating remote sensing biodiversity products that are accurate for the purpose.	Indicates that no or very limited action has been taken to generate accurate remote sensing biodiversity products.
Remote sensing status: maturity	Institutions/organizations with hopes to generate remote sensing biodiversity products can be identified and/or proposed to a funding body.	Operationally implemented with satellite remote sensing. It is known who needs to act and what action needs to be taken so that the remote sensing biodiversity product can now be produced.	Indicates a complete lack of relevant infrastructure or relevant implementation organizations that would allow a remote sensing biodiversity product to be conceivably produced from satellites within the next decade.

Several approaches can be used for inferring EBVs using remote sensing products with statistical or physical models, which incorporate ground-based data. This allows statistically rigorous spatial assessment of EBVs. Table 2, taken from Skidmore et al. (2021), lists the most relevant remote sensing products identified that can be used to estimate EBVs and specify for each product the technical satellite observation requirements for mapping and monitoring biodiversity. It should be noted that spatial resolution has strong impact on biodiversity metrics.

It should be noted that not all the remote sensing products in Table 2 and partly in the following Table 3 are ready to be operationally applied to assess biodiversity on a wider scale. In some cases, products and their use for biodiversity have been demonstrated in specific studies or local applications but still requires significant research efforts and investments before being mature enough to be upscaled and operationalised in the European context. Next chapters will address operational use cases and discuss possible existing operational solutions.

Table 2. Remote sensing biodiversity products summarised in terms of their technical satellite observation requirements for mapping and monitoring biodiversity (from Skidmore et al. 2021).

EBV class	Candidate EBVs (GEO BON)	Typical RS-enabled biodiversity variable name	RS-biodiversity products	Satellite observation requirements				
				Temp. R	Spec. R.	Spectral domain	Spat. R	Sensor type
Species Population	Species distributions	species distribution	species richness	Monthly	High	VIS/NIR/SWIR/TIR	<5m /≤30m	Comb.
			species diversity indices (Simpson, Shannon, alpha, beta, gamma)	1-5 yrs. + time series	High	VIS/NIR/SWIR	<5m	Comb.
	Species abundance	species abundance	species abundance	1-5 yrs. + time series	High	Whole	<5m	Comb.
			Relative species abundance	Monthly	High	Whole	<5m	Comb.
		population structure by age/size class	forest species and age class	1 -5 yr	High	Whole	<5m	Comb.
			population density (distribution)	Monthly	Medium	Whole	≤30m	Comb.
Species Traits	Phenology	species phenology	green-up (start of season)	10 days+ time series	Medium	Whole	≤30m	Opti./TIR/Lid/Rad
			senescence (end of season)	10 days+ time series	Medium	VIS/NIR/SWIR/MW	≤30m	Opti./Rad
			peak season (max of season)	10 day+ time series	Medium	VIS/NIR/SWIR/MW	≤30m	Opti./Rad
	Morphology	species morphology	leaf dry matter content	Monthly	High	VIS/NIR/SWIR	≤30m	Opti.
			specific leaf area	Monthly	High	SWIR	≤30m	Opti.
	Physiology	species physiology	gross primary productivity (GPP)	Monthly	Medium	VIS/NIR/SWIR	≤30m	Opti.
			net primary productivity (NPP)	Monthly	Medium	VIS/NIR/SWIR	≤30m	Opti.
			leaf area index (LAI)	Monthly	Medium	VIS/NIR/SWIR/TIR	≤30m	Opti./TIR/Lid
			chlorophyll content and flux	Monthly	High	VIS	≤30m	Opti.
			foliar N/P/K content	Monthly	High	VIS/NIR/SWIR	≤5m	Opti.
			polyphenols	Monthly	High	Whole	≤30m	Opti.
			lignin	Monthly	High	SWIR/TIR	≤20m	Opti./TIR
			cellulose	Monthly	High	VIS/NIR/SWIR/TIR	≤20m	Opti./TIR
			non-structural carbohydrates	Monthly	High	VIS/NIR/SWIR	≤30m	Opti.
Community Composition	Taxonomic/ Phylogenetic diversity	community diversity	taxonomic (species diversity/ richness)	Weekly to Monthly	High	VIS/SWIR	≤30m	Comb.
			functional diversity	Weekly to Monthly	High	VIS/NIR/SWIR	≤30m	Comb.
			phylogenetic diversity	Seasonal or Monthly	High	VIS/NIR/SWIR	<5m	Opti.
	Community abundance	species composition	percentage of species which occur together	Weekly to Monthly	Medium	VIS/SWIR	≤30m	Comb.
Ecosystem Function	Ecosystem phenology	ecosystem phenology	land surface peak (max of season)	10 days+ time series	Medium	VIS/NIR/SWIR/MW	≤30m	Opti./Rad
			land surface green-up (start of season)	10 days+ time series	Medium	Whole	≤30m	Opti./TIR/Lid/Rad
			land surface senescence (end of season)	10 days+ time series	Medium	VIS/NIR/SWIR/MW	≤30m	Opti./Rad
	Primary productivity	ecosystem physiology	gross primary productivity	Monthly	Medium	VIS/NIR/SWIR	≤30m	Opti.
			net primary productivity	Monthly	Medium	VIS/NIR/SWIR	≤30m	Opti.
			leaf area index	Monthly	Medium	VIS/NIR/SWIR/TIR	≤30m	Opti./TIR/Lid
			Specific leaf area	Monthly	High	SWIR	≤30m	Opti.
			foliar N/P/K content	Monthly	High	VIS/NIR/SWIR	≤5m	Opti.
			evapotranspiration	Daily	Medium	VIS/TIR	≤30m	Opti.
			fraction of absorbed photosynthetically active radiation	Weekly/Monthly	Medium	VIS	≤30m	Opti.
			ecosystem soil moisture	Weekly/Monthly	Medium	Whole	≤30m	Opti./TIR/SAR
			carbon cycle (sequestration)	Seasonal or Monthly	Medium	Whole	≤30m	Comb.
			carbon cycle (below-ground biomass and carbon)	Seasonal or Monthly	Medium	Whole	≤30m	Opti./TIR/Lid/Rad
			carbon cycle (above-ground biomass)	Seasonal or Monthly	Medium	Whole	≤30m	Opti./TIR/Lid/Rad
			chlorophyll content and flux	Monthly	High	VIS	≤30m	Opti.
	Ecosystem disturbance	ecosystem disturbance	biological effects of Irregular inundation	Monthly	Medium	VIS/NIR/SWIR	≤30m	Opti./Rad
			biological effects of fire disturbance (direction, duration, abruptness, magnitude, extent, frequency)	Daily or Weekly	Medium	VIS/NIR/SWIR/TIR	≤30m	Opti./TIR
			biological effects of Pest and disease outbreak	Monthly	Medium	VIS/NIR/SWIR	≤30m	Opti.
Ecosystem Structure	Ecosystem distribution	spatial configuration	ecosystem structural variance	1-3 yrs	Medium	Whole	<20	Opti./Rad
			ecosystem fragmentation	1 yr.	High	whole	≤5m	Comb.

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Table 2. Remote sensing biodiversity products summarised in terms of their technical satellite observation requirements for mapping and monitoring biodiversity (from Skidmore et al. 2021).

EBV class	Candidate EBVs (GEO BON)	Typical RS-enabled biodiversity variable name	RS-biodiversity products	Satellite observation requirements				
				Temp. R	Spec. R.	Spectral domain	Spat. R	Sensor type
	Live cover fraction	habitat structure	land cover (vegetation type)	Weekly to Monthly	High	Whole	≤30m	Comb.
			fraction of vegetation cover	Weekly to Monthly	High	VIS/NIR/SWIR/TIR	≤5m	Opti./Lid
			Canopy cover	Monthly	High	VIS/NIR/SWIR	≤30m	Opti./Lid
	Ecosystem Vertical Profile		above-ground biomass	Seasonal or Monthly	Medium	Whole	≤30m	Opti./TIR/Lid/Rad
			leaf area index	Monthly	Medium	VIS/NIR/SWIR/TIR	≤30m	Opti./TIR/Lid
			urban habitat	Seasonal	Medium	Whole	<20	Comb.
			ice cover habitat	Seasonal	Medium	Whole	<20	Comb.
			deadwood habitat	1 yr.	High	Whole	≤5m	Comb.
			vegetation height	1 yr.	Medium	VIS/ NIR/ MW	≤30m	Rad/Lid
			habitat structure	Seasonal	Medium	Whole	<20	Comb.
			biological effects fire disturbance (direction, duration, abruptness, magnitude, extent, frequency)	Daily or Weekly	Medium	VIS/NIR/SWIR/TIR	≤30m	Opti./TIR
			biological effects of Irregular inundation	Monthly	Medium	VIS/NIR/SWIR	≤30m	Opti./Rad

Spectral domain: VIS= Visible, NIR= Near-infrared, SWIR= Short-wave Infrared, TIR= Thermal infrared, MW= Microwave, Whole= Visible to Thermal Infrared wavelength.
Sensor type: Opti.= Optical, TIR= Thermal infrared, Lid= Lidar, SAR= Synthetic-aperture radar, Rad= Radar, Comb.= data fusion & need ancillary data or ecological models

Additional examples of biodiversity variables and their assessment with EO are provided in Table 3.

Table 3. Examples of biodiversity variables measured by or inferred from satellite EO

Biodiversity variables	**Notes on how the variables can be measured with satellite EO and their importance for biodiversity monitoring**
Species distribution	Species distribution can be mapped directly via remote sensing for some plant species; distribution may also be inferred by various other means that utilize EO data (e.g., species distribution modelling). Although spaceborne observation using very high-resolution commercial instrument has sometimes been used for directly observing large (e.g. elephants) or conspicuous and gregarious (e.g. seals and penguins on ice) animals, this so far has not proved to be cost-effective in most cases. As spaceborne hyperspectral (e.g. DESIS (DE), PRISMA (IT), ENMAP (DL), CHIME (ESA), SBG (NASA)) and LiDAR instruments (e.g. national airborne imagery that is free and open) become more available, species distribution monitoring from space will become increasingly common and viable. Species distribution is important because changes may indicate a decline or threat.
Species abundance	Species abundance can be estimated from space for certain plant species. Although spaceborne observation using very high-resolution commercial instrument has sometimes been used for directly observing large animals, and thus for estimating population size, so far this has not proved to be cost-effective. Abundance is important because changes in it can indicate species decline.
Phenology	This is a family of related sub-variables on the timing of biological events, and most phenological parameters based on spaceborne EO will be those of plants. Although the exact variables defining phenology are still under discussion they include: • Leaf-on and leaf-off dates • Start, end, and peak of season • Difference in greenness between leaf-on and leaf-off • Rate of greening up and senescence These phenological parameters are extracted from image time series during the vegetation growing season exploiting the spectral properties of vegetation as with the normalised difference vegetation index (NDVI). NDVI is calculated for each pixel at every date in the time series and it can then be used to calculate the phenological variable(s) of interest such as leaf on and leaf off dates. Global data sets of NDVI are available from Sentinel-3 and PROBA-V such as from the Copernicus Land Monitoring Service (https://land.copernicus.eu/global/products/ndvi).

Biodiversity variables	**Notes on how the variables can be measured with satellite EO and their importance for biodiversity monitoring**
Plant Traits	Many plant traits can be ascertained from remote sensing and so can contribute to the Plant Traits EBV. Traits are important because differences between species, such as leaf shape or chlorophyll concentration, can affect competitive ability, level of specialization, and community diversity. Plant species traits comprise numerous variables that may be directly obtained from remote sensing and include for example: Vegetation nitrogen content, which has a significant role in ecosystem processes and the functional aspects of biodiversity because it is often a limiting factor for plant growth. It is a primary regulator for many leaf physiological processes such as photosynthesis, is strongly linked to net primary production and the carbon cycle, and is an important parameter for ecosystem process models. Examples of canopy nitrogen content detection and mapping can be found in Ferwerda et al. (2005), Loozen et al. (2020), Wang et al. (2018). Specific Leaf Area (SLA) is defined as the leaf area per unit of dry leaf mass (m2/kg) and is important for assessing functional diversity. It is a key parameter in ecosystem modelling, linking plant carbon and water cycles and is an indicator for plant physiological processes such as growth rate and light capture. Thus, it provides information on the spatial variation of photosynthetic capacity and leaf nitrogen content. SLA has been obtained from Landsat for pilot areas (Ali et al. 2017) also through the leaf mass per area (LMA) which is the inverse of SLA (Serbin et al. 2019, Asner et al. 2011). Other traits successfully retrieved from remote sensing include leaf dry matter content (LDMC), leaf and canopy chlorophyll concentration, leaf polyphenols, leaf angle and leaf clumping, etc.
Taxonomic diversity	Spaceborne remote sensing has been used to estimate the taxonomic diversity of plants. This is important because changes in taxonomic diversity can indicate threats such as climate change and can result in biodiversity loss as well as changes in ecosystem services. We can expect taxonomic discrimination to increase as hyperspectral and LiDAR sensors become more widely available. Methods have been demonstrated in a number of pilots using satellite remote sensing (e.g., Landsat, Sentinel) as well as very high-resolution airborne image spectroscopy (Rocchini et al. 2018, Rocchini et al. 2022, Asner and Martin 2009).
Productivity	While there are various types of productivity and related variables, all of them relate to how much carbon an ecosystem assimilates. Net Primary Productivity (NPP) is a measure of the net rate of photosynthesis by an ecosystem and indicates the net rate of carbon accumulation. It is important because, among other things, changes in NPP reflect changes in the health of an ecosystem, it is a key component of the carbon cycle, and it represents the amount of energy available to an ecosystem. NPP has been estimated using physical models of productivity derived from time series of MERIS and SPOT image data sets. Examples are in https://land.copernicus.eu/global/products/dmp. Leaf area index (LAI) is defined as the ratio of the one-sided area of the leaf per unit ground area. LAI is important because it allows exchange of carbon, water, and energy between atmosphere and leaves and it has an important role in ecosystem processes and functions. It has been widely retrieved using remote sensing data and is a key input for climate and large-scale ecosystem models and it is a key structural characteristic of forest ecosystems. Global data sets of LAI have been generated by the Copernicus Land Service using Sentinel-3 and PROBA-V (http://land.copernicus.eu/global/). The fraction of absorbed photosynthetically active radiation (FAPAR, fAPAR or fPAR) quantifies the fraction of the solar radiation absorbed by live leaves for the photosynthesis activity. Then, it refers only to the green and alive elements of the canopy. The FAPAR depends on the canopy structure, vegetation element optical properties, atmospheric conditions, and angular configuration. FAPAR is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS) and is produced in an operational manner by the Copernicus Land Monitoring Service (https://land.copernicus.eu/global/products/fapar).

Biodiversity variables	Notes on how the variables can be measured with satellite EO and their importance for biodiversity monitoring
Biological impact of irregular disturbance (fire and inundation)	The decline in biodiversity is strongly affected by disturbances (e.g., fires, forest logging, urbanization, intense fishing, pollution and climate change). Furthermore, disturbance regimes (e.g., fire or inundation regime) characterize many ecosystems such as savannas, grasslands, chaparral, wetlands and coastal ecosystems. Monitoring these regimes is important because changes in them are likely to cause changes in the ecosystems that depend upon them. Monitoring of fire occurrence and extent are globally available from existing satellite observation systems such as NASA MODIS and even geostationary systems such as GOES. https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/v1-vnp14imgt. The European Forest Fire Information System (EFFIS - https://effis.jrc.ec.europa.eu/) routinely maps burned areas in the EU and neighbour countries, based on the integration between MODIS and Sentinel-2 imagery. Coastal as well as inland wetland inundation is routinely mapped and monitored using synthetic aperture radar as well as optical systems like MODIS, SPOT, Landsat and the Sentinels.
Functional diversity	Functional diversity refers to the variety of biological processes or functions of a particular ecosystem. Functional diversity reflects the biological complexity of an ecosystem and can be thought of as the amount of work (function) being done by different components of an ecosystem or biological process. Most work on functional diversity to date has been tried using plot-based data, though direct and indirect remote sensing proxies are being developed. Directly measuring functional diversity from remote sensing would include, for example, estimates of productivity within different structural components and monitoring this variation of productivity. Indirect approaches are based on applying plot-based species traits to estimate the functional structure of different communities. Up scaling of functional diversity can be achieved with higher resolution optical imagery such as Landsat or Sentinel-2 as well as LiDAR.
Habitat structure	Forest canopy height, crown cover and density are important because they are key to understanding and estimating a variety of parameters including biomass, vegetation coverage, and biodiversity. Canopy density, or canopy cover, is the ratio of vegetation to ground as seen from above, while canopy height measures how far above the ground the top of the canopy is. LiDAR can be used to determine these structural variables, however existing satellite systems do not include suitable LiDAR instruments. The GEDI (Global Ecosystem Dynamics Investigation) mission installed on the International Space Station (ISS) provides high-resolution laser ranging of Earth's forests and topography and has been used for mapping global forest canopy height through integration of GEDI and Landsat data (Potapov, et. al., 2021), however the mission will end in 2023. Even so, an increasing number of countries have blanket lidar coverage from airborne systems and satellite-based LiDAR systems are under discussion. Some vegetation structural elements can be retrieved using currently available radar, for example, basal area.
Ecosystem fragmentation and structural variance	This EBV captures the geographic boundaries and areal extent of ecosystems and the degree to which a previously contiguous ecosystem has been divided. It is important because changes in these parameters have implications for biodiversity and ecosystem services and are an indicator of driving forces such as climate and land use change. Ecosystem extent indicates the physical boundaries and areal arrangement of an ecosystem, which may change, for example, as the climate changes. Extent represents the areal size of an ecosystem, which may change, for example, due to human activities such as a forest being converted to cropland. Satellite remote sensing is commonly used to map land cover, which can correspond to ecosystems if the land cover classes are selected accordingly. There are limits to the ability to discriminate between different ecosystem types from space, though as hyperspectral and LiDAR instruments, for example, become more widely available discrimination capabilities will increase. Combining satellite EO with other types of datasets, such as soils and elevation models, also increase ecosystem discrimination capabilities, for

Biodiversity variables	Notes on how the variables can be measured with satellite EO and their importance for biodiversity monitoring
	example, see https://www.usgs.gov/centers/geosciences-and-environmental-change-science-center/science/global-ecosystems-global-data. Fragmentation is the level of discontinuity in a once-continuous ecosystem, a highly fragmented ecosystem thus being composed of small patches. Fragmentation is important because it can directly affect both the distribution and abundance of species as well as a variety of ecosystem functions. Satellite remote sensing is commonly used to estimate fragmentation through spatial statistics and techniques, dedicated tools are available and increasingly used for the analysis of spatial patterns in environmental applications (Vogt and Riiters, 2017; Vogt et al. 2022).

Clearly, remote sensing products to assess biodiversity variables have different level of maturity, and not all approaches are mature enough to operationally support policies. A metric that can be used to rate the level of maturity of remote sensing products is the Technology Readiness Level (TRL)[9], a benchmarking tool for tracking progress and supporting development of a specific technology through the early stages of the innovation chain. TRL measures the maturity level of a technology throughout its research, development and deployment phase progression, ranging from blue sky research through to actual demonstration of the full range of expected conditions. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology (Figure 2).

Figure 2. Schematic of Technology Readiness Levels (TRL).

RESEARCH	1	**Basic principles observed**
	2	**Technology concept formulated**
	3	**Experimental proof of concept**
DEVELOPMENT	4	**Technology validated in Lab**
	5	**Technology validated in relevant environment**
	6	**Technology demonstrated in relevant environment**
DEPLOYMENT	7	**System prototype demonstrated in operational environment**
	8	**System complete and qualified**
	9	**Actual system proven in operational envirnment**

Numerous studies have applied Copernicus data in the biodiversity domain, enhancing the complementarity between Sentinel-1 and Sentinel-2 missions, highlighting the growing demand for free and open access to data and the importance to build long-term archives for Copernicus data.

According to Turner et al. (2014), although satellite remote sensing is an essential tool to monitor the status of habitats and associated environmental parameters, data are still underused within the biodiversity community. The main factors relate to the continuity, i.e., availability of long-term satellite data archives, affordability for many datasets despite the growing amount of free and open access data available, and access to satellite data, which has to do with the ability of biodiversity researchers to discover, retrieve, manipulate, and extract value from satellite imagery (Turner et al., 2014). Cross-sectorial dialogue between disciplines, such as the remote sensing community and the community of biologists, ecologists, and conservationists, and the modelling community, is essential for creating an improved understanding of each discipline's assets and challenges. These is even more important considering that the lack of suitable ground-based biodiversity data is a challenge for the potential of satellite EO products in monitoring biodiversity in the European environment.

It is worth noting that, pursuant the Open Data Directive[10], the European Commission has recently adopted the Implementing Regulation laying down a list of high-value datasets and the arrangements for their publication and re-use[11]. The main objective is to ensure that public data of highest socio-economic potential are made available for re-use with minimal legal and technical restriction and free of charge. "Earth observation and environment" falls within the thematic categories with high value datasets. Under this category are data from earth observation, space-based as well as ground-based or in situ, falling within the scope of the INSPIRE data themes that include protected sites, land cover, environmental monitoring facilities, habitats and biotopes, land use, sea regions, species distribution and others.

The advent of Copernicus and European Space Agency (ESA) constellations Sentinel-1 and Sentinel-2, complemented with NASA Landsat Data Continuity Mission, ensures continuous provision of high spatial resolution satellite EO data (10-30 m) and high time frequency (3-5 days combining Landsat 8 and Sentinel-2 satellites) (Scholes and Walters, 2017). Spectral light obtained from Sentinel-3 A/B Ocean and Land Colour

[9] https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/Technology_Readiness_Levels_TRL
[10] Directive (EU) 2019/1024 of the European Parliament and of the Council of 20 June 2019 on open data and the re-use of public sector information
[11] C(2022) 9562 final

Instrument (OLCI) sensor bands has been used to study phytoplankton community (Kraus et al., 2021) and monitor coastal terrestrial and aquatic habitats. However, marine biodiversity monitoring would require different technical specifications (Muller-Karger, et al., 2018). The new EO data flows, methodologies and cloud computing infrastructures triggered a paradigm shift in continuous, near real time monitoring, small vegetated areas over large spatial extents (Fauvel et al, 2019), physiological diversity (Helfestein et al., 2022), plant functional diversity (Ma et al., 2019), forest monitoring and forest responses to management interventions and disturbances (Chraibi, et al, 2022; Parisi et al., 2023). A global monitoring system for biodiversity requires an agreed set of ground-based and remote sensing products (Pettorelli et al., 2016) as it is emerging for terrestrial ecosystems (Skidmore et al. 2021). However, marine ecosystems still lack a set of operational biodiversity products, including for those marine regions that are relatively well monitored with *in-situ* sensors (Costello et al., 2010; Canonico, et al., 2019; Ramirez et al., 2022).

Studies showed that high-resolution spaceborne multispectral radiometer Sentinel-2 imagery could be used for tropical forest monitoring (Chraibi et al., 2022; Aguirre-Gutiérrez et al., 2021), and to identify areas for nature conservation and monitor potential forested biodiversity hotspots in remote areas such as mountains reducing ground acquisition data efforts in Europe (Parisi et al., 2023). Sentinel-1 and Sentinel-2 time series could complement field botanical and ecological surveys techniques to predict grassland biodiversity abundance and dominance-based indices such as Simpson's index over large areas (Fauvel et al, 2019).

Moreover, Sentinel-2 data showed potentials to map physiological diversity in temperate forest ecosystems using multispectral indices as proxies for physical traits and diversity metrics that can be derived from satellite remote sensing data (Helfestein et al., 2022). Functional diversity is usually assessed through labour intensive field assessment, while functional diversity maps could quickly be generated using Sentinel-2 data and could support analysis and reporting providing quick biodiversity change assessments (Ma et al., 2019). Multi-temporal analysis of Sentinel-1 C-band and Sentinel-2A images, and a fusion of the two datasets, can be used to detect several plant species with similar morphological (narrow-leaf) characteristics in densely vegetated environments such as savannas. However, a detailed biodiversity assessment and species diversity monitoring activities would require the integration images with improved spatial (<10 m) and spectral resolutions (>10 bands) (Funtisi et al., 2022).

Advances in remote sensing technologies aim to enable *in-situ* observation to be made from space and are promising solutions to enhance cross-community interactions between biodiversity and remote sensing communities. Constellations such as the Copernicus Sentinel missions build on long term freely accessible archives and are widely used as complementary tools for biodiversity monitoring, thus representing a valuable set of tools in support of EU biodiversity related policies.

3 EU and international context

To preserve and support the restoration of biodiversity, the diversity of life on Earth and the variability among living organisms, the European Commission has put forward an ambitious Biodiversity Strategy for 2030 (COM/2020/380)[12]. The Strategy contains long-term plans and commitments to protect nature and ecosystems and it aims to set Europe's biodiversity on a path to recovery by 2030. The EU Biodiversity Strategy for 2030 has helped Europe lead the way in addressing the global biodiversity crisis by promoting and adopting the Kunming-Montreal Global Biodiversity Framework (GBF) under the Convention on Biological Diversity (CBD). The EU and its Member States, as parties to the CDB, will now work on the implementation of the GBF to reach its targets, and also to achieve the Sustainable Development Goals (SDGs) 14 and 15, respectively on life below water and life on land. The need to protect and restore biodiversity is also at the core of the European Green Deal, marking the EU willingness and determination to address some of the most pressing challenges of our time.

Satellite EO and the services offered by the Copernicus programme, in particular the Land Monitoring Service (CLMS)[13], the Climate Change Service (C3S)[14] and the Marine Environment Monitoring Service (CMEMS)[15] have come to play an increasingly important role in support of biodiversity conservation and restoration. Today, products and tools offered by these services contribute to monitoring changes in ecosystems and biodiversity loss and are utilized in the context of the EU Biodiversity Strategy, the Convention on Biological Diversity and SDG reporting.

The European Commission itself has successfully used Earth Observation to generate geospatial intelligence in infringement procedures to protect European forests and their biodiversity[16]. Furthermore, in its Forest Strategy, one of the flagship communications of the Biodiversity Strategy, the Commission committed to promoting the use of geo-spatial intelligence in the Member States and at EU level by developing its own capacity to use geospatial intelligence for environmental compliance assurance[17].

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380
[13] https://land.copernicus.eu/
[14] https://climate.copernicus.eu/
[15] https://marine.copernicus.eu/
[16] COM(2022) 518 final; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0518&qid=1677846008800
[17] COM(2021) 572 final; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0572&qid=1677846086310

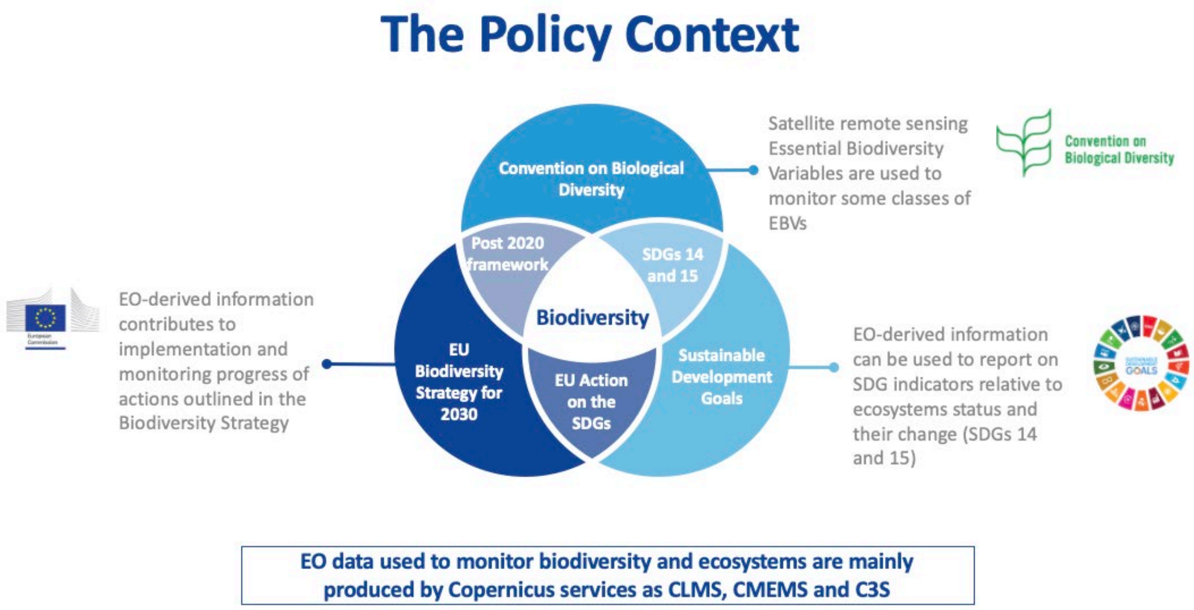


Figure 3. Schematic of the EU and international policy context of biodiversity and Earth Observation

3.1 The EU Biodiversity Strategy for 2030 and the Knowledge Centre for Biodiversity

The EU Biodiversity Strategy for 2030 (BDS) has been adopted in May 2020. It contains 16 targets to be reached by 2030 and more than one hundred actions to be taken to help reach those targets, with the general aim of putting Europe's biodiversity on the path to recovery by 2030 for the benefit of people, climate, and the planet. The BDS targets and actions are organised around four main pillars:

1. establishing a coherent network of protected areas
2. launching an EU nature restoration plan
3. enabling transformative change
4. taking action to address the global biodiversity crisis, including working towards the successful adoption of an ambitious global biodiversity framework under the Convention on Biological Diversity[18].

The Knowledge Centre for Biodiversity[19] (KCBD) has been established in October 2020 by the European Commission and in close cooperation with the European Environment Agency (EEA), as one of the first implemented actions of the BDS.

The BDS provides that the KCBD will:

1. track and assess progress by the EU and its partners, including in relation to implementation of biodiversity-related international instruments
2. foster cooperation and partnership, including between climate and biodiversity scientists
3. underpin policy development.

The KCBD is co-chaired by DG Environment and the Joint Research Centre (JRC) and it is steered by a committee with members from four other Commission services and the EEA. The KCBD is establishing a close cooperation with other Commission services and with a broad range of research networks and collaborators.

In essence, the work of the KCBD is coordinated by a team based at the JRC, and is organised around four main streams:

[18] https://www.cbd.int/
[19] https://knowledge4policy.ec.europa.eu/biodiversity_en

1. develop tools to track progress on the implementation of the BDS (see section "Monitoring tools for the EU Biodiversity Strategy")
2. highlight interlinkages between policies on complex topics related to biodiversity
3. orchestrate ad-hoc replies to specific and urgent policy needs
4. act as a knowledge broker between research and policy making.

3.2 The international context and the Global Biodiversity Framework

Europe is actively involved in international discussions on information and knowledge support from Earth observation for biodiversity monitoring and assessment. Both from a policy perspective and through active involvement in the coordination mechanisms for the provision of data, products and services.

For the policy context, recent developments include the fact that Parties to the Convention on Biological Diversity (CBD), including EU and its 27 Member States, have met in December 2022 to determine the post-2020 GBF. The final text adopted is organised around four main goals, which are:

- protecting biodiversity at all levels and preventing extinctions (goal A)
- ensuring that biodiversity can meet people's needs and support their human rights (goal B)
- ensuring that benefits from the use of biodiversity and genetic resources are shared with equity, and the traditional knowledge and indigenous people and local communities' rights are respected (goal C)
- enabling adequate level of the means of implementation (goal D).

On that occasion the EU, also joined a high ambition **Accelerator Partnership** to support the future implementation of the GBF under negotiations at COP15 in Montreal. In addition, the EU and many other partners are committed to create a **Global Knowledge Support Service for Biodiversity**[20] (GKSSB)**.**

These two complementary initiatives will be instrumental in addressing key issues for the implementation of future global biodiversity objectives by developing countries. The Accelerator Partnership will help increase finance flows to biodiversity in developing countries. The Knowledge Support Service will make available data and knowledge to help countries monitor progress in fulfilling biodiversity objectives.

The purpose of the Global Knowledge Support Service will be to help monitor progress so countries deliver on the Global Biodiversity Framework's goals and targets, it will support national efforts to monitor and report on progress, by enhancing the access to and use of data and knowledge at national, regional and global level. Its scope is currently under consultation with countries, to best respond to knowledge and capacity needs identified during the COP15 conference. It is expected that it will operate in all parts of the world, bringing together national and regional capacities and knowledge.

The EU is also providing financial and technical support to a wide range of knowledge and capacity building programmes, like BIOPAMA[21] for better management and governance of protected areas. BIOPAMA builds on the DOPA[22] to provide services and applications that can be used to assess, monitor, report the state of and the pressure on protected areas at multiple scales. Additionally, there is the Biodiversity Information for Development programme[23] for effective use of biodiversity data in research and policy, and the upcoming Centres of Excellence for Biodiversity in Sub-Saharan Africa.

There are also a number of significant efforts through global mechanisms for EO coordination. For example, within the Group on Earth Observation (GEO) is the Initiative GEOBON whose goal is to improve the acquisition, coordination and delivery of biodiversity observations and related services to users including decision makers and the scientific community. As mentioned earlier, GEOBON maintains and monitores the EBVs and the European contribution to GEOBON, EuropaBON[24] , and ensures the systematic production of a number of EBVs and their derived indicators. More recently within GEO, and at the time of the COP-15 in

[20] https://gkssb.chm-cbd.net/
[21] https://biopama.org/
[22] https://dopa.jrc.ec.europa.eu/dopa/
[23] https://www.gbif.org/programme/82243/bid-biodiversity-information-for-development#:~:text=Biodiversity%20Information%20for%20Development%20(BID,the%20Caribbean%20and%20the%20Pacific.
[24] https://europabon.org/

Montreal, a new initiative was announced. This new initiative is the Global Ecosystem Atlas that aims to offer a scalable view of any part of the world's ecosystems in unprecedented detail and will be constantly updated. Users will have access to a range of useful analytical functions that can assist with ecosystems monitoring, forecasting changes and designing effective warning systems. The Atlas aims not only to support the needs of the CBD but also other conventions and global initiatives, such as UNFCCC and System of Environmental Economic Accounting (SEEA)

Additional international contributions on data provision come from the global coordination of space agencies, in particular through the Committee on Earth Observation Satellites (CEOS). CEOS started discussions on biodiversity collaboration already back in 2012. This effort was reinvigorated starting in 2020 with the decision at the 2022 Plenary to start a dedicated activity on Ecosystem Extent. With the recognition that Ecosystem Systems extent is a ubiquitous need across policies, that it is amenable to space-based earth observation and that there will be a number of new satellite mission over the next decade that will help further develop these products.

It is clear that at the international level there is both a strong demand in the policy content, through the CBD and other treaties where the EU is engaged and has commitments, and in the coordination of data, services, information and knowledge through initiatives such as GEO and CEOS where the EU is and active contributor. The GBF monitoring needs and indicators provide a template on which the necessary contribution of Earth Observations can be developed and refined, and the new Global Knowledge Support Service for Biodiversity should provide the programmatic basis for this implementation, coordination to evolve. In addressing this, we see the following short to mid-term areas where Europe should try to engage at global scale with its EO capacity:

- Ensure that European institutions and agencies are involved in the initial implementation of the GKSSB to ensure that, where relevant, Earth Observation data and information is most effectively integrated in this process
- Make an in-depth assessment of the synergistic use of EO in addressing both the BDS indicators and the GBF monitoring indicators
- Target any additional research and development activities required to ensure that EO products are fit-for-purpose to address the needs for baseline global scale information
- Through Copernicus, ensure the required products and Services are further tailored to address the needs of the GBF monitoring indicators, as a way to ensure the longer term sustainability of European products and information
- In the planned Copernicus Thematic Hub on Biodiversity, ensure that the global baseline products are also provided to the hub from the relevant Copernicus Services in support of GBF and GKSSB
- The Commission should also ensure that targeted capacity building efforts should be in place to support the uptake and co-development of tailored products, building on European core products and services in less-developed regions (also linking to the planned Copernicus Thematic Hub on international partnerships where relevant)
- The KCEO should further refine the characterisation of EO needs and requirements for less-developed regions through activities with DG INTPA and the EU Delegations.
- Continue active European participation to the relevant coordination mechanisms for the provision of data and information from EO for Biodiversity e.g. such as through GEO and CEOS.
- Promote and encourage the exchange of *in-situ* and ground-based data on biodiversity with international partners including; though data exchange agreements established with third countries in Copernicus; and; institutional agreements with UN agencies and NGOs.
- Investigate the optimum use of European data and information system infrastructure to support the sustained access to the global scale data and product in support of the GKSSB

4 Deep Dive methodology

This chapter outlines the general protocol envisaged for policy deep dive studies of the Knowledge Centre on Earth Observation (KCEO).

The main objective of the KCEO deep dives is to identify and analyse policy needs in a defined policy area, to verify that these are being met, to present available EO products and their features and highlight existing gaps, providing recommendations on how to address these.

The deep dive starts with the identification of the policy DGs and the other key actors to involve in the process (the actors involved in the biodiversity deep dives are presented in chapter 5).

After identifying the user community, the following steps are addressed:

- Assessment of policy context and needs
- Earth Observation Value Chain
- Translation of needs into technical requirements
- Fitness-for-purpose of existing solutions
- Gap analysis and recommendations

4.1 Analysis of policy context and needs

The analysis of the policy context and needs is carried out through workshops, and/or questionnaires/interviews with the policy DGs having an interest or a role in the policy area of the deep dive.

The interviews with the policy DGs are the main instrument. Their aim is to elaborate on the decisions that need to be taken in the different policy contexts and how Earth Observation products can support/facilitate such process of decision and policy making.

The interviews are structured in 4 parts (see complete structure with the full list of questions in Annex 2):

1. User profile
2. Policy area, user needs and selection of use cases
3. Use case detailed description
4. Use case technical assessment

The first part is critical since EU policy makers have varying degrees of maturity and/or preparedness with respect to the use of EO data in policies the DG is following. It is important to assess this at an early stage of engagement with a new policy user. It is worth noting that all policy needs, whether they originate from an emerging partner or a mature partner, have implications for the type, quantity, and duration of resources that Copernicus and other EO investments would be asked to make available, and for the time required to implement new products and Services in operations. Therefore, these indicators should be ascertained at an early stage.

The second part is intended to provide details on the policy context handled by the DGs and the specific policy needs that EO could potentially or better support, across the entire policy cycle, from policy anticipation to policy evaluation (Figure *4*). One or more "use cases" are selected as a result that become the central focus of the subsequent analysis.

Selected use cases are described in detail in the third part of the interview and some preliminary technical assessment is carried out, particularly useful in case the DG has already some experience in the use of EO in the policy area.

Depending on the experience in the use of EO products and application and the specific needs expressed, each use case can have a varying degree of detail and technical content and be therefore articulated differently in the following steps of the methodology.

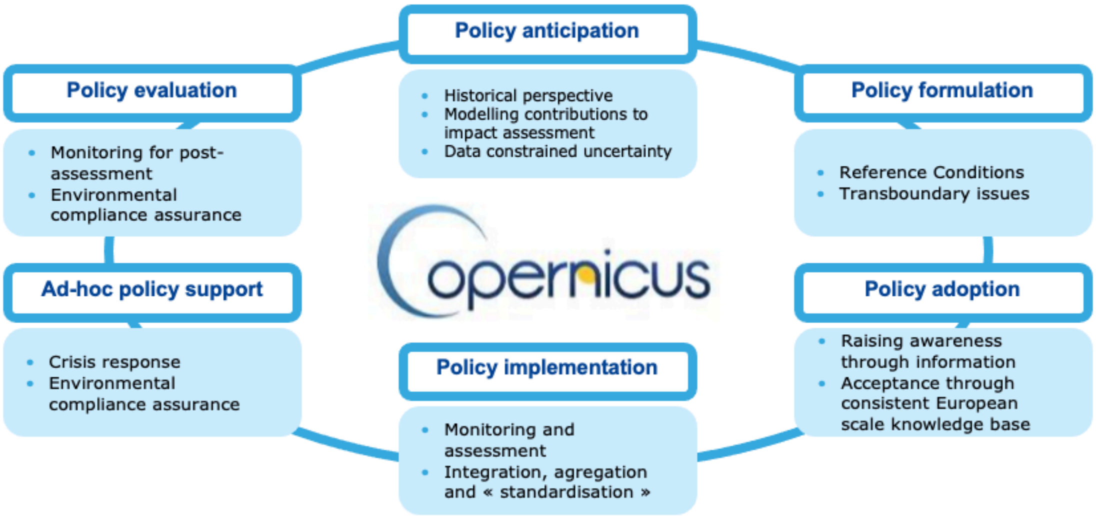


Figure 4 Copernicus products and services support to the EU Policy Cycle.

4.2 Earth Observation value chain

For selected use cases a value chain assessment is conducted (Figure 5).

The value chain assessment is intended to help define best practices in the identification of user requirements and their translation into quantitative information. This assessment will also help determine the value of EO data in specific use cases, and review existing practices in the four key steps of the EO value chain from a technologically-agnostic perspective.

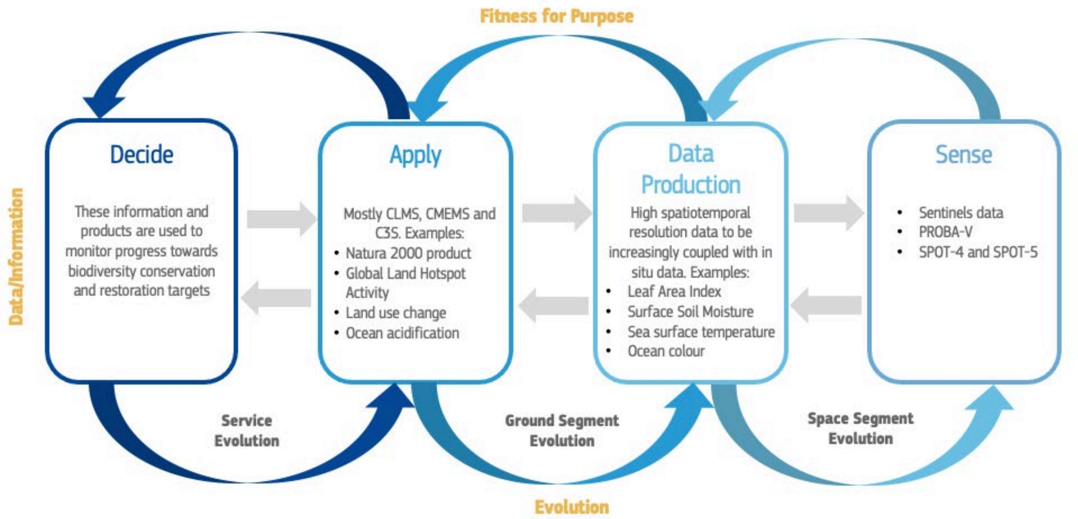


Figure 5. Earth Observation value chain example.

4.3 Translation of needs into technical requirements

The needs emerged from the use cases must be translated into technical requirements for EO products and services. The set of parameters used to describe technical requirements was adapted from the specification scheme used by the Polar Expert Group, which worked on the identification of user requirements for a Copernicus Polar Mission (Duchossois et al., 2018). The parameters include:

- Geographical Area of interest
- Spatial resolution
- Time of year
- Temporal frequency
- Latency
- Continuity of time series
- Uncertainty and accuracy
- Thematic detail/granularity

Depending on the user needs formulated in each use case, only a selection of parameters can be assessed during the deep dive analysis; the parameters more frequently clearly indicated by users are area of interest, temporal and spatial resolutions.

Uncertainty is a key attribute of any EO product, that indicates how well the value is known, whereas the accuracy describes the level of agreement or closeness of a measurement with the “true” value. This means the accuracy of product can be assessed for any parameter (including geometric or thematic ones) against requirements.

4.4 Fitness for purpose

The fitness for purpose step is based on the review of existing EO products, services, infrastructure, and capacities with respect to the expressed needs and related basic technical requirements. This can be done also considering what is made available beyond Copernicus by other space agencies and/or providers, bearing in mind the accessibility of the products and the capacity for uptake of the different DGs.

The assessment of fitness for purpose of EO products as defined in QA4EO[25], in the context of the deep dive is focused on some technical specifications, which are in most cases limited to spatial, temporal and thematic features of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products, require to be assessed extensive analysis which are beyond the scope of the deep dive, furthermore they are often not reported as specific user requirements and in actual product specifications. In this respect, it is worth recalling that training and reference data used for the accuracy assessment of products should be openly published to enhance transparent and reproducible reporting on the quality of the same products.

In the fitness-for-purpose assessment, possible overlaps, complementarities, and synergies with existing products must be considered, and how these can be best harnessed to develop cross-cutting applications across different domains.

The accessibility of EO products and services, including the user-interfaces providing access to data are part of the criteria defining the fitness-for-purpose. Relevant information should be made available to users from the different DGs in the most appropriate format.

It should be also considered whether further capacity to use the products/services is needed or existing capacity is adequate. In case existing capacity to use EO derived products does not meet the required skills, it may be worth considering including an analysis of the current capacity gap and adding a recommendation on how to close this gap, highlighting what would be the skills required to take advantage of the available products/services.

[25] https://qa4eo.org/docs/QA4EO_Principles_v4.0.pdf

4.5 Gap analysis and recommendations

The final step is a summary highlighting current gaps and shortfalls of the observation capacities and formulating related recommendations for evolution.

Recommendations should highlight priority requirements and what improvements are suggested for the ground and space segments, for services, infrastructures and regarding R&I investment.

5 Actors involved

The deep dive on biodiversity has been coordinated by the KCEO secretariat, which comprises staff from the JRC and DG DEFIS and has been supported by a small pool of external experts.

Policy DGs having an interest on biodiversity have been involved namely DGs ENV, REGIO, CLIMA, INTPA, MARE, AGRI. In addition, ESTAT, RTD and CNECT have been following the process.

Representatives from the relevant Copernicus Entrusted Entities managing the Land Monitoring Services (the JRC and EEA), Marine Environment Monitoring Service (Mercator Ocean), the Climate Change Service (ECMWF) and the Copernicus Partners (ESA and EUMETSAT) have been involved in dedicated workshops.

Other external experts from Member States institutions and agencies, research community, academia and the private sector were also invited to a stakeholder workshop with panel discussion developed around which EO products and applications are available from Copernicus to support EU policy needs regarding biodiversity, but also what existing technologies and opportunities are available outside Copernicus to address those needs.

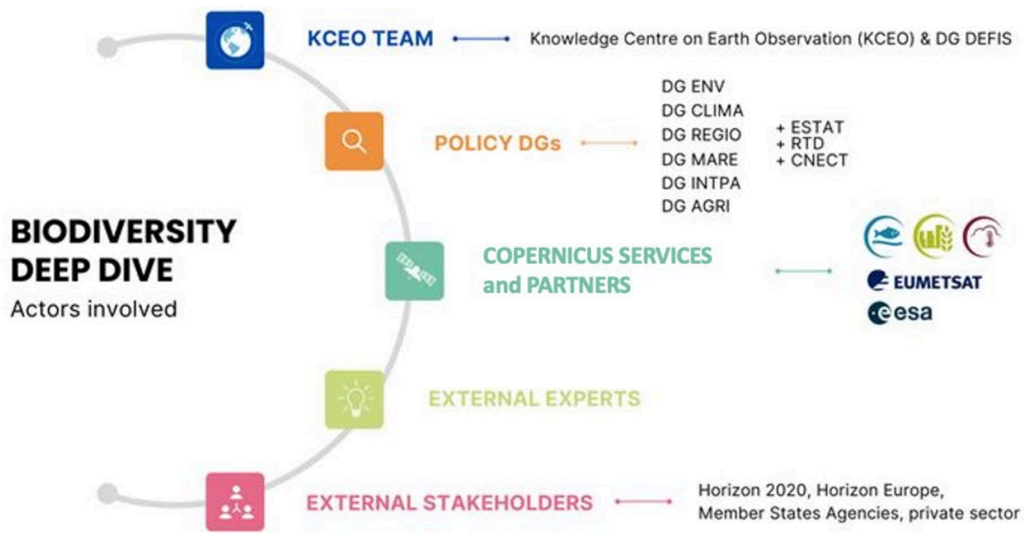


Figure 6 Key Actors in the deep dive on biodiversity

6 Description of use cases

As mentioned earlier, the needs expressed by the policy DGs have been translated into specific “use cases”, one or more for each of the involved DGs (Figure 7). A special use case regards the EO support to the monitoring of the EU Biodiversity Strategy that has been developed involving the KCBD, in charge of implementing the EU biodiversity monitoring system.

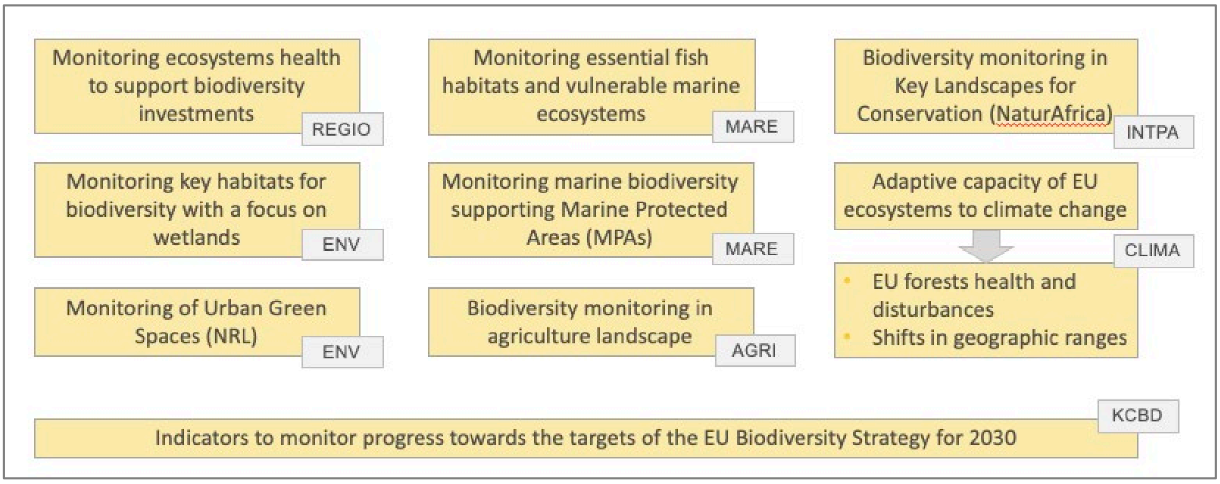


Figure 7. Overview of the Use Cases in the biodiversity deep dive

It is worth noting that the methodological steps illustrated in Chapter 4 apply separately to each use case, with variations depending on the specific needs and context. For example, the EO value chain, although conceptually useful as reference frame for the assessment, was not always directly applicable to translate the needs of the use cases into technical requirements and thus has not been always explicitly implemented.

6.1 Monitoring the EU Biodiversity Strategy

Credit: European Union, Copernicus Sentinel-2 imagery

6.1.1 Policy context

The policy context for this use case has been described in Chapter 3.

6.1.2 Description of the use case

The JRC team coordinating the work of the KCBD, together with Commission services and the EEA, have developed two online tools for supporting the tracking and reporting of progress of EU and its Member States on actions and targets of the EU Biodiversity Strategy (BDS):

- an actions tracker[26], to track progress in the implementation of the more than 100 actions listed in the BDS and highlight whether they are completed or not
- a dashboard[27] to show where the EU and its Member States stand regarding the 16 targets listed in the BDS, using a set of the best available indicators already used by the EEA and Eurostat to measure progress towards these targets, and displaying their current values in a distance to target graph at EU level and, if national data are available, on a map at national level.

These tools are accessible from the website of the KCBD[28] to everybody. The actions tracker is updated by the Commission services each time an action is completed. The BDS dashboard is not yet completed with the full set of indicators for all targets, its state of play and outlook, including specific possible support from Earth Observation are detailed in what follows.

The process for identifying and selecting indicators for the BDS dashboard currently functions as follows:

- the KCBD coordination team maintains and regularly updates a list of candidate indicators based on input from EEA, Eurostat and JRC
- once or twice a year, the KCBD coordination team extracts a set of indicators from this list, corresponding to the most relevant and mature indicators
- this indicator set is discussed first in the meeting of the EU Biodiversity Platform expert subgroup on monitoring and assessment[29] and then in the meeting of the EU Biodiversity Platform[30]
- once the indicators are endorsed by the EU Biodiversity Platform, the KCBD coordination team collects information on indicator values and documentation and publish it on the BDS dashboard.

[26] https://dopa.jrc.ec.europa.eu/kcbd/actions-tracker/
[27] https://dopa.jrc.ec.europa.eu/kcbd/dashboard/
[28] https://knowledge4policy.ec.europa.eu/biodiversity_en
[29] https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vk66hj8g5eyd
[30] The EU Biodiversity Platform and its subgroups of experts constitute the governance body of the EU Biodiversity Strategy

The BDS dashboard currently contains 7 indicators to monitor progress on 4 out of the 16 targets. Three other indicators are in the pipeline, so the BDS dashboard will soon contain 10 indicators to monitor progress on 5 targets (see Table 4). These indicators come from either the EEA or Eurostat, and the data are automatically collected from their databases, using the latest available updates. Therefore, at the time of writing this report there are still 11 targets without indicator in the BDS dashboard, in this respect a larger set of candidate indicators are being considered and 2 of them have been already proposed to the EU Biodiversity Platform (Table 4).

The on-going work to identify suitable candidate indicators includes an in-depth assessment for targets related to agro-ecosystems, carried out by two experts on the topic – one from the JRC and one external expert, as well as the assessment of the potential contribution of EO to biodiversity monitoring carried out in the context of the biodiversity deep dive of the KCEO.

EO derived products can provide evidence to monitor progress towards the 16 targets of the BDS helping to assess specific sub-targets and indicators, and it can provide as well data supporting the monitoring of several targets included in the European Commission proposal for a Nature Restoration Law (NRL)[31], a key element of the EU Biodiversity Strategy.

[31] https://environment.ec.europa.eu/system/files/2022-06/Proposal%20for%20a%20Regulation%20on%20nature%20restoration.pdf

Table 4. EU Biodiversity Strategy targets and corresponding indicators already published in the KCBD dashboard (green), that will be soon integrated in the dashboard (orange), or that have been proposed to the EU Biodiversity Platform but not endorsed yet (red). For the rest of the targets, candidate indicators have been identified by the KCBD coordination team based on inputs from EEA, ESTAT and JRC. They are still to be evaluated, hence they are not detailed in this table.

Targets	Indicators (provider)
Target 1 - Legally protect a minimum of 30% of the EU's land area and a minimum of 30% of the EU's sea area, and integrate ecological corridors, as part of a true Trans-European Nature Network	- Terrestrial protected area coverage (EEA) - N2000 terrestrial protected area coverage (EEA) - Nationally designated terrestrial protected area coverage (EEA) - Marine protected area coverage (EEA) - N2000 marine protected area coverage (EEA) - Nationally designated marine protected area coverage (EEA)
Target 4 - Legally binding EU nature restoration targets to be proposed in 2021, subject to an impact assessment. By 2030, significant areas of degraded and carbon-rich ecosystems are restored; habitats and species show no deterioration in conservation trends and status; and at least 30% reach favourable conservation status or at least show a positive trend.	- Common bird index by type of species (Eurostat)
Target 5 - The decline in pollinators is reversed	- Grassland butterfly index (Eurostat)
Target 6 - The risk and use of chemical pesticides is reduced by 50%, and the use of more hazardous pesticides is reduced by 50%	- Use of more hazardous pesticides (Eurostat) - Use and risk of chemical pesticides (Eurostat)
Target 8 - At least 25% of agricultural land is under organic farming management, and the uptake of agro-ecological practices is significantly increased	- Area under organic farming (Eurostat)
Target 9 - Three billion additional trees are planted in the EU, in full respect of ecological principles	- Number of trees planted in the EU as part of the 3 billion Trees Pledge (EEA)

6.1.3 Value chain analysis and EO technical requirements

In what follows, the results of the analysis of EO contribution to the assessment of indicators to monitor targets and sub-targets of the BDS are summarised. The analytical results with the full list of candidate indicators examined and the related potential EO contribution is provided as a separate MS-Excel file, Annex 3 of this report.

Indicators already implemented in KCBD dashboard, as well as all indicators shortlisted as potential candidates at the time of writing were considered. Furthermore, a few additional new indicators that could potentially be monitored through EO products, including some specifically referring to the targets set in the proposal of a Nature Restoration Law, were identified.

The analysis had the following objectives:

a) identification of EO products which could be used to support the monitoring of the EU Biodiversity Strategy for 2030 based on the existing list of candidate indicators;
b) proposal of additional new indicators that could be derived from existing EO products and that could be added to the existing list of candidate indicators;
c) assessment of the EO products identified in points a) and b) above, with respect to whether they would enable the estimation of the indicator or just contribute to the same estimation, hence providing partial input. In some cases, EO products were identified that would not provide input useful to estimate or support the estimation of an indicator but rather to further characterise it;
d) assessment of the level of match of the identified EO products with the requirement for the estimation of the indicator (hereafter referred to as "user requirements"). The match was assessed mostly in terms of temporal and spatial resolution requirements.

Since for a given indicator existing EO products could be relevant either for its estimation or for contributing to its estimation or for providing additional information regarding the indicator/target of the BDS, in summary there could be:

- EO products enabling the estimation of the indicator, which can be used directly to calculate its value. This is for example the case of Corine Land Cover (CLC) dataset, when used to estimate the indicator "land cover and change 2000-2018";
- EO products contributing to the estimation of the indicator, which must be combined with other datasets to estimate the indicator. This is for example the case of the EFFIS burned area product[32], which may contribute to the estimation of the indicator "% of habitats deteriorated by fire disturbances" when combined with habitat maps;
- EO products providing additional information which are not useful to calculate the indicator but can provide additional relevant information related to the same indicator or target. This is for example the case of the CLMS product N2K[33] with respect to the indicator "Terrestrial protected area coverage" linked to sub-target "Legally protect a minimum of 30% of the EU's land area". The indicator is calculated from the layer of the official boundaries of protected areas, however N2K can provide relevant detailed land use / land cover information on those areas.

Technical requirements for the identified satellite EO products (mainly temporal and spatial resolution) were in the first place derived considering the technical specifications of the 20 top ranking remote sensing biodiversity products identified in the paper by Skidmore et al. (2021) discussed in Chapter 2. These were mapped against the BDS indicators to see which products could be used to monitor the targets set in the strategy and also to identify potential new candidate indicators from satellite EO.

For the selected EO products that were not in the priority list of products identified by Skidmore et al. (2021), technical requirements were derived from scientific literature and other sources.

6.1.4 Fitness for purpose of EO products

It is important to recall that the assessment of fitness for purpose discussed here is focused on the technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products, were not considered since they would require to be assessed extensive analysis which are beyond the scope of the deep dive.

In summary the following can result from the appraisal of user requirements against EO products:

- Match: the temporal and spatial resolutions of the product match the ones defined by user requirements;
- Partial Match: either the temporal or the spatial resolution of the product matches the values defined by user requirements;
- No Match: neither the temporal nor the spatial resolution of the product matches the values defined by the user requirements;
- Not Available: no EO product has been identified the estimate or support the estimation of the indicator.

In total 78 indicators were considered in relation to the 16 targets of the EU Biodiversity Strategy, namely:

- 10 indicators already implemented in the KCBD dashboard;
- 53 candidate indicators;
- 15 new suggested indicators.

No satellite EO product resulted applicable/available for 36 indicators out of 78 (46%) (see Figure 8). In 4 cases (5%), EO products could enable the direct estimation of the indicator, while for 22 indicators (28%) EO products could support the estimation if complemented with other datasets. In 16 cases (21%) EO products identified would not help to estimate the indicator but were considered useful to provide additional information related to the same indicator.

[32] https://effis.jrc.ec.europa.eu
[33] https://land.copernicus.eu/local/natura

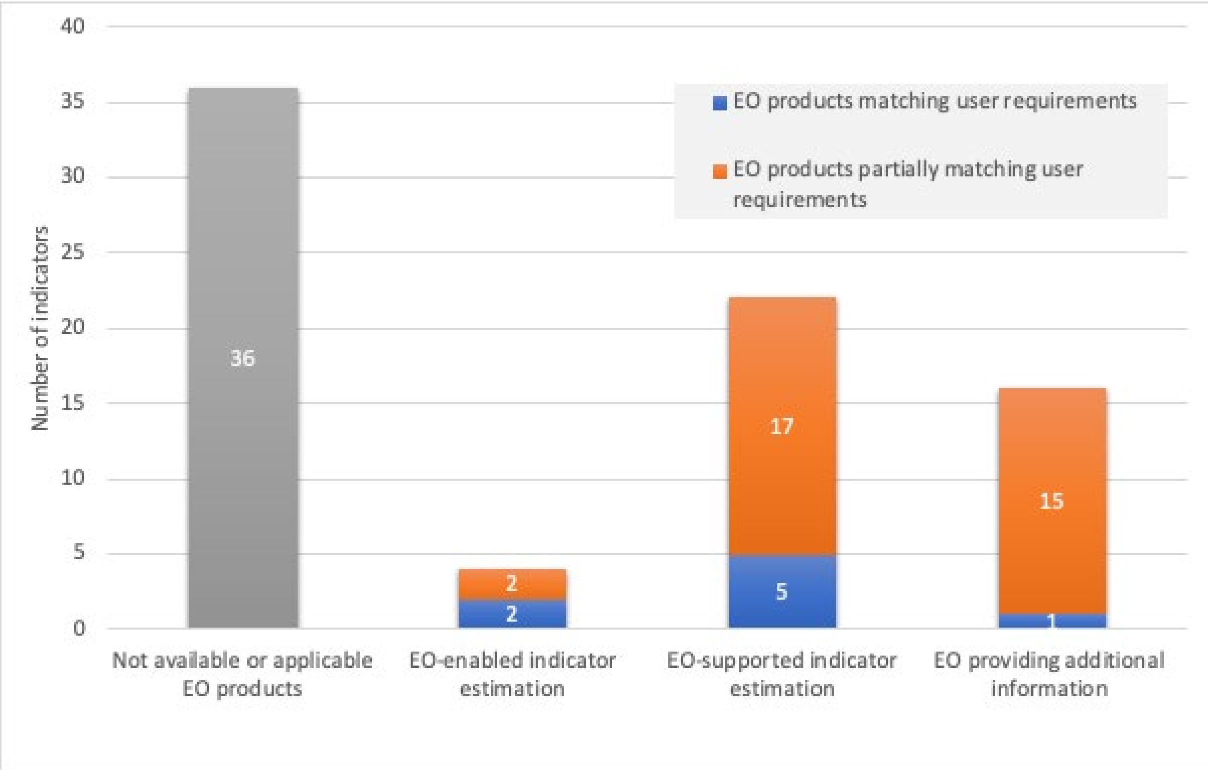


Figure 8. Number of indicators that could be potentially estimated or partially estimated with EO

In terms of matching user requirements, in 8 cases EO products were found matching both temporal and spatial resolution, while in 34 cases they matched partially the requirements, failing to satisfy either temporal or spatial resolution specifications.

The majority of the EO products identified that could support the estimation of indicators proposed for the BDS are from the CLMS and CMEMS Services. When the match between the product and the user requirements is only partial, in most cases what needs to be improved is the temporal resolution of the product. This is because in most cases the BDS indicators should be monitored on a yearly basis, hence EO products should be released with yearly frequency.

In what follows, satellite EO products found more relevant for BDS monitoring are briefly recalled, further descriptions and specifications are provided in Annex 4. The full list of BDS indicators and EO products assessed is given in a separate file as Annex 3 of this report, Table 5 on page 37 contains a summary of BDS Targets and main EO products.

The CLMS CLC+ Backbone (BB)[34] provides a European wall-to wall map of 11 basic land cover classes with 10m spatial resolution. It is available for the reference year 2018, soon the year 2021 should be released and thereafter the updates will be every 2 years. The product could be used to support the estimation of proposed indicators related to Target 1 such as connectivity/fragmentation, Landscape Mosaic and other indicators from the NaturaConnect project[35]. Equally, this product could be used to provide additional information on some of the indicators related to Target 2. Regarding Target 4, the CLC+ BB can enable the estimation of the proposed indicator on land cover change statistics, representing a partial match with the requirements because of the temporal resolution.

[34] https://land.copernicus.eu/pan-european/clc-plus/clc-backbone
[35] https://naturaconnect.eu/

The CLMS N2K product[36] can provide additional information on Targets 1 and 2, aiming to assess whether Natura 2000 sites are effectively preserved and whether the decline of certain grassland habitat types is halted. The CLMS N2K product provides land use/land cover maps for 4790 Natura 2000 sites with a MMU of 0.5 ha for the years 2006, 2012 and 2018. Unfortunately, the product does not cover all Natura 2000 sites, update frequency should move to 3 years after 2021.

The CLMS High-Resolution Forest layers[37] are potential source of additional information regarding Targets 2 and 9. These products include both status maps covering 2012, 2015 and 2018 and tree cover change masks covering 2015-2012 and 2018-2015. The specific products of interest are Tree Cover Density (TCD) and Dominant Leaf Type (DLT), mapping all trees independently on whether they are part of what is technically qualified as "forest". The HRL Forest bundle also includes a Forest Type product (FTY), where the forests mapped match the FAO definition (MMU of 0.5 ha and 10% tree cover density threshold. HRL Forest will soon be integrated in the upcoming HRL Vegetated Land Cover Characteristics product suite[38]. Hence, from the 2018 release onwards, update frequency should move to yearly for the main status layers while the change layers and the Forest Type product updates will be maintained every 3 years. The new product suite will also include the former HRL Grassland and a new Crop Type layer, also updated on a yearly basis.

The CLMS High-Resolution Vegetation Phenology and Productivity suite[39] (HR-VPP) can support indicator estimates in relation to Targets 4 and 8. These products are provided at 10m spatial resolution with 10 days expected update frequency and they can inform on the status of vegetation health. In most cases the products from the HR-VPP suite match user needs in terms of spatial and temporal resolutions. This suite, when combined with other information, could be used to support the assessment of the restoration needs per habitat (Target 4) and the percentage change in vegetation productivity (Target 8). Future updates of the HR-VPP should include mapping of vegetation disturbances areas with tree cover and mapping of above ground biomass.

The HRL Imperviousness captures the change of soil sealing, i.e., the substitution of natural land cover with artificial and impervious cover for five reference years (2006, 2009, 2012, 2015, 2018), and it shows the status and change at pan-European extent every 3 years. The 20m, and after 2015 10m, spatial resolution of imperviousness data can support mapping of the soil sealing index proposed for Target 4. From 2018 onwards the HRL Imperviousness status and change layers will be integrated in the new Non Vegetated Land Cover Characteristics (HRL NVLCC) suite[40], This will also include the Built up Area status and change layers, with information on sealed soil in built up areas and a status layer on Permanent Bare Soil and Rock.

Target 7 aims to at least 10% of agricultural area under high-diversity landscape and the candidate indicator for this Target is the share of agricultural area under high diversity landscape features. The HRL Small Woody Features[41] provides information on woody linear structures such as hedgerows, scrubs or tree rows along field boundaries, riparian and roadside vegetation as well as isolated patches of trees and scrubs (between 200 m² and 5000 m² in size) across the EEA39 countries (EEA38 in the future). The product, with a spatial resolution of 5m, has so far been produced for two reference years, i.e., 2015 and 2018, and it will be updated for 2021. Unfortunately, only woody features are mapped within the CLMS. The product partially matches user requirements because of its temporal resolution and it should be complemented with other sources (see Chapter 6.9 for further discussion).

The Global Surface Water Explorer[42] (GSWE) maps location and temporal distribution of water surfaces with 30m spatial resolution with Landsat data with yearly updates starting from 1984. Statistics on the extent and change of those water surfaces can support monitoring Target 11 on restoration of free-flowing rivers.

As regards Target 13 on reducing the losses of nutrients from fertilisers, proposed indicators are mostly referring to ground-based data with the exception of a marine eutrophication indicator that could be assessed exploiting variables in the biogeochemical global ocean analysis and forecast system of CMEMS.

Support to estimate indicators under Target 14 on Urban Greening Plans can derive from the Copernicus Urban Atlas and HRL Forest – Tree Cover Density for the indicator % of urban tree canopy cover in all cities

[36] https://land.copernicus.eu/local/natura
[37] https://land.copernicus.eu/pan-european/high-resolution-layers/forests
[38] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=8630
[39] https://land.copernicus.eu/pan-european/biophysical-parameters/high-resolution-vegetation-phenology-and-productivity
[40] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=12042
[41] https://land.copernicus.eu/pan-european/high-resolution-layers/small-woody-features
[42] https://global-surface-water.appspot.com/

and in towns and suburbs. Further details and discussion regarding monitoring of green urban spaces for this Target and the related Nature Restoration Law proposal are in the use case presented in Chapter 6.3

Regarding Target 15 on marine environment, EUSeaMap[43] from EMODnet provides a broad-scale seabed map of physical habitats using CMEMS ocean currents reanalysis to predict values at the sea floor from a predictive model. EUSeaMap can contribute to estimate some of the proposed indicators such as physical loss and disturbance to seabed, % of seabed restored, European seafloor integrity account. In addition, variables in the biogeochemical global ocean analysis and forecast system of CMEMS can contribute to estimate indicators on Good Environmental Status of marine habitats.

Table 6 provides the overall summary of the satellite EO products that could enable/support the estimation of adopted or proposed indicators to monitor BDS Targets. EO products were also identified that although not directly useful to estimate the indicators, could provide additional related information.

As mentioned earlier, the full list of indicators examined and the related EO products is provided in Annex 3, the description of EO products is in Annex 4. Table 5 below contains a summary of BDS Targets and main EO products assessed,

[43] https://emodnet.ec.europa.eu/en/seabed-habitats

Table 5. Summary of indicators and satellite EO products. In the column "EO products relevance in monitoring" in blue are the products that contribute to the estimation of the indicator or provide additional information with respect to the target or indicator, while in green are the ones that enable the estimation of the indicator. More details on BDS indicators and EO products in Annex 3, full description of products is in Annex 4.

Target	BDS Indicators	Satellite EO products and derived indicators	EO products relevance in monitoring	Match with requirements
1- Legally protect a minimum of 30% of the EU's land area and a minimum of 30% of the EU's sea area, and integrate ecological corridors, as part of a true Trans-European Nature Network.	6 adopted 6 proposed 1 new	CLMS N2K CLMS CLC+ BB CLMS HRL Water & Wetness EMODnet EUSeaMap	additional information indicator estimation indicator estimation additional information	Partial match Partial match Partial match Partial match
2-Strictly protect at least a third of the EU's protected areas, including all remaining EU primary and old-growth forests.	4 proposed	CLMS N2K CLMS CLC+ BB CLMS HRL Forest	additional information additional information additional information	Partial Match Partial Match Partial Match
3-Effectively manage all protected areas, defining clear conservation objectives and measures, and monitoring them appropriately.	2 proposed 1 new	CMEMS Ocean Monitoring indicators	indicator estimation	Partial Match
4-Legally binding EU nature restoration targets to be proposed in 2021, subject to an impact assessment. By 2030, significant areas of degraded and carbon-rich ecosystems are restored. Habitats and species show no deterioration in conservation trends and status; and at least 30% reach favourable conservation status or at least show a positive trend.	1 adopted 8 proposed 8 new	CLMS HR-VPP CLMS HRL CLMS CLC+ BB CLMS HR-VPP and S2GM FAPAR CEMS Burnt Area CGLS Soil Water Index CLMS HR-VPP and S2GM LAI CLMS HRL Imperviousness	indicator estimation indicator estimation indicator estimation indicator estimation indicator estimation additional information indicator estimation indicator estimation	Match Partial Match Partial Match Match Match Partial Match Match Partial Match
5-The decline of pollinators is reversed.	1 adopted 2 proposed	NA	NA	NA
6-The risk and use of chemical pesticides is reduced by 50%, and the use of more hazardous pesticides is reduced by 50%	5 proposed	NA	NA	NA
7-At least 10% of agricultural area is under high-diversity landscape features.	1 proposed	CLMS HRL Small Woody Features	indicator estimation	Partial Match
8-At least 10% of agricultural area is under high-diversity landscape features.	1 adopted 2 new	CLMS FCOVER CLMS HR-VPP	additional information indicator estimation	Partial Match Match
9-Three billion additional trees are planted in the EU, in full respect of ecological principles.	1 adopted	CLMS HRL Forest	additional information	Partial Match

Target	BDS Indicators	Satellite EO products and derived indicators	EO products relevance in monitoring	Match with requirements
10-Significant progress in the remediation of contaminated soil sites.	3 proposed	CLMS Urban Atlas and CLC+ BB	indicator estimation	Partial Match
11-At least 25,000 km of free-flowing rivers are restored.	2 proposed	JRC GSWE CLMS HRL Water and Wetness CLMS CLC+BB	indicator estimation indicator estimation indicator estimation	Match Partial Match Partial Match
12-There is a 50% reduction in the number of Red List species threatened by invasive alien species.	3 proposed	NA	NA	NA
13-The losses of nutrients from fertilisers are reduced by 50%, resulting in the reduction of the use of fertilisers by at least 20%	9 proposed	CMEMS variables in the biogeochemical global ocean analysis and forecast system	indicator estimation	Partial Match
14-Cities with at least 20,000 inhabitants have an ambitious Urban Greening Plan.	1 proposed 2 new	CLMS Urban Atlas CLMS GHSL CLMS HRL Forest – Tree Cover Density	indicator estimation indicator estimation indicator estimation	Partial Match Partial Match Partial Match
15-The negative impacts on sensitive species and habitats, including on the seabed through fishing and extraction activities, are substantially reduced to achieve good environmental status.	7 proposed 2 new	CMEMS variables in the biogeochemical global ocean analysis and forecast system EMODnet EUSeaMap	indicator estimation indicator estimation	Partial Match Partial Match
16- The by-catch of species is eliminated or reduced to a level that allows species recovery and conservation.	1 proposed	NA	NA	NA

6.1.5 Conclusions and recommendations

While the results of this analysis show that there is a huge potential for the use of satellite EO data to monitor the targets of the Biodiversity Strategy 2030, the following remarks can be made:

- A large number of products match only partially the user requirements and in the majority of cases this is due to a mismatch of temporal resolution, with maps being updated once every three or six years, and products not always comparable between releases. Especially when the BDS requires indicators that can track the change in land and sea area status on a yearly basis while most of the product provided by Copernicus are characterized by maps which are currently not being updated with this frequency. Hence, a recommendation resulting from this study is to increase the temporal resolution of products that do not match user requirements; It is worth recalling though that many Copernicus CLMS products are already planned to switch to yearly updates soon.

- Biodiversity monitoring requires long term efforts to establish trends, it is complex because it is about multi-scalar and multi-temporal structures and processes. EO can help in this regard, but in many cases alternative ways to gather data to build indicators have to be explored. Furthermore, the role of spatial resolution and the impact it has on biodiversity metrics should also be considered.

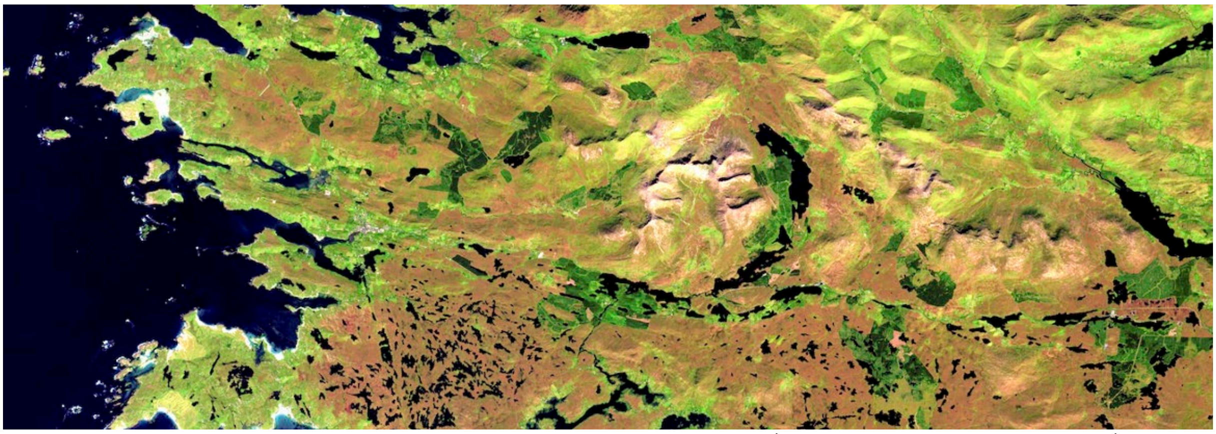
- Integration of satellite data with ground-based observations should be strengthened to improve the products and enhance their use by policy-makers. The current lack of suitable ground-based biodiversity data challenges the potential of satellite EO products in monitoring biodiversity in the European environment. The availability of ground-based and more broadly *in-situ* data is key and would require a concurrent investment in building spatially referenced *in-situ* datasets as ground truth for validation and interpretation, both on land and even more in the marine environment, where additional challenges to monitor biodiversity are encountered.

- Satellite EO can certainly help to monitor some of the Targets set by the BDS, however quality assurance of EO products should always be ensured and their uncertainties provided to reach high level confidences of their uses. It is worth recalling that in the context of the analysis presented in this report, accuracy and quality of the EO products examined has not been assessed. In this respect, publishing training and reference data used for the accuracy assessment of Copernicus products, openly reporting on the quality the products would enhance transparency and reproducibility.

- The integration with global policies, in particular with the mentioned GBF, would ensure consistency in the use of EO products for the tracking of targets related to biodiversity. This may also leverage research efforts for the development of new satellite EO-based products, exploiting the consequent generated synergies. In addition, it will also increase the capacity to monitor the impacts of EU biodiversity policies using available EO products. In this respect there is a key role to play for the KCBD and the biodiversity monitoring system under construction.

- The identification of EO products that are useful for monitoring BDS targets is a first step to improve EO uptake. In this context, an additional effort to cover the 'last mile' would be required, namely the processing of EO products to calculate the required indicator and the delivery of the result to the KCBD in a format fitting the requirements of the BDS monitoring dashboard of KCBD.

6.2 Monitoring key habitats for biodiversity with a focus on wetlands (DG ENV)



Credit: European Union, Copernicus Sentinel-2 imagery

6.2.1 Policy context

Inland waters and freshwater biodiversity constitute a valuable natural resource, in economic, cultural, aesthetic, scientific and educational terms. Wetlands are recognised to contribute to a large set of ecosystem services: flood detention and water storage, nutrients and contaminant retention, carbon fixation and storage, enhancement of offshore fisheries, feeding grounds for river fish, cultural heritage, ecotourism and biodiversity (Verhoeven, 2014).

Wetlands are widely recognised to be key ecosystems for biodiversity, providing habitat and refuge for a multitude of species. Fresh water makes up only 0.01% of the global water and approximately 0.8 % of the Earth's surface, yet this tiny fraction of global water supports at least almost 6% of all described species. Their conservation and management are critical to the interests of all humans, nations and governments (Dudgeon et al., 2006).

These habitats are experiencing declines in biodiversity far greater than those in the most affected terrestrial ecosystems due to overexploitation; water pollution; flow modification; destruction or degradation of habitat; and invasion by exotic species.

Inland wetlands (peatlands and marshes) cover about 2% of the EU land, and more when coastal wetlands are included. Wetlands represent the ecosystem with the worst condition in Europe and all wetlands are protected by the Habitats Directive. There is no evidence that pressures are decreasing or that condition is improving. Additionally, climate changes can trigger a degradation of these habitats. For example, changes in precipitation and rising temperatures can contribute to deteriorating wetlands condition and they impact their capacity to provide key ecosystem services, such as carbon retention and flood regulation (Maes et al., 2020).

Wetland restoration programs exist in The Netherlands (Schut et al., 2010), the U.K., Denmark, Belgium, Austria, Germany and many other European countries, frequently supported by the EU-LIFE program (Buijse et al., 2002; Tockner et al., 1999). Restoration and monitoring measures are often partly funded by the EU, and partly by regional stakeholders and authorities.

The EU legal background for this use case is on certain provisions of the Habitats and Birds Directives (Council Directive 92/43/EEC, and Directive 2009/147/EC respectively). Annex I of the Habitats Directive includes a list of open water and wetland habitats. Many of these habitats are biodiversity rich, some of them are also carbon-rich sites, often highly threatened and in bad conservation status. However, the available information on the conservation status of these habitats tend to be highly aggregated.

Annex I of the Habitats Directive includes 20 freshwater habitats (of which 3 priority habitats), 12 raised bogs and mires and fens (7 priority). Habitats such as 91E0 alluvial forests, and 91F0 Riparian mixed forests are formally classified as forest habitats but may nevertheless also be considered wetlands. Furthermore, the Birds and Habitats Directives require the MS to protect certain species by protecting their habitats, many of these are freshwater or wetland bound species (including many bird species). It is therefore appropriate to assume that the legal protection requirements for aquatic or wetland habitats extends far beyond the list of habitats in Annex I. Hence, in the context of this use case, any habitat type with soil/ground moisture and/or within a certain distance from surface waters is worth looking at.

Article 6 of the Habitats Directive sets the legal provisions for the protection of habitats and species in the Natura 2000 Sites. Article 11 provides that "*Member States shall undertake surveillance of the conservation status of the natural habitats and species referred to in Article 2 with particular regard to priority natural habitat types and priority species*" On the basis of these monitoring data, Article 17 of the Directive requires that MS report every 6 years on the status and trends of the protected species and habitats.

The outcome of this use case assessment may result in technical input to further research and development efforts that could potentially involve a community of experts, as provided in Article 18(1) "*Member States and the Commission shall encourage the necessary research and scientific work having regard to the objectives set out in Article 2 and the obligation referred to in Article 11. They shall exchange information for the purposes of proper coordination of research carried out at Member State and at Community level*."

6.2.2 Description of the use case

Humid habitats can be found in different types of terrestrial ecosystems such as forests, peatlands or grasslands. As working definition[44] (and first approximation) to frame the assessment in this use case, wetlands are those sites which are more humid/wet compared to the average land in the region.

The aim of this use case is to elaborate recommendations for the development of an information system supporting the monitoring of surface water and humid areas (both coastal such as salt marshes, inland humid areas, as well as transitional humid areas), considering scientific (remote sensing, biological) and technical (e.g., processing capacity) aspects.

Important elements include assessing the feasibility of: (1) creating EU level detailed land cover / land use in Natura 2000 sites, coupled with surface water and soil moisture indicators in order to delineate humid habitats and their changes; (2) creating updated information every year, and possibly even seasonal assessments; (3) data available to users (e.g., national authorities, experts, NGOs) providing a basis for more detailed analysis (e.g., using local information).

The web-based platform could be similar to the EU Grasslands Watch[45]. It would be accessible to users for viewing the data and possibly also editing. Ideally, MS would have the possibility to review/update/integrate Natura 2000 Site data directly through the platform, moving from a website provided by a community of practitioners to a more interactive platform where experts would contribute with local information, integrating and validating the content.

Key elements that the information system should include:

- European view showing hot spots of changes/degradation
- Local details, including evolution over time (yearly update would be ideal)
- Allow experts to contribute with local information/provide, local correction to the information

The information may be used to create a compliance promotion tool as MS need to act in compliance with the Directives. For instance, according to Article 6 of the Habitats Directive, MS need to avoid any degradation of habitats and habitats of species in their Natura 2000 sites. In order to do this, there is a need to implement accurate mapping tools, ensuring, *inter alia*, the compliance promotion. Ideally, such tool would be able to show at EU level the losses of surface water and humid areas in time, as well as where the hotspots of losses are located. The availability of this type of information would allow a direct and clear communication to the society and to the MS/local authorities to act against degradation.

Currently, the only available data in this respect are those provided by the MS under article 12 of the Birds Directive and under art 17 of the Habitats Directive. The only spatial data provided in this reporting are presence/absence data with a coarse grid (10x10 km^2 gridded data). This reporting provides a basic information on geographical ranges and identifies which habitats are increasing and/or improving at national scale, but does not provide any higher resolution spatial information. For a compliance promotion tool focused on the Natura 2000 sites, it would be necessary to have much higher resolution data showing the location

[44] Several definitions of wetlands exist. The Ramsar Convention on Wetlands (https://www.ramsar.org/) uses a very broad definition of wetlands that includes "all lakes and rivers, underground aquifers, swamps and marshes, wet grasslands, peatlands, oases, estuaries, deltas and tidal flats, mangroves and other coastal areas, coral reefs, and all human-made sites such as fish ponds, rice paddies, reservoirs and salt pans". For this use case a working definition to drive the EO-based assessment was needed.

[45] https://ec.europa.eu/eu-grassland-watch/

and extent of different types of habitats, as well as their evolution over time. A need for such data is also included in the recently published Commission proposal for a Nature Restoration Law.

6.2.3 Value chain analysis and EO technical requirements

For wetland monitoring the use of satellite EO tools is essential (Jantke et al., 2013). A long history of satellite-based attempts for mapping wetlands exists. The most promising results are obtained with the integration of radar and optical imagery, and with the use of time series analysis (Ozesmi & Bauer, 2002; Alsdorf et al., 2007) and topographic information.

The application requested by DG ENV should identify and map the location and extent of humid areas in the EU, characterise the ecosystems and habitat types, reconstruct to the possible extent their past evolution and, most importantly, monitor their change over time. For such a purpose, existing datasets should be integrated maximising the added value of different information sources.

More specifically, high-resolution land cover layers should be integrated together with the mapping of surface water and soil moisture at medium resolution (with a target resolution of 100 m) which can be obtained using EO data from visible or microwave sensors, eventually integrated by other geospatial layers (Schleupner, 2010) or Airborne Laser Scanning (ALS) (Shadaydeh et al., 2017). Ground-based observations networks are key to support the assessment.

The starting point for this use case is the definition of wetlands based on objective criteria. Maes et al. (2020) already underlined this element discussing the different definitions of wetland currently adopted by policy and technical/mapping tools in the EU.

DG ENV considers important to augment the detail of the system of nomenclature, following the Annex I of the Habitats Directive, classifying “humid areas” on the basis of land cover and type of wetland (for example being able to identify “alluvial forests”, the habitat type 91E0 of the Habitat Directive). This could be achieved integrating multiple data sources providing bio-physical properties of interest, information on vegetation condition, phenology and historical changes. While ground-based data are essential, the analysis of long time series of optical satellite imagery (Landsat/Sentinel-2) can be the basis for reconstructing phenology trajectories and tracking ecosystem trends.

Overlapping land cover maps with surface water occurrence and soil moisture data may enable the identification of specific Annex I habitat types. However, there is a need to understand whether and to what extent these assessments are possible, what the accuracy of the generated information would be, how long going back in time is possible for reliable analysis of trends, which update frequency and spatial resolution could be attained. For example, currently there are no existing soil moisture products with medium to high spatial resolution, however the literature shows promising machine learning techniques that may achieve those target resolutions using ground-based soil moisture observations networks (Greifeneder et al. 2020; Batchu et al. 2022).

For a compliance monitoring tool, a sufficient level of detail and accuracy should be reached. Currently, the ideal requirements for such habitat maps are a good geometric and thematic accuracy (minimum overall accuracy of 85%) and pixel level uncertainty, high spatial resolution for habit mapping (10m), medium resolution for soil moisture (100 m).

Regarding the temporal resolution, it is important to underline that wetland monitoring and assessments need to take into consideration both seasonal and yearly changes, due to the highly dynamic nature of wetlands. In addition, reference baseline assessments are needed, feasible on the basis of the analysis of historical remotely sensed data. The ideal situation would be to be able to map the status of wetland at the time of designation of the specific Natura 2000.

Two aspects are deemed very important: i) Soil moisture anomaly maps at the wetland scale (around 100 m) should be put into the broader context of regional soil moisture changes; ii) The assessment of surface water and soil moisture changes should be primarily based on observations, either from remote sensing or ground-based or both.

Still, in combination with EO, processed-based and conceptual modelling may be useful to better understand humid areas formation, maintenance, restoration trajectories e.g., understanding the impact of changing climate on specific habitats could enable the development of predictive scenarios (Pierdicca et al., 2015). Keeping in mind though that deterioration most of the times is caused by human activity such as drainage.

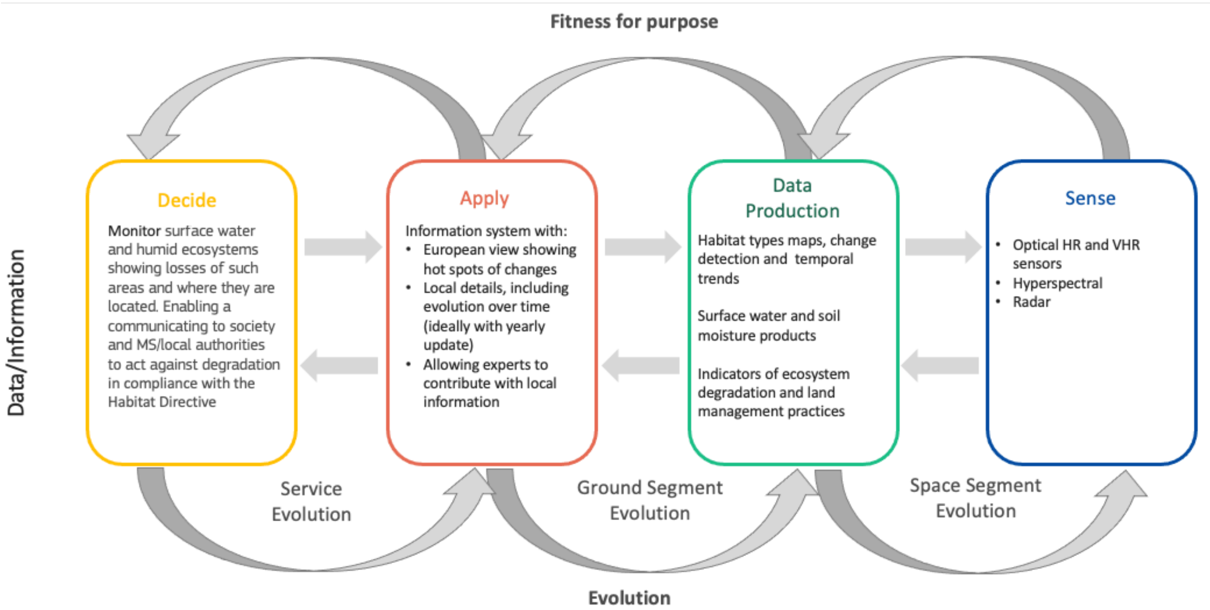


Figure 9. EO value chain of the use case Monitoring key habitats for biodiversity with a focus on wetlands

6.2.4 Fitness for purpose of existing EO products and services

The Copernicus Land Monitoring Service (CLMS) provides several potential products for this use case. Further descriptions and specifications for these products are provided in Annex 4.

It is important to recall that the assessment of fitness for purpose discussed here is focused on the technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products, could not be considered and no recommendations could be made in this respect,

Copernicus Riparian Zones

Riparian Zones[46] is a product of the Local Component of CLMS generated from VHR satellite imagery in the riparian zones of Europe. It consists in land use/land cover maps of riparian zones of selected rivers with 55 distinct thematic classes following the MAES typology of ecosystems (Maes et al., 2020), with a Minimum Mapping Unit (MMU) of 0.5 ha and a Minimum Mapping Width (MMW) of 10m. These maps are available only for the reference years 2012 and 2018 (Figure 10). The spatial resolution and the thematic detail are potentially of interest for the use case, unfortunately the spatial coverage (it does not consider isolated or groundwater-fed wetlands), the time resolution, and the update frequency (2012 and 2018, i.e. every 6 years) are not matching the user requirements.

[46] https://land.copernicus.eu/local/riparian-zones/view

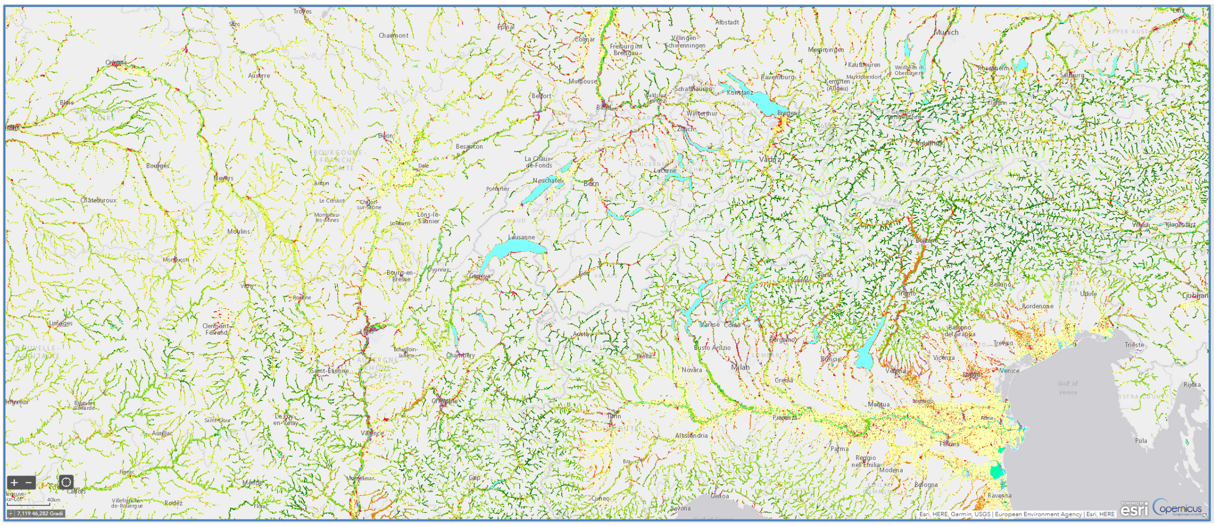


Figure 10. Example of the Riparian Zones product of CLMS for 2018.

Copernicus N2K

N2K[47] is a product of the Local Component of CLMS. The aim of N2K is to assess whether Natura 2000 sites are effectively preserved and whether the decline of certain grassland habitat types is halted. The CLMS N2K product provides land use/land cover maps for 4790 Natura 2000 sites with a MMU of 0.5 ha for the years 2006, 2012 and 2018. The product is of potential interest for the use case, even though not all Natura 2000 sites are mapped, and the frequency of update so far (6 years) is not ideal. The update frequency will move to every 3 years from 2021 onwards.

CORINE Land Cover (CLC)

The CORINE Land Cover (CLC) provides the longest running time series within the CLMS portfolio. It was first created in 1990 and has been updated every 6 years from 2000 onwards. From 2000 onwards it includes change mapping between releases, in a process that entails the correction of possible mistakes spotted in the previous update. The CORINE system of nomenclature reserves the class "4" to wetlands distinguished into a total of 5 classes of inland wetlands (inland marches, peatbogs) and coastal wetlands (salt marches, salines, intertidal flats). All land use/land cover maps developed at different scale levels and with different techniques can be used as a source of information. The Minimum Mapping Unit (25 ha) and the low update frequency (6 years) of CLC are strong limitations for its application in this use case.

Copernicus HRL Water & Wetness

The water & wetness product[48] is a High-Resolution Layer (HRL) of the Pan-European Component of CLMS, mapping the occurrence of water and wet surfaces with 10m resolution on a pan-European scale using four classes: (1) permanent water, (2) temporary water, (3) permanent wetness and (4) temporary wetness (Figure 11).

The product, based on multi-temporal and multi-seasonal optical high-resolution satellite imagery and on radar data (Sentinel-1), Currently it is only available for the years 2015 and 2018 and there have not been new releases since. This product is planned to be moved to the upcoming High Resolution Water, Snow and Ice (HR WSI)[49], which will merge the current HR Snow and Ice products with the former HRL Water and Wetness, while introducing the continuous monitoring of water occurrence. Continuity will be given to permanent water and temporary water classes but wetness classes will be discontinued.

Since the Water and Wetness layers are proving information only for two reference years the product does not meet the requirements. The exact, quantitative definition of the categories in the product is unclear.

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47 https://land.copernicus.eu/local/natura
48 https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness
49 https://etendering.ted.europa.eu/cft/cft-display.html?cftId=13505

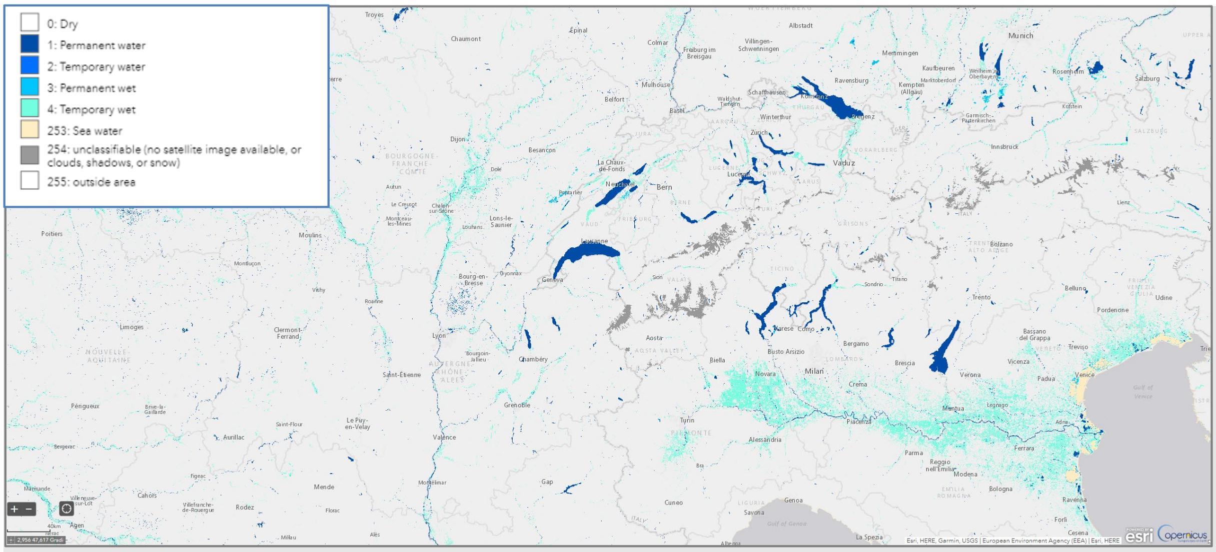

Figure 11. Example from the High Resolution Layer of CLMS – Water & Wetness.

Extended wetland ecosystem layer

The dataset Extended wetland ecosystem[50] is a product derived from the Corine Land Cover (CLC), reclassified into 19 wetland classes and 1 "no wetland" on the basis of ancillary spatial layers ("Water and Wetness" and "Riparian Zone Layer" Copernicus products, the "Ecosystem types of Europe" v3.1 and "The Global Spatial Water Explorer" datasets). It was first developed from CLC 2012[51] and then updated with CLC 2018 data.

Besides the traditional types of inland and coastal wetlands (i.e. marshes, rivers, lakes, lagoons, estuaries), the layer also covers forest, grassland and agricultural ecosystems which are seasonally or permanently flooded (i.e. riparian forests, wet grasslands, rice fields) and are therefore classified as wetlands in line with the Ramsar Convention (1971) definition and typologies. This wetland reclassification and mapping considers the hydro-ecological characteristics of habitats and provides information about the real spatial extent and distribution of varied wetland habitats with a spatial resolution of 100 m.

The product is of interest for the thematic detail on wetlands types it provides and the information on their spatial extent. Currently two years are available (2012 and 2018) and there is no provision regarding future updates, which limits the analysis of trends in land dynamics as requested in this use case. The spatial resolution should be improved to match the user requirement. Unfortunately, the algorithm and processing workflow are not fully documented.

[50] https://www.eea.europa.eu/data-and-maps/data/extended-wetland-ecosystem-layer
[51] https://sdi.eea.europa.eu/catalogue/idp/api/records/5fc1b45a-715a-466e-b576-1be0ced40e2a

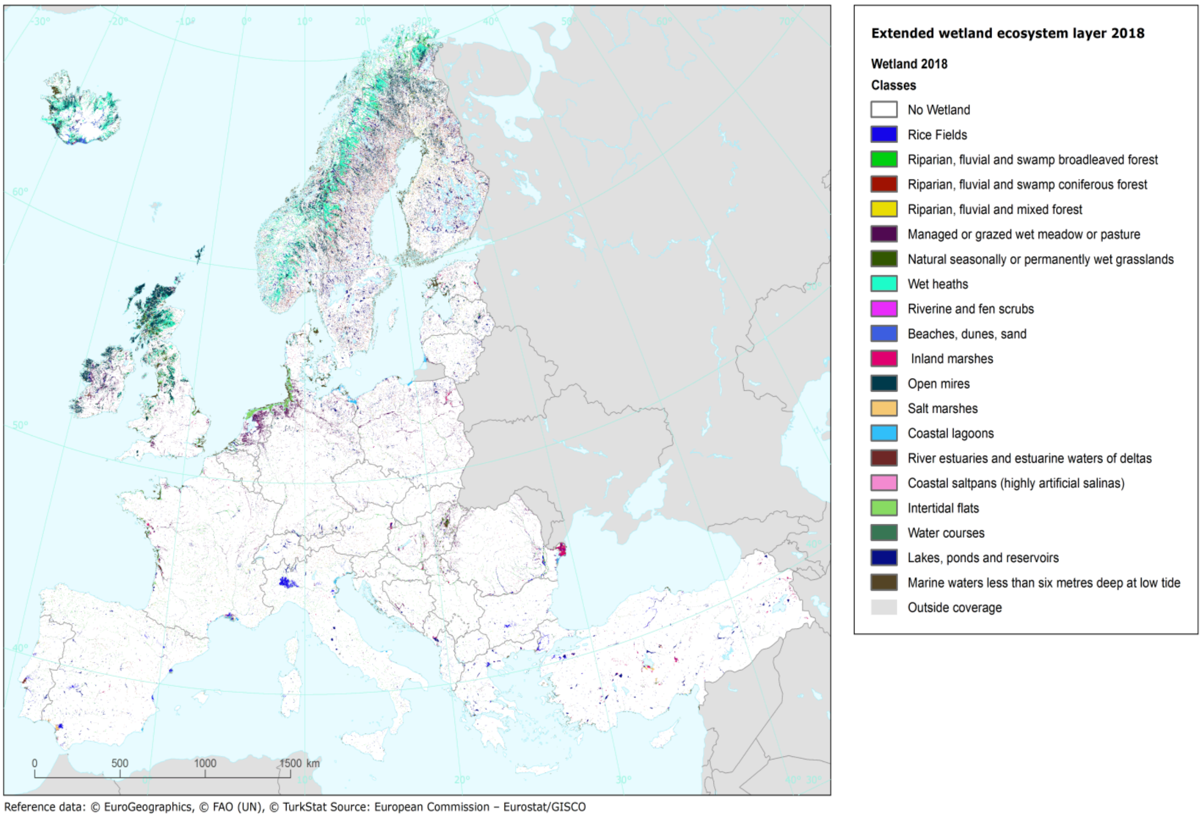

Figure 12. Extended wetland ecosystem layer 2018.

COP4N2K Project

COP4N2K (Copernicus for Natura 2000)[52] is a project to develop a prototype service for monitoring Natura 2000 sites with Copernicus data, with a specific focus on natural/semi natural grasslands listed in Annex I of Habitat Directive. Shortcomings in this prototype for future use are the following. Only a subset of Natura 2000 sites is selected where grasslands are sufficiently abundant (roughly 3800 sites), the delineation of the management units is not always matching current site boundaries as it is based on images of 2018. Some of these units are very large patches of lands, with many different land parcels and different habitat types inside, the changes of which over time (e.g., at individual land parcel level) are causing erratic fluctuations inthe representation of the whole patch. Ground-truthing data for training algorithm/validating products (for both land use land cover and for practices such as ploughing/mowing) are also lacking.

Despite the limitations in the products, the web application developed after this project, the "EU Grassland Watch" [53], is an interesting tool to consider for the functionalities offered rather than for the topic addressed. EU Grassland Watch grants access to the information to end users (which includes national authorities) in a representation that is close enough to their actual needs (linked to the application of the Habitats directive). The point is to take these users directly to the data interpretation rather requiring them to interpret EO-based products, which requires technical and scientific expertise.

Global Surface Water Explorer

The JRC/Google product Global Surface Water Explorer (GSWE)[54] provides unique temporal information regarding surface water: long historical records, monthly synthesis, historical and annual recurrence.

52 http://www.cop4n2k.eu/
53 https://ec.europa.eu/eu-grassland-watch/
54 https://global-surface-water.appspot.com/

The timeline (since 1985 until 2021) and frequency (monthly synthesis) enable assessments regarding historical occurrences, seasonality (when a site is filled during the year), water regime (permanent, semi-permanent) and their changes over time. The product is based on Landsat data (30m resolution) and it is provided by JRC and Google (EC and Google are partnering to provide the data for UN SDG 6.6.1 "Change in the extent of water-related ecosystems over time").

GSWE could potentially contribute to the mapping of wetlands ecosystems and their monitoring over time covering surface water assessments. However, there would still be a need to complement the monthly surface water data with data capturing soil moisture. Also, it has to be noted that, being only based on optical imagery, the number of valid observations suffers from cloud cover and soil freezing events, in particular at high latitude.

WISE Water Framework Directive Service Map Discovery

In the context of the Water Framework Directive, EEA has produced a geospatial database of surface water objects[55] which could be explored to understand the potential integration with Copernicus layers. The WISE WFD database contains data from the 1st and 2nd River Basin Management Plans reported by EU Members States according to article 13 of the Water Framework Directive (WFD).

International Soil Moisture Network

The International Soil Moisture Network[56] is an international cooperation to establish and maintain a global ground-based soil moisture database (Figure 13). This dataset is relevant for validating and improving the assessments of global satellite products, and land surface, climate, and hydrological models.

Figure 13. Location of the ground measures available in Europe from the International Soil Moisture Network

In addition to the data from the Soil Moisture Network, other ground-based observations shall be considered from existing networks to integrate and complement the assessments. The level of detail requested can hardly be reached with satellite EO data alone.

55 https://www.eea.europa.eu/data-and-maps/dashboards/wise-wfd

56 https://ismn.earth/en/

6.2.5 Conclusions and recommendations

A reference definition of wetlands based on generalised, objective and measurable criteria applicable for this use case is not available. To frame an EO-based assessment of wetlands, "humid areas" should be classified on the basis of land cover type and soil moisture regimes. Hence, identifying and mapping the location and extent of wetlands in the EU as requested, implies that the joint analysis of relevant datasets and products regarding soil moisture, surface water and ecosystem typology would be part of the assessment.

The basic building blocks ideally needed are a time series with medium resolution layers of soil moisture and surface water occurrence, seasonality and change over time coupled with a high-resolution layer of habitats, with typology consistent with Annex I of the Habitat Directive. The application should be able to disentangle meteorological anomalies from local pressures due to site management failures.

A dedicated study is suggested to understand the feasibility of this approach. The challenging objectives of this use case require the integration of different datasets, ground-based data, hydrological modelling, local knowledge, multi-sourced remote sensing (multi-temporal, optical and radar) data.

None of the products assessed is fully matching the requirements, either thematically or for lacking the requested temporal or spatial resolutions. The Riparian Zones layer methodology is promising and may be considered as a starting point for extending the exercise to non-riparian wetlands. The Extended wetland ecosystem layer is thematically interesting, however does not match the spatial and temporal requirements. Furthermore, as for the Water & wetness HRL, quantitative criteria and thresholds to qualify humid areas are not explicit, thus making the products less interesting for this use case.

Coupled with the thematic assessment, the most important aspect to consider is time, with respect to the reconstruction of the historical series starting from a given baseline, the assessment of the seasonality aspects and the monitoring of temporal trends of wetlands evolution.

6.3 Monitoring of Urban Green Spaces (DG ENV)

Credit: European Union, Copernicus Sentinel-2 imagery

6.3.1 Policy context

The EU Biodiversity Strategy for 2030 encompasses a new comprehensive program for nature restoration including the recent European Commission proposal for a Nature Restoration Law (NRL)[57] with legally binding targets for a wide range of ecosystems[58]. The overarching objectives of the NRL are: (a) by 2030, restoration measures will cover 20% of EU lands and seas, (b) by 2050, measures shall be in place for all ecosystems that are considered in need of restoration actions. The NRL goes beyond the habitats listed in the Habitats Directive Annex I and II (Council Directive 92/43/EEC) for which definitions, baselines, targets and monitoring are available. For the other ecosystems, for which data and monitoring mechanisms are not yet fully developed, a process must be established for developing an EU-wide methodology for assessing their conditions, allowing for a later setting of additional specific baselines and targets.

Urbanization is often considered a threat to biodiversity: 12% of all species assessed for the IUCN Red List and 18% of all threatened species are impacted by urbanization. Key threats to urban biodiversity are in particular the high rates of habitat conversion and fragmentation, local pollution and eutrophication, traffic, and introductions of invasive alien species (Simkin et al., 2022).

Valuation and assessment of ecosystem services produced by green urban spaces (including natural disaster risk reduction and control, floods, heat island effects, cooling, recreation, water, and air filtration) is of crucial importance in order to justify and legitimise strategies for urban sustainability. It is argued that valuation of their worth to society must start from the appraisal of the needs, wants and beliefs of the individuals composing the society. Public involvement, citizens' participation and a qualitative appraisal of their needs and interests are believed to help urban communities to articulate commonly shared values which, in turn, can serve as reference criteria for local planners to envision more sustainable city strategies.

Urban ecosystems are recognised as crucially important in the Biodiversity Strategy for 2030 as well as in the MAES assessment (Maes et al. 2020). Urban green spaces provide important habitats for biodiversity, in particular plants, birds, and insects, including pollinators. They also provide vital ecosystem services, including natural disaster risk reduction and control (e.g., floods, heat island effects), cooling, recreation, water, and air filtration, as well as linked climate change mitigation and adaptation.

Specific targets for restoration of urban ecosystems have been included in the proposal for the NRL in particular: (1) no net loss of urban green space, and of urban tree canopy cover by 2030, compared to 2021, in all cities and in towns and suburbs; (2) increase, compared to 2021, in the total national area of urban green space in cities and in towns and suburbs of at least 3 % by 2040, and at least 5 % by 2050; (3) minimum of 10 % urban tree canopy cover in all cities and in towns and suburbs by 2050; (4) a net gain of urban green space that is integrated into existing and new buildings and infrastructure developments, including through renovations and renewals, in all cities and in towns and suburbs.

57 https://environment.ec.europa.eu/system/files/2022-06/Proposal%20for%20a%20Regulation%20on%20nature%20restoration.pdf
58 https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm

Local Area Units (LAUs) are the low-level administrative divisions within Member States (MS), ranked below a province, region, or state. In line with the Methodological Manual on Territorial Typologies, (EUROSTAT, 2018), LAUs are classified in 'Cities', 'Towns and suburbs', and 'Rural areas'. 'Cities' when at least 50 % of the population lives in one or more urban centres, 'Towns and suburbs' when less than 50 % of the population lives in an urban centre, but at least 50 % of the population lives in an urban cluster.

The entire territory of all LAUs classified as 'cities' and as 'towns and suburbs' are considered as urban areas in the context of the NRL. Hence, urban areas are not only the built-up 'grey' fabric, but include the surrounding peri-urban areas making up the municipality.

It is worth recalling that in MAES, the concept of 'functional urban area' is used, which does not correspond to the same 'urban area' concept adopted in the NRL. Functional urban areas include LAUs classified as cities, along with those LAUs classified as 'towns and suburbs' where a majority of the inhabitants commute to the city, and any LAUs caught between them (even if rural).

6.3.2 Description of the use case

The objective this use case adresses is to map quantity and quality of urban green spaces and their evolution in time maximising the use of existing satellite EO information.

What are needed are accurate and spatially detailed map of both private and public urban green spaces in all LAUs classified as Cities or Towns and suburbs in a baseline year and in the following years, in order to measure and track progress of the urban greening targets.

A wide variety of "green" spaces should be mapped. In this context, there is the need to also define and discriminate different types of green areas (an official categorisation still not adopted), including all urban green spaces and vegetation, public and private, including parks and gardens, all types of urban forest, and tree canopy cover (down to tree lined streets level), urban farms, meadows hedges, types of grass and vegetation cover.

Also, with a strong emphasis on 'greening' of new development and renovations, there is a need to detect (different types of) green roofs and green walls (if the latter is possible), permeable 'greener' parking spaces and indeed any green infrastructure. Ideally, some form of hierarchy might be attributed to these different types of urban green in terms of their biodiversity and value of the ecosystem service.

Tracking the evolution of urban green areas also implies assessing the connectivity of urban ecosystems such as urban corridors and urban forests.

The ideal output would be easily accessible and digestible datasets, e.g. through platform where local planners, city authorities, and all interested stakeholders which need simple tools harmonised across data sets, could access for viewing and mapping their local green spaces.

6.3.3 Value chain analysis and EO technical requirements

Mapping urban green spaces with the accuracy and the thematic detail required, implies the use of very high-resolution (VHR) EO data, with spatial resolution down to 2.5 m. For efficiency and containment of acquisition costs, VHR data could be limited to the core area of LAUs i.e., the built-up 'grey' fabric. The surrounding peri-urban areas making up the rest of the municipality could be assessed by lower resolution imagery (10m).

Thus, the assessment would follow a multistep approach: i) delineation of Cities and Towns and suburbs, ii) broad mapping of green spaces with 10m resolution and delineation of core areas, iii) mapping of green spaces in core areas with VHR imagery. In EU27 as of 2020, out of total 95,217 LAUs, 2,449 are classified as Cities, 14,209 are classified as Towns and suburbs (the remaining are Rural)[59].

In terms of temporal resolution, the assessment should be ideally carried out at least every three years, preferably annually. Since NRL targets are defined with reference to 2021, this would be the baseline year. The need to assess greening dynamics may imply multiple season acquisitions.

[59] https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/degurba

In the NRL 'green urban spaces' refers to all urban ecosystems: forests, shrubs, grasslands, moors and heathlands, sparsely vegetated areas.

Such spatial data could be then the basis for applying a number of possible technical solutions for estimating ecosystem services, including relevant indicators of biodiversity.

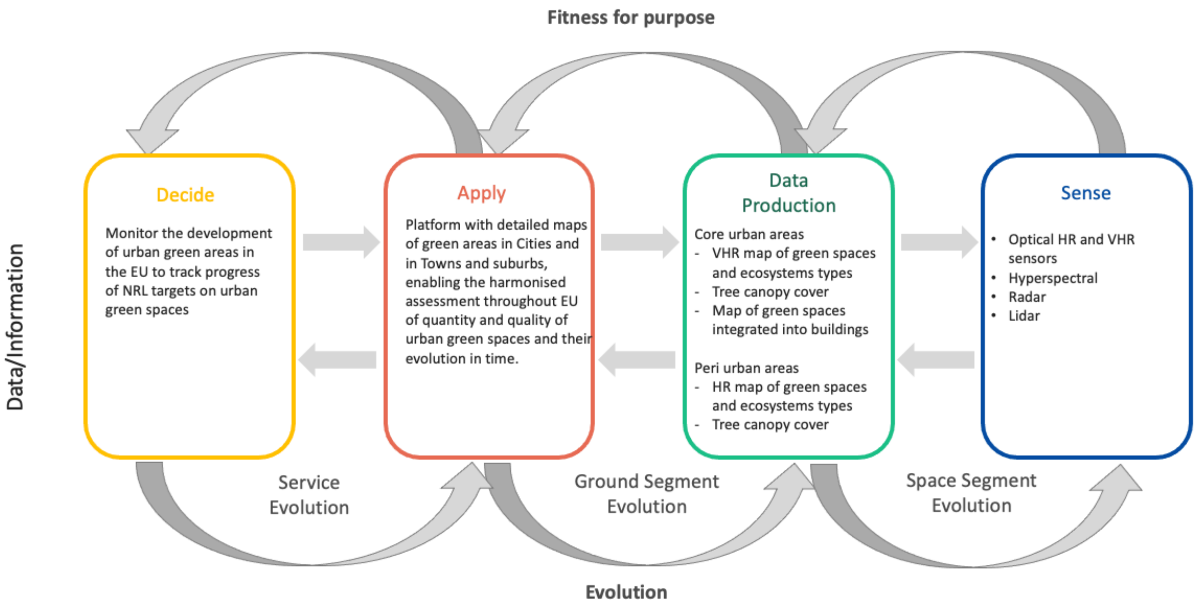

Figure 14. EO value chain of the use case Monitoring of Urban Green Spaces

6.3.4 Fitness for purpose of existing EO products and services

What follows examines a few datasets that could contribute to the assessment. Further descriptions and specifications of Copernicus products mentioned are provided in Annex 4.

It is important to recall that the assessment of fitness for purpose discussed here is focused on the technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products, could not be considered and no recommendations could be made in this respect,

Degree of urbanisation of LAUs

The spatial domain of the assessment for this use case are LAUs labelled as Cities or Town and suburbs. To this end LAUs must be classified according to their degree of urbanization. Such classification of LAUs (Figure 15) is published by EUROSTAT[60] with the underlying population density data based on the Global Human Settlement Layer developed by the JRC[61]. The product is currently operationally used to classify LAUs according to their degree of urbanization. In 2020, EU27 counted 2,449 Cities and 14,209 Towns and suburbs[62].

[60] https://ec.europa.eu/eurostat/web/degree-of-urbanisation/background
[61] https://ghsl.jrc.ec.europa.eu/degurba.php
[62] https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/degurba

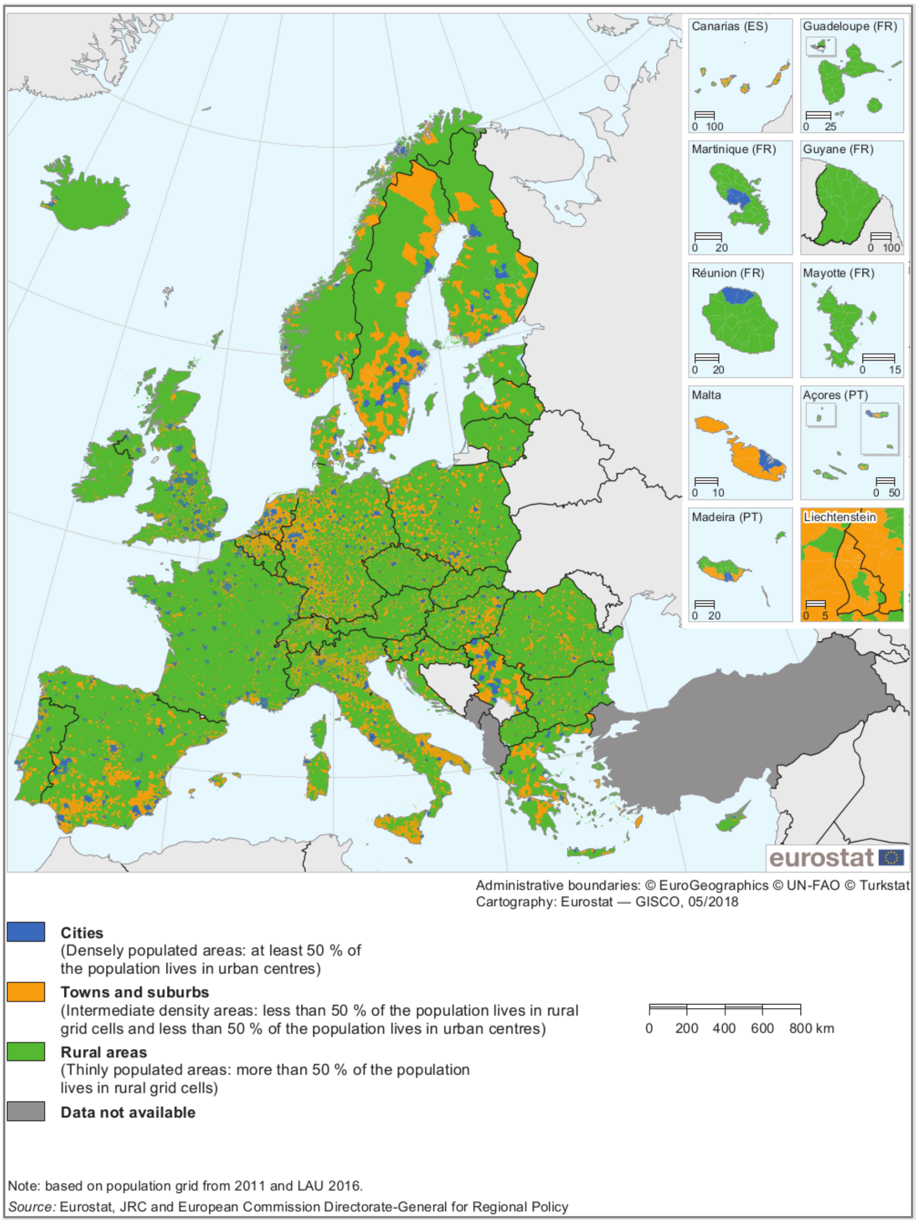

Figure 15. Local Administrative Units (LAU) boundaries classified on the basis of the DEGURBA.

CORINE Land Cover (CLC)

Many of the land cover types needed for mapping urban green spaces are included within the Copernicus Corine Land Cover (CLC)[63] database. However, both the thematic detail, the spatial resolution (100 m) and Minimum Mapping Unit (MMU) of 25 ha are not enough for the assessment.

Copernicus CLC+ Backbone (CLC+ BB)

CLC+ BB[64] is the new land cover product of the Pan-European component of CLMS. The product provides the European wall-to wall spatial distribution of 11 basic land cover classes with 10m spatial resolution:

1: Sealed;
2: Woody – needle leaved trees;
3: Woody – Broadleaved deciduous trees;

[63] https://land.copernicus.eu/pan-european/corine-land-cover
[64] https://land.copernicus.eu/pan-european/clc-plus/clc-backbone

4: Woody – Broadleaved evergreen trees;
5: Low-growing woody plants (bushes, shrubs);
6: Permanent herbaceous;
7: Periodically herbaceous;
8: Lichens and mosses;
9: Non-vegetated and sparsely-vegetated;
10: Water;
11: Snow and ice.

Currently CLC+ BB is available for the reference year 2018. The product for reference year 2021 should become available in late 2023. After this, product updates will take place every two years.

The product has certain thematic overlaps with some of the CLMS High Resolution Layers (see below), however it is an independent product and the classification method and class definitions also differ slightly

As a general remark, the following essential difference is worth recalling: in CLC+ BB, a dominant land cover among the 11 basic land cover classes is assigned to each pixel; in HRLs instead, each single land cover type is mapped in a separate layer, allowing low density or small (= not-dominant) portions of the land cover class within a pixel to be mapped. In this sense the HRLs seems fitting better the requirement of this use case.

Copernicus CLMS High Resolution Layers

The Pan-European High Resolution Layers (HRL)[65] of CLMS provide information on imperviousness, forests, grasslands, water and wetness, for 2012 (only forest and imperviousness), 2015 and 2018. Imperviousness data is also available for 2006 and 2009.

Since the 2015 reference year, the production is increasingly based on time series of satellite images from different sensors, including the combination of optical and radar data. Since the 2018 reference year the main sources are the Sentinel Satellites (in particular Sentinel-2 and Sentinel-1). For 2012 and 2015 the spatial resolution is 20m, since 2018, the products have 10m resolution, thus following the source resolution of Sentinel-2.

Among the HRL of CLMS, Forest and Grassland product groups are of potential interest for this use case.

- HRL Forest. The specific products of interest are Tree Cover Density (TCD) and Dominant Leaf Type (DLT). These map all trees independently on whether they are part of what is technically qualified as "forest". In particular, TCD pixels can have a range of tree cover between 1-100%. To be noted that shrubs and dwarf trees are not mapped, while the spatial resolution and the Minimum Mapping Width (10m) make the product not ideal for consistently mapping isolated trees and linear tree features.
- HRL Grassland. It includes natural, semi-natural and managed grasslands (according to their origin and utilization) as well as all types of grassland (permanent or seasonal), in all cases with at least 30% ground cover.

For data from 2018 onwards, a layer named Herbaceous cover is planned to be included in the upcoming HRL Vegetated Land Cover Characteristics (HRL VLCC) product suite[66], together with information on mowing events to allow advanced users to derive grassland information according to different criteria, e.g. number of mowing events. The HR-VLCC will integrate the former HRL Forest and HRL Grassland, with production moving to yearly updates for status layers while keeping change layers and the Forest Type product every 3 years. There will also be a new Crop type layer with annual updates of crop type classification together with a set of layers showing agricultural cropping patterns.

These HRL products could be considered as potentially contributing to the peri-urban assessments of the use case (limited to tree and grassland cover types) for which the spatial resolution of 10m may be enough, although not being alone sufficient since not all "green" cover types are mapped. The frequency of updates (3 years) is not ideal against the requirements, and, so far, only 2018 has sufficient spatial resolution. Althou gh for the future yearly updates are planned, the product latency may become a matter of concern since at the time of writing the latest available year is 2018.

[65] https://land.copernicus.eu/pan-european/high-resolution-layers
[66] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=8630

Green cover types not mapped with HRLs might be complemented with CLC+ BB, as a sub-optimal option in the absence of better alternatives.

Copernicus CLMS Small Woody Features

The Small Woody Features[67] (SWF) is a High Resolution Layer (HRL) CLMS product, which provides harmonized information on linear structures such as hedgerows, as well as patches (200 m^2 ≤ area ≤ 5000 m^2) of woody features. The dataset is available for 2015 and 2018 reference years and it is produced in different vector and aggregated raster formats.

While the spatial resolution appears interesting for this use case (5m), it must be noted that the product has been designed and is particularly meaningful in agricultural and managed landscapes with distinct hedgerows and/or woody vegetation patches, embedded in an agricultural matrix. Furthermore, it only covers woody features and within those, because of its purpose, tree plantations, vineyards and orchards are explicitly excluded from the product. Additional features of the SWF product are provided in Chapter 6.9.4 and Annex 4.

Copernicus CLMS Urban Atlas

The Copernicus Urban Atlas[68] contains land use/land cover maps of Functional Urban Areas (FUAs) for 2006 (319 FUAs), 2012 (785 FUAs) and 2018 (788 FUAs), covering EU27, EFTA countries, West Balkans, Turkey, UK.

This product is based on different very high-resolution satellite images (Pléiades, KOMPSAT, Planet, SPOT6, SuperView, etc. having a resolution of 2 - 4 meters) and ancillary data from Google Earth and OpenStreet Map. On the basis of the multitemporal analysis 2006-2012 and 2012-2018 change products are also available.

The nomenclature includes 17 urban classes and 10 Rural Classes, the former with MMU=0.25 ha, the latter with MMU=1ha. For the purpose of this use case only the rural classes are of interest namely agricultural areas (annual crops, permanent crops, pastures, complex and mixed cultivation), natural and semi-natural areas (forests, herbaceous vegetation associations, open spaces with little or no vegetation), wetlands.

The frequency of update is 6 years, although from 2021 onwards should be updated every 3 years.

The Urban Atlas also includes a vector Street Tree Layer for the years 2012 and 2018 having a MMU of 500 m^2 and based on the same imagery used for the Urban Atlas. In the future, the Street Layers will be continued in the frame of the HRL SWF.

The product can be potentially considered a basis for the use case, unfortunately it does not have the full coverage requested since, as of 2018 it covers 788 Functional Urban Areas and not all the urban LAUs (Cities, Town and suburbs) targeted by the use case. The spatial resolution is good but for thematic classes, of interest for the use case the minimum mapping unit is 1 ha, which might fit the assessment in peri-urban areas although sub-optimally. The temporal resolution is not fully matching the requirements.

6.3.5 Conclusions and recommendations

A multitemporal high-resolution map for European urban LAUs (Cities, Town and suburbs) is not available. Some satellite EO products exist that are potentially useful to support this use case, however there is not a unique product addressing the full set of needs and having the required technical specifications.

The Copernicus Land Monitoring Service (CLMS) offers a number of spatial layers (High Resolution Layers for both forests and grasslands, Urban Atlas, Small Woody Features and Street Tree Layer) each partially matching the requirements in different ways. Once integrated, harmonised and complemented with additional elements, they should produce a unique dataset to monitor urban green spaces in time.

It should be noted though that merging products built with different objectives and methodologies requires some caution as it may result in some thematic inconsistencies (e.g. the same area can be classified in different ways depending of the product considered) as well as geometric, as can emerge comparing layers from the HRL product suite with Small Woody Features and the Urban Atlas.

The Urban Atlas could be a candidate core product for the use case. However, the frequency of update should be improved to at least every 3 years with a product latency of 1 year maximum and, following the

[67] https://land.copernicus.eu/pan-european/high-resolution-layers/small-woody-features
[68] https://land.copernicus.eu/local/urban-atlas

requirements of this use case, the spatial coverage should be augmented to cover all "cities" and "towns and suburbs" rather than the functional urban areas as it currently does. Furthermore, despite the high spatial resolution, because of the minimum mapping unit applied to rural classes, it could only match an assessment in the peri-urban areas.

For all products examined, augmenting the thematic detail and the temporal resolution appear to be common key issues for matching the requirements of this use case.

Although the investments to derive a robust, detailed and regularly updated dataset on urban areas may be considerable, the support of the same or combined products to other urban policies, the further analysis it may trigger (e.g. urban ecosystem services, green space and climate change adaptation in urban context, heat islands etc.), and the resulting synergies should be positively valuated.

6.4 Monitoring ecosystems' health to support biodiversity investments (DG REGIO)

Credit: European Union, Copernicus Sentinel-2 imagery

6.4.1 Policy context

The Cohesion Policy supports the EU's cities and regions with specific objectives relevant to biodiversity, including a special emphasis on environmental protection, resource efficiency, and supporting the shift towards a low-carbon economy[69]. The overall vision is a lasting improvement in the quality of life for everyone.

EU Cohesion Policy is a key instrument to support Member States' (MS) investment in biodiversity, nature, and green infrastructures. The Cohesion Fund provides support for MS with a gross national income per capita below 90% EU average in order to strengthen the economic, social, and territorial cohesion of the EU. The Cohesion Fund supports investments in the fields of environment and Trans-European Networks in the area of transport infrastructure (TEN-T).

European Regional Development Funds (ERDF) aim to strengthen economic, social, and territorial cohesion in the European Union by correcting imbalances between its regions. In 2021-2027 it will enable investments in a smarter, greener, more connected, and more social Europe that is closer to its citizens.

The tracking of biodiversity relevant investments is possible using the Cohesion Policy and the ERDF monitoring system that allow DG REGIO to identify and monitor the planned financial investments and its implementation over time. The main areas of investment interventions are tracked under the Cohesion Policy for their biodiversity contribution. Categories of interventions were selected because they help biodiversity protection indirectly by reducing pressures. The three main intervention fields for nature listed in Annex I of the Cohesion Policy Reporting[70] are (between brackets the reference to Annex I numbering): (78) Protection, restoration and sustainable use of Natura 2000 sites, (79) Nature and biodiversity protection, natural heritage and resources, green and blue infrastructure, and (80) Other measures to reduce greenhouse gas emissions in the area of preservation and restoration of natural areas with high potential for carbon absorption and storage, e.g., by rewetting of moorlands, the capture of landfill gas. These three areas receive a significant contribution of 100% weighting for spending allocations.

Additional areas which are less directly related to biodiversity are: (73) Rehabilitation of industrial sites and contaminated land, (74) Rehabilitation of industrial sites and contaminated land compliant with efficiency criteria, and (64) Water management and water resource conservation (including river basin management, specific climate change adaptation measures, reuse, leakage reduction), as well as those areas (58-61) related to climate and risk prevention measures include also ecosystem based approaches.

[69] https://ec.europa.eu/info/topics/regional-policy_en
[70] REGULATION (EU) 2021/1060, Annex I https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021R1060&from=EN#d1e32-252-1

6.4.2 Description of the use case

Earth Observation (EO) data support the analysis and contribute to monitor the results and outcomes of each project in the EU supported by biodiversity funding allocated by the regional budgets[71]. Ecosystem condition is defined in this context as the physical, chemical and biological quality of an ecosystem and its capacity to deliver ecosystem services.

Better knowledge and high-resolution spatial data on the condition of ecosystems is particularly relevant to guide or evaluate the impact of investments in biodiversity and ecosystems under the Cohesion Policy. In addition, a better understanding of the trends in the condition of ecosystems can be used for the reporting of the quality of ecosystems for different territories in the Cohesion Report, a three yearly assessment that describes territorial convergence and disparities. Updated information on ecosystems' condition is needed to know where ecosystems are already degraded or if they are going through a degradation process.

These assessments are fundamental:

1. to decide where to help prioritize the allocation of funds to restoration projects;
2. to monitor the trend in condition of sites where regions are funded for restoration projects.

Ecosystem condition is important to assess ecosystems' health, including areas of change at a local scale, and the assessment would need to include species occurrence, ecosystems' structure and functioning, community composition, species populations, as well as the natural/seminatural/managed level of the ecosystems under study. In this context, 'health' expresses the change in value of ecosystem services for humans, as well as being a term to describe the degree of naturalness of an ecosystem such as higher alpha, beta, and gamma diversity or lowered human disturbance. In a changing ecosystem, there can be 'winning' species and 'losing' species which act as indicators of change in response, for instance, to less pollution, more fragmentation or less disturbance. EO can greatly contribute to these assessments using remote sensing imagery to derive biodiversity products such as biomass productivity, the fraction of absorbed photosynthetically active radiation, forest tree species distribution, biological effects of irregular inundation, functional diversity, species abundance, vegetation water content, as well as connectivity metrics based on land cover data. These EO derived products can be combined and modelled into an indicator such as 'health' or 'condition'.

High spatial resolution data coupled with ecosystem condition are required in order to track the biodiversity outcomes of funded projects. For example, LIFE projects have to report the impact of projects based on guidelines defining what is to be measured before/after the project to check if there is any detectable impact of the project on the condition of the ecosystem. The geographic coordinates or areas where project money has been expended, as well as the amount of funding, needs to be tracked in relation to the project impact and restoration activities. For example, a project within the Cohesion Policy Budget on wastewater treatment plants/buildings included water analysis upstream and downstream to understand the water quality. Therefore, they tried to relate the water quality results to the use of Cohesion Budget for wastewater treatment: this quantified the impact of the investments, as well as the expenditure, with respect to the ecosystem condition. It is anticipated that biodiversity products derived from EO (remote sensing) could be used to monitor ecosystem condition accurately and operationally. For example, in a long-term data set, elevated turbidity (as measured by remote sensing) may be associated with decreased fish species richness and diversity and higher abundances of benthic species that rely more on chemoreception for foraging and predator avoidance (e.g., crabs).

6.4.3 Value chain analysis and EO technical requirements

This use case can be divided in two sub-cases:

1. Assessment of ecosystem condition across the EU to identify degraded areas across the EU where infrastructure funds could be justified or prioritized.
2. Assessment of the impact of a new infrastructure on biodiversity, especially through linking changes in biodiversity to the targets and outcomes of funded projects. Examples addressed here are biodiversity impact of a new sewage system infrastructure, or, biodiversity impact of restoring disturbed Natura 2000 sites, or, restoring nature through reduced nitrogen deposition.

[71] https://cohesiondata.ec.europa.eu/stories/s/tdxi-ibcn

What is common between the sub-cases is the need to generate baseline indicators using remote sensing biodiversity products to inform about changes in ecosystem condition based on the EBV concept.

Table 6 details some of the remote sensing biodiversity products, from a priority list of +120 products identified by Skidmore et al. (2021), that can be combined to map ecosystem condition as a baseline indicator of biodiversity, and that may contribute to solving the sub-cases. From the scientific literature, example references of how each remote sensing biodiversity product has been applied to monitor biodiversity and ecosystem condition are included, in addition, the TRL of each product is estimated, based on its maturity, accuracy and feasibility for the problem at stake.

Table 6. Remote sensing biodiversity products that can be combined to map Ecosystem Condition as a baseline indicator of biodiversity – see Skidmore et al. (2021) for details.

Baseline indicator	scale	Remote sensing biodiversity products	Satellite requirement (sensor)	Technology Readiness Level (TRL)	example references of monitoring with remote sensing
Phenology	local to continental	green-up (start of season) - monitored with long term NDVI data*	S2, Landsat (OLI)	6	(Zhang et al. 2003)
		senescence (end of season)- monitored with long term NDVI data*	S2, Landsat (OLI)	6	
		peak season (max of season) - monitored with long term NDVI data*	S2, Landsat (OLI)	6	
Ecosystem Vertical Profile/ habitat structure (3D)	local to continental	fraction of vegetation cover	S2, VHR, (CHIME)	6	(Carlson et al. 1990; Carlson and Ripley 1997; Gutman and Ignatov 1998; Wittich and Hansing 1995)
		Canopy cover	S2, LiDAR, (CHIME)	6	(Carreiras et al. 2006; Stojanova et al. 2010; Walton et al. 2008)
		above-ground biomass	S2, S1, LiDAR	6	(Baccini et al. 2008; Drake et al. 2003; Lefsky et al. 2001)
		leaf area index	S2, LiDAR	7,8	(Asner et al. 2003; Spanner et al. 1990; Zheng and Moskal 2009)
		urban habitat	S2, S1, LiDAR	7,8	(Esch et al. 2009; Höfle et al. 2012; Shrestha and Wynne 2012; Zhang et al. 2004)
		land cover (vegetation type)	VHR, (CHIME), LiDAR	7,8	(Sobrino and Raissouni 2000; Townshend et al. 1991; Yuan et al. 2005)
		vegetation height	S1, LiDAR	7,8	(Means et al. 2000; Streutker and Glenn 2006)
		habitat structure	S1, S2, LiDAR	7,8	(Hinsley et al. 2002; Hyde et al. 2006)
Ecosystem disturbance	local to continental	biological effects of Irregular inundation	S2, S1, VHR	7	(Bates 2004; Khan et al. 2010; Smith 1997; Tralli et al. 2005)
		biological effects of Pest and disease outbreak	S2, S1, VHR	5	(Dash et al. 2017; Kalluri et al. 2007; Wulder et al. 2006)
Spatial configuration (2D)	local to continental	ecosystem structural variance	S2, S1, VHR, (CHIME), LiDAR	6	(Gaitán et al. 2013)
		ecosystem fragmentation	S2, S1, VHR optical, LiDAR	6	(Gong et al. 2013; Heilman et al. 2002; Vogelmann 1995)
Impact of soil impervious on biological processes	local to continental	land cover (vegetation type)	S2, LOI (Landsat)	8	(Sobrino and Raissouni 2000; Townshend et al. 1991; Yuan et al. 2005)
		soil type**	S2, LOI (Landsat)	6	
		evapotranspiration	MODIS (CHIME)	7,8	(Anderson et al. 2012; Courault et al. 2005; Kustas and Norman 1996)
		ecosystem soil moisture **	S2, LOI (Landsat)	3	(Njoku and Entekhabi 1996; Schmugge et al. 1974; Wagner et al. 2007)

Baseline indicator	scale	Remote sensing biodiversity products	Satellite requirement (sensor)	Technology Readiness Level (TRL)	example references of monitoring with remote sensing
		Soil imperviousness	Satellite or aircraft source is not described but the end resolution is 10-20m and 100m	5,6	https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness
Water quality	local to continental	chlorophyll content (suspended)	S2, Landsat (OLI)	5	(Darvishzadeh et al. 2019; Datt 1998; Gitelson 2005)
		biological effects of suspended matter impact	S2, Landsat (OLI)	4	(Ritchie et al. 1990)
		Biological impact of irregular inundation from surface water mask	S2, Landsat (OLI)	6	(Pekel et al. 2016)
Species distribution	local	species richness***	S2, (CHIME)	4	(Goetz et al. 2007; Gould 2000; Kerr et al. 2001)
		species diversity indices (Simpson, Shannon, alpha, beta, gamma)***	S2, (CHIME)	6	(Jha et al. 2005; Nagendra et al. 2013; Rocchini et al. 2010; Saatchi et al. 2008)
Species abundance	local	species abundance***	S2, (CHIME)	6	(Jones 2011; Purkis et al. 2008)
		Relative species abundance***	S2, (CHIME)	7	(Krishna et al. 2008)
Ecosystem function (incl. physiology & primary productivity)	local to continental	gross primary productivity	S2, (CHIME)	6	(Hilker et al. 2008; Xiao et al. 2004; Zhao et al. 2005)
		net primary productivity	S2, (CHIME)	6	(Field et al. 1995; Running et al. 2000; Zhao et al. 2005)
		Leaf Area Index (LAI)	S2, LANDSAT(OLI), LIDAR, (CHIME)	7,8	(Asner et al. 2003; Spanner et al. 1990; Zheng and Moskal 2009)
		Specific leaf area	S2, (CHIME)	5	(Ali et al. 2017a; Ali et al. 2017b; Pierce et al. 1994)
		foliar N/P/K content	S2, (CHIME)	6	(Curran 1989; Knyazikhin et al. 2013; Mahajan et al. 2014)
		evapotranspiration	MODIS (CHIME)		(Anderson et al. 2012; Courault et al. 2005; Kustas and Norman 1996)
		fraction of absorbed photosynthetically active radiation	S2, (CHIME)	7,8	(Asrar et al. 1992; Chen 1996; Knyazikhin et al. 1998; Viña and Gitelson 2005)
		ecosystem soil moisture**	S2, LOI (Landsat)	3	(Njoku and Entekhabi 1996; Schmugge et al. 1974; Wagner et al. 2007)
		carbon cycle (sequestration)	S2, LANDSAT(OLI), LIDAR, (CHIME)	4	(Jackson 1993; Myeong et al. 2006; Turner et al. 2004; Watts et al. 2009)
		carbon cycle (below-ground biomass and carbon)	S2, LANDSAT(OLI), LIDAR, RADAR, (CHIME)	3	(Jung et al. 2006)
		carbon cycle (above-ground biomass)	S2, LANDSAT(OLI), LIDAR, RADAR, (CHIME)	6	(Baccini et al. 2008; Drake et al. 2003; Lefsky et al. 2001),(J. et al. 2014)
		chlorophyll content and flux	S2, (CHIME)	5	(Darvishzadeh et al. 2019; Datt 1998; Gitelson 2005)
community diversity	local to continental	taxonomic (species diversity/ richness)*	S2, (CHIME)	1	(Asrar et al. 1992; Chen 1996; Knyazikhin et al. 1998; Viña and Gitelson 2005)
		functional diversity	S2, (CHIME)	2	(Asrar et al. 1992; Chen 1996; Knyazikhin et al. 1998; Viña and Gitelson 2005)
		phylogenetic diversity	S2, (CHIME)	1	(Asrar et al. 1992; Chen 1996; Knyazikhin et al. 1998; Viña and Gitelson 2005)

<u>Ancillary field (ground-based) data required:</u>
* time-series NDVI data
**soil map and soil wetness index e.g., NDWI
***ground-based field observations of species

The assessment of ecosystem condition to identify areas of Europe with a priority for investing EU funds to increase biodiversity (sub-case 1) involves mapping ecosystem condition using baseline indicator derived from remote sensing biodiversity product(s)[72] in order to assess the degradation relative to other similar areas and identify priority areas in Europe for investing EU funds to increase biodiversity.

The approach followed has been to take the set of indicators for mapping and assessing ecosystem condition proposed in Maes et al. (2020) and identify which remote sensing biodiversity products (Table 6) with Technology Readiness Level 6 to 9 (see Chapter 2.3) may be used to generate those indicators. Results are shown in Table 7.

Table 7. Examples remote sensing biodiversity products with TRL 6-9 available to generate Indicators of ecosystem pressure and condition in Maes et al. (2020).

Classes of indicators of Ecosystem Pressure and Condition	Remote sensing biodiversity products with TRL level 6-9 available to generate the indicators
Habitat conversion and degradation	Land cover, fraction of vegetation cover, canopy cover, above-ground biomass, leaf area index, ecosystem fragmentation, ecosystem structural variance, soil type, carbon cycle above ground biomass,
Pollution and nutrient enrichment	Soil water mask, foliar N/P/K nutrient content, soil type
Over-exploitation	Land cover, fraction of vegetation cover, canopy cover, above-ground biomass, leaf area index, ecosystem fragmentation, ecosystem structural variance, soil type, carbon cycle above ground biomass,
Invasive alien species	Species diversity, species abundance
Environmental quality	Land cover, fraction of vegetation cover, canopy cover, above-ground biomass, leaf area index, ecosystem fragmentation, ecosystem structural variance
Structural ecosystem attributes	Land cover, fraction of vegetation cover, canopy cover, above-ground biomass, leaf area index, ecosystem fragmentation, ecosystem structural variance, vegetation height, carbon cycle above ground biomass,
Species diversity and abundance	Species diversity, species abundance
Functional ecosystem attributes	Gross and net primary production, leaf area index, specific leaf area, evapotranspiration, fAPAR, chlorophyll content and flux
Functional soil attributes impacting biodiversity	Evapotranspiration, land cover

Assessing the impact of EU funded projects on biodiversity (sub-case 2), can be tackled comparing a baseline of biodiversity against the impact of a new infrastructure thereby generating the future impact of a proposed infrastructure. This sub-case provides evidence of the improvement in ecosystem condition resulting from EU funded projects, based on remote sensing biodiversity products. Specific remote sensing derived biodiversity products that can be generated to measure the impact of infrastructure on ecosystem condition are provided in Table 6.

With reference to example projects such as:

- the biodiversity impact of a new sewage system infrastructure,
- restoring disturbed Natura 2000 sites,
- restoring nature through reduced nitrogen deposition,

the remote sensing biodiversity products are listed with their relative relevance/importance in the assessment for each specific project category (estimated by expert opinion).

Table 8. Estimated relevance/importance of remote sensing biodiversity products in assessing the impact of selected project categories (1 = not relevant/important, to 9 = highly relevant/important).

Baseline Indicator	Remote sensing biodiversity product	Project category		
		Sewage works	Restoring Natura	Restoring nature

[72] Including remote sensing biodiversity products and biodiversity indicators available for immediate download, as well as remote sensing biodiversity products and biodiversity indicators which methods are known but not yet available for download.

			2000 sites	through Reduced N deposition
Phenology	phenology green-up	1	5	2
	phenology senescence	1	5	2
	peak season (max of season) - monitored with long- term time series of NDVI data	1	5	7
Ecosystem Vertical Profile/ habitat structure (3D)	fraction of vegetation cover	1	7	5
	Canopy cover	1	7	5
	above-ground biomass	1	6	5
	leaf area index	1	5	5
	urban habitat	5	2	1
	land cover (vegetation type)	5	8	7
	vegetation height	2	7	7
	habitat structure	3	8	8
Ecosystem disturbance	biological effects of Irregular inundation	8	3	1
	biological effects of Pest and disease outbreak	3	6	1
Spatial configuration (2D)	ecosystem structural variance	1	6	7
Impact of soil impervious on biological processes	land cover (vegetation type)	1	7	7
	soil type	4	4	8
	evapotranspiration	5	4	3
	ecosystem soil moisture	6	4	3

For detailed infrastructure projects, high-resolution imagery (10-20 m) is required to measure the impact over small areas. Such fine resolution imagery can be used to assess improvements (or degradation) in the condition of biodiversity after projects of new infrastructures such as a wildlife bridge, sewage treatment system, or enlargement of parks associated to a higher level of biodiversity in cities. These projects can take 4-5 years, and it would be important to effectively measure the impacts before/after the investments. Such high-resolution imagery can also be operationally delivered by aircraft, or UAVs, over small areas.

6.4.4 Fitness for purpose of existing EO products and services

Satellite EO products and indicators of ecosystem pressure and condition, and their associated satellite EO biodiversity products are summarized in Table 6 and Table 7. Although most indicators and products are proven at the research level (i.e., technology is developed and demonstrated) only some of these are readily available as operational products for immediate download over the EU. Further descriptions and specifications of Copernicus products mentioned are provided in Annex 4.

It is important to recall that the assessment of fitness for purpose discussed here is focused on the technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products, could not be considered and no recommendations could be made in this respect,

A number of critical indicators are not yet operationally available from Copernicus or other publicly available sources and most indicators and remote sensing biodiversity products will require further development to bring them up to an operational level (i.e., TRL 9). General technical requirements for the satellite EO biodiversity products indicated in Table 6 and Table 7 are provided in Table 2 (Chapter 2.3) as derived by Skidmore et al. (2021). It is worth noting that temporal and spatial resolutions indicated Table 2 are preliminary estimates by the authors in Skidmore et al. (2021) of satellite observations necessary to capture relevant biodiversity products. Hence are to be taken as indicative reference values and elaborated around observation requirements rather than end user products requirements of the specific use cases of this report.

Temporal consistency of data is a key element for this use case. Having a good and consistent time series of user products with an update frequency of 1-2 years would be ideal.

High spatial resolution is also critical, the resolution of last generation Copernicus CLMS Pan-European and Local components is generally matching the requirements.

Thematic granularity of categorical maps is not yet matching the level of the expectations that would aim at discriminating habitat types beyond standard land cover categories.

Existing Copernicus products that may be used to derive indicators for this use case are summarised in Table 9 against their fitness for purpose with respect to the technical requirements. Descriptions and specifications of these products are provided in Annex 4.

Table 9. Copernicus products that may be used to generate indicators for DG REGIO use case (all products are from CLMS except where another source is specified).

Classes of indicators of ecosystem pressure and condition (from Maes et al. 2020)	Copernicus products	Limitations against technical requirements
Habitat conversion and degradation (land conversion)	Corine Land Cover	Low spatial and temporal resolutions
	CLC+ BB	Low thematic resolution (11 classes)
	HRL Forest	Partly matching (3 years update freq.)
	HRL Grassland	Partly matching (3 years update freq.)
	HR VPP (Phenology)	Matching
	HR VPP (Productivity)	Matching
Invasive alien species	nil	
Pollution and nutrient enrichment	Lake Water quality	Low spatial resolution
Over-exploitation	Corine Land Cover	Low spatial and temporal resolutions
	CLC+ BB	Low thematic resolution (11 classes)
	HRL Forest	Partly matching (3 years update freq.)
	HRL Grassland	Partly matching (3 years update freq.)
	HR VPP (Phenology)	Matching
	HR VPP (Productivity)	Matching
Climate change	EFFIS burnt areas (CEMS)	Matching
	Bioclimatic datasets (C3S)	Matching
Environmental quality (physical and chemical quality)	Corine Land Cover	Low spatial and temporal resolutions
	CLC+ BB	Low thematic resolution (11 classes)
	HRL Forest	Partly matching (3 years update freq.)
	HRL Grassland	Partly matching (3 years update freq.)
	HR VPP (Phenology)	Matching
	HR VPP (Productivity)	Matching
	HR-VPP Leaf Area Index (LAI)	Matching
	HR-VPP Fraction of absorbed photosynthetically active radiation (fAPAR)	Matching
Structural ecosystem attributes	Corine Land Cover	Low spatial and temporal resolutions

Classes of indicators of ecosystem pressure and condition (from Maes et al. 2020)	Copernicus products	Limitations against technical requirements
	CLC+ BB	Low thematic resolution (11 classes)
Species diversity and abundance	nil	
Functional ecosystem attributes	HR-VPP Leaf Area Index (LAI)	Matching
	HR-VPP Fraction of absorbed photosynthetically active radiation (fAPAR)	Matching
	HR VPP (Phenology)	Matching
	HR VPP (Productivity)	Matching
Structural and functional soil attributes	HRL Imperviousness	Partly matching (3 years update freq.)
	Surface Soil Moisture	Partly matching (spatial resolution 1 km)

Remote Sensing biodiversity products as indicators of ecosystem condition should be combined with ground-based data for calibration and/or validation of products. For example, there is a need for ground-based data to train and validate a sufficiently detailed ecosystem typology of habitats (beyond classical land cover). A second example is using field observations of species to train and then validate the distribution of species using species distribution models (also known as environmental niche models).

A GIS mapping service where it would be possible to integrate different indicators with a consistent time series, and extract data when needed would also be beneficial for this use case.

6.4.5 Conclusions and recommendations

Satellite EO can greatly contribute to the assessment of ecosystem condition. Several EO derived products exist that can provide estimates of biodiversity relevant indicators or metrics, such products can be combined and modelled into an indicator of 'health' or 'condition'. This use case does not elaborate around methods to combine indicators to estimate ecosystem condition, it rather provides a review of main remote sensing biodiversity products that can contribute and constitute building blocks of the assessment of ecosystem condition.

Several remote sensing products have been reported as being developed or under development, encompassing various constituents of the Essential Biodiversity Variables (EBV) framework. However only some products are mature enough to be deployed operationally. Efforts to operationalise promising solutions should be pursued, also and most importantly, further integrating ground-based data in the workflows generating end products. The application of satellite EO to the operational assessment of ecosystem condition has still the potential for a remarkable growth.

Regarding EO indicators on ecosystem pressure and condition currently available, the spatial resolution of more recent Copernicus products is considered in most cases matching the requirements for this use case.

On the other hand, regular and more frequent updates are considered key aspects and here product performances are still to be improved. Consistency of time series is also critical; the evolution of sensors can cause changes in the series that must be handled with care (see e.g. the change between 2015 and 2018 of the spatial resolution of the imperviousness layer from 20 to 10m, of critical importance for this use case).

The improvement in the thematic granularity of land cover categories is also considered a priority in this use case. There is a strong need of being able to count on maps of habitats that use classification schemes of ecosystem types that go beyond the high level vegetation categories of currently available land cover maps.

Some of the available EO products such as phenology or productivity indices have certainly the potential to be further processed into targeted variables for the users, carrying additional information of great value for the policy needs expressed in this use case.

6.5 Monitoring Marine Biodiversity to support Marine Protected Areas (use case 1) and assessing Essential Fish Habitats and Vulnerable Marine Ecosystems (use case 2) (DG MARE)

Credit: European Union, Copernicus Sentinel-2 imagery

6.5.1 Policy context

DG MARE is responsible for the implementation of the Common Fisheries Policy (CFP)[73] and thus for the protection, conservation and management of the EU marine living resources. Some key biodiversity aspects relevant to this policy area are:

- Ensuring coherence and complementarity between the CFP and environmental policies;
- Improving knowledge about the impacts of fisheries/fishing on the marine environment;
- Monitoring changes in marine biodiversity, while ensuring socio-economic benefits for fisheries;
- Contributing to the implementation of the EU Biodiversity Strategy (BDS) for 2030, the Marine Strategy Framework Directive and the development of the Nature Restoration Law;
- Contributing to the development of the Action Plan to conserve fisheries resources and protect marine ecosystems under the BDS 2030.

Beyond fisheries, DG MARE works in Marine Spatial Planning (MSP)[74] and other sectors of the Blue Economy[75]. Thus, marine biodiversity is directly and indirectly related to all lines of work in DG MARE, including the mandate that the sustainable development of the Blue Economy should not harm (marine) biodiversity. More concretely, the MSP Directive[76] includes a component on Marine Protected Areas (MPA), which are also relevant from the perspective of the management and the achievement of fisheries sustainability if MPAs are understood from an inclusive perspective. This implies considering different types of protection scheme with complementary goals (e.g., from no-take areas to Fisheries Restricted Areas and other Area-Based Fisheries Management Measures). In this context, MPAs should constitute a connected system (in MPA networks, or collections of individual MPAs operating cooperatively and synergistically at various spatial scales), for safeguarding biodiversity and maintaining marine ecosystem health and the supply of ecosystem services, including their contribution to fisheries. The implementation of the MSP Directive is relevant for multiple uses/policies since objectives overlap to assess MPAs effectiveness under the Habitats Directive and the EU Biodiversity Strategy, as well as effectiveness and coherence under the Marine Strategy Framework Directive (MSFD)[77].

DG MARE is also the co-manager of the HE Mission Ocean[78], where one of the main priorities is "to contribute to the 30% target of protected marine areas", directly connected to the protection of marine biodiversity. As

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73 https://oceans-and-fisheries.ec.europa.eu/policy/common-fisheries-policy-cfp_en
74 https://maritime-spatial-planning.ec.europa.eu/
75 https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/sustainable-blue-economy_en
76 Directive 2014/89/EU
77 https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm
78 https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters_en

part of the HE Mission, the European Digital Twin Ocean (DTO)[79] - a consistent, high-resolution, multi-dimensional and near real-time virtual representation of the ocean, combining ocean observations, artificial intelligence, advanced modelling operating on high-performance computers and accessible to all[80] - will build on the already existing marine knowledge assets of the Commission (Copernicus Marine[81], EMODnet[82], and Marine Research Infrastructures[83]) and will require enriched marine biodiversity observations (from satellite Earth Observation (EO) and *in-situ* data) and their harmonization and integration to sufficiently support research, policy, blue economy and societal engagement. Currently, DG MARE is developing the Ocean Observation initiative, which aims to bring more transparency and collaboration in the way EU Member States plan and undertake ocean observations[84].

The EU is also supporting the expansion of fishing spatial measures by activating multiple political channels. Among others it includes the conservation and protection of Vulnerable Marine Ecosystems (VMEs) and Essential Fish Habitats (EFHs) in the EU fisheries multiannual plans, promoting their development, financing their implementation using public funding, and promoting their expansion through political strategies such as the EU Biodiversity Strategy for 2030 (with target 15 as the main related goal). The European Commission has also expressed its support in multiple high-level multilateral political declarations and has included MPAs, VMEs and EFHs as key elements in its new proposal of Nature Restoration Regulation[85] that is currently under negotiation with the European Council and the European Parliament.

Nevertheless, there are scientific and social challenges in the definition, prioritization and implementation of these marine spaces. While there is a consensus that they should be backed by clear scientific information, the methods of identification, prioritization, evaluation and monitoring of MPAs, VMEs and EFHs are still evolving and are under discussion, particularly due to the limited availability and, in some cases, difficult access to the necessary data.

6.5.2 Description of the use cases

a) Monitoring marine biodiversity to support MPAs

Many of the existing MPAs in European waters may be sufficient for protecting single vulnerable biodiversity elements, but may be too small to sustain the provision of ecosystem services. This is so because approximately 50 % of EU MPAs measure less than 30 km^2 and a high proportion of these are below 5 km^2. In addition, to be representative, an MPA network should protect the range of biodiversity found in the area it covers and ensure connections between protected sites. Current EU MPA networks show that deeper sea habitats are not well represented. Larger MPAs could improve the provision of services from European seas through a systemic approach to spatial conservation action. This could also contribute to the spill-over effect of fish biomass, which would support fisheries outside the MPAs, while protecting biodiversity inside. For this reason, the EU may consider the establishment of larger MPAs beyond coastal waters[86]. In addition, not all MPAs have the same effects on marine biodiversity and ecosystem services. Those effects depend strongly on the MPA characteristics and the activities that are permitted within and around the MPAs (Grorud-Colvert et al. 2021, Sala et al. 2021). The current extent and levels of protection of European MPAs are considered to be insufficient to achieve international and EU targets, especially in southern European regional seas (Horta e Costa et al. 2016, Claudet et al. 2020).

The process of establishing, monitoring and assessing MPAs is challenging and costly, and both satellite and *in-situ* EO products are needed. Available observations are patchy, resulting in assessments of the status of

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79 https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters/european-digital-twin-ocean-european-dto_en

80 https://digitaltwinocean.mercator-ocean.eu/#:~:text=The%20Digital%20Twin%20Ocean%20is,computers%20and%20accessible%20to%20all

81 https://marine.copernicus.eu/

82 https://emodnet.ec.europa.eu/en

83 https://research-and-innovation.ec.europa.eu/research-area/environment/oceans-and-seas/marine-research-infrastructures_en

84 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12539-Ocean-observation-sharing-responsibility_en

85 https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

86 https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/marine-protected-areas

the MPA and its surroundings with high uncertainty. When available, data are difficult to integrate to obtain a comprehensive picture of the state and evolution of the sites (Corrales et al. 2020). In addition, the impact of future changes in climate needs to be taken into account in this evaluation (Vilas et al. 2021).

There are a number of actions that could be taken to steadily support the further uptake of satellite and *in-situ* EO data regarding marine biodiversity and MPA establishment, monitoring and assessment: for instance, (1) the development of dedicated products showing the spatial and temporal distribution and abundance of multiple marine species with special relevance for conservation and biodiversity, and their changes within and around MPAs, (2) the tracking of the dynamics of biodiversity in the oceans associated with climate variability and change, and (3) the tracking of human activities, pressures and impacts, such as the ones associated with specific fishing fleets and gears, within and around MPAs. Such products should, ultimately, enable the calculation of informative indicators, such as those needed to track the progress of the EU Biodiversity Strategy for 2030, and be made available in the dashboard[87] implemented by the Knowledge Centre for Biodiversity[88].

A key question regarding MPAs is about their final effect in protecting biodiversity, which is related to their coverage or total percentage of area protected as well as their effectiveness, understood as the result of the combination of features that ensure the beneficial effect of protection and that include location, implementation and management. In this context, satellite EO products can complement *in-situ* data collection by validating ecological elements, processes and changes (e.g., species and habitats occurrences and distributions, connectivity between MPAs, environmental conditions) and by tracking human activities within and around MPAs (e.g. occurrence and intensity of various fisheries and recreational activities and placement of additional activities within the blue economy such as wind parks and aquaculture settings) in EU waters and to support MSP and MSFD. The issue of MPA monitoring is especially relevant from an ecological point of view (to detect beneficial effects, including spillovers, for example) and from an economic evaluation point of view, where decision makers need to regulate activities around MPAs and need to identify trade-offs and synergies to develop rules and management measures.

b) Monitoring and assessing Essential Fish Habitats and Vulnerable Marine Ecosystems

Vulnerable Marine Ecosystems (VMEs) are special parts of the ocean floor where habitat-forming animals such as deep-sea sponges, stony corals, sea pens, sea fans, lace corals and black corals form three-dimensional underwater forests[89]. According to FAO, VMEs are groups of species, communities or habitats that may be vulnerable to impacts from fishing activities. They are considered hotspots of biodiversity and ecosystem functioning in the (deep) sea and they provide habitat, nursery areas and feeding grounds for fish and invertebrates. They are fundamental to maintaining healthy ecosystems, as they perform a wide range of ecosystem services (e.g., storing carbon, filtering water and supporting food provision) and some VME animals have potential for bio-discovery. Overall, they have low productivity and can only sustain low exploitation rate, and recovery can be slow and uncertain. Therefore, to ensure that VMEs maintain their roles in providing important services and ensuring healthy ecosystems, they need to be effectively identified, mapped, protected and managed.

Essential Fish Habitats (EFH) include all types of aquatic habitats where fish spawn, breed, feed, or grow to maturity, such as wetlands, coral reefs, seagrasses and rivers. In the marine environment, coral gardens, kelp forests, sponge beds, seagrass meadows and submarine canyons represent EFH since they are essential for the survival of fish. EFH are very sensitive to human activities, mostly fishing by trawling and dredging, and their protection can contribute to the rebuilding and sustainable exploitation of fish stocks.

All over the world, the use of marine spatial measures, integrated in an ecosystem-based approach, to protect both VMEs and EFH, has proved to be useful to manage fisheries and to improve ecosystem health (McConnaughey et al. 2020). More broadly, if they are properly designed and implemented, these protected areas can also be considered as a Nature Based Solutions (Cohen-Shacham et al. 2019) that contribute simultaneously to solve different societal problems such as “climate change mitigation and adaptation”, “economical & society development”, “food security”, and “environmental degradation & biodiversity loss” (Riisager-Simonsen et al. 2022).

87 https://dopa.jrc.ec.europa.eu/kcbd/actions-tracker/
88 https://knowledge4policy.ec.europa.eu/biodiversity_en
89 https://www.fao.org/in-action/vulnerable-marine-ecosystems/vme-indicators/ru/

Overall, satellite and *in-situ* EO products are key in the context of VMEs and EFHs, from the identification and mapping of initial efforts, to the monitoring, evaluation, modelling and validation according to spatial-temporal data available and considering management measures and human activities in place.

An important challenge is the availability and accessibility of products for the identification and monitoring of VMEs and EFH. They have been usually identified using scientific fishing campaigns (Giannoulaki et al. 2013b, Druon et al. 2015, Paradinas et al. 2015, Delahoz et al. 2018, Pennino et al. 2020) and non-invasive observation technology (Giakoumi et al. 2013, Chimienti et al. 2021), but local ecological knowledge can also be relevant (Bastari et al. 2022). In addition, statistical modelling efforts are frequently used to predict the distribution of VMEs and EFHs, and more recently, they include climate change projections (Morato et al. 2020, Bleuel et al. 2021, Izquierdo et al. 2021). However, in most cases, these identification and modelling exercises are limited by data availability and lack proper spatial and temporal resolution, and model validation is still very limited (but see Pennino et al. 2020, Paradinas et al. 2022).

One of the main bottlenecks is the fact that *in-situ* EO observations are, in general, difficult to access and in several regions not always freely available. Few examples of data from benthic scientific surveys are available and accessible through data servers such as EMODnet or ICES DATRA[90,91]. However, this data is not always complete and up to date, and in many cases does not include non-commercial species, which can be essential elements of VMEs.

Overall, a recent evaluation of data available in the Global Biodiversity Information Facility[92] in terms of marine biodiversity in European Regional Seas, highlights the current limitations (Ramírez et al. 2022). The availability of seasonal data is also important since it is evident from the literature that EFHs and VMEs can change seasonally and that the presence, abundance and biomass of marine organisms varies between seasons. In addition, temporal data is also needed since EFHs and VMEs can show inter-annual variability (Delahoz et al. 2018, Lloret Lloret et al. 2020, Vilas et al. 2020, Lloret-Lloret et al. 2021, Paradinas et al. 2022).

6.5.3 Value chain analysis and EO technical requirements of the use case

Usually, DG MARE does not process or make direct use of EO data, and it relies on third parties to process and analyse EO data and products. DG MARE mostly relies on syntheses, briefs and targeted assessments provided by technical implementing entities. There are, however, a variety of stakeholders that appreciate data provided through a platform, and a mixed approach can be ideal also for transparency. In this deep dive, from what has been described so far, EO requirements can be articulated into one use case related to MPAs and a second use case related to EFH and VMEs.

To assess the state and change of marine biodiversity and MPAs, data that has enough resolution in time and space is needed. However, at present, there are many knowledge gaps in data and products to monitor and assess marine biodiversity and MPAs state and change: satellite EO data is only partially available to support the analyses needed and collecting i*n-situ* data for marine biodiversity is very much needed but also quite expensive, while its integration is not always easy. Thus, DG MARE relies very much on model outputs. These model outputs can be very useful, but can have a high uncertainty and their validation and scaling to relevant spatial scales is a challenge.

Likewise, available products to monitor and model VMEs and EFH with a sufficient resolution and accuracy are mostly lacking. Spatial statistical modelling is frequently used to create predictions of habitat suitability and probability of occurrence of EFH and VMEs (e.g., Giannoulaki et al. 2011, Giannoulaki et al. 2013a, Giannoulaki et al. 2013b, Morato et al. 2020, Pennino et al. 2020, Bleuel et al. 2021, Izquierdo et al. 2021, Paradinas et al 2022). Although these exercises are useful to understand EFH and VMEs suitability under different climate regimes, these approaches do not frequently include data with enough spatial and temporal resolution to enable updates and validation.

90 https://datras.ices.dk/
91 https://www.emodnet-biology.eu/data-catalog?dasid=5760
92 https://www.gbif.org/

An overview of EO products requirements in terms of spatial and temporal resolution can be derived from the information collected during the "Copernicus biodiversity in coastal ecosystems" workshop[93] held on 11 and 12 October 2022. In this workshop, several products related to the monitoring and assessment of marine biodiversity and MPAs were identified and listed, as well as products related to the monitoring and assessment of VMEs and EFHs (Table 10). These requirements can inform future development of satellite and *in-situ* EO products to fulfil the community needs.

[93] https://marine.copernicus.eu/events/copernicus-biodiversity-coastal-ecosystems-workshop

Table 10. EO products performance requirements, collected during the Copernicus biodiversity in coastal ecosystems workshop, directly related to marine biodiversity and MPAs (use case 1), and VMEs and EFH (use case 2). The original table from the workshop has been modified, rearranged and additional information has been added to provide relevant information for the analysis of both use cases. Spatial resolution refers to pixel size needed to assess the specific variables.

Ecosystems and species requiring EO improvements	Spatial resolution	Temporal resolution	Relevance to use cases (1 & 2)
Marine life (consumers)			
Anchovies	<1-5 hectares	Monthly; Annual; Seasonal; every 2 years; every 5 years; early warning on automated detection	1, 2
Balearic shearwater	<1 hectare	Monthly; Annual; Seasonal	1
Benthos	<1-5 hectares	Monthly; Annual; Seasonal	1, 2
Birds	<1-5 hectares	Monthly; Annual; Seasonal	1
Commercial species	<1-5 hectares	Monthly; Annual; Seasonal; every 2 years; every 5 years; early warning on automated detection	1, 2
Deep corals	1 hectare	Annual; early warning on automated detection	1, 2
Fish	<1-5 hectares	Monthly; Annual; Seasonal; every 2 years; every 5 years; early warning on automated detection	1, 2
Green sea turtle	<1 hectare	Monthly; Annual; Seasonal	1
Marine mammals	<1-5 hectares	Monthly; Annual; Seasonal; every 2 years; every 5 years; early warning on automated detection	1
Mediterranean monk seals	<1 hectare	Monthly; Annual; Seasonal	1
MPA species	<1-5 hectares	Monthly; Annual; Seasonal; every 2 years; every 5 years; early warning on automated detection	1
Pinna nobilis	<1 hectare	Monthly, Seasonal	1, 2
Ringed plover (*Charadrius hiaticula*)	<1 hectare	Weekly; Monthly; Annual; Seasonal	1
Salmon, cod, shrimp, eel, crab, sea urchin	<1 hectare	Weekly; Monthly; Annual; Seasonal	1, 2
Sea turtles	<1 hectare	Monthly; Monthly; Annual; Seasonal	1
Species on the move	<1 hectare	Weekly; Monthly; Annual; early warning on automated detection	1, 2
Sturgeons	<1-5 hectares	Weekly; Monthly; Annual; Seasonal; every 2 years; every 5 years; early warning on automated detection	2
Zooplankton	<1 hectare	Monthly; Annual; Seasonal	1
Marine life (producers)			
Aquatic plants	1-5 km²	Seasonal	1, 2
Cymodocea	<1 hectare	Monthly	1, 2
Phytoplankton	<1 hectare	Monthly; Annual; Seasonal	1, 2

Ecosystems and species requiring EO improvements	Spatial resolution	Temporal resolution	Relevance to use cases (1 & 2)
Posidonia	<1-5 hectares	Monthly; Annual; Seasonal	1, 2
Sea lettuce (*Ulva lactuca*)	<1 hectare	Monthly; Annual; Seasonal	1, 2
Seabed vegetation	<1 hectare	Seasonal	1, 2
Seagrass	<1-5 hectares	Monthly; Annual; Seasonal; early warning on automated detection	1, 2
Seaweed	<1 hectare	Monthly	1, 2
Vegetation mapping	<1 hectare	Annual	1, 2
Species maps	<1-5 hectares	Monthly; Annual; Seasonal	1, 2
Ecological and environmental variables			
Biogeochemical trends	<1 hectare	Weekly; Monthly; Annual; Seasonal	1, 2
Coral, coralligenous	<1 hectare	Monthly; Annual; Seasonal	1, 2
Deep environments	1 hectare	Annual; early warning on automated detection	1, 2
EBV	<1 hectare	Weekly; Monthly; Annual; Seasonal	1, 2
Ecosystem valuation and accounting	<1-5 hectares	Every 2 years	1, 2
Eel grass meadows	<1-5 hectares	Annual; every 2 years	1, 2
Estuaries	<1 hectare	Weekly; Annual; Seasonal	1, 2
Habitats	<1-5 hectares	Seasonal; Annual	1, 2
Intertidal imagery	<1 hectare	Weekly; Monthly; Seasonal	1, 2
Maërl community	<1-5 hectares	Monthly; Annual	1, 2
Mangroves	1 hectare	Monthly; Annual; early warning on automated detection	1, 2
Offshore shoals	1 hectare	Monthly; Seasonal; Annual; early warning on automated detection	1, 2
Reef	1 hectare	Seasonal; Annual; early warning on automated detection	1, 2
River deltas	<1-5 hectares	Annual; Seasonal	1, 2
Saltmarshes	<1 hectare	Weekly; Monthly; early warning on automated detection	1, 2
Seascape pelagic habitats	<1-5 hectares	Weekly; Monthly; Seasonal	1, 2
Shorelines including deltas	<1-5 hectares	Annual; Seasonal	1, 2
Soft coasts	<1 hectare	Weekly; Monthly; Annual	1, 2
Sub-tidal habitats and intertidal	<1-5 hectares	Weekly; Monthly; Annual	1, 2
Wetland	<1 hectare	Seasonal; Annual	1, 2
Human activities: pressures and impacts			
Eutrophication impact	<1 hectare	Seasonal; Monthly	1
Gridded fishing pressure	1 hectare	Monthly; Annual	1, 2
Habitat degradation	<1-5 hectares	Monthly; Annual	1, 2
Oil spill	<1-5 hectares	Weekly; Monthly; Annual	1, 2
Plastic littering	<1 hectare	Monthly; Seasonal; Annual	1

Ecosystems and species requiring EO improvements	Spatial resolution	Temporal resolution	Relevance to use cases (1 & 2)
Pollution from rivers to sea	1 hectare	Seasonal; Annual	1, 2
Sand deposition	<1 hectare	Monthly; Seasonal; Annual	1, 2
Sand excavation impact	<1 hectare	Seasonal; Annual	1, 2
Sea level rise impact	<1-5 hectares	Weekly; Monthly; Annual; Seasonal; every 2 years; every 5 years; early warning on automated detection	1, 2
Sediment transport	<1-5 hectares	Weekly; Monthly; Annual	1, 2
Urbanization pressure	1 hectare	Seasonal; Annual	1, 2

6.5.4 Fitness for purpose of existing EO products and services

Main relevant data sources, services and products are summarised in what follows. Further descriptions and specifications of Copernicus products mentioned are provided in Annex 4.

It is important to recall that for the assessment of fitness for purpose the key aspects of uncertainty and accuracy, ratings of the overall quality of EO products, could not be considered and no recommendations could be made in this respect,

European Marine Observation and Data Network (EMODnet)

In-situ marine data and observations in Europe, through the European Marine Observation and Data Network (EMODnet), includes data on bathymetry, biology, chemistry, geology, human activities, physics and seabed habitats, products that are based in many cases on statistics and models. Some relevant products regarding MPAs, EFHs and VMEs of EMODnet are:

- EMODnet Biology[94]: the Atlas of Marine Life is a data portal that showcases available data on species occurrence, abundance and distributions by taxa within European Seas, including information on EFHs from commercial species (e.g., nursery areas, spawning areas). This portal also includes information about primary production data that can be related to biodiversity metrics and fisheries productivity.
- EMODnet Seabed habitats[95]: includes a diversity of seabed habitats and associated datasets covering European Seas, including data on VMEs such as coralligenous communities, maërl and seagrasses. VMEs could be especially relevant to define Fisheries Restricted Areas or other types of fisheries spatial management measures that explicitly recognize the value of biodiversity of key demersal components (e.g., coralligenous species and communities and other habitat forming species).
- EMODnet Physics[96]: a variety of environmental layers and maps are available, including temperature, salinity, winds and underwater noise, which can be related to biological data and are relevant in the implementation of marine ecosystem models and statistical modelling techniques.
- EMODnet Human activities[97]: a variety of human activity datasets and spatial layers are listed, including aquaculture, fisheries, shipping density, wind farms, and management activities such as Nationally Designated areas and Natura 2000 sites.

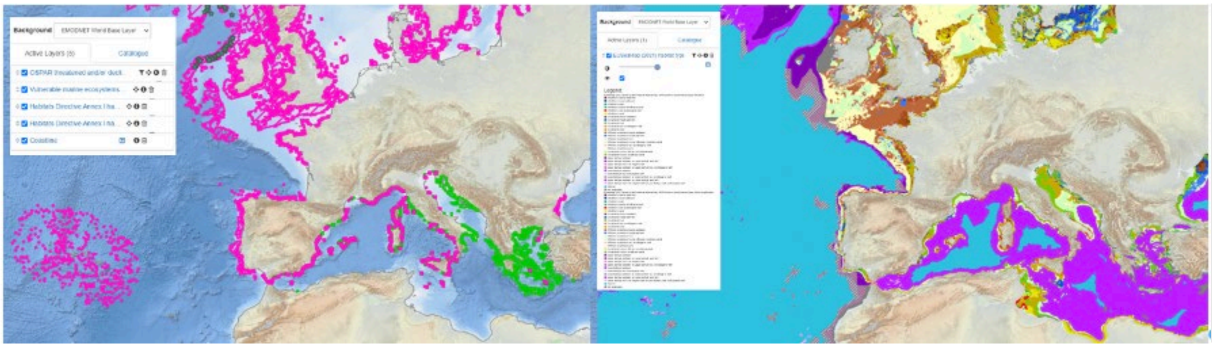
Overall, compared with data requirements in Table 1, available data from EMODnet frequently have partial coverage of European Seas, spatial resolution is variable and temporal resolution is low. Another important issue is the access to *in-situ* EO observations produced within Member States. For example, outputs of scientific campaigns to monitor the state of marine biodiversity are not accessible: e.g., this is the case of the acoustic MEDIAS campaigns (Giannoulaki et al. 2021, Leonori et al. 2021) that monitors marine pelagic resources, or the MEDITS demersal resources campaign (Bertrand et al. 2002, Spedicato et al. 2019) that monitors benthic and demersal marine life, both funded with EU funds to collect information in the

[94] https://emodnet.ec.europa.eu/en/biology
[95] https://emodnet.ec.europa.eu/en/seabed-habitats
[96] https://portal.emodnet-physics.eu/
[97] https://www.emodnet-humanactivities.eu/

Mediterranean Sea. In situ observations could be provided through EMODnet with the spatial and temporal resolution needed to be of use for marine biodiversity assessments.

Within EMODnet, promising initiatives are taking steps in the right direction, integrating and visualizing multiple spatial datasets[98]. For example, the EMODnet Seabed habitats[99] provides access to seabed habitat data in Europe. This includes new products such as the EMODnet broad-scale seabed habitat map for Europe (EUSeaMap) and habitat maps and observations gathered from surveys across Europe (Figure 16).

Figure 16. European Marine Observation and Data Network (EMODnet) Seabed habitats capabilities (source: https://emodnet.ec.europa.eu/en/seabed-habitats).



Copernicus Marine Service (CMEMS)

The Copernicus Marine Service (CMEMS) provides free and open data and services related to the marine environment with the final goal to "enable marine policy implementation, and support Blue growth and scientific innovation"[100].

The Ocean Products[101] and Ocean Monitoring Indicators[102] include a series of ocean data and model outputs (hindcasts/reanalysis, nowcasts and forecasts) and are available through MyOcean[103] viewer and WeKO[104]. Some of these EO products and data can be useful to contribute to the monitoring of marine biodiversity and MPAs and come from satellite and *in-situ* EO observations and numerical models. The catalogue of products and indicators is available online[105] and a selection of products relevant for the use cases of DG MARE are listed in Annex 4. Ocean monitoring indicators are organized in four main topics: Ocean Circulation, Ocean Climate, Ocean Variability and Extremes, and Ocean Health, and include indicators such as Sea Surface Temperature, Marine Heat Waves or Coral Health.

A list of collaborative applications, some of them relevant for the topic of this deep dive, are also available online as bottom-up initiatives from the scientific community and practitioners with CMEMS[106]. These case studies are downstream applications where data is produced by both CMEMS and a complementary application. For example, the *Marine Analyst*[107] is a web service for augmented data access and reproducible data analysis based on computational notebooks. It provides an easier access to a wide variety of marine data for Europe, processing of comprehensive analyses and advanced use cases for specific areas of interest on climate change, renewable marine energy, MSFD, MSP, etc. Data providers are CMEMS, EMODnet Bathymetry, Geology, Physics, EEA/WISE MARINE[108] and Eurostat, among others. The Marine Analyst is a relevant environmental assessment tool for the European seas and World Ocean.

[98] https://emodnet.ec.europa.eu/geoviewer/
[99] https://emodnet.ec.europa.eu/en/seabed-habitats
[100] https://marine.copernicus.eu/
[101] https://data.marine.copernicus.eu/products
[102] https://marine.copernicus.eu/access-data/ocean-monitoring-indicators
[103] https://data.marine.copernicus.eu/viewer/expert
[104] https://www.wekeo.eu/
[105] https://marine.copernicus.eu/access-data/ocean-monitoring-indicators
[106] https://marine.copernicus.eu/services/use-cases
[107] https://marine.copernicus.eu/services/use-cases/open-data-marine-knowledge-service-augmented-data-access-and-reproducible-data
[108] https://water.europa.eu/marine

Another example is *T-MEDNet*[109], an initiative that aims to set up a fully operative and cost-effective Marine Protected Area climate change observation network in Mediterranean coastal ecosystems, based on collaborative approaches. Its mission is to foster pan-Mediterranean cooperation and support climate change monitoring, build databases, facilitate data and information sharing and capacity building and contribute to national, regional and international monitoring and reporting activities. Additional examples with both EMODNet and CMEMS can be found online (such as CEOS[110], Cadeau project[111], and OCEANA[112]). Some case studies have been developed with the aim to support MSFD policy although they are not related to the aims of this deep dive.

In spite of the potential of CMEMS, available EO products are currently somewhat sparse and difficult to comprehensively map and navigate, although the new capabilities gained with MyOcean viewer and the different versions available (Light, Learn and Pro) have contributed to solve this challenge. The Service appears to be shaped for intermediate users with specific expertise, for a larger public it may be still challenging to understand how to use them for the purpose of both use cases investigated in the deep dive. In addition, the use of EO products from CMEMS include technical challenges that can prevent users from maximising their utility (such as harmonizing spatial and temporal data needs with data products available, or depth resolutions needed).

CMEMS numerical models[113] and future marine ecosystem models aim to better describe the food webs and fisheries displacements caused by climate change and/or other environmental conditions (favourable/unfavourable). There is currently one project started in January 2023 (NECCTON[114], New Copernicus Capabilities for Trophic Ocean Networks), which is dedicated to the development of future services in CMEMS related to marine biodiversity conservation, by advancing marine ecosystem modelling, forecasting and projection (including biogeochemistry, organisms placed at different trophic levels and models that can better describe and forecast species distributions and habitats depending on environmental conditions and climate scenarios). The project includes thirteen case studies focussing on MPAs planning and monitoring and fisheries management. These modelling initiatives, in addition to the European DTO and the MSFD Modelling Framework (see below) can become very relevant to provide biodiversity related products and information within DG MARE activities. Future actions aim to be dedicated to biodiversity and marine ecosystems focussing on observations and models to better understand and describe food webs and the lower-/mid-/upper- trophic levels.

European Digital Twin of the Ocean (DTO)

As part of the Horizon Europe Mission, the DTO[115] will be based on the already existing marine knowledge assets of the European Commission (CMEMS, EMODnet, Marine Research Infrastructures) and will require enriched marine biodiversity observations (satellite Earth Observation and *in-situ* data) to sufficiently support research, policy, blue economy and societal engagement. The EU DTO is aimed to provide new alternatives in how to work with marine observations, and closer to the users, including policy. For the DTO to reach its highest potential, EO of the marine environment, especially regarding biodiversity, should evolve to cover known knowledge gaps to achieve completeness and allow validation of products in European Seas.

MSFD Common Implementation Strategy (CIS) support

Through the MSFD Common Implementation Strategy (CIS)[116], EU Member States committed to provide assessments of their marine environment, based on monitoring plans and agreed assessment methodologies. These are then the basis for implementing mitigation and restoration measures where Good Environmental Status has not yet been reached. Monitoring and assessments are organised through specific Descriptors including pelagic and seafloor biodiversity, pelagic and seafloor, as well as marine food webs. Anthropogenic pressures are addressed by Descriptors on Alien Species, Fisheries, Eutrophication, Hydrographic Conditions,

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[109] https://marine.copernicus.eu/services/use-cases/t-mednet-tracking-effects-climate-change-mediterranean
[110] https://marine.copernicus.eu/services/use-cases/ceos-ocean-variables-enabling-research-and-applications-geo-coverage
[111] https://marine.copernicus.eu/services/use-cases/northern-adriatic-sea-water-quality-aquaculture-and-tourism-sectors-cadeau
[112] https://marine.copernicus.eu/services/use-cases/oceana-marine-expeditions-fill-key-gaps-biodiversity-data
[113] https://data.marine.copernicus.eu/products?facets=sources%7ENumerical+models
[114] www.neccton.eu
[115] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters/european-digital-twin-ocean-european-dto_en#what-is-the-european-digital-twin-of-the-ocean
[116] https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/pdf/MSFD%20CIS%20future%20work%20programme%202014.pdf

Contaminants, Litter, Noise and other Energy. MPAs play an important role for the MSFD as they are focal points for combined key mitigation measures in one area or in a network of spatially connected MPAs.

Efforts under the MSFD are underway to enhance accessibility of data from different sources, enabling their use for MSFD assessments, as well as data sharing in close collaboration with the Regional Sea Conventions around EU. This includes data from national monitoring efforts, data derived from large scale research projects as well as data from multinational efforts, also related to the management of MPAs.

The use of emerging EO methodologies, based on new technologies, such as *in-situ* image-based monitoring combined with artificial Intelligence, airborne or underwater, have potential to provide access to new types of datasets.

The JRC is supporting the MSFD implementation by operating networks of MS experts for bi-directional exchanges and providing fora for agreement on harmonised approaches based on scientific knowledge. The EEA is directly involved in MSFD reporting through WISE marine and MSFD dashboard, and in the production of integrated spatial analysis of cumulative pressures and combined effects.

MSFD Modelling Framework

The MSFD modelling framework[117] has been developed by the JRC upon DG ENV request and offers end-to-end modelling to represent large parts of the marine ecosystem by including the most relevant processes in the ecosystem, from physics to chemistry, and plankton to fish and human activities. This system is explicitly linked to descriptors of the MSFD and four types of models are incorporated into a single modelling framework/toolbox: (a) Hydrological models that provide information on river discharge in terms of flow and nutrients; (b) Hydrodynamic models (that simulate marine water transport); (c) Lower-trophic-level biogeochemical models (including phytoplankton and zooplankton); and (d) Higher-trophic-level food-web models (from phytoplankton to marine mammals/seabirds), including fisheries.

The models considered are aligned for comparison with policies, e.g. higher-trophic-level food-web models with biodiversity policies, which can be highly relevant to assess MPA performance and contributions to fisheries sustainability. An example for the Mediterranean Sea already exists (Piroddi et al. 2021, Piroddi et al. 2022). If models incorporate reliable data, DG MARE could adapt the stock assessments models towards ecosystem models or link both approaches using different approximations, something the research community and DG MARE have been analysing for some time (Bentley et al. 2021, Pennino et al. In press).

Although these models do not fully include VMEs and have not yet been used to assess MPAs, they do include EFHs and can be improved in the future to explicitly represent VMEs and their ecological roles in space and time. The assessment of these models with EO in situ observations to validate modelling results, and the use of satellite EO products to drive environmental dynamics and human activities as drivers of change, are key methodological challenges that the scientific community is trying to address and need further resources to progress (Steenbeek et al. 2021).

JRC initiatives: species habitats, marine fronts, European Alien Species Information Network (EASIN) and Marine Information Systems (EMIS and GMIS)

Several additional JRC initiatives regarding data analysis and modelling have resulted in relevant products about the distribution of key marine species (cetaceans, commercial species) and marine productivity fronts and zooplankton that may be of interest for specific analyses regarding MPAs and biodiversity monitoring[118]. They include the mapping of nursery areas of European hake *Merluccius merluccius* (Druon et al. 2015) (Figure 17), the feeding and spawning habitats of Atlantic Bluefin tuna *Thunnus thynnus* (Druon et al. 2011, Druon et al. 2016) and the feeding grounds of fin whales *Balaenoptera physalus* (Druon et al. 2012). Results from these initiatives are available but difficult to discover online and their use is not always straightforward.

Alien species are non-native organisms that establish in a new environment. Some of them may become invasive species and can affect native biodiversity and ecosystems and social well-being. Others may have commercial interest and become exploited, or may affect commercial species. EASIN facilitates information on Alien Species and officially supports the EU Regulation 1143/2014[119]. The EASIN server includes search

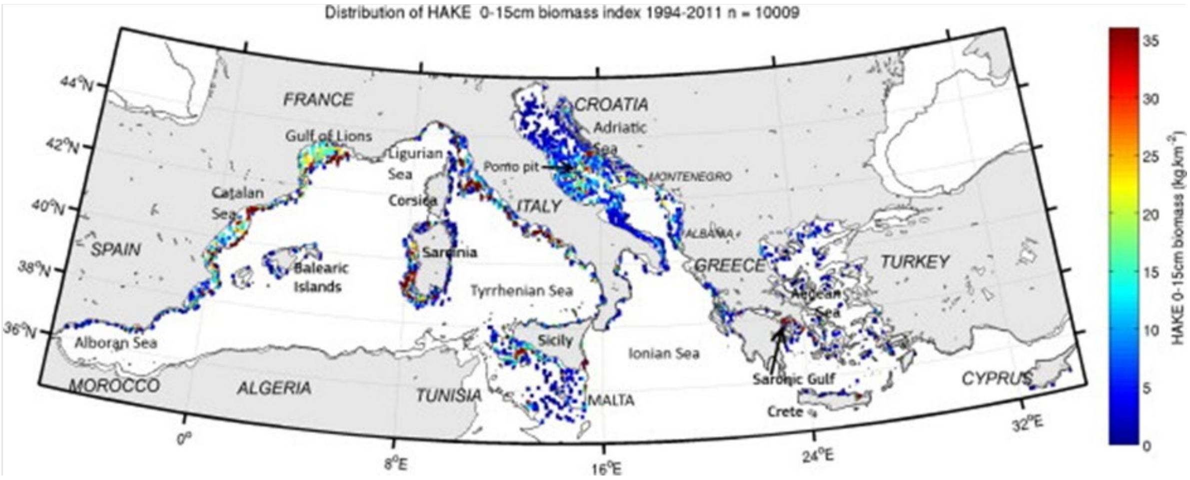
117 https://mcc.jrc.ec.europa.eu/main/dev.py?N=simple&O=11&titre_page=MSFD%20Modelling%20Framework&titre_chap=MODELLING

118 https://data.jrc.ec.europa.eu/dataset?contributor=Druon%20Jean-Noel

119 https://easin.jrc.ec.europa.eu/easin/

and mapping tools that allow the exploration of the EASIN Catalogue including impact, level of concern, partly native in Europe, alien status, type of environment, taxonomy and pathways. The occurrence and abundance of alien species in MPAs can be of interest within the European Biodiversity Strategy, and could be of importance if those alien species can become commercially relevant or can be threats to endemic or commercial species. However, data available is currently limited in terms of spatial resolution to be useful in MPA monitoring activities and its accessibility is challenging for the general users.

Figure 17. Mean biomass of 0-group hake (TL < 15 cm) from the 1994 to 2011 annual MEDITS campaigns (Druon et al. 2015).



Additionally, past JRC initiatives such as the Environmental Marine Information System (EMIS)[120] and Global Marine Information System (GMIS[121]) were interesting to facilitate discovery and access of scientific and technical environmental products, such as satellite remote sensing data, and relied on biological and physical variables generated from both hydrodynamic models and satellite remote sensing and/or numerical modelling. These initiatives have been discontinued, despite their usability for the general community.

BlueHub EU project

Through the EC BlueHub project[122], relevant information can be found on European Regional Seas, such as the Automatic Identification System (AIS) fishery footprint[123] and MSP processes related information[124].

Currently, the access to the complementary Vessel Monitoring System (VMS)[125] and logbook data is very restricted by Member States. This and similar EU initiatives should move towards making additional data, such as fishing effort data, fully available to develop spatial analyses[126]. This data is of special relevance to assess fishing impact within MPAs and other spatial management areas and to plan for the conservation and management of EFHs and VMEs.

EU H2020 and Missions research projects

Several past, ongoing and future research EU projects produced or will produce highly relevant biodiversity data that can inform marine biodiversity assessments of MPAs, VMEs and EFHs.

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120 https://joint-research-centre.ec.europa.eu/scientific-tools-and-databases/environmental-marine-information-system-emis_en
121 https://joint-research-centre.ec.europa.eu/scientific-tools-and-databases/global-marine-information-system-gmis_en
122 https://bluehub.jrc.ec.europa.eu/
123 https://maritime-spatial-planning.ec.europa.eu/practices/mapping-fishing-activities
124 https://maritime-spatial-planning.ec.europa.eu/
125 https://eur-lex.europa.eu/EN/legal-content/summary/satellite-based-vessel-monitoring-system-vms.html
126 https://globalfishingwatch.org/faqs/what-is-vms/

Some examples of these projects include: MEDISEH[127], CERES[128], MERCES[129], DEVOTES[130], FutureMares[131], AtlantECO[132], EcoScope[133], Marbefes[134], Ges4Seas[135], MarinePlan[136], MarineSABRES[137], and others starting (NECCTON[138], OBAMA-Next[139], MSP4BIO[140], BlueMission, BIOcean5D[141] and ActNow[142]).

However, the harmonization of data gathered and produced during research EU projects in not easy to access and discovery of the data is challenging. There are some upcoming initiatives trying to improve the situation in this regard, such as the new upcoming Horizon project MARCO-BOLO[143]. In the context of the HORIZON Mission on Ocean and Water, dedicated studies on the Monitoring of Marine Biodiversity and on its harmonisation, are exploring the readiness of the current systems for providing data to support the implementation such as the MSFD.

ISIMIP/FishMIP initiative

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP[144]) and, within it, the Fisheries and Marine Ecosystem Model Intercomparison Project (FishMIP[145]), brings together disparate marine ecosystem models to help better understand and project the long-term impacts of climate change on fisheries and marine ecosystems, and to use our findings to help inform policy. Questions targeted are related to fish and fisheries, seafood supply, marine biodiversity and marine ecosystem function. The application of FishMIP includes global and regional analyses covering several European Seas and can be relevant to provide specific products for DG MARE.

Under this initiative, standardized datasets are available to the users (both as inputs and outputs of models)[146], but their manipulation and use is a challenge to many users due to the technical skills required. In addition, the global models developed under this initiative have a coarse resolution and have limited interest for regional analysis, while the regional models are not standardized in terms of structure and regional comparisons are limited by this lack of standardization.

Global Fishing Watch initiative and satellite radar imagery

The Global Fishing Watch initiative (GFW[147]) is an open-access online platform for visualization and analysis of vessel-based human activity at sea, including fishing activity, encounters between vessels, night light vessel detection and vessel presence.

Specifically relevant can be the satellite radar imagery, a technology currently expanding for fisheries applications and allowing documenting previously unseen fishing patterns around the world, including European waters[148]. This new technology, known as synthetic aperture radar (SAR), is based on the use of recently available satellite radar imagery and artificial intelligence, functions day and night in all types of weather and can generate imagery despite cloud cover or storm systems, resulting in detection capabilities that are significantly advanced over other satellite-mounted sensors, to reveal vessels at sea. Interesting

127 https://imbriw.hcmr.gr/mediseh/
128 https://ceresproject.eu/
129 http://www.merces-project.eu/
130 https://mcc.jrc.ec.europa.eu/main/dev.py?N=simple&O=309&titre_page=DEVOTES
131 https://www.futuremares.eu/
132 https://www.atlanteco.eu/
133 https://ecoscopium.eu/
134 https://cordis.europa.eu/project/id/101060937
135 https://www.ges4seas.eu/
136 https://www.marineplan.eu/
137 https://www.marei.ie/project/marinesabres/
138 www.neccton.eu
139 https://obama-next.eu/
140 https://msp4bio.eu/
141 https://www.biocean5d.org/
142 https://www.nioz.nl/en/news/eu-horizon-europe-funding-for-actnow-project
143 https://cordis.europa.eu/project/id/101082021
144 https://www.isimip.org
145 https://www.isimip.org/about/marine-ecosystems-fisheries/
146 https://data.isimip.org/
147 https://globalfishingwatch.org/
148 https://globalfishingwatch.org/press-release/technology-highlights-hidden-vessels/

products are already available for specific European regional seas, such as the Mediterranean[149], and comparing fishing activity and MPAs[150].

A promising initiative that is taking steps to integrate and visualize multiple spatial-temporal datasets is the marine manager portal of the Global fishing Watch initiative[151]. This initiative allows, for specific regions, to visualize MPAs, human activities (such as fishing) and climate change together (Figure 18), and include non-broadcasted fishing activity.

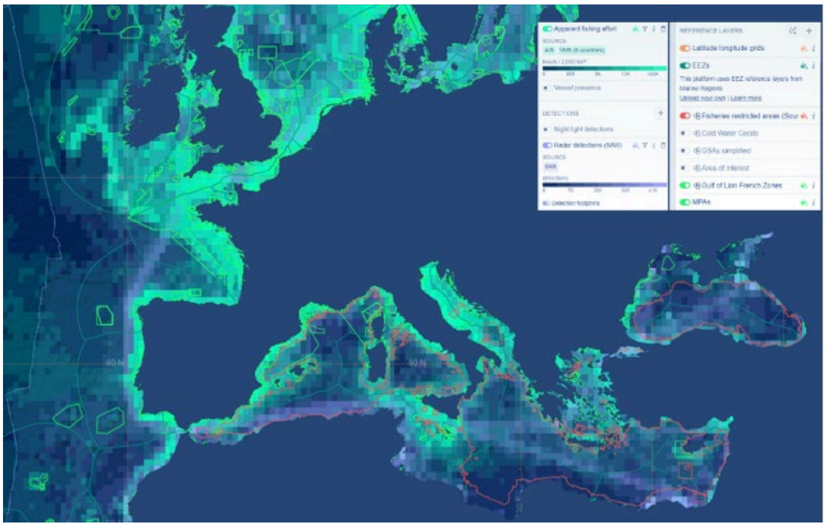


Figure 18. Options to visualize multiple data layers within the Marine Manager of Global Fishing Watch (source: https://globalfishingwatch.org/map/marine-manager).

Currently, some countries have provided access to the complementary Vessel Monitoring System (VMS) through GFW[152], which is needed to complement the available picture about fishing activity in the ocean, including in the EU Regional Seas. However, VMS data is not provided by many countries and the temporal resolution of the GFW data is limited to recent years.

MSFD and MSP initiatives of EU Member States

The MSFD is producing important amounts of data, in some cases spatial, which are being used within the MSP process to progress towards the achievement of Good Environmental Status (GES), the identification of deficiencies in the marine environment and the action towards pressures through mitigation measures. Under MSP initiatives, Member States of the EU are currently developing their initial marine spatial plans[153]. These plans represent a large effort within countries to harmonize and integrate available spatial data to contribute to the marine and maritime spatial planning. It is thus expected that these efforts will deliver novel data servers and portals that will provide relevant information in an integrative way, allowing users to obtain data on biodiversity indicators and stressors.

An example of such tools is the Spanish Marine Geographic Information Viewer or "*Visor de Información Geográfica Marina*"[154] that integrates the data generated under MSFD and MSP in the country (Figure 19 and Figure 20), including VME data. Currently, these efforts are still limited in terms of spatial and temporal resolution of the data, and data documentation within the visualization efforts is limited. In addition, in situ EO data produced by Member States is not available through these efforts yet.

149 https://globalfishingwatch.org/data/radar-illuminated-ocean/
150 https://globalfishingwatch.org/marine-protected-areas/
151 https://globalfishingwatch.org/map/marine-manager
152 https://globalfishingwatch.org/faqs/what-is-vms/
153 https://maritime-spatial-planning.ec.europa.eu/countries-overview
154 http://www.infomar.miteco.es/visor.html

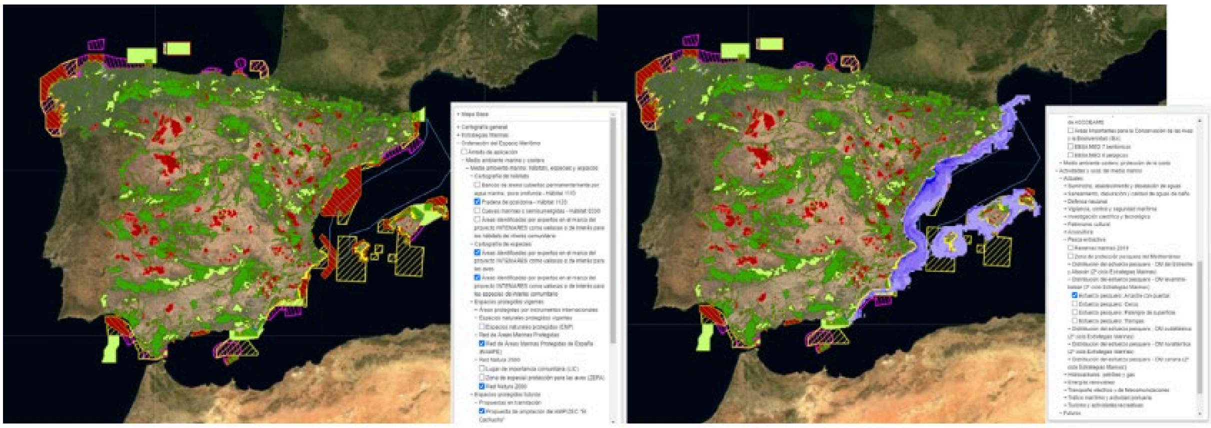


Figure 19. Options to visualize multiple data layers within the Spanish Marine Geographic Information Viewer (http://www.infomar.miteco.es/visor.html), including MPAs (use case 1).

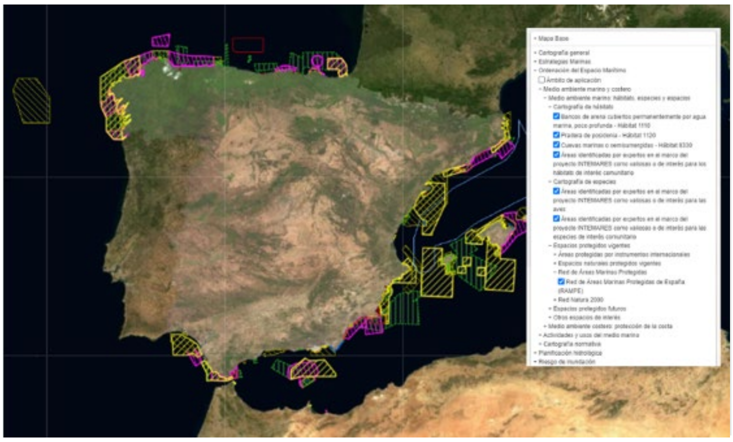


Figure 20. Options to visualize multiple data layers within the Spanish Marine Geographic Information Viewer related with VMEs (http://www.infomar.miteco.es/visor.html) (use case 2).

Global online databases and initiatives

Numerous additional data providers and data servers with a global scope produce relevant information around the topic of marine biodiversity, including EFHs and VMEs, and MPAs monitoring and assessment. Some of the most relevant ones are:

- **GBIF**[155] is a data server related to biodiversity data. Many marine species are included and occurrence data can be extracted. The data server is updated regularly and advanced users can access and download the data using automated queries.
- **AquaMaps**[156] provides information about species distributions of marine life, including future projections. Data access is easy but spatial and temporal resolution is low. The update of these products is not regular and projections to the future are limited regarding temporal resolutions.
- **Movebank**[157] is a data server to track movement of relevant species from a biodiversity point of view. It can be used to assess locations of specific species and the overlap of these species with high fishing intensity areas or MPAs. The discovery of data and access can be challenging for general users.
- **Marine Protection Atlas**[158] provides a global database of marine protected areas classified by their different types. Data available may not be up to date.
- **Protected Planet**[159] provides an up to date source of data on protected areas and other effective area-based conservation measures (OECMs). The usability of available data may be limited.
- **FAO Fisheries and Aquaculture data**[160] houses relevant information, including spatial distributions of commercial species[161]. Data access is limited and spatial and temporal resolution is low.
- **Sea Around Us project** data and services[162] can be relevant in some aspects of marine biodiversity and MPA assessments. However, data accessibility is limited and spatial resolution is low.
- **Global Human Impact Map**[163] provides global data on several impacts of humans in marine ecosystems. Spatial and temporal resolution is low.
- **MARSPEC**[164] and **BioOracle**[165] databases of environmental parameters and **NASA Earth Observation project**[166] are data portals that can be relevant to extract information about biogeochemical and physical properties of marine ecosystems and can be of use for species distribution models. Spatial and/or temporal resolution can be low.
- **Ocean InfoHub Initiative**[167], implemented by IOC/UNESCO, aims to facilitate access to global oceans information, data and knowledge products for management and sustainable development, supporting discovery and interoperability of existing information systems through the development of a lightweight Ocean Data and Information System (ODIS) architecture.
- The **IPBES core indicators**[168] select a series of indicators relevant at the UN IPBES framework that could be relevant within the EU context.

6.5.5 Conclusions and recommendations

We can conclude that there are several interesting initiatives and data regarding marine biodiversity knowledge in European waters, especially relevant for characterising MPAs, Vulnerable Marine Ecosystems (VME) and Essential Fish Habitats (EFH).

155 https://www.gbif.org/
156 https://www.aquamaps.org/
157 https://www.movebank.org/
158 https://mpatlas.org/
159 https://www.protectedplanet.net/en
160 https://www.fao.org/fishery/en/home
161 https://www.fao.org/figis/geoserver/factsheets/species.html
162 https://www.seaaroundus.org/
163 https://knb.ecoinformatics.org/view/doi:10.5063/F1S180FS
164 http://www.marspec.org
165 https://www.bio-oracle.org/
166 http://neo.sci.gsfc.nasa.gov
167 https://oceaninfohub.org/
168 https://ipbes.net/core-indicators-0

However, many gaps have been identified, even if current initiatives, such as EMODnet and Copernicus Marine Service, can meaningfully contribute to the needed knowledge. Overall, available EO products are only partially useful to support the analyses needed (Table 10), *in-situ* EO data for marine biodiversity is very much needed but its access is restricted, while satellite EO products discovery, access and integration is not always straightforward.

More specifically:

1) Several relevant data, data servers, products and initiatives exist, which are relevant to the monitoring of marine biodiversity and MPAs and to the assessment and management of VMEs and EFHs in European seas. However, an important limitation of the current capacity is the large dispersion of EO data and products available, with multiple and overlapping data servers that provide relevant (but partial and redundant) information, which are difficult to discover. Efforts to map, integrate and visualize multiple data are still limited in terms of their use to calculate informative indicators, their temporal dimension and their ability to incorporate the impacts of climate variability and change and human activities.

Available data should be further mapped, coordinated, improving the harmonisation of methodologies, optimizing resources and delivering clear and useful products. End users should be provided with clear options to discover and use the data, to decide which products are most useful for their needs.

2) The validation and integration of EO satellite, and *in-situ* products and modelling outputs is a challenge to be tackled and needs much more development in the future. Due to the nature of marine ecosystems and the difficulties to observe the ocean from space, to advance on this challenge, satellite imagery analysts, modellers and fieldwork researchers should work together towards fully validated and useful modelling products and indicators for the marine environment.

Within this topic, an important limitation in European research is the access to *in-situ* EO observations produced within Member States that can be used to validate other EO products and modelling outputs. Moreover, when data is accessible, analyses are mostly limited by the spatial and temporal resolution of the data. Producing and accessing *in-situ* data and its harmonization and regular integration with modelling and satellite EO products is a process that has started in the context of physical and biochemical parameters (such as temperature and chlorophyll), but that is still at its infancy when looking at other variables such as biodiversity indicators. The integration of Local Ecological Knowledge into these assessments can also be useful to capture data on non-commercial species (Maynou et al. 2011, Coll et al. 2014, Bastari et al. 2022).

3) Several future improvements are planned to advance on available products and their integration, bringing together satellite EO products with *in-situ* observations and modelling outputs. Future improvements of services, especially at the European Marine Observation and Data Network (EMODnet), at Copernicus Marine Service (CMEMS), and new initiatives such as Digital Twin of the Oceans (DTOs) and marine ecosystem modelling initiatives towards MSFD and MSP, could substantially improve the available products and advance on the challenges identified.

It is envisioned that these new initiatives may deliver, for example, (i) novel biogeochemical and biology *in-situ* and satellite EO products, (ii) advanced data assimilation techniques, (iii) new products from fully developed and validated ecosystem models, (iv) products to assess habitats for key protected species, (v) products from present and future sentinel mission and *in-situ* observations (hyperspectral ocean colour, acoustic data, plankton imaging, omics monitoring, fish surveys and fisheries statistics), and (vi) new capabilities to develop what-if-scenarios and project the future ocean under contrasting climate change scenarios. In addition, marine ecosystem modelling efforts, such as the ones developed by the EU (e.g., MSFD modelling framework NECCTON project), or scientific initiatives (e.g., FishMIP[169], SafeNet project (Gomei et al. 2021)) can also contribute to integrate available *in-situ* and satellite EO products and derive informative indicators. The numerous EU funded research projects can also play an important role and contribute to advance the identified challenges.

These future initiatives may cover the current gaps and allow the calculation of simple, informative and easy to communicate indicators to monitor marine biodiversity and MPAs with relevant in time and space resolution. However, an effort to map and simplify the choice of options to end users will become more urgent as new products and initiatives become available.

[169] https://www.isimip.org/about/marine-ecosystems-fisheries/

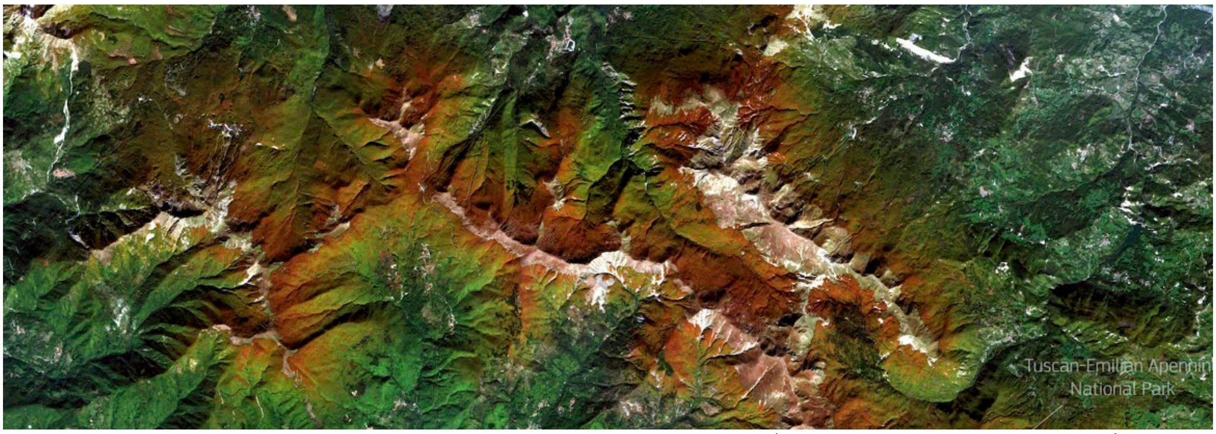
4) When the integration, harmonization and validation of satellite EO products and model outputs with *in-situ* data is achieved, informative indicators can be developed to track the state and change of marine biodiversity and MPAs.

Basic biodiversity and MPA indicators to use may include: (i) species richness hotspots, (ii) species mean abundance hotspots, (iii) surface of territory covered by fully protected or highly protected MPAs, (iv) overlap of species mean abundance and richness hotspots with fully protected and highly protected MPAs, (v) surface of territory covered by highly impacted areas, and (vi) overlaps between hotspots of biodiversity, protection and cumulative impacts. Candidate indicators related to VMEs and EFHs could be: (i) the surface or percentage of areas of VMEs and EFHs concentration, (ii) area covered by VMEs and/or EFHs that are fully or highly protected, (iii) area covered by VMEs and/or EFHs that are highly impacted by cumulative impacts, and (iv) areas VMEs and EFHs concentration that can may be climate refuges or conservation bright spots. These indicators are needed to inform EU policies. For example, they can contribute to track the progress of the EU Biodiversity Strategy for 2030[170], implemented by the Knowledge Centre for Biodiversity[171].

[170] https://dopa.jrc.ec.europa.eu/kcbd/actions-tracker/

[171] https://knowledge4policy.ec.europa.eu/biodiversity_en

6.6 Assessment and monitoring of EU forests health and disturbances (DG CLIMA)



Credit: European Union, Copernicus Sentinel-2 imagery

6.6.1 Policy context

Forests and other wooded lands cover almost 40% of the land area in the EU27 (Forest Europe, 2020). Forests are some of the most biodiverse ecosystems and at the same time provide a wide range of ecosystem services. They produce wood and non-wood products with a strategic economic and social relevance, remove and stock carbon dioxide and pollutants from the atmosphere, sequestering up to 60% of anthropogenic carbon emissions (Pan et al., 2011). Forests are relevant for purifying water, protecting against soil erosion and flooding, and serve as places of high recreational and spiritual value.

Sustainable forest management practices are aimed at managing and protecting forests maximising their multifunctional role in providing such a wide spectrum of ecosystem services. Forests have intrinsic regulating systems (based on resistance and resilience strategies) adapted to specific disturbance regimes. Climate change and other anthropogenic disturbances (such as urban sprawl, pollution and the alteration of fire regimes) are in turn reducing the capability of forest ecosystems to resist and react to disturbances, especially when different concurrent disturbances occur (Buma, 2015; Seidl and Rammer, 2017).

Especially increased drought and frequency and intensity of windstorms, heat waves in summer and frosts in late spring are increasing tree mortality (Allen et al., 2015; Senf et al., 2018). This has negative effects on the resilience capacity of forests to subsequent disturbances (Johnstone et al., 2016) such as wildfire and insect outbreaks (Jakoby et al., 2019; McDowell et al., 2020; Seidl et al., 2017). Some consequences are already visible, in Europe unprecedented bark beetle outbreaks are being registered (Sommerfeld et al., 2020).

Changes in forest health conditions have a dramatic impact on the functioning of the ecosystem and the services they provide; monitoring forest health is widely recognised as a priority.

The Food and Agriculture Organization of the United Nations (FAO) defines forest degradation as "changes within the forest which negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or services". In its Global Forest Resource Assessment, FAO suggests to monitor and report "forest health and vitality" globally and at country level based on the combined presence of abiotic and biotic stresses (FAO, 2020).

The Ministerial Conference on the Protection of Forests in Europe (MCPFE), also known as Forest Europe, recognised the importance of monitoring forests condition, introducing a full set of indicators related to forest health in the list of the Improved Pan-European Indicators for Sustainable Forest Management (MCPFE, 2002). Suggested indicators are related to: deposition of air pollutants, soil condition, defoliation and forest damage.

DG CLIMA has been directly involved in the development and implementation of the EU Biodiversity Strategy for 2030 as well as with the proposal of the Nature Restoration Law. While a high degree of biodiversity is a key factor for adaptation, we still need to better monitor and understand how ecosystems react to climate change, to help reduce their vulnerability, and improve their resilience and adaptive capacity. Pursuant to the

EU Climate Law[172] the collective progress made by MS in climate change mitigation and adaptation actions shall be assessed every 5 years starting in 2023.

Within this context, EU Member States require reliable forest health and condition monitoring, with adequate spatial and temporal granularity, transparent governance and coordinated exchange at EU level to deliver on EU objectives, especially on the European Green Deal's goals for the transition to a climate-neutral and circular economy, the adaptation of Europe's forests to climate change and the protection and restoration of biodiversity.

As announced in the EU Forest Strategy for 2030[173] the European Commission will "put forward a new legislative proposal on EU Forest Observation, Reporting and Data Collection to ensure a coordinated EU forest monitoring" in 2023. One of the guiding ideas is that of establishing an EU-wide integrated forest monitoring system, which combines the greater use of remote sensing technologies and geospatial data with ground-based monitoring. As part of FISE and based on improved Copernicus products and other remote-sensing and ground-based data, the monitoring of climate effects and other natural or human-induced disturbances on forests is intended to be strengthened.

Following the ecological, economic, and social relevance of forests, the global climatic trends and the increase of disturbances regimes, it is crucial to be able to count on a pan-European system for monitoring forest health condition (Jaime et al., 2022). Forest health condition monitoring should be intended as a key component for assessing biodiversity and its trend (Corona et al., 2011), thereby also informing specific restoration targets and supporting the restoration process for forest ecosystems and their biodiversity.

6.6.2 Description of the use case

The specific interest expressed by DG CLIMA for this use case is on the trends of forest health and forest disturbances in a rapidly changing climate. What is considered relevant in this respect is assessing whether, or to what extent, European forest are able to maintain ecosystem services in a changing climate, are resilient to disturbances, and are able to adapt well to new climatic conditions.

Within this frame, this use case explores how EO can support the monitoring of forest health and forest disturbances, recalling some of the approaches and products available with higher level of technology readiness, with a specific focus on satellite EO and Copernicus and how they could potentially contribute towards the setting up a pan-European, accurate and statistically rigorous system for monitoring forest health condition and for mapping forest disturbances in the EU.

Forest health refers to the overall condition of a forest ecosystem. A healthy forest ecosystem can maintain its ecological processes and sustain its biodiversity over time. At the scale of an individual tree, health can refer to the absence of disease or damage (Figure 21). However, as the scale shifts to a forest stand or a region, indicators of forest health become more complex to define and assess (Trumbore et al., 2015). Existing measures of forest health range from strictly utilitarian and related to local human needs, to more ecologically oriented definitions related to the persistence of forests or stands within a given landscape (Figure 21).

[172] COM (2020) 80
[173] COM (2021) 572

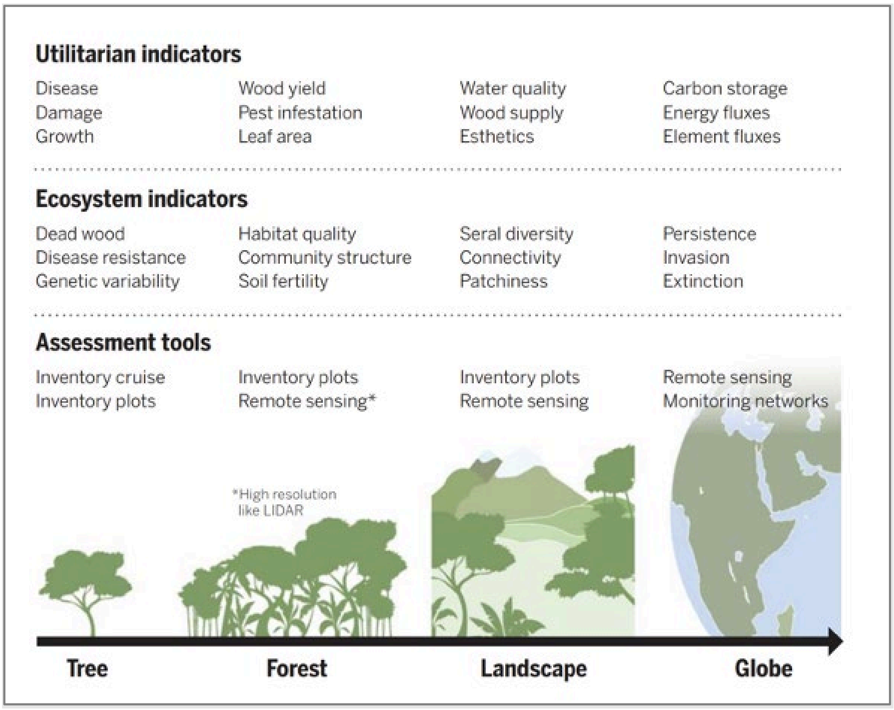


Figure 21. Examples of forest-health indicators for utilitarian and ecosystem-centred perspectives (from Trumbore et al., 2015)

It is widely recognized that satellite EO can provide useful information that can be combined with ground-based data for monitoring forest health conditions (Hirschmugl et al., 2017). As a matter fact, multiple approaches and EO methods exist for collecting data useful to assess indicators of forest health.

At ground level, methods are based on i) visual assessment of crown conditions or ii) measures made by instruments. Within the first group, various methods have been designed to standardise visual assessments of tree canopy transparency and discoloration. In Europe the most relevant ones are those developed by the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) (Ferretti et al., 2020). Regarding the second group, several instruments can be operated on the ground either with direct measurement of different variables or with proximal sensing. Terrestrial Laser Scanning (TLS) can be used to reconstruct the three-dimensional (3D) structure of the forest (Orwig et al., 2018). From TLS point clouds several indicators related to the canopy condition can be then calculated in an objective and repeatable way. A similar approach can be used when reconstructing 3D point clouds from Structure from Motion or with hemispherical photography (Moeser et al., 2014). Other optical instruments can be used to measure sub-canopy solar irradiance deriving direct estimation of important variables such as the Leaf Area Index (LAI) (Hardy et al., 2004). More recently data loggers like the “tree-talkers” or similar instruments can measure and transmit in real time multiple tree level variables such as diameter growth, solar energy quantity and quality penetrating through the crown, sap flow, etc. (Zorzi et al., 2021).

With satellite EO, crown conditions can be monitored by several different remote sensing instruments. Spectral reflectance in the visible bands were very useful for deriving an objective assessment of canopy health conditions since the pioneering applications of aerial photography after the WWII (Miller, 1963).

Instruments on board of satellite platforms are able to track directly (optical sensors), or indirectly (radar or LiDAR sensors), the photosynthetic activity of crowns, and many studies emerged to develop automatic, objective and replicable methods to detect the crown alteration from their normal undisturbed conditions in the last decades (Senf et al. 2017, Stone and Mohammed, 2017, Torres et al. 2021).

Disturbances can have different impacts on forest health conditions, they can alter the structure and function of a forest ecosystem. Natural disturbances, such as wildfires, insect outbreaks, and windstorms, have been occurring for millions of years and are a natural part of the ecosystem dynamics. However, human activities such as management, mining, land use change, can also cause forest disturbances that can have significant impacts on forest health. While in some cases disturbances can be beneficial for forest health by e.g., clearing out dead and dying vegetation and promoting new growth, in other cases they can be detrimental, altering negatively the forest structure and reducing its ability to provide ecosystem services.

Satellite EO data can be used to attempt classifying the type of disturbance. Stahl et al. (2023) recently reviewed these studies and proposed a common system for classifying forest disturbances. For automatically classifying disturbance types, long times series of land variables (have to be acquired and processed to reconstruct timing, intensity, duration, and recovery pattern of disturbances (Figure 22).

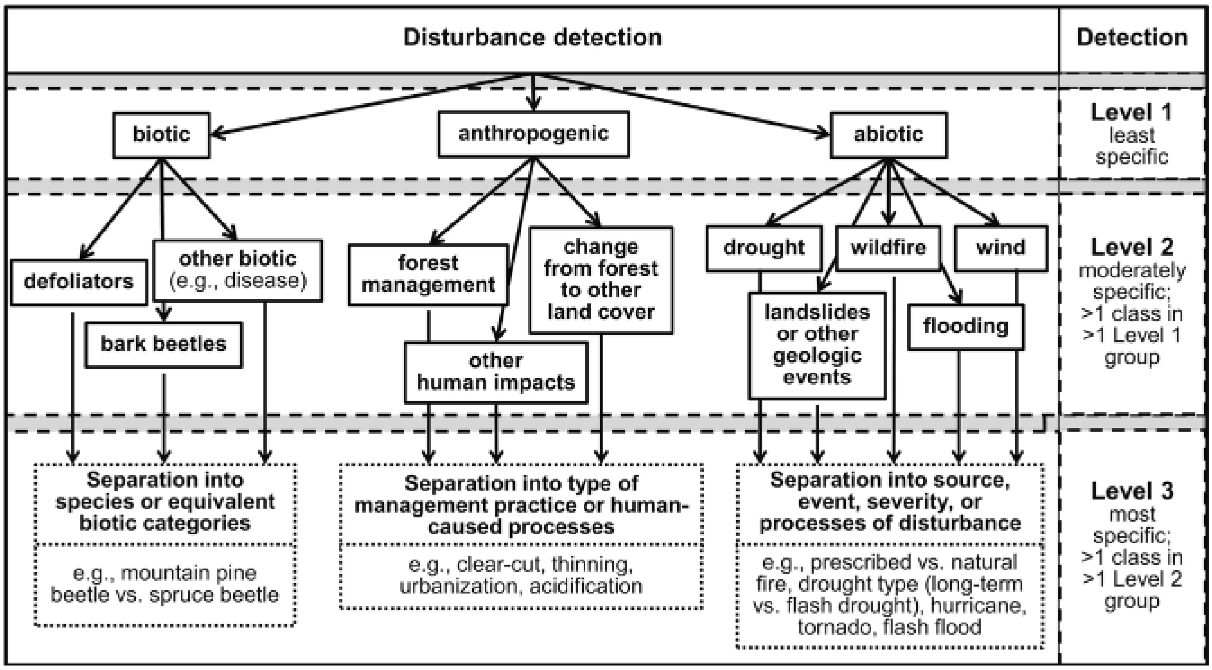


Figure 22. Types of forest disturbances (from Stahl et al., 2023).

The increase in openly available satellite imagery, improvements in computing power and the development of machine learning algorithms have resulted in an increasing number of studies aiming at detecting forest disturbances, quantifying their characteristics and classifying their sources (Zhu et al., 2020). Examples of wall-to-wall disturbance mapping are available globally (Hansen et al., 2013) and at pan-European level (Senf and Seidl, 2021). Stahl et al. (2023) includes a comprehensive review of such applications. Forest disturbance maps derived are also used to develop global spatial tools[174].

6.6.3 Value chain analysis and EO technical requirements

An essential step is the setting up of a reference forest map for EU27 to identify the spatial domain where the assessment has to be carried out with a spatial resolution a medium (100m) to high (10m) in any case comparable with the one used for monitoring forest health and an update frequency of 1-2 years. Also critical is mapping relevant forest types possibly beyond the simple conifer/broadleaved distinction, e.g., following the nomenclature of EEA (2006).

The EO products required for monitoring forest health depend very much on the scope of the assessment. For this use case, products that are worth considering include high-resolution multitemporal (multiannual and interannual) series of tree cover density, biophysical parameters such as phenology, primary productivity, LAI (Leaf Area Index), FAPAR (Fraction of Absorbed Photosynthetically Active Radiation).

[174] See for example the Global Forest Watch at https://www.globalforestwatch.org/

Mapping and classification of forest disturbances can be based on the analysis of multitemporal remotely sensed data, with an approach similar to the more general problem of forest phenology monitoring (see e.g. Cohen et al., 2010). This is because changes in forest conditions can be easily tracked by passive and active sensors wall-to-wall at pan-European level with high temporal frequency and high spatial details.

Satellite EO products must be then validated with field observations in sampled locations. Traditional ground-based methods based on observing plots in the field at fixed locations, such as those used in forest inventories or in ICP Forest, should be paired with system based on satellite EO, intended to identify areas where forest health condition is altered or affected by some kind of disturbance. The role of ground surveys should be focused on the one hand acquiring more detailed information and on the other hand validating early alert from remote sensing.

Forest disturbances should be ideally characterised by several attributes such as forest type, type of disturbance (see Figure 22), intensity, duration or recovery pattern. The changes in forest ecosystems caused by disturbances ultimately driven by climate change include products to support attribution such as irregular inundation, drought, fire, pest and disease outbreaks as well as nitrogen deposition.

Further to the assessment of forest health and forest disturbances, an additional step would be to try and better understand the linkages between forest biodiversity on the one hand, and forest vulnerability and resilience on the other hand. This implies assessing the impact of disturbances on forest ecosystem structure and forest ecosystem functions with indicators at stand or landscape level. Better knowledge in these fields can inform forest ecosystem restoration and adaptive forest management, helping to tackle uncertainties by regularly observing forest responses to interventions, evaluating these responses, and adjusting the management strategy accordingly.

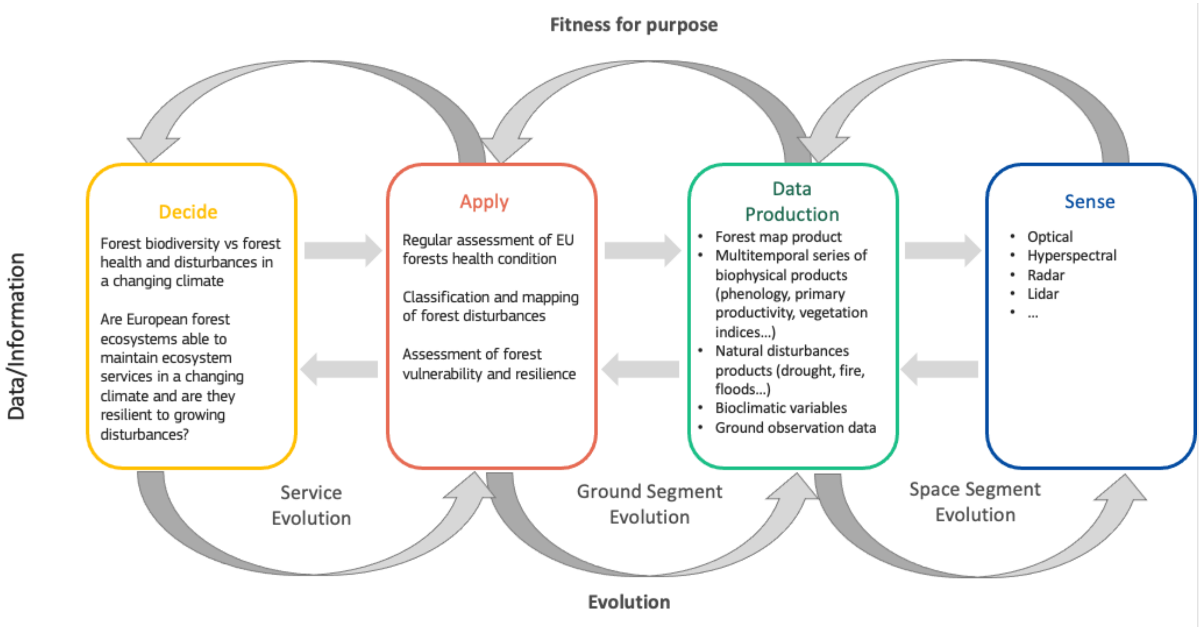


Figure 23. EO value chain of the use case Assessment and monitoring of EU forests health and disturbances

6.6.4 Fitness for purpose of existing EO products and services

The most relevant source of information for pan-European forest health condition monitoring are provided and discussed in what follows. Further descriptions and specifications of Copernicus products mentioned are provided in Annex 4.

It is important to recall that the assessment of fitness for purpose discussed here is focused on the technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products could not be considered.

ICP Forests

The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) has been launched in 1985 under the Convention on Long-range Transboundary Air Pollution (Air Convention, formerly CLRTAP) of the United Nations Economic Commission for Europe (UNECE).

Since its launch, the ICP Forests programme collects yearly standardised data on forest health conditions across Europe on the basis of two extensive ground inventory networks with different monitoring intensity levels.

The Level I monitoring network is based on 5624 observation plots (as of 2021) on a systematic transnational grid of 16 x 16 km throughout Europe, aimed to gain insight into the geographic and temporal variations in forest condition. The Level I information refer mainly to crown cover and discoloration.

The Level II intensive monitoring network comprises 561 plots (as of 2020) in selected forest ecosystems, with the aim to clarify cause-effect relationships between disturbing effects and tree conditions. A very long list of variables is measured in Level II plots for studying the bio-chemical and physical conditions of trees in the plots. At present 42 countries in Europe participate in the programme.

ICP Forests is based on standardized ground surveys, and should be considered as the backbone of any European system for monitoring forest health conditions in Europe (Ferretti, 2021). Several examples exist in literature regarding the use of ICP forest plots for creating models and validating predictions based on remote sensing imagery[175].

The system is operational since 1985 and all data are available upon request[176].

ICP Forest provides large scale assessments, robust estimates at specific locations are not possible due to the limited number of plots. In the future the ground plot data should be integrated with a remote sensing component for a wall-to-wall scaling up of the information at Pan-European level.

Copernicus CLMS High Resolution Vegetation Phenology and Productivity

The High-Resolution Vegetation Phenology and Productivity (HR-VPP) product suite is part of the Pan-European CLMS portfolio. This set of products are derived from Sentinel-2 imagery for monitoring vegetation status with high-resolution (10m) data that can potentially enable a detailed assessment of vegetation responses to disturbances.

The HR-VPP suite include 3 product groups delivered since 2017:

- Vegetation Indices (VIs) provided in near real-time (NRT) every 10 days. Maps are currently generated for Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Normalized Difference Vegetation Index (NDVI) and Plant Phenology Index (PPI);
- Seasonal Trajectories (STs) delivered yearly after the end of the vegetation growing season. These are derived as smoothed and gap filled 10 days time-series of PPI;
- Vegetation Phenology Parameters (VPPs) derived from STs product group and consisting of 13 yearly metrics of PPI such as start and end of the growing season, seasonal productivity.

In terms of frequency of update, HR-VPP products match the requirements for forest disturbance mapping and forest health monitoring. However, examples of their successful application in this domain are not yet available, specific studies should be carried out to demonstrate and develop ad hoc methodologies to this end.

In the frame of the evolution of the HR-VPP product suite, mapping of detected disturbances in forest areas are planned to be included in the future.

175 http://icp-forests.net/page/scientific-publications
176 http://icp-forests.net/

Copernicus CLC+ Backbone (CLC+ BB)

CLC+ BB[177] is the new land cover product on the Pan-European component of CLMS. The product provides the European wall-to wall spatial distribution of 11 basic land cover classes with 10m resolution (see Annex 4). The land cover classes of CLC+ BB relevant for this use case are the following:

- Woody – needle leaved trees;
- Woody – Broadleaved deciduous trees;
- Woody – Broadleaved evergreen trees;

The product has certain thematic overlaps with some of the CLMS High Resolution Layers (HRLs), however it is an independent product. The classification method and class definitions are also slightly different to those of the HRLs, the latter being considered more appropriate for this use case (see HRL Forest description below).

Currently CLC+ BB is available for the reference year 2018. The product for 2021 should become available in late 2023. After this, product updates will take place every two years.

Copernicus CLMS High Resolution Layer Forest

The High Resolution Layer (HRL) Forest[178] is a Pan-European product group of CLMS. It is available for 2012, 2015 and 2018. Since the 2018 reference year the main sources are Sentinel-2 and Sentinel-1. For 2012 and 2015 the spatial resolution is 20m, since 2018 the products are at 10m resolution. From 2018 release onwards, update frequency should move to yearly for most of the status layers except for Forest Type, after the inclusion of HRL Forest in the upcoming HRL Vegetated Land Cover Characteristics product suite[179].

Among the HRL Forest product group, the layer of potential interest is the Forest Type product (FTY) since it matches the FAO definition of forest (MMU of 0.5 ha and 10% tree cover density threshold), hence it is considered suitable to be used as forest mask for the assessment of forest condition.

On the other hand, if the assessment does not have to be tight to a specific definition of "forest", the HRL product of interest is the Tree Cover Density (TCD) mapping the level of tree cover in a range from 0 to 100% independently from any forest definition.

It is worth noting that for the reference Forest Type product 2018, agricultural/urban trees have been removed. The expected update frequency should be yearly from 2018 onwards which is considered matching the user requirements. The product latency should also be improved since at the time of writing the latest available year is 2018.

Copernicus Emergency Management Service – Mapping

The Copernicus Emergency Management Service (CEMS) portfolio covers floods, earthquakes, landslides, major storms, fires, technological disasters, volcanic eruptions, humanitarian crises, tsunamis. Mapping services are provided during all phases of the emergency management cycle. Maps based on satellite EO are produced by CEMS as Rapid Mapping service in support of emergency management within hours or days from the activation or as Risk and Recovery Mapping service, produced on-demand in support of activities not related to the immediate response.

In most cases maps must be requested by MS that "activate" the service. Therefore, CEMS products could be available only when large forest disturbances (e.g. windstorms) trigger the service activation.

In the case of forest fires, the European Forest Fire Information System (EFFIS)[180] routinely monitors active fires and maps burned areas in the EU and neighbour countries, through specific applications based on satellite EO. Burned area are mapped based on the integration between MODIS and Sentinel-2 imagery. Maps and area estimate provided by EFFIS, crossed with land cover products such as Corine Land Cover is a consistent source of information for monitoring the effects of fires in forest ecosystems.

Databases of forest disturbances

Following the growing attention to forest disturbances in the EU, few initiatives and databases have been recently initiated.

[177] https://land.copernicus.eu/pan-european/clc-plus/clc-backbone
[178] https://land.copernicus.eu/pan-european/high-resolution-layers/forests
[179] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=8630
[180] https://effis.jrc.ec.europa.eu/

DEFID2[181] - A recent collaborative initiative launched by the JRC aims to develop a comprehensive spatially explicit database of insect and disease outbreaks in European forests and neighbouring regions. It is a joint effort of research institutes and forestry services, called to collect and harmonize data on forest damages due to insect and disease outbreaks in a consistent Database of European Forest Insect & Disease Disturbances (DEFID2) covering the 1981- to present period.

DFDE[182] - The Database on Forest Disturbances in Europe aims at providing historic information about disturbances in the forests of Europe. After a first version of the DFDE launched in 2002 the database has not been maintained or updated but has been recently redesigned and published.

FORWIND[183] - The database of wind disturbances in European forests that comprises more than 80,000 spatially delineated areas in Europe that were disturbed by wind in the period 2000-2018, and describes them in a harmonized and consistent geographical vector format. The data set has been presented in a paper by Forzieri et al. (2020).

6.6.5 Conclusions and recommendations

Forest health monitoring is key to maintain biodiversity in forest ecosystems and their capability to deliver ecosystems services. A pan-European forest monitoring system does not exist; it should ideally be established based on the integration of multiple sources: ground-based, airborne and spaceborne observations.

Regularly updated, accurate, high-resolution reference forest maps of Europe geometrically and thematically consistent through time are essential, ideally delineating forest types beyond the simple conifer/broadleaved distinction. The key aspects of uncertainty and accuracy of EO products could not be considered and no recommendations can be made in this respect. It must be noted however that publishing training and reference data used for the accuracy assessment of Copernicus products should always be ensured, to openly reporting on the quality of the products and enhance transparency and reproducibility.

Disturbance maps should be validated on the ground. Both ground and satellite components are needed for the assessment. Once integrated, these can be further analysed to delineate the impact on forest ecosystem structure and functions at different scales.

Several Copernicus products are potentially useful for monitoring forest health conditions, the spectral, spatial and temporal resolution of Sentinel-2 imagery make it an essential data source for this use case. Methods based of the analysis of temporal trajectories of satellite EO products are sufficiently robust for assessing and providing early warning of forest health conditions and for mapping forest disturbances.

The service could produce yearly maps as well as near real time alarms as soon as new disturbances are identified. These maps can then be analysed to identify relationships with climate changes, support predicting potential areas of future potential disturbances and for assessing the impact on biodiversity and other forest ecosystem services.

[181] https://forest.jrc.ec.europa.eu/media/filer_public/c1/1e/c11e2b28-b263-4cbe-ad99-4a0447d1f7fc/defid2_protocol-for-data-collection_v01-1.pdf
[182] https://dfde.efi.int/db/dfde_app.php
[183] https://figshare.com/articles/dataset/A_spatially-explicit_database_of_wind_disturbances_in_European_forests_over_the_period_2000-2018/9555008

6.7 Shifts in geographic ranges, distribution and conditions of species populations and ecosystems as a function of changing climate (DG CLIMA)

Credit: European Union, Copernicus Sentinel-2 imagery

6.7.1 Policy context

Biodiversity plays an important role in regulating the climate and is key to climate change mitigation and adaptation. At the same time, climate change affects ecosystem dynamics, ecosystem structure, ecosystem function, as well as the distribution and abundance of species and habitats. This intrinsically links biodiversity conservation and climate action. Reducing the vulnerability of biodiversity to climate change can be achieved through, for example, habitat and species management, hydrological measures and enhancing the ecological infrastructure to increase resilience of local populations and habitats. The modification and loss of ecosystem structure, landscape phenology, community composition, ecosystem function and species populations are all essential biodiversity variables (EBVs) (Pereira et al. 2013) which can be monitored with remote sensing biodiversity products (Skidmore et al. 2021) and Copernicus products. Biodiversity conservation needs to embrace the inevitable ecosystem transformations resulting directly from changing climatic conditions. It can do so by increasing the space for ecosystem function through the conservation and restoration of ecosystems and landscapes. This will not only reduce the vulnerability and enhance the resilience and adaptive capacity of nature. It will also help to reduce climate related risks, long term storage of carbon in landscapes through soil organic matter as well as plant biomass, and can mitigate global warming. Biodiversity and adaptation to climate change are elements which should be integrated into all EU policies. Therefore, DG CLIMA has been directly involved in the development and implementation of the EU Biodiversity Strategy extensively as well as with the proposal of the Nature Restoration Law.

The EU Climate Law[184] establishes the framework for achieving climate neutrality by 2050 but also, in Article 5, it establishes a legal 'duty to adapt' to climate change. It requires 'relevant Union Institutions and the Member States' to 'ensure continuous progress in enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change in accordance with Article 7 of the Paris Agreement'. This article also stresses that Member States' adaptation policies 'shall take into account the particular vulnerability of the relevant sectors', 'promote nature-based solutions and ecosystem-based adaptation', integrate 'adaptation to climate change in a consistent manner in all policy areas', and 'focus, in particular, on the most vulnerable and impacted populations and sectors'.

The EU Strategy on Adaptation to Climate Change[185] outlines a long-term vision for the EU to become a climate-resilient society, fully adapted to the unavoidable impacts of climate change by 2050. This strategy aims to reinforce the adaptive capacity of the EU and build a climate resilient society by improving knowledge of climate impacts and adaptation solutions; by stepping up adaptation planning and climate risk assessments; by accelerating adaptation action; and by helping to strengthen climate resilience globally. Among the actions proposed are integrating adaptation into Nature Based Solutions (NBS)[186] and enhancing

[184] COM/2020/80
[185] COM/2021/82
[186] https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en

and expanding Climate-ADAPT[187] as the European platform for adaptation knowledge. Moreover, GHG/global warming and the occurrence of extreme events (e.g., forest fires, floods) is increasing over time. Since extreme events impact biodiversity and ecosystems, trends in biodiversity change are of increasing importance in the EU.

Taking a coherent approach by complementing the activities of Member States, the EU Strategy on Adaptation to Climate Change promotes adaptation action across the EU, ensuring that adaptation considerations are addressed in all relevant EU policies, promoting greater coordination, coherence, and information-sharing including the development of methods and tools to:

1. assess the vulnerability and resilience of planned NBS to projected climate change;
2. determine cost-efficiency effectiveness and benefits of adaptation actions;

Life on Earth is impacted by the 4 risks reported for the EU in the IPCC "6th Assessment Report on Adaptation": (1) heat, (2) agriculture and crop production, (3) water scarcity, (4) flooding and sea level rise. Change in heat (temperature), water scarcity as well as flooding impact the species population (or community composition) especially in terms of distribution and abundance. Incorporating future climate impacts with land cover/use change can facilitate biodiversity conservation, for instance by establishing migration pathways for species across elevation, topography, latitude, and longitude.

Integrating biodiversity assessment with climate change can further inform about species abundance and distribution, especially when land cover change impacts the projected range shifts of individual species under future climate conditions.

Predicting future species geographic ranges under climate change is the central theme of this use case.

6.7.2 Description of the use case

Predicting future species geographic ranges under climate change and land use impacts summarises this use case. To understand this, we need to understand the numerous terms and technologies that are used (some interchangeably) to describe how species are predicted under climate change impacts.

The concept of "bioclimatic models" to predict shifts in species distribution and abundance was initially proposed in the 1950s (Hutchinson 1957). A series of environmental variables with ranges of suitable conditions were conceived as an 'n'-dimensional hyperspace within which a species can survive and reproduce.

Confusingly, the terms "bioclimatic envelope models", "ecological niche models", "habitat suitability models", and "species distribution models" have been used almost interchangeably by a variety of authors and service providers. However, these terms do have some differences, and nuances. "Bioclimatic envelope models" are used to predict the geographic ranges of organisms and species as a function of a climatic envelope (e.g., maximum, and minimum, rainfall/precipitation per year, or climatic extremes such as the coldest month of the year) thereby defining the habitat for a species. The first bioclimatic envelope model for predicting species distribution was published in 1986 and named 'BIOCLIM' (Nix 1986). More recently the terms "species distribution models" (SDM) and "ecological niche models" (ENM) are being commonly used, which predict the suitability of a location for species based on their observed relationship with a more broadly defined set of ecological/environmental variables (e.g., to include more biotic as well as abiotic variables). Remote sensing vegetation variables have been included in models as proxy of biological variables (e.g., representing biomass or primary productivity), by combining with climatic variables to better capture the total 'habitat' or 'niche' of a species. A distinction is emerging whereby "species distribution models" attempt to estimate objects in geographic space, whilst "ecological niche models" (ENM) estimate the fundamental niches of species in order to estimate their future distribution e.g., invasive species, as well as movement of species populations under climate change. "Habitat suitability models" are essentially the same as "species distribution models", though different groups of researchers and application/domain companies and government departments seem to prefer one term over the other, reflecting more the 'marketing' preferences for their services. Here the term "species distribution models" (SDM) is adopted as species population models in the EU are mostly calculated using a defined set of ecological/environmental variables (e.g., to include biotic as well as abiotic variables such as climatic envelopes).

[187] https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/strategy/index_html#:~:text=The%20Strategy%20aims%20to%20build,to%20strengthen%20climate%20resilience%20globally.

Both SDM and ENM models can contribute to the EU-level spatial assessments of future climate risks and vulnerabilities of biodiversity envisaged under the EU climate Adaptation Strategy (and as requested by the post-2020 biodiversity framework of the Convention on Biodiversity [CBD]), as well as providing evidence for policy-making and for spatial planning under climate and land cover change. Moreover, bioclimatic envelope models linked to ecosystem changes are relevant for the proposed EU Nature Restoration Law because it is important to consider ecosystem changes such as in land cover when setting biodiversity restoration targets.

SDM and ENM models rely on bioclimatic predictors, to generate the 'n'-dimensional hyperspace, as well as require adequate and good quality species occurrence data as prerequisites for developing accurate models.

6.7.3 Value chain analysis and EO technical requirements

The first published species distribution model (SDM) package, known as 'BIOCLIM' (Nix 1986), used interpolation to define an 'envelope' for a species using interpolated climatic variables such as mean annual temperature and mean annual precipitation. The 'n'-dimensional hyperspace was expanded to include metrics capturing extreme outlier values (e.g., wettest month in the coldest year) as well as other biological and human-pressure variables such as a phenology (time series of a vegetation index such as NDVI), topography (e.g., slope, aspect, topographic position), proximity to water, and anthropogenic pressures (e.g., pollution level, distance to human infrastructure such as roads etc) (Herkt et al. 2016).

Since BIOCLIM was developed, three main categories of models have developed: 1) correlative (statistical) models linking the ecological requirements of a species with a set of environmental variables based on their known geographic and habitat requirements (including climate envelope models, general linear models, general additive models, classification and regression trees, genetic algorithms and deep learning); 2) mechanistic models that use detailed physiological information and first principles of biophysics; and 3) process-orientated models which estimate species distribution in terms of dispersal capability and biotic interactions. Of the 1) correlative model, the climate envelope models still essentially utilise the BIOCLIM modelling approach (i.e., a 'n'-dimensional hyperspace within which a species can survive and reproduce), with the correlative models emerging as a main operational model of choice, though deep learning approaches are currently being widely researched and are increasingly being shown to yield high accuracies in map outputs.

The vulnerability of biodiversity under climate change requires forecasting how future climate scenarios as well as biological conditions (e.g., land cover) at a location may impact species and community composition (Yu et al. 2021). Such forecasting of future vulnerability of biodiversity involves generating a plausible range of future climate and land cover scenarios using global or regional climate models and land use change models. A prioritised selection of climatic variables and land cover over time, contributes to operationally estimating community composition and species populations across the EU and globally (Herkt et al. 2016, Skidmore et al. 2021). This is important because future species and habitats' distributions/size will change, and there is a need to understand how to protect and restore ecosystems in the future. For instance, will it be useful to restore boreal forests in Southern Finland, under a climate shift towards hemiboreal and temperate zones? Or consider a second question, namely: are local, Member State, EU, and global reserve systems adequate to allow long-term survival and reproduction of (umbrella, keystone, indicator, and flagship) species, community composition, and biodiversity guilds? Such questions can be answered by combining SDM and ENM models with future climate and land use/cover projections.

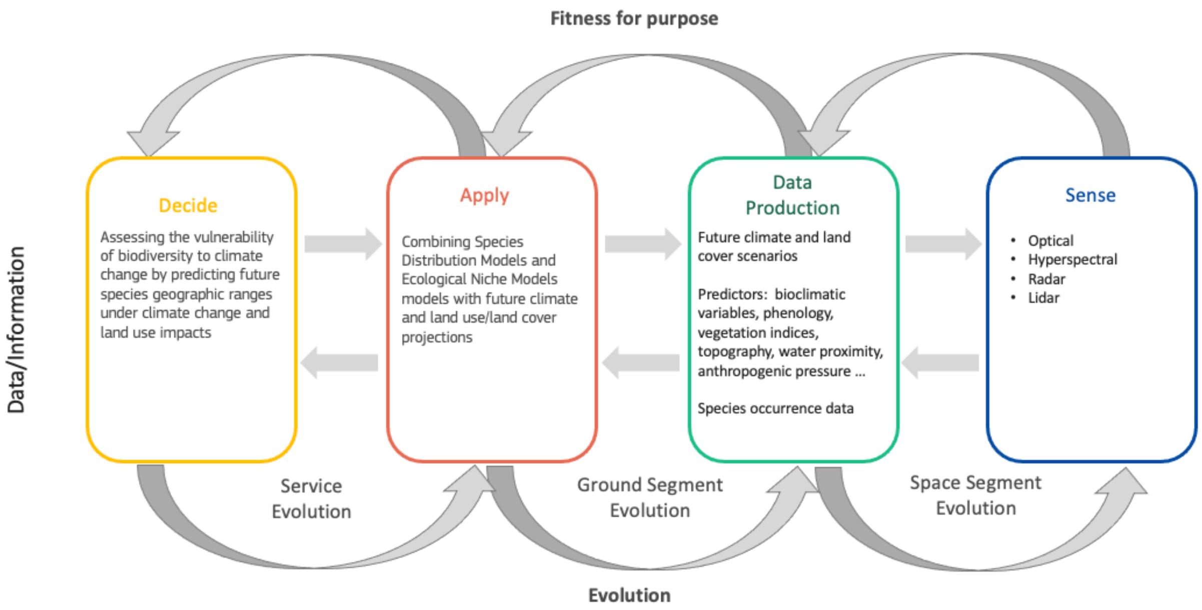


Figure 24. EO value chain of the use case Shifts in geographic ranges, distribution and conditions of species populations and ecosystems as a function of changing climate

6.7.4 Fitness for purpose of existing EO products and services

When considering EO products and services that may be used to support predictions of future species geographic ranges under climate change, a few questions must be addressed, some requiring pre-operational pilot studies.

1) The first question regards which species populations, community compositions, and biodiversity guilds occur where, and in what abundance, and under future climate change scenarios require new reserves and movement corridors for survival.

This question needs to be addressed by specialist ecologists with knowledge of the long-term survival and reproduction requirements of species especially with respect to the species status. Many species act as surrogate species for monitoring change. For example, if an umbrella species thrives, then all organism's "underneath" this species thrives as well, such as large animals and large predators. If the composition, structure, and function of an ecosystem depend on one species, then this is a keystone species and ecosystem engineer e.g., the beaver. Ecologist and taxonomist experts can provide critical knowledge about community composition, as well as an understanding the biogeographical requirements of species and key biodiversity guilds. Then, with this understanding of species populations, community compositions, and biodiversity guilds occurrence, scenarios of future climate predictions can be used to assess communities at risk, as well as allow new conservation reserves and movement corridors to be designed to ensure long-term survival.

2) The second question concerns which species populations, community compositions, and biodiversity guilds have an adequate number of field observation samples to accurately predict species geographic ranges.

An adequate number of ground-based observations of a species in the field are needed for high accuracy in output maps. At one level, field observation samples can be achieved by extracting information from databases such as Global Biodiversity Information facility (GBIF)[188], the TRY database[189], the CESTES data base[190], and the PREDICTS database[191], (note there are many such databases – e.g., (Jeliazkov et al. 2020) concatenated 80 global and local databases). Volumes of data specific to local species may not be publicly available in data portals. Finding, as well as accessing, these species observations require specialist

[188] https://www.gbif.org/
[189] https://www.try-db.org/TryWeb/Home.php
[190] https://icestes.github.io/
[191] https://www.nhm.ac.uk/our-science/our-work/biodiversity/predicts.html

knowledge, connections to ecological networks across terrestrial, freshwater, and marine environments, as well as communication in local languages. Indigenous information about species observations is often also a critical and underexplored aspect of generating data. A final challenge with accessing data bases of species observations is that the species data may require extensive curation for any given application, because i) the distances between observations may vary greatly (e.g., metres to many kilometres) as well as the location (latitude/longitude) of the observation or plot be located with very different accuracy, and, ii) the taxonomy (name) of the species can be incorrectly recorded by the field worker. 3) A third question concerns which species distribution models should be adopted for predicting species geographic ranges and how can the reproducibility and accuracy of ecological niche models be maximised.

This point continues to be widely debated in the scientific literature. Each species distribution model has pros and cons. Models are evolving, and the accuracy and performance is continually being improved. Table 11 lists species distribution models employed for scientific and operational applications. The reproducibility and accuracy of species distribution model output maps is critical when used as evidence for policy, or funding and impact decisions. Errors in the evidence (maps) will lead to poor decisions at best, or irreversible and catastrophic decisions at worst. In order to reproduce the work, minimum information should include the version or access date of the underlying information, a report on the model parameters used, the spatial and temporal extent of the data used, how the evaluation dataset was generated, the method used to forecast predicted distributions, and the methods used to convert continuous to binary thresholds. Undoubtedly, species distribution maps (or forecasts under climate change) will become increasingly critical for evidence-based policy in the EU for environmental impact studies, or for financial decisions when assessing ecosystem health or ecosystem restoration needs(Feng et al. 2019).

Table 11. Commonly used species distribution model employed for operational applications

Model	Model type	Technology Readiness Level (TRL)	URL	Reference
BIOCLIM	Correlative (SDM/ENM)	6	https://rdrr.io/cran/dismo/man/bioclim.html	(Nix 1986)
MaxEnt	Correlative (SDM/ENM)	8	https://cran.r-project.org/web/packages/maxnet/index.html	(Phillips, Anderson et al. 2006)
GARP - Genetic Algorithm for Rule-Set Prediction (GARP)	Machine Learning	6	https://github.com/cghaase/GARPTools	(Stockwell and Peters 1999)
GLM family (e.g., Lasso, Elastic-net, Cox model)	Correlative (SDM/ENM)	6	https://cran.r-project.org/web/packages/glm2/index.html https://cran.r-project.org/web/packages/glmnet/index.html https://cran.r-project.org/web/packages/glm2/index.html	(Franklin 1998)
Random Forest	Correlative (SDM/ENM)	7	https://cran.r-project.org/web/packages/SSDM/index.html	(Freeman, Moisen et al. 2012)
Bioclimatic model with Random Forest	Correlative (SDM/ENM)+ Machine Learning	5	n/a	(Hill, Hector et al. 2017)
Boosted tree regression (BRT)	Correlative (SDM/ENM)	6	https://cran.r-project.org/web/packages/gbm/index.html	(Elith, Leathwick et al. 2008)
Ensemble Models (EM)	Correlative (SDM/ENM)+ Machine learning	6	https://cran.r-project.org/web/packages/sdm/index.html https://cran.r-project.org/web/packages/eSDM/index.html https://cran.r-project.org/web/packages/biomod2/index.html	(Hao, Elith et al. 2019)
Bioclimatic model SDM with neural networks	Correlative (SDM/ENM)+ Machine Learning	3/4	n/a	(Deneu, Servajean et al. 2021)
Convolution neural networks	Machine Learning	3/4	n/a	(Mayra, Keski-Saari et al. 2021)

4) Another important aspect is which data should be prioritised to generate the necessary remote sensing biodiversity products and bioclimatic layers. This demands carefully selecting relevant and feasible predictor variables that can be retrieved from satellite EO. The Copernicus Climate Change Service (C3S) implements a set of bioclimatic indicators and variables that provide *some* of the required relevant predictor variables for a variety of biodiversity and wildlife conservation applications[192]. The prioritised remote sensing biodiversity products to estimate EBV have been detailed in Chapter 2.3. Such products are potentially useful for support

[192] https://cds.climate.copernicus.eu/cdsapp#!/search?type=dataset&text=biodiversity

predicting future species geographic ranges under climate and land cover change (Jeschke and Strayer 2008). The predictors should accurately capture the environmental requirements of a species for survival and reproduction, and usually include biological relevant climatic variables, topographic and edaphic variables, anthropogenic pressures on the species (e.g., pollution or proximity to human infrastructure) and phenology. Many of these data layers and products are estimated directly or indirectly by EO. An analysis of the relevance and importance, as well as the maturity of EO derived bioclimatic variables, following the prioritisation process developed for EBVs (Skidmore et al. 2021) and ECVs[193] (Bojinski et al. 2014) can accurately determine which data services should be selected to generate the necessary remote sensing biodiversity products and bioclimatic variables. Fitness for purpose Table 9 (see use case in Chapter 6.4).

5) A last fundamental question regards how to protect and restore ecosystems in the future. This requires context of the application for which the bioclimatic model is being constructed, in this case aiming at forecasting areas with changes in species populations under future climate change scenarios. Such information is useful for conservation managers to understand and manage how species ranges will contract or expand, in which direction, uphill or downhill, under climate change scenarios. Using this information, policy makers and managers can develop strategies to protect natural areas. Migration pathways within and between Member States (as well as cross-border pathways for third countries) may need to be established.

Overall, prediction of future species geographic ranges under climate change impacts, benefits from the mature species distribution model technologies available with Technology Readiness Level (TRL) at a level of 8-9. As mentioned in Chapter 2.3, TRL is a benchmarking tool for tracking progress and supporting development of a specific technology through the early stages of the innovation chain. TRL stages range from blue sky research (TRL 1) through to actual demonstration of the full range of expected conditions (TRL 9). In addition, the bioclimatic data products input to a species distribution model must be mature and operational at TRL =7-9.

From Copernicus EO climate products for species distribution models are available. The C3S offers 78 global bioclimatic indicators, both derived from reanalysis historical reconstruct (1979-2018)[194] and from climate projections (1950-2100)[195], albeit at coarser resolution (spatial resolution 0.5° for global products and 1 km for Europe). These coarse-scale Copernicus climate products are suitable for EU continental policy and assessment by EC Services, but may need to be downscaled for local level applications (e.g., reserve managers, or project impact assessment) which require spatial resolution at 10-30 m (see Table 2). For local level applications including evidence-based environmental impact assessment or determining the cost-efficiency effectiveness and benefits of adaptation actions, Copernicus climate products should be generated at a still finer resolution or downscaled, for which R&D efforts may be needed.

Successful species distribution model pilot studies (Yang et al. 2006, Herkt et al. 2016, Yu et al. 2021) at TRL 5/6 have demonstrated that additional (i.e., non-climate) remote sensing products are required. Some non-climatic products are available from the CLMS such as high-resolution vegetation phenology and productivity[196] but further Copernicus service development could prioritise remote sensing derived products such as ecosystem structure (average tree height, tree cover, basal area, shrub cover), ecosystem function, community composition, species populations, elevation and terrain variables (e.g., slope, aspect, topographic position, topographic variation in solar radiation, terrain ruggedness, terrain complexity), and impact of human disturbance (e.g. distance to human infrastructure).

It is worth recalling that there is a demand for bioclimatic (species distribution), topographic, human pressure, and remote sensing products by land managers (e.g., for forestry, nature conservation, agriculture, environmental impact companies) at a local level across the EU, requiring operational products with high spatial resolution (e.g., 10-30 m from Sentinel-2). Examples of products at higher resolutions freely available to download can be found[197,198,199].

Species distribution models are often developed or validated for specific terrestrial, aquatic or marine ecosystems and perform poorly when used for different areas. Indeed, species distribution models may

[193] https://gcos.wmo.int/en/essential-climate-variables
[194] https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-biodiversity-era5-global?tab=overview
[195] https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-biodiversity-cmip5-global?tab=overview
[196] https://land.copernicus.eu/pan-european/biophysical-parameters/high-resolution-vegetation-phenology-and-productivity
[197] https://catalogue-2.nextgeoss.eu/organization/itc-university-of-twente
[198] https://catalogue.nextgeoss.eu/
[199] https://e-shape.eu/

perform poorly with few species observations on which to train and/or limited predictors, thereby restricting a model's generality, accuracy, and robustness when applied to new areas. If the predictor variables input to a SDM do not include species interactions as well as the dispersal potential of species, then models perform poorly. Similarly, landscape fragmentation metrics need to be added to SDMs and ENMs. When used jointly as input to species distribution models, the 78 bioclimatic products from the C3S will have high spatial autocorrelation and collinearity between predictors, requiring expert data knowledge to avoid causing bias and errors in map products. Species distribution models especially for projecting range shifts in response to climate change and land cover, are being rapidly developed, and yielding good predictions (Jeschke and Strayer 2008, Herkt et al. 2016, Yuet al. 2021).

How to measure a 'good prediction' is often neglected or missing when species distribution models are operationally applied. Both the degree of fit between the model and test data, as well as the type of data used to evaluate the model output, are required. The common method for judging model performance is simply whether the model performs better than random (i.e., using area under the curve AUC, Cohens kappa, true skill statistic, sensitivity, specificity). There is no single value of Kappa of AUC which shows that a species distribution model is adequate for all (or even a specific) purposes and species.

Combining mature species distribution model technologies (Table 11) with bioclimatic products would be an important development step to demonstrate species distribution model *and bioclimatic envelope modelling* in an operational environment (TRL 7-9). There are however several challenges to overcome, especially to ensure that a bioclimatic model, and more generally a species distribution model incorporating biotic and terrain variables, is adequate for all (or even a specific) purpose and species.

6.7.5 Conclusions and recommendations

Climate data products suitable for bioclimatic models are now operational. Efforts to further develop and improve the spatial resolution would further support biodiversity applications.

With respect to this use case, it is also recommended to pursuing the combination of mature bioclimatic modelling technologies with bioclimatic products, as currently under development by C3S, to demonstrate bioclimatic envelope modelling in an operational environment that would implement a suite of bioclimatic models.

Biological models should also evolve in the direction of being able to account for biological processes such as species interactions, dispersion and spatial requirements (e.g., tolerance of landscape fragmentation) of species.

The accuracy and performance of bioclimatic models should be assessed checking the degree of fit between the model output and test data. In order to assess the model outputs quality, uncertainties of inputs data are also mandatory.

6.8 Biodiversity monitoring in Key Landscapes for Conservation – NaturAfrica (DG INTPA)

Credit: European Union, Copernicus Sentinel-2 Global Mosaic 2

6.8.1 Policy context

The EU is committed to supporting Africa with its transition to a green economy and to cooperating on the environment as outlined in the EU-Africa Strategy. Within this context, NaturAfrica is an initiative that aims at supporting biodiversity conservation in Africa by following an innovative people-centred approach (European Commission - DG INTPA, 2021). Based on the Key Landscape for Conservation (KLC) approach developed within the Larger than Elephants initiative (European Commission – DG INTPA, 2016) NaturAfrica identifies (predominantly transboundary) Key Landscapes for Conservation and Development where the EU will focus support for job creation, improved security and sustainable livelihoods, while preserving the ecosystems and wildlife that are vital to all. The implementation of NaturAfrica is subject to the local context and national priorities. EU delegations (EUDs) will define and implement NaturAfrica programmes after wide consultation and in agreement with all stakeholders of the landscapes: national and regional government, local communities, civil society and the private sector. Working with indigenous communities and women will be at the heart of the NaturAfrica approach. Support will be structured around 2 pillars:

1. In the short term, it will develop actions in Key Landscapes for Conservation and Development, building on the positive benefits that protected areas bring to society and the economy, encouraging networks of protected areas and knowledge-sharing.
2. In the medium term, it will extend support beyond Key Landscapes to address the root causes of biodiversity loss and environmental degradation and integrate these concerns into other sectors ('mainstreaming biodiversity').

Furthermore, NaturAfrica is fully aligned with the African Union Agenda 2063 and in particular on Aspiration 1 (*A prosperous Africa, based on inclusive Growth and Sustainable Development*), addressing priority areas such as sustainable natural resource management and biodiversity conservation, sustainable and inclusive economic growth and poverty, inequality and hunger among others. Moreover, NaturAfrica is following the concept of the European Green Deal, which identifies climate change and environmental degradation as an existential threat to Europe and the world. The Green Deal emphasises the need to decouple economic growth from resource use and provides a mandate to step up the integration of environment and climate change objectives, in particular on biodiversity, forests, oceans and soil in EU-supported policies, plans and investments across all sectors of cooperation. Finally, NaturAfrica contributes to EU global commitments on biodiversity under the Convention on Biological Diversity, including to preserve ecosystems, fight wildlife crime and increase financial flows to developing countries for global biodiversity protection. The scale of its ambition matches the EU's drive for an ambitious post-2020 agenda on global biodiversity.

6.8.2 Description of the use case

Africa has the highest population growth rate of any continent. Due to this, the pressure on land has increased dramatically in recent decades. The exploitation of natural resources is often related to loss and degradation of forests and woodlands, loss of animal and plant species, land degradation, increasing water shortages and declining water quality. Protected Areas (PAs) play a vital role in this context and have to be at the heart of any strategic approach to habitat and wildlife conservation as these are the areas where the most intact assemblages of Africa's wildlife are found. However, conservation has to go beyond the boundaries of PAs, addressing not only the conservation of large functioning ecosystems or landscapes supporting key African wildlife populations, but also supporting livelihoods and human development (people centred approach).

The priority areas (KLC) defined in the NaturAfrica initiative (Figure 25) are characterised by different environmental conditions, pressure and threats and policy contexts. The strategic elements of NaturAfrica will need to be translated into action through a series of regional and national programmes and projects for which detailed results and indicators will have to be developed, including performance monitoring and accountability measures.

In order to monitor, understand and track progress for the NaturAfrica targets, policy and decision makers (DG INTPA, EUD, local stakeholders) need to map and monitor in a quantitative and qualitative way the status and evolution of a series of environmental indicators (among others) within the KLCs. The implementation of this in a standardised and homogenised manner may be provided by Earth Observation and the Copernicus program in particular.

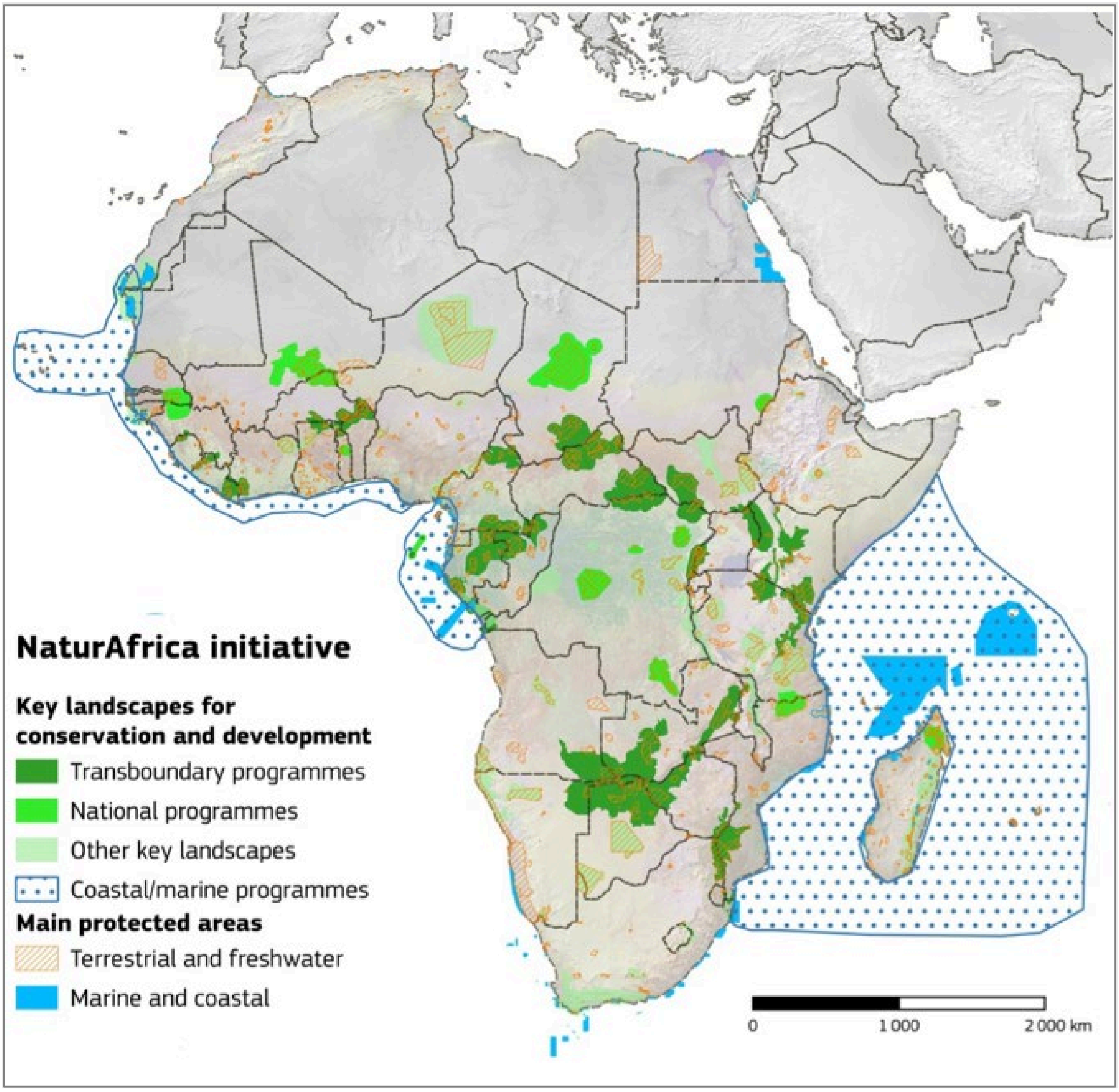


Figure 25. NaturAfrica priority areas (KLC) for support (provisional). Source: NaturAfrica

6.8.3 Value chain analysis and EO technical requirements

Monitoring vast and often inaccessible landscapes such as the NaturAfrica KLC's with satellite EO is a prerequisite to understand the status and evolution of these biomes.

A list of biodiversity metrics which are observable from space and their priority has been developed in a recent paper by Skidmore et. al. (2021). Such list could be the basis to identify the remote sensing biodiversity products that are considered relevant to map and monitor the KLCs status.

The main ones include:

- Land cover. It represents spatial information on different types (classes) of physical coverage of the Earth's surface, e.g., forests, grasslands, croplands, lakes, wetlands. Dynamic land cover maps include transitions of land cover classes over time and hence captures land cover changes. Land use maps contain spatial information on the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it
- Normalized difference vegetation index (NDVI), and its derived condition (VCI) and productivity (VPI) indices. These give an indication on the current greenness of the biomes as well as on their situation comparing to the long-term average
- Leaf area index (LAI), the fraction of vegetation cover, and the fraction of radiation absorbed for the photosynthesis. Respectively they quantify the density/thickness, the extent and the health of the vegetation.
- Dry matter Productivity. Representing the overall growth rate or dry biomass increase of the vegetation, directly related to ecosystem Net Primary Productivity (NPP).
- Burnt area. Mapping of burn scars, surfaces which have been sufficiently affected by fire to display significant changes in the vegetation cover (destruction of dry material, reduction or loss of green material) and in the ground surface (temporarily darker because of ash)
- Urban and build-up areas

In terms of temporal and spatial resolution medium resolution information between 100m to 1km should provide sufficiently accurate data to monitor such vast areas (KLCs are usually larger than 10k km2 up to 200k km^2 and even 500k km^2) on a regular basis. Land cover status maps produced every 3 to 5 years would provide generic status quo information. However, decadal and or monthly monitoring of the long-term seasonal evolution of vegetation is required to analyse the evolution of vegetation and eventually highlight deviations from the long-term average. Similar information is needed for the monitoring of fire and burnt area patterns.

Beyond the systematic monitoring of all KLCs, for specific requests and assessments higher spatial and temporal information may be required. In particular detailed land cover and change information may be necessary for specific field applications.

A single entry point and web based information system giving access in a user friendly manner to the relevant satellite EO products would allow the different users to visualise and analyse the data and information in a standardised way.

The EO value chain for the use case with respect to existing products and services is illustrated in Figure 26.

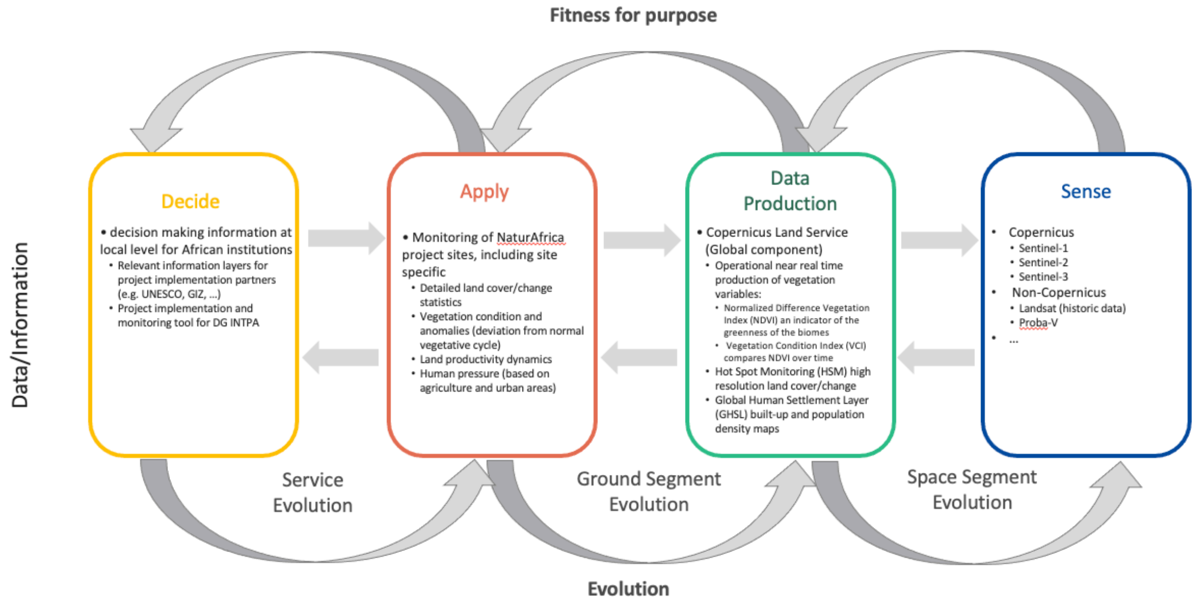


Figure 26. EO value chain of the use case Biodiversity monitoring in Key Landscapes for Conservation – NaturAfrica

6.8.4 Fitness for purpose of existing EO products and services

The Copernicus Global Land Service (CGLS) systematically produces a series of qualified bio-geophysical products on the status and evolution of the land surface, at global scale and at mid to low spatial resolution, complemented by the constitution of long-term time series. The products are used to monitor the vegetation, the water cycle, the energy budget and the terrestrial cryosphere.

In addition, the Copernicus Hot Spot Monitoring (HSM) land cover/change products provide on request detailed high to very high-resolution land cover/change data over KLCs. This data is used for land management and planning purposes at landscape level.

Moreover, the Copernicus high-resolution Global Human Settlement Layer (GHLS) is responsible of the periodic production of global geospatial information on human settlements in the form of built-up area. This dataset provides detailed information on the level of urbanisation over time, allowing to analyse the human pressure on natural areas.

Building on the above listed products, a dedicated NaturAfrica dashboard providing access to tailored Copernicus Global Land indicators (including Hot Spot Monitoring and GHSL data), could be developed. The dashboard would grant access to the EO based indicators and provide user friendly interactive analytical tools. Beyond the status maps and the seasonal monitoring an alert system highlighting areas of unusual change (both positive and negative) could be implemented.

The CGLS based NaturAfrica dashboard should be linked to other relevant activities and web information systems such as the BIOPAMA project and GMES&Africa and embedded in the Africa Knowledge Platform.

Copernicus components such as the HSM activity include already a capacity building component. This should be extended and integrated with other components.

Satellite EO is fundamental in providing a holistic view for environmental variables over the NaturAfrica KLC sites. It provides generic (CGLS) to highly detailed and accurate (HMS) land cover status maps to near real time monitoring of vegetation dynamics. Furthermore, EO provides information on human pressure derived from build-up layers and mapping of agriculture.

6.8.5 Conclusions and recommendations

The satellite EO products and variables listed for this use case provide systematic and standardised monitoring over the entire selected KLCs. Integrated in an AKP based NaturAfrica dashboard application they form a robust basis for creating a valid source of information for a consistent and valuable monitoring.

Further discussions are needed to agree on integrated and composite indicators, including also socio-economic data and information.

Moreover, in addition to the standardised information layers, specific KLCs may require dedicated products and indicators for specific use cases/projects defined by users such as the EU Delegations or UNESCO.

A dedicated user-friendly dashboard or web-based information system customised for NaturAfrica and implemented within the Africa Knowledge Platform would allow easy access and analysis of the EO based information, facilitating further downstream data integration and application for reporting and decision making purposes.

A training and capacity building component should be envisaged to facilitate and multiply the utility of such information system.

6.9 Biodiversity monitoring in agricultural landscapes (DG AGRI)

Credit: European Union, Copernicus Sentinel-2 imagery

6.9.1 Policy context

This use case is relevant for the Performance monitoring and evaluation framework (PMEF) of the Common Agricultural Policy (CAP), linked with the contribution of the agricultural sector and rural areas to the Green Deal ambitions and specifically to the EU Biodiversity Strategy targets. Within this framework quantified EU level targets have been defined and among these targets on high diversity landscape features.

It also specifically relates to the new architecture of the CAP, which implies an enhanced conditionality and mandatory requirements as well as voluntary measures linked to payments to CAP beneficiaries. For example, on every farm at least 3% of arable land shall be dedicated to biodiversity and non-productive elements.

The elements considered in the CAP are land lying fallow and non-productive features as indicated in the description of the GAEC 8[200] in the ANNEX III of the CAP regulation[201]. However, the 10% target on High Diversity Landscape Features does not relate to GAEC 8 alone, eco-schemes and agri-environmental measures will also contribute towards the target.

A non-exhaustive list of landscape elements contributing to the general objectives of the Green Deal can be found in the text adopted of the EU Biodiversity Strategy, it is worth noting that the landscape features defined in GAEC 8 and those of the Biodiversity Strategy are not fully aligned, which for the implementation of the assessments is an issue..

6.9.2 Description of the use case

The use case should support biodiversity monitoring in agriculture with indicators at Member State (MS) level, informing the evaluation of related CAP indicators.

The objective is the identification and mapping of landscape elements with a potential positive contribution to maintain biodiversity in the European agricultural land, for which currently quantitative knowledge, comparable data among Member Stats are lacking.

The nature of the elements relevant as Landscape Features is quite diverse and could vary depending on the area, examples are buffer strips, rotational or non-rotational fallow land, hedges, non-productive trees, terrace walls, and ponds.

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200 The Good Agricultural and Environmental Condition (GAEC) 8 of the CAP is about crop rotation in arable land.

201 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2115&from=EN

6.9.3 Value chain analysis and EO technical requirements

The targets, indicators and obligations for which the assessment needs are expressed, refer to multiple landscape elements with variable size, mapping of landscape features in agricultural land (buffer strips, rotational or non-rotational fallow land, hedges, non-productive trees, terrace walls, and ponds) recognised as having potential positive contribution to maintain biodiversity, entailing in most cases spatial resolutions in the High Resolution (HR) and Very High Resolution (VHR) ranges, i.e. below 5 m.

Time series of HR/VHR images are required to extract and monitor the targeted elements with a temporal resolution of the assessments of one year. Within the annual assessment, ideally various seasonal acquisitions are to be considered since the season when the different landscape elements are better observed may vary.

In addition, the target landscape elements should be referred to as land share with respect to specific land uses and land covers; thus, the use of reference maps of the target areas is required (i.e., agricultural area or arable land) and these are not always available. Provisions for delimiting these target areas of interest are also required.

The identification using exclusively EO data can be challenging and should be complemented with ground-based observations.

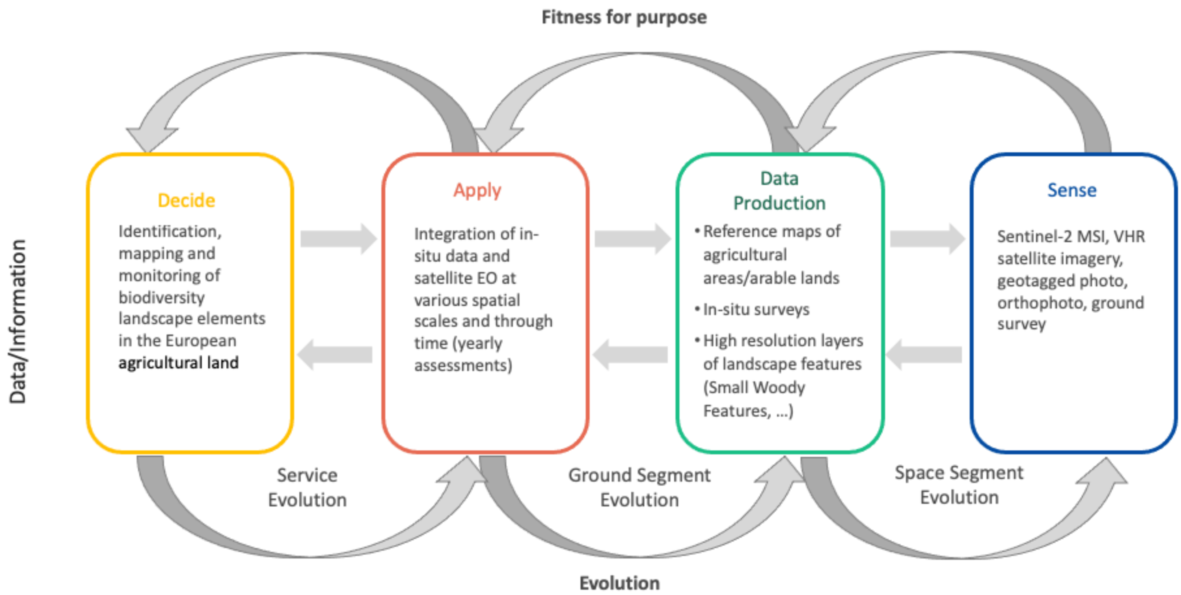

Figure 27. EO value chain of the use case Biodiversity monitoring in agricultural landscapes

6.9.4 Fitness for purpose of existing EO products and services

Products and initiatives potentially relevant for this use case are mentioned in what follows. Further descriptions and specifications of Copernicus products mentioned are provided in Annex 4.

It is important to recall that the assessment of fitness for purpose discussed here is focused on the technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products could not be considered and no recommendations could be made in this respect,

Copernicus CLMS Small Woody Features

The HRL Small Woody Features[202] (SWF) is a wall-to-wall (Europe) high-resolution layer developed by the Copernicus Land Monitoring Service (CLMS), for the reference years 2015 and 2018 it provides information on woody linear structures such as hedgerows, scrubs or tree rows along field boundaries, riparian and roadside vegetation as well as isolated patches of trees and scrubs (between 200 m² and 5000 m² in size). Specifications of 2018 release were updated after feedback received on 2015 release (Table 12).

Table 12. Geometric specifications of SWF 2018 and differences compared to 2015.

	Linear Structures	Patchy Structures
Width	≤ 30 m	n/a
Length	≥ 30 m (was 50 m in 2015)	n/a
Area	n/a	200 m² ≤ area ≤ 5000 m²
Compactness	≤ 0.785 (was 0.75 in 2015)	> 0.785 (was 0.75 in 2015)

It is worth noting that in SWF 2018 product the distinction between linear, patchy or out of specification features is not visible, and all the elements are in one unique class. Moreover, in SWF 2018 a forest mask is applied to prevent mapping of SWF in forested areas (with forest defined according to FAO definition[203]). The forest mark is derived from the HRL Tree Cover Density 2018 and CLC 2018 products. Furthermore, a Woody Vegetation Mask (WVM), the base layer for the creation of SWF, and for which no geometry rules have been applied, is made available as a separate product, to allow potential more advance users to apply their own geometric specifications.

With respect to this use case, it must be noted that the product excludes grassy elements (e.g., margins along field boundaries), wet elements (drainage ditches, water courses) or artificial elements (any kind of 'grey' infrastructure such as roads or stone walls). In addition, tree plantations, vineyards and orchards are not included in the product.

The product is particularly meaningful in agricultural and managed landscapes with distinct hedgerows and/or woody vegetation patches, embedded in an agricultural matrix. It is certainly relevant although it only covers woody features (hence excluding grass margin, ditches, ponds, wetlands, terraces ...).

The spatial resolution (5m) appears almost adequate (requirement is <5m). The temporal resolution (update frequency) declared in the product specifications is 3 years which does not match the required annual update. Furthermore, product latency appears to be more than 3 years, since 2018 is being released in 2023.

LUCAS Landscape Feature module

The Land Use/Cover Area frame Survey (LUCAS) [204] is a standardized sample-based survey covering the whole EU's territory. Data are gathered through direct observations made by surveyors on the ground.

LUCAS started as agricultural land survey, in 2006 shifted to a broader land use, land cover (LULC) and landscape survey. Today it provides harmonized unbiased area estimates on LULC and other land characteristics of EU policy relevance. The survey is carried out every 3 years, the latest survey is from 2022.

In LUCAS 2022 a Landscape Features module was introduced with specific observations on different types of landscape features in 93,000 LUCAS points. Landscape features (LF) are defined in LUCAS as small fragments of natural or semi-natural vegetation in agricultural landscape, which provide ecosystem services and support for biodiversity.

The LUCAS nomenclature classifies landscape features into the following categories: Woody vegetation; Permanent grass/herbaceous; Temporary herbaceous; Ditches and streams; Small ponds and small wetlands; Stone walls, cairns and terraces; Cultural features (local elements of cultural heritage that provide ecosystem services).

[202] https://land.copernicus.eu/pan-european/high-resolution-layers/small-woody-features
[203] www.fao.org/docrep/006/ad665e/ad665e06.htm
[204] LUCAS: The Land Use-Land Cover Area Frame Survey — Copernicus In-situ Component

The field survey and interpretation of LUCAS points selected for the Landscape Features module, provides relevant data from ground- based observation to complement satellite EO products. The update frequency of 3 years does not match the required annual update.

Member States maps and statistics of landscape elements.

It is worth noting that few member States (e.g., Spain, but also Slovenia and Czech Republic) have, or are still working, to complete their national maps of landscape elements. Furthermore, statistics of lying fallow are available for all Member States annually[205].

6.9.5 Conclusions and Recommendations

The Copernicus Small Woody Feature (SWF) layer should be combined with systematic representative ground survey data from LUCAS Landscape Features module. Czúcz et al. (2022) made an overview of the concept of landscape features in EU policy documents and of the available datasets that can provide consistent information at the EU-level. According to the authors, with a careful attention to the underlying semantic inconsistencies, Copernicus SWF and LUCAS LF could be tested for the computation of an unbiased estimator of landscape feature for any region of interest in the EU. The JRC is exploring options for implementing such estimator.

It is suggested an independent evaluation of the Copernicus SWF quality assessment with respect to the requirements of the Common Agricultural Policy and the EU Biodiversity Strategy for 2030, including traceability of all steps. Benchmark between products should be done, as well as with reference data to be established with the aim to propose recommendations for improvements.

Both the update frequency and the latency of available products do not match the user requirements and should be improved to be fully applicable to this use case. Furthermore, it is noted that not all relevant landscape features required in the use case are covered by available products which therefore should be complemented with additional sources.

[205] https://ec.europa.eu/eurostat/web/agriculture/data/database

7 Discussion and conclusions

The biodiversity deep dive has been a pilot study to test the general deep dive protocol. Concerning the overall exercise and the methodology followed, the 5 steps envisaged proved to be a good way of organising the analysis in a structured and efficient way, also maintaining a "technologically agnostic" approach in the first parts when assessing the needs and the quantitative requirements of the users.

However, we found that the clear distinction and full articulation of all the steps originally envisaged by the protocol have not always been possible, as it very much depended on the specificity of the needs put forward by the DGs and the previous experience in the use of EO in the respective policy area. For example, use cases developed around generic assessment requests could hardly be translated into a full EO value chain diagram and had to be addressed differently.

We also found that for an efficient uptake of EO technology in support of EU policy makers, sustained assistance to cover the "last mile", so as to precisely tailor the products or applications to the specific request, is unavoidable, some efforts have to be anyway foreseen for that.

An interesting outcome of the exercise has been found in the cross-policy needs being highlighted during the assessment; these can be made even more explicit to enable efficiency gain and enhanced coherence in EU policy making.

On the specific aim to explore how EO products and services can be used to support EU policies related to the biodiversity domain, we also found interesting thematic synergies, for example three DGs have an interest in the assessment of wetlands from slightly different perspectives. Regarding the capacity to monitor the impacts of EU biodiversity policies using available EO products, a key role could be played by the KCBD and the biodiversity monitoring system under construction. Biodiversity monitoring requires long term efforts to establish trends, it is complex because it is about multi-scalar and multi-temporal structures and processes. EO can help in this regard, but in many cases alternative ways to gather data to build indicators have to be explored.

Also, there is certainly potential to streamline across policies EO applications focused on common spatial environments, such as for example urban areas, where the high cost of very high-resolution imagery could be shared between different policy areas.

The analysis of technical requirements identified in the biodiversity deep dive revealed that policy makers in this field consider spatial resolution and thematic detail more important than high temporal frequency. However, considering to what extent existing products match specific requirements, the spatial resolution of relevant recent Copernicus products is considered appropriate in most cases. Improvements are suggested to focus on more regular and frequent updates of available products, as well as on products latency (i.e., the total time elapsed between when a sensor acquires data and when a product is made available to the users). In addition, the length of time series and their consistency over time are considered generally important although not always adequate. Other areas of improvement are related to the thematic detail of EO products; typical land cover maps are not considered sufficient for many biodiversity applications, and this is as well applicable to land use and sea use products. There is a need to apply reference ecosystem typologies further refining more aggregated land cover classes, to drive the assessment and mapping of health/condition of habitats and ecosystems. In the marine and freshwater environments, key *in-situ* data are still lacking or too heterogeneous to be efficiently exploited.

In this respect, although satellite EO can already offer significant and valuable datasets to support biodiversity related policies, for advanced products and applications and the full exploitation of available technology, the integration of ground-based and more broadly *in-situ* data is key but unfortunately difficult to implement operationally in many cases. This would require a concurrent investment in building spatially referenced *in-situ* datasets as ground truth for validation and interpretation, both on land and even more in the marine environment, where additional challenges to monitor biodiversity are encountered.

The assessment of available EO products has been focused on technical features such as spatial, temporal and thematic content of products, and their matching with respect to the needs of EU policies. The key aspects of uncertainty and accuracy, ratings of the overall quality of EO products could not be considered and no recommendations could be made in this respect. However, publishing training and reference data used for the accuracy assessment of Copernicus products should always be ensured, to openly reporting on the quality of the products and enhance transparency and reproducibility.

As a final remark and recommendation resulting from the deep dive on biodiversity, the efficient use of EO products and services appears to be partly hampered by the difficulty in navigating the vast amount of existing resources and in using the variety of available interfaces to access them. This has been recognised as a limiting factor for their full exploitation in EU policy making.

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List of abbreviations and definitions

BDS	Biodiversity Strategy
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CEOS	Committee on Earth Observation Satellites
CFP	Common Fisheries Policy
CLC	Corine Land Cover
CLC+BB	Corine Land Cover + – Backbone
C3S	Copernicus Climate Change Service
CLMS	Copernicus Land Monitoring Service
CMEMS	Copernicus Marine Environment Monitoring Service
DG AGRI	Directorate – General Agriculture and Rural Development
DG CLIMA	Directorate – General Climate Action
DG CNECT	Directorate – General Communications Networks, Content and Technology
DG DEFIS	Directorate – General Defence Industry and Space
DG ENV	Directorate – General Environment
DG INTPA	Directorate - General International Partnerships
DG MARE	Directorate – General Maritime Affairs and Fisheries
DG REGIO	Directorate – General Regional and Urban Policy
DG RTD	Directorate – General Research and Innovation
DTO	Digital Twin Ocean
EARSC	European Association of Remote Sensing Companies
EBV	Essential Biodiversity Variable
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EEA	European Environment Agency
EFH	Essential Fish Habitat
ENM	Ecological niche Model
EO	Earth Observation
ERDF	European Regional Development Funds
ESA	European Space Agency
ESTAT	Eurostat
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EuropaBON	Europa Biodiversity Observation Network
EUSPA	European Union Agency for the Space Programme
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GAEC	Good Agricultural and Environmental Condition
GBF	Global Biodiversity Framework
GEO	Group of Earth Observation
GKSSB	Global Knowledge Support Service for Biodiversity
HE	Horizon Europe
HR	High Resolution
ICP	International Cooperative Programme
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
KCBD	Knowledge Centre for Biodiversity
KCEO	Knowledge Centre on Earth Observation
KLC	Key Landscape for Conservation
LAI	Leaf Area Index
LAU	Local Area Unit
LF	Landscape Features
MAES	Mapping and Assessment of Ecosystem and their Services
MFF	Multiannual Financial Framework
MPA	Marine Protected Area
MS	Member State
NBR	Normalized Burn Ratio
NBS	Nature Based Solutions

NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NIR	Near Infra-Red
NRL	Nature Restoration Law
PA	Protected Area
PPI	Plant Phenology Index
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goals
SDM	Species Distribution Model
SEEA	System of Environmental Economic Accounting
TLS	Terrestrial Laser Scanning
UNFCCC	United Nations Framework Convention on Climate Change
VHR	Very High Resolution
VME	Vulnerable Marine Environment

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Annexes

Annex 1. Taxonomy of EU policies for the uptake analysis in KCEO

The identification of EU policies that can benefit from Earth Observation (EO) sets the boundaries of the uptake analysis in KCEO. The list of policies to be addressed is intended to be comprehensive and inclusive, but also flexible to eventually adapt to the changing context.

Since requirements and priorities for Copernicus products and services are highly diversified depending on policy areas, the arrangement of the latter into groups or thematic domains is a fundamental building block of the KCEO assessment framework, being the link between on one side the EC departments dealing with a given domain and expressing the requirements for the related policies, and on the other side the Copernicus services and products fulfilling their needs. They will be the base for the “deep dive” assessments of KCEO.

Thus, we have grouped EU policy areas according to thematic domains, also having in mind in a broad sense the type of EO support the different policies may entail. As a matter of fact, since different interpretations are always possible, depending on the perspective the proposed “taxonomy of EU policies” may be considered artificial or arbitrary, while partial overlaps are unavoidable.

As a consequence, it is an initial classification open for discussion and open to future modifications where appropriate. Categories are intended to be sufficiently specific to enable a focused analysis, but also sufficiently broad to embrace different policy files, hence enabling some flexibility for the deep dive assessments. The details may change within a given category depending on the political priorities and specific policy dossiers being tackled by EC services.

To establish the list, we started by looking into various sources. The classification proposed is largely inspired by the grouping in the SWD/2019/394 - User needs for the Copernicus Programme – which has also been retaken, at a very high level of aggregation, by the GSA/EUSPA proposed User Characterisation presented at the Copernicus User Forum of 1st December 2020.

To check for comprehensiveness, we also looked into the list of EU Departments Topics (https://ec.europa.eu/info/departments_en) and the Tags used in the Copernicus web portal (https://www.copernicus.eu/), covering respectively EU policies and EO products perspectives.

Finally, we considered the Thematic Hubs foreseen by the Space Regulation and the current state of play of the related discussion within EC Services in terms of thematic areas to be addressed.

The result of our initial assessment is the following list of 28 themes, the ones which are also named to be Thematic Hubs are marked with an asterisk.

1* Agriculture
2* Food security
3 Forestry
4* Biodiversity
5 Plant health
6 Soils
7 Raw materials
8* Inland Water
9* Coastal management
10 Fisheries and aquaculture
11 Marine pollution
12 Marine strategy and Maritime Spatial Planning
13* Climate change mitigation
14* Climate change adaptation
15* Arctic policy and polar areas
16 Air quality
17* Environmental compliances
18 Transport
19* Energy
20 Regional and urban policies
21* Health
22 Tourism
23* Cultural heritages

24* Support to natural and man-made disasters
25* International development and cooperation
26* Sustainable Development Goals
27 Migration and Home affairs
28 Defence and Security

Annex 2. Questionnaire to guide the interviews with policy DGs

1. User profile (type of user, use of EO maturity)

   1.1. Knowledge of Copernicus and specific services & products for the policy area

   1.2. Already making active use of EO data/products? -> Type of EO user (direct/indirect/potential/support)

   1.3. Which data/products and for which specific DG activities?

   1.4. ICT/data processing skills within the DG

   - any direct data processing?
   - data processing from third parties?
   - data processing for third parties?
   - Collaboration with modelling community or application developers in the field?

   1.5. Obstacles/constraints in EO uptake in the DG?

   1.6. Any needs or plans for capacity building / training on EO in the DG?

   1.7. Which type of EO output generally (or ideally) used or more useful for policy support in the DG (tables, graphs, briefs, maps, reports, web platforms…)?

2. Policy area and use case selection

   2.1. Current (and future) policy files where EO has or can have a role, in the DG (or Unit) related to Biodiversity (policy area, reference legislation and specific related projects, if any)

   2.2. Selection of a Biodiversity related use case, relevance and priority

3. Use case detailed description

   3.1. Units and actors in the DG and beyond for the use case

   3.2. Provide details on why EO is needed, what is the end-user application, or how it is or would be used

   3.3. Stage in the policy cycle (formulation/implementation/evaluation)

   3.4. Time frame foreseen and level of (policy) urgency

   3.5. Is this use case linked to other DGs' activities?

   3.6. Is this use case linked to SDGs?

   3.7. How much EO is key for policy support in this specific use case? (Importance 1-5)

   3.8. Is the DG capable in assessing the outcome of the support received from EO (Copernicus or contributing missions) through demonstrable long-term impact on its application or policy area?

4. Use case technical assessment

   4.1. Further details on what is the end-user output/application expected and how it is or would be used.

   4.2. Type of output required (tables, graphs, maps, online platform, tools, synthesis…)

   4.3. Type of support data needed to implement the use case (satellite, ground-based, airborne observations)

4.4. Needs and accessibility of complementary geospatial data (socio-economic, etc.)

4.5. Understanding of type of integration needed (e.g., modelling, multiple data sources)

4.6. In case of information system requirement (platform, tools etc.) understanding of interfaces to make best use of the data. Would the DG sustain the infrastructure on its own in the long-term?

4.7. Is there already a tool or product or service used/under development related to the use case?

4.8. Describe briefly the application and how the data is accessed.

- what type of data format is it providing?
- who is the service provider?
- What is the level of satisfaction? (e.g., needs more accuracy, less latency etc.)
- Is the tool shared with other DGs activities or linked to other policy file?

4.9. Specific quantitative requirements, whatever is already known/anticipated at this stage

- Area of interest
- Spatial resolution
- Thematic detail/granularity
- Temporal frequency
- Time of year
- Continuity / need of long stable time series (and time range)
- Latency of data products, assessment impact of different latency of delivery on application
- Uncertainty/accuracy. How will the uncertainty information used if provided?

Annex 3. List of EU Biodiversity Strategy indicators examined in the deep dive and potential Earth Observation contribution to the implementation.

See MS Excel worksheet attached.

Annex 4. Copernicus products relevant for the use cases analysed

Copernicus Land Monitoring Service (CLMS)

Component	Product name	Description	Temporal coverage	Geographical coverage[206]	Spatial resolution	Update frequency	EO data sources
CLMS - Pan European	CLC+ Backbone (CLC+ BB)	The CLC+ BB is the first component of the CLC+ product suite and the new land cover product on the Pan-European component of CLMS. The product provides the European wall-to wall spatial distribution of 11 basic land cover classes with 10m resolution (raster version) and 0.5 ha minimum mapping unit (vector version). Currently available for 2018, next product update, for the reference year 2021, will become available in late 2023. After this, product updates will take place every two years. The mapped land cover classes are the following: 1: Sealed; 2: Woody – needle leaved trees; 3: Woody – Broadleaved deciduous trees; 4: Woody – Broadleaved evergreen trees; 5: Low-growing woody plants (bushes, shrubs); 6: Permanent herbaceous; 7: Periodically herbaceous; 8: Lichens and mosses; 9: Non-vegetated and sparsely-vegetated; 10: Water; 11: Snow and ice.	2018	EEA38+UK	10 m, MMU 0.5 ha	2 years from 2021 onwards	Optical/radar time series of Sentinel-1/-2 satellite imagery and auxiliary data
CLMS - Pan European	CORINE Land Cover	CLC product is based on the classification of satellite images produced by the national teams of the participating countries. National CLC inventories are then further integrated into a seamless land cover map of Europe. The resulting European database relies on standard methodology and nomenclature with 44 classes in the hierarchical 3-level CLC nomenclature in 5 major groups, namely artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands, water bodies.	1990, 2000, 2006, 2012, 2018	Increasing with time: EEA38+UK for the 2018 reference year	100 m, MMU 25 ha	6 years from 2000 onwards	Sentinel-2 for the 2018 reference year

[206] The 2021 updates of products will no longer include UK

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Pan European	CORINE Land Cover change	CLCC is one of the Corine Land Cover (CLC) datasets produced within the frame the Copernicus Land Monitoring Service referring to changes in land cover / land use status. CLC changes are derived from satellite imagery by the direct mapping of changes based on image-to-image comparison. CLCC follows the standard hierarchical CLC nomenclature.	1990-2000, 2000-2006, 2006-2012, 2012-2018	Increasing with time: EEA38+UK for the 2018 reference year	100 m, MMU 5ha	6 years from 2000 onwards	IRS P6 LISS III, RapidEye for the 2012 reference year and Sentinel-2 for the 2018 reference year
CLMS - Pan European	HRL Forest - Tree Cover Density	The Tree Cover Density (TCD) represents one of the primary status layers of the HRL Forest product portfolio. TCD is defined as the vertical projection of the tree crowns to a horizontal earth's surface and provides information on the proportional crown coverage per pixel. The range of tree cover per pixel is between 1-100%. Shrubs and dwarf trees are not mapped	2012, 2015, 2018	EEA38+UK	10 m (2018), 20 m (2012 and 2015), 100 m	Reference years in 3 years intervals (in future 1 year)	Sentinel-1, Sentinel-2 for the 2018 reference year
CLMS - Pan European	HRL Forest - Tree Cover Change Mask	A simple tree cover change mask product mapping pixels with new or lost tree cover between 2015-2012 and 2018-2015.	2012-2015, 2015-2018	EEA38+UK	20 m	Reference years in 3 years intervals (in future 1 year)	Sentinel-1, Sentinel-2 for the 2018 reference year
CLMS - Pan European	HRL Forest - Dominant Leaf Type	The DLT is one of the primary status layers of the HRL Forest, it provides information on the dominant leaf type, i.e., broadleaved or coniferous, in the Tree Cover Density product).	2012, 2015, 2018	EEA38+UK	10 m (2018), 20 m (2012 and 2015),	Reference years in 3 years intervals (in future 1 year)	Sentinel-1, Sentinel-2 for the 2018 reference year
CLMS - Pan European	HRL Forest - Forest Type	The forest type product follows the Food and Agriculture Organisation (FAO) definition of forest (www.fao.org/docrep/006/ad665e/ad665e06.htm). Trees outside forest according to this definition are excluded. It consists of a dominant leaf type product with a MMU of 0.5 ha and a 10% tree cover density threshold applied (resolution 10m (2018) / 20m (2012, 2015)). An additional support layer separates from the main forest type product, forest under agricultural use and in urban context (as derived from CLC and imperviousness data).	2012, 2015, 2018	EEA38+UK	10 m (2018), 20 m (2012 and 2015), 100 m	Reference years in 3 years intervals	Sentinel-1, Sentinel-2 for the 2018 reference year

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Pan European	HRL - Grassland	The High Resolution Layer Grassland aims at providing a synoptic view on the distribution, extent and dynamics of grasslands in Europe. It includes natural, semi-natural and managed grasslands (according to their origin and utilization) as well as all types of grassland (permanent or seasonal), in all cases with at least 30% ground cover. In future releases (with data after 2018) a layer named Herbaceous cover is planned to be included together with information on mowing events	2015, 2018	EEA38+UK	10 m (2018), 20 m (2015), 100 m	Reference years in 3 years intervals (in future 1 year)	Sentinel-1, Sentinel-2 for the 2018 reference year
CLMS - Pan European	HRL - Grassland change	The HRL Grassland Change product maps the change between the reference years 2015 and 2018. It distinguishes new grassland, loss of grassland, as well as unverified losses and gains. Since grassland shows only little dynamics over time in general, real changes are moderate. Additional support products are the Grassland Vegetation Probability Index (GRAVPI 2018), providing details on the soundness of the grassland class assignment and on the EO data situation and the PLOUGH 2018, providing thematic information on ploughing events derived from historic data (PLOUGH 2018).	2015-2018	EEA38+UK	20 m	Reference years in 3 years intervals (in future 1 year)	Sentinel-1, Sentinel-2 for the 2018 reference year
CLMS - Pan European	HRL - Imperviousness	High Resolution Layer Imperviousness captures the spatial distribution of artificially sealed areas including the level of sealing of the soil per area unit at pan-European level.	2006, 2009, 2012, 2015, 2018	EEA38+UK	10 m, 20 m, 100 m	Reference years in 3 years intervals	Sentinel-1, Sentinel-2 for the 2018 reference year
CLMS - Pan European	HRL - Imperviousness change	The imperviousness change indicator is defined as the yearly average imperviousness change between two reference years. The product maps the degree of Imperviousness change (increase and decrease in %), or soil sealing and is based primarily on the analysis of NDVI (Normalized Difference Vegetation Index).	2006-2009, 2009-2012, 2012-2015, 2015-2018 (temporal reference), 2006-2012	EEA38+UK	20 m, 100 m	Reference years in 3/6 years intervals	Sentinel-1, Sentinel-2 for the 2018 reference year

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Pan European	HRL - Small Woody Features	The SWF layer provides harmonized information on linear structures of woody vegetation, such as hedgerows as well as patches of woody features (200m² ≤ area ≤ 5000m²). The product is most meaningful in agricultural and managed landscapes with distinct hedgerows and/or woody vegetation patches, embedded in an agricultural matrix.	2015, 2018	EEA38+UK	5 m, 100 m and vector	Reference years in 3 years intervals	DEIMOS-2, Pleiades 1A, Pleiades 1B, GeoEye-1, SPOT 6, SPOT 7, WorldView-2, WorldView-3
CLMS - Pan European	HRL - Water and Wetness	The combined Water and Wetness product is a thematic product showing the occurrence of water and wet surfaces over the period from 2012 to 2018. Two products are available: i) The main Water and Wetness (WAW) product with defined classes of (1) permanent water, (2) temporary water, (3) permanent wetness and (4) temporary wetness. ii) The additional expert product: Water Wetness Probability Index (WWPI). The product shows the occurrence of water and indicate the degree of wetness in a physical sense, assessed independently of the actual vegetation cover and are thus not limited to a specific land cover class and their relative frequencies.	2015, 2018	EEA38+UK	20 m, 100 m	Reference years in 3 years intervals	Landsat 5, 7, 8 for the years 2012-2015, Sentinel-1, Sentinel-2 for the years 2016-2018
CLMS - Pan European	HR-VPP Vegetation Indices	High Resolution Vegetation Indices products are provided in near real-time (NRT) every 10 days. Four indices are generated: Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Normalized Difference Vegetation Index (NDVI) and Plant Phenology Index (PPI)	2017 -	EEA38+UK	10 m	10 days	Sentinel-2 A/B (Level 2A)
CLMS - Pan European	HR-VPP Seasonal Trajectories of Vegetation Indices	HR Seasonal Trajectories of Vegetation Indices products are provided yearly after the end of the vegetation growing season. These are derived as a regular time-series of every 10 days by fitting a smoothing and gap filling function to the raw Plant Phenology Index (PPI), generated in the product group Vegetation Indices.	2017 -	EEA38+UK	10 m	Yearly	Sentinel-2 A/B (Level 2A)

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Pan European	HR-VPP Vegetation Phenology Parameters	Products of this group are derived from the Seasonal Trajectories of the PPI index, on a yearly basis, after the end of the growing season. VPP metrics are provided for up to two growing seasons, being e.g. (a) start of season (date, PPI value and slope), (b) end of season (date, PPI value and slope), (c) length of season, (d) minimum of season, (e) peak of the season (date and PPI value), (f) amplitude, (g) small integrated value, (h) large integrated value.	2017 -	EEA38+UK	10 m	Yearly	Sentinel-2 A/B (Level 2A)
CLMS - Pan European	HR Snow and Ice - Fractional Snow Cover / Snow Cover Extent	Two types of snow cover products (1) Fractional Snow Cover (FSC): For each pixel, fraction (0% – 100%) of the surface covered by snow at the top of canopy (FSC-TOC) and on ground (FSC-OG) (also available under the forest canopy). (2) Gap-filled Fractional Snow Cover (GFSC). For each pixel, fraction (0% – 100%) of the surface covered by snow. It uses FSC (FSC-OG),	September 2016 -	EEA38+UK	20 m x 20 m	As Sentinel-2 data	Sentinel-2A/B
CLMS - Pan European	HR Snow and Ice - Persistent Snow Area	The Persistent Snow Area (PSA) product results from the temporal aggregation of the fractional snow cover (FSC) products, and it provides the extent of persistent snow cover, i.e., the area where snow is present throughout the hydrological year.	September 2016 -	EEA38+UK	20 m x 20 m	Yearly	Based on High Resolution Fractional Snow Cover
CLMS - Pan European	HR Snow and Ice - River and Lake Ice Extent - Sentinel-2 and Sentinel-1 based	Three HR-S&I products describe the surface water condition of rivers and lakes. In specific, the product provides information the presence of snow-covered or snow-free ice on the various water bodies described by the EU-HYDRO river and lake network database.	September 2016 -	EEA38+UK	20 m x 20 m	As Sentinel-2 data	Sentinel-2A/B
CLMS - Local	Costal Zones– Status layers	The Coastal Zones Land Cover/Land Use product is providing a detailed dataset for areas along the marine coastline of the EEA39 countries. A 10 km inland buffer zone and the CLC (Corine Land Cover) buffer zone seawards along the coastline define the Area of Interest of the CZ mapping.	2012, 2018	10 km landwards strip of EEA38+UK coast area	0.5 ha MMU	6 years	GeoEye1, Pléiades, SPOT-5 HRG, SPOT-6, WorldView-2

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Local	Costal Zones – Change layer	Coastal Zones change mapping is carried out by visual interpretation of 2012 LC/LU vector data and satellite imagery of the timeframe 2018 and subsequent direct delineation of change polygons. The basis of identification of changes is the interpretation of detectable land cover differences on satellite images from 2012 and 2018. The use of ancillary data is recommended.	2012-2018	10 km landwards strip of EEA38+UK coast area	0.5 ha MMU		GeoEye1, Pléiades, SPOT-5 HRG, SPOT-6, WorldView-2
CLMS - Local	N2K	The N2K product provides detailed Land Cover / Land Use (LC/LU) maps of 4790 grassland-rich Natura 2000 sites. The selection of Natura 2000 sites to be mapped has been prioritized on the basis of occurrence of 32 different grassland habitat types across Europe, as defined by Annex I of the Habitats Directive. The aim of the N2K product is to assess whether those selected sites are being effectively preserved and if a decline of certain grassland habitat types is being halted. The classification provides 55 distinct thematic classes and the class definitions follow a pre-defined nomenclature based on the Mapping and Assessment of Ecosystems and their Services (MAES) typology of ecosystems (at level 1).	2006, 2012, 2018	Selected grassland-rich sites in EU27 countries, Switzerland and the UK	0.5 ha MMU	6 years	GeoEye1, Pléiades, SPOT-5 HRG, SPOT-6, WorldView-2
CLMS - Local	N2K change	N2K change is a change detection of LC/LU as mapped in two subsequent releases of N2K. The change dataset only shows the areas that have changed between the reference years. The production of this dataset is the basis for the status map 2018 as well as for the revision of the previous time steps 2012 and 2006. The classification provides 55 distinct thematic classes. Each change polygon is identified with a Change code that shows the initial class and the change class. The Overall Accuracy is higher than 80%	2006-2012, 2012-2018	Selected grassland-rich sites in EU27 countries, Switzerland and the UK	0.5 ha MMU		GeoEye1, Pléiades, SPOT-5 HRG, SPOT-6, WorldView-2

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Local	Riparian Zones	The Riparian Zones products provide 55 distinct thematic classes and the class definitions follow a pre-defined nomenclature based on the Mapping and Assessment of Ecosystems and their Services (MAES) typology of ecosystems, further harmonised with Corine Land Cover and adapted to the specific characteristics of riparian zones. It offers two types of products: status maps for the two reference years and a change product.	2012, 2018	Areas along a buffer zone of selected rivers in EEA38 countries and UK	0.5 ha MMU	6 years	VHR2 SPOT-6, VHR2 SPOT-5, HRG
CLMS - Local	Urban Atlas – Status layers	The European Urban Atlas provides inter-comparable, HR land use maps for over 300 Large Urban Zones and their surroundings (more than 100.000 inhabitants) in 2006 and for about 800 Functional Urban Area (FUA) and their surroundings (more than 50.000 inhabitants) for the 2012 and 2018 reference year in EEA39. The first change layers were produced in 2012.The Urban Atlas is composed of a suite of products that encompasses: - Land Cover Land Use products in Functional Urban Areas (FUA). - Street Tree Layer produced within the level 1 urban mask for each FUA - Population estimates per Urban Atlas polygons - Building Block Height in cities in a 10 x 10 m grid	2006, 2012, 2018	Increasing: 785 FUAs in EEA38 countries +UK for the 2012 reference year	Class dependent 0.25 ha or 1 ha MMU	6 years (in future 3 years)	Multispectral SPOT 5, 6, Formosat-2 pan-sharpened
CLMS - Local	Urban Atlas - Change layers	Urban Atlas Change layers have become available from 2012 and only for all FUAs that have been covered in both 2006 and 2012 reference years and corresponds only to the changes of Land use/Land cover between those two years. It concerns 305 FUAs produced for both the 2006 and 2012 reference years. The 2012-2018 LU/LC change layer is derived from the combined UA2012 and UA2018 data products with exceptions in order to correspond only to the actual changes of Land Use/Land Cover between those two years. The product uses ancillary data e.g., Google Earth and OpenStreet Map)	2006-2012, 2012-2018	319 FUAs in EU27 and EFTA countries and UK	Class dependent 1 ha or 0.25 ha MMU		Multispectral SPOT 5, 6, Formosat-2 pan-sharpened

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update fre- quency	EO data sources
CLMS - Local	Urban Atlas - Street Tree Layer	The Urban Atlas provides pan-European comparable land use and land cover data for Functional Urban Areas (FUA). The Street Tree Layer (STL) is a separate layer from the Urban Atlas LC/LU layer produced within the level 1 urban mask for each FUA. It includes contiguous rows or a patches of trees covering 500 m² or more and with a minimum width of 10 meter over "Artificial surfaces" (nomenclature class 1) inside FUA (i.e. rows of trees along the road network outside urban areas or forest adjacent to urban areas should not be included).	2012, 2018	Within select- ed FUAs in Urban Atlas 2012	0.05 ha MMU		SPOT 5 Supermode
CLMS - Global	Global Dynamic Land Cover	Land cover maps represent spatial information on different clas- ses of physical coverage of the Earth's surface, e.g., forests, grasslands, croplands, lakes, wetlands. Dynamic land cover maps include transitions of land cover classes over time and hence captures land cover changes. Land use maps contain spatial information on the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it.	2015, 2016, 2017, 2018, 2019	Global	100m	Yearly	PROBA-V
CLMS - Global	Dry Matter Productivi- ty	Dry matter Productivity (DMP) represents the overall growth rate or dry biomass increase of the vegetation and is directly related to ecosystem Net Primary Productivity (NPP), however with units customized for agro-statistical purposes (kg/ha/day). Similarly the Gross Dry Matter Productivity (GDMP) is equivalent to Gross Primary Productivity (GPP). The main difference between DMP and GDMP lies in the inclu- sion of the autotrophic respiration.	2014 - present	Global	300 m	10-daily with consolidations	PROBA-V, Sentinel- 3/OLCI
CLMS - Global	Dry Matter Productivi- ty - archived	See Dry Matter Productivity	1999 - June 2020	Global	1 km	archive only	SPOT-VGT, PROBA-V

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Global	Burnt Area	The Burnt Area products map burn scars, surfaces which have been sufficiently affected by fire to display significant changes in the vegetation cover (destruction of dry material, reduction or loss of green material) and in the ground surface (temporarily darker because of ash). Moreover, they give temporal information on the fire season. The maps of Burnt Area are recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).	April 2018 - present	Global	300 m	10-daily	PROBA-V
CLMS - Global	Burnt Area - archived	See Burnt area product	Apr 2014 - Aug 2018	Global	1 km	archive only	PROBA-V
CLMS - Global	Fraction of Photosynthetically Active Radiation Absorbed by the Vegetation (FAPAR)	The FAPAR quantifies the fraction of the solar radiation absorbed by live leaves for the photosynthesis activity. Then, it refers only to the green and alive elements of the canopy. The FAPAR depends on the canopy structure, vegetation element optical properties, atmospheric conditions, and angular configuration. To overcome this latter dependency, a daily integrated FAPAR value is assessed. FAPAR is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).	Jan 2014 - present	Global	300 m	10-daily with consolidations	PROBA-V, Sentinel-3
CLMS - Global	Fraction of Photosynthetically Active Radiation Absorbed by the Vegetation (FAPAR) - archive	See Fraction of Photosynthetically Active Radiation Absorbed by the Vegetation (FAPAR)	1999 - June 2020	Global	1 km	archive only	SPOT-VGT, PROBA-V
CLMS - Global	Fraction of Green Vegetation Cover	The Fraction of Vegetation Cover (FCover) corresponds to the fraction of ground covered by green vegetation. It quantifies the spatial extent of the vegetation. Since, it is independent from the illumination direction and it is sensitive to the vegetation amount, FCover is a very good candidate for the replacement of classical vegetation indices for the monitoring of ecosystems.	Jan 2014 - present	Global	300 m	10-daily with consolidations	PROBA-V, Sentinel-3

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update fre-quency	EO data sources
CLMS - Global	Fraction of Green Vegetation Cover - archived	See Fraction of Green Vegetation Cover	1999 - June 2020	Global	1 km	Archive only	SPOT-VGT, PROBA-V
CLMS - Global	Gross Dry Matter Productivity	Dry matter Productivity (DMP) represents the overall growth rate or dry biomass increase of the vegetation and is directly related to ecosystem Net Primary Productivity (NPP), however with units customized for agro-statistical purposes (kg/ha/day). Similarly, the Gross Dry Matter Productivity (GDMP) is equiva-lent to Gross Primary Productivity (GPP). The main difference between DMP and GDMP lies in the inclusion of the autotrophic respiration.	2014 - present	Global	300 m	10-daily with consolidations	PROBA-V, Sentinel-3
CLMS - Global	Gross Dry Matter Productivity - archive	See Gross Dry Matter Productivity	1999 - June 2020	Global	1 km	archive only	SPOT-VGT, PROBA-V
CLMS - Global	Leaf Area Index	The Leaf Area Index is defined as half the total area of green elements of the canopy per unit horizontal ground area. The satellite-derived value corresponds to the total green LAI of all the canopy layers, including the understory which may repre-sent a very significant contribution, particularly for forests. Prac-tically, the LAI quantifies the thickness of the vegetation cover. LAI is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).	Jan 2014 - present	Global	300 m	10-daily with consolidations	Sentinel-3/OLCI data
CLMS - Global	Leaf Area Index - ar-chive	See Leaf Area Index	1999 - June 2020	Global	1 km	Archive only	SPOT-VGT, PROBA-V
CLMS - Global	Normalized Difference Vegetation Index (NDVI) - archived	See Normalized Difference Vegetation Index (NDVI)	April 1998 - June 2020	Global	1 km	Archive only	SPOT-VGT, PROBA-V

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update fre- quency	EO data sources
CLMS - Global	Normalized Difference Vegetation Index (NDVI)	The Normalized Difference Vegetation Index (NDVI) is an indicator of the greenness of the biomes. Even though it is not a physical property of the vegetation cover, it has a very simple formulation: NDVI = (REF_nir – REF_red)/(REF_nir + REF_red) where REF_nir and REF_red are the spectral reflectances measured in the near infrared and red wavebands respectively, makes it widely used for ecosystems monitoring.	Jan 2014 - present	Global	300 m	10-daily	PROBA-V, Sentinel-3
CLMS – Global	Vegetation Productivity Index (VPI)	The Vegetation Productivity Index (VPI) assesses the overall vegetation condition by referencing the current value of the NDVI with the long-term statistics for the same period. The VPI is a percentile ranking of the current NDVI value against its historical range of variability: values of 0%, 50% and 100% respectively indicate that the current observation corresponds with the historical minimum (worst vegetation state), median (normal) or maximum (best situation) ever observed.	Jan 2013 - Aug 2018	Global	1 km	Archive only	SPOT/VEGETATION, PROBA-V
CLMS - Global	Vegetation Condition Index (VCI)	The Vegetation Condition Index (VCI) compares the current NDVI to the range of values observed in the same period in previous years. The VCI is expressed in % and gives an idea where the observed value is situated between the extreme values (minimum and maximum) in the previous years. Lower and higher values indicate bad and good vegetation state conditions, respectively.	June 2014 - June 2020	Global	1 km	Archive only	SPOT-VGT, PROBA-V
CLMS – Global	Surface Albedo	The surface albedo quantifies the fraction of the sunlight reflected by the surface of the Earth. Different albedo concepts are defined: 1. The directional albedo or directional-hemispherical reflectance (also called black-sky albedo) is the integration of the bi-directional reflectance over the viewing hemisphere. It assumes all energy is coming from a direct radiation from the sun and is computed for a specific time.	June 2014 - June 2020	Global	1 km	Archive only	PROBA-V

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
		2. The hemispherical albedo or bi-hemispherical reflectance (also called white-sky albedo) is the integration of the directional albedo over the illumination hemisphere. It assumes a complete diffuse illumination. The Global Climate Observing System (GCOS) specified the black-sky albedo (directional albedo) as an Essential Climate Variable and the product is required for climate change purposes.					
CLMS - Global	Surface Soil Moisture	Surface Soil Moisture (SSM) is the relative water content of the top few centimetres soil, describing how wet or dry the soil is in its topmost layer, expressed in percent saturation. It is measured by satellite radar sensors and allows insights in local precipitation impacts and soil conditions. SSM is both an integrator of climatic conditions and a driver of local weather and climate, and plays a major role in global water-, energy- and carbon-cycles. Soil Moisture is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).	2014 - present	Europe	1 km	Daily	Sentinel-1/C-SAR
CLMS - Global	Soil Water Index - Europe	The Soil Water Index quantifies the moisture condition at various depths in the soil. It is mainly driven by the precipitation via the process of infiltration. Soil moisture is a very heterogeneous variable and varies on small scales with soil properties and drainage patterns. Satellite measurements integrate over relative large-scale areas, with the presence of vegetation adding complexity to the interpretation. The soil moisture, up to 5cm soil depth, is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).	May 2014 - present	Europe	1 km	Daily	Sentinel-1/C-band SAR, and EUMETSAT HSAF ETOP/ASCAT

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update frequency	EO data sources
CLMS - Global	Soil Water Index - Global	The Soil Water Index quantifies the moisture condition at various depths in the soil. It is mainly driven by the precipitation via the process of infiltration. Soil moisture is a very heterogeneous variable and varies on small scales with soil properties and drainage patterns. Satellite measurements integrate over relative large-scale areas, with the presence of vegetation adding complexity to the interpretation. The soil moisture, up to 5cm soil depth, is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).	2007 - present	Global	12.5km	Daily	METOP/ASCAT
CLMS – Global	Lake Surface Water Temperature	Lake surface water temperature (LSWT) describes the temperature of the lake surface, one important indicator of lake hydrology and biogeochemistry. Temperature trends observed over many years can be an indicator of how climate change affects the lake. LSWT	Nov 2016 - present	Global	1 km	10-daily	Sentinel3/SLSTR
CLMS – Global	Lake Surface Water Temperature - archive	See Lake Surface Water Temperature	May 2002 - March 2012	Global	1 km	Archive only	ENVISAT/AATSR
CLMS – Global	Lake Water Quality	The Lake Water Products (lake water quality, lake surface water temperature) provide a semi-continuous observation record for a large number (nominally 4,200) of medium and large-sized lakes, according to the Global Lakes and Wetlands Database (GLWD) or otherwise of specific environmental monitoring interest. Next to the lake surface water temperature that is provided separately, this record consists of three water quality parameters: turbidity, trophic state index, and lake surface reflectance.	May 2016 - present	Global	300 m	10-daily	Sentinel3/OLCI

Component	Product name	Description	Temporal coverage	Geographical coverage [206]	Spatial resolution	Update fre-quency	EO data sources
CLMS – Global	Lake Water Quality - archive	See Lake Water Quality	May 2002 - March 2012	Global	300 m, 1 km	Archive only	ENVISAT/MERIS
CLMS – Global	Lake Water Quality – archive	See Lake Water quality	May 2016 – October 2018	Global	1 km	Archive only	Sentinel3/OLCI
CLMS – Global	Lake Water Quality – Europe and Africa	See Lake Water Quality	Jan 2019 – March 2020	Europe and Africa	100 m	Archive only	Sentinel-2 MSI

Copernicus Marine Environment Monitoring Service (CMEMS)

Product name	Product description
Global total surface and 15m current (Copernicus GLO CURRENT)	This product is a Near Real Time (NRT) L4 global total velocity field at 0m and 15m. It consists of the zonal and meridional velocity at 6h frequency and at 1/4 degree (circa 25 km) regular grid produced on a daily basis. These total velocity fields are obtained by combining CMEMS NRT satel Geostrophic Surface Currents and modelled Ekman current at the surface and 15m depth (using ECMWF NRT wind). It is a 6 hourly product, daily and monthly mean are also available.
Sea Surface Salinity (SMOS CATDS)	Sea Surface Salinity (SSS) is an essential variable in oceanography, influencing ocean circulation, climate, and marine ecosystems. The SSS is a difficult variable to measure from space as it requir an accurate measurement of the water temperature, and pressure, while in situ measurements are based on the conductivity of seawater. The satellite measurements of SSS are a valuable complement to in situ measurements, as they provide a synoptic and global view of the ocean salinity. One of the satellite missions that measure SSS is Soil Moisture Ocean Salinity (SMOS) launched in 2009 by ESA. SSS data are further processed by the "Centre Aval de Traitement des Données SMOS" (CATDS). The product is available on a global grid, at 25 km spatial resolution and daily temporal resolution (ascending and descending passes separately), for a period from 2010 to the present, with about 1 day delay.
SSS SMOS L4 OI LOPS v2021	The product is a reformatting and a simplified version of the CATDS L4 product called "SMOS-OI". This product is obtained using optimal interpolation (OI) algorithm, that combine ISAS *in-situ* SSS OI analyses to reduce large scale and temporal variable bias and Soil Moisture Ocean Salinity (SMO satellite image with satellite Sea Surface Temperature information.

Product name	Product description
Sea Surface Temperature, sea ice and wind - OSI TAC	During the first phase of the Copernicus Marine Service (2015-2018), the Sea Surface Teperature (SST) products were included in the “Wind, Ice and Temperature at the Sea Surface” project, ope ating under the Ocean and Sea Ice Thematic Assembly Centre (OSI TAC). The Sea Surface Temper-ature Thematic Assembly Centre (SST TAC) will provide state of the art Level 3 and 4 products based primarily on satellite observational data. These will be provided operationally both in near real time, and multi-year reprocessed products. The Sea Ice Thematic Assembly Centre (SEA ICE TAC) of the Copernicus Marine Service will provide elaborated operational (Level 3 and 4) obser tional multi-mission data products derived from upstream satellite earth observation (L2) data. These data products include sea ice variables. They will be both disseminated directly to users as Copernicus Marine Service products as well as used internally within the overall system for assimi-lation into, and/or validation of ocean analysis and forecasting systems
Global Ocean OSTIA Sea Surface Temperature and Se Ice Reprocessed	The OSTIA global sea surface temperature reprocessed product provides daily gap-free maps of foundation sea surface temperature and ice concentration (referred to as an L4 product) at 0.05deg.x0.05deg. (circa 5 km x 5 km) horizontal grid resolution, using *in-situ* and satellite data. This product provides the foundation Sea Surface Temperature, which is the temperature free of diur variability.
ESA SST CCI and C3S reprocessed sea surface temp ture analyses	The ESA Sea Surface Temperature (SST) Climate Change Initiative (CCI) and Copernicus Climate Change Service (C3S) global Sea Surface Temperature Reprocessed product provides gap-free maps of daily average SST at 20 cm depth at 0.05deg. x 0.05deg (circa 5 km x 5 km) horizontal grid resolution. The ESA SST CCI and C3S level 4 analyses were produced by running the Operatio Sea Surface Temperature and Sea Ice Analysis (OSTIA) to provide a high-resolution daily analysis of the daily average sea surface temperature (SST) at 20 cm depth for the global ocean.
Baltic Sea - Sea Surface Temperature Reprocessed	For the Baltic Sea - The DMI Sea Surface Temperature reprocessed analysis aims at providing da gap-free maps of sea surface temperature, referred as L4 product, at 0.02deg. x 0.02deg. horizont resolution, using satellite data from infra-red radiometers. The product uses SST satellite product from the ESA Climate Change Initiative (CCI) and the Copernicus Climate Change Service (C3S)

Product name	Product description
European North West Shelf/Iberia Biscay Irish Seas - High Resolution L4 Sea Surface Temperature Reprocessed	For the European North West Shelf Ocean Iberia Biscay Irish Seas. The IFREMER Sea Surface Temperature reprocessed analysis aims at providing daily gap-free maps of sea surface temperature, referred as L4 product, at 0.05deg. x 0.05deg. horizontal resolution, over the 1982-2020 period, using satellite data from the European Space Agency Sea Surface Temperature Climate Change Initiative (ESA SST CCI) L3 products (1982-2016) and from the Copernicus Climate Chang Service (C3S) L3 product (2017-2020). The gridded SST product is intended to represent a daily mean SST field at 20 cm depth.
Mediterranean Sea High Resolution L4 Sea Surface Temperature Reprocessed	The reprocessed (REP) Mediterranean (MED) Sea Surface Temperature (SST) dataset provides a stable and consistent long-term SST time series over the Mediterranean Sea (and the adjacent North Atlantic box) developed for climate applications. The REP MED SST product consists of daily (night time), optimally interpolated (L4), satellite-based estimates of the foundation SST (namely, the temperature free, or nearly-free, of any diurnal cycle) at 0.05° resolution grid (circa 5 km) covering the period from January 1st 1982 to present (currently, up to six months before real time). This product is built from a consistent reprocessing of the climate data record provided by the ES Climate Change Initiative (CCI) and the Copernicus Climate Change Service (C3S), also includes in input an adjusted version of the AVHRR Pathfinder dataset increase the input observation cov erage.
Black Sea- High Resolution L4 Sea Surface Temperat Reprocessed	The reprocessed (REP) Black Sea (BS) Sea Surface Temperature (SST) dataset provides a stable and consistent long-term SST time series over the Black Sea developed for climate applications. The REP BS SST product consists of daily (night-time), optimally interpolated (L4), satellite-based estimates of the foundation SST (namely, the temperature free, or nearly-free, of any diurnal cycle) at 0.05° (circa 5 km) resolution grid covering the period from January 1st 1982 to present (currently, up to six months before real time).
Ocean Colour (OCTAC)	OCTAC provides in a timely and sustained manner a set of the Essential Ocean Variables (EOVs that can be retrieved from Ocean Colour radiometry, i.e., CHL, IOPs and PFTs/PSCs (Phytoplan ton Functional Groups and community structure). Global and regional products are higher level o servational combined products providing an added value to standard products delivered by the space agencies. Regional products provide higher accuracy than standard global products as th regionalisation of processing chains takes into account the bio-optical characteristics of each regional sea. Blended datasets are generated by applying the appropriate algorithms across the o ocean and coastal waters.

Product name	Product description
Mediterranean Sea Biogeochemistry Analysis and Forcast	The biogeochemical analysis and forecasts of the Mediterranean Sea at 1/24° of horizontal resolution (circa 4 km) are produced by means of the MedBFM4 model system. MedBFM4 consists of coupling of the multi-stream atmosphere radiative model OASIM, the multi-stream in-water radiative and tracer transport model OGSTM_BIOPTIMOD v4.3, and the biogeochemical flux model BFM v5. Additionally, MedBFM4 features a 3D variational data assimilation scheme with the assimilation of surface chlorophyll (CMEMS OCTAC product) and of vertical profiles of chlorophyll, nitrate and oxygen. The biogeochemical MedBFM system produces one day of hindcast and ten days of forecast (every day) and seven days of analysis (weekly on Tuesday). The variables currently include Mole concentration in sea water of: ammonium, dissolved inorganic carbon, dissolved molecular oxygen, nitrate, phosphate, phytoplankton expressed as carbon, silicate, zooplankton expressed as carbon, Mass concentration of chlorophyll a in sea water, Net primary production of biomass, Sea floor depth below geoid, Sea water alkalinity, Sea water pH reported on total scale, Surface downward mass flux of carbon dioxide, Surface partial pressure of carbon dioxide in sea water, Volume attenuation coefficient of downwelling radiative flux in sea water
In-situ high level products	Mediterranean Sea - Near Real-time (NRT) *in-situ* quality-controlled observations, hourly updated and distributed by the In situ Thematic Data Assembly Center (INSTAC) within 24-48 hours from acquisition on average

Copernicus Climate Change Service (C3S)

Name	Description	Variables in the dataset
sis-biodiversity-era5-global	This dataset provides a historical global reconstruction of bioclimatic indicators derived from ERA5 reanalysis on a latitude-longitude grid. These bioclimate indicators describe how the climate affects ecosystems, the services they deliver, and nature's biodiversity. They are specifically relevant for applications within the biodiversity and ecosystem services community. The 78 indicators cover bioclimatic variables from both land and marine environments characterising surface energy, drought, soil moisture and the (near-)surface climate including wind as well as Essential Climate Variables (ECV) relevant to the biodiversity community and are based on hourly or monthly ERA5 reanalysis data. The bioclimatic indicators are widely used within the biodiversity community and have been chosen based on user requirements and consultation with stakeholders, in order to facilitate the direct use of climate information in screening analyses or in diverse downstream applications. The temporal resolution differs depending on the indicator varying between monthly, annual, and multi-annual averages. This dataset was produced on behalf of the Copernicus Climate Change Service.	Annual mean temperature (BIO01), Annual precipitation (BIO12), Aridity annual mean, Aridity coldest quarter, Aridity driest quarter, Aridity warmest quarter, Aridity wettest quarter, Cloud cover, Dry days, Evaporative fraction annual mean, Evaporative fraction coldest quarter, Evaporative fraction driest quarter, Evaporative fraction warmest quarter, Evaporative fraction wettest quarter, Frost days, Growing degree days, Growing degree days during growing season length, Growing season end of season, Growing season length, Growing season start of season, Isothermality (BIO03), Koeppen-Geiger class, Maximum 2m temperature, Maximum length of dry spells, Maximum precipitation, Maximum temperature of the warmest month (BIO05), Mean diurnal range (BIO02), Mean intensity of dry spells, Mean length of dry spells, Mean precipitation, Mean temperature of coldest quarter (BIO11), Mean temperature of driest quarter (BIO09), Mean temperature of warmest quarter (BIO10), Mean temperature of wettest quarter (BIO08), Meridional wind speed, Minimum 2m temperature, Minimum temperature of the coldest month (BIO06), Number of dry spells, Potential evaporation annual mean, Potential evaporation coldest quarter, Potential evaporation driest quarter, Potential evaporation warmest quarter, Potential evaporation wettest quarter, Precipitation of coldest quarter (BIO19), Precipitation of driest month (BIO14), Precipitation of driest quarter (BIO17), Precipitation of warmest quarter (BIO18), Precipitation of wettest month (BIO13), Precipitation of wettest quarter (BIO16), Precipitation seasonality (BIO15), Sea ice concentration, Sea surface temperature, Summer days, Surface latent heat flux annual mean, Surface latent heat flux coldest quarter, Surface latent heat flux driest quarter, Surface latent heat flux warmest quarter, Surface latent heat flux wettest quarter, Surface sensible heat flux annual mean, Surface sensible heat flux coldest quarter, Surface sensible heat flux driest quarter, Surface sensible heat flux warmest quarter, Surface sensible heat flux wettest quarter, Temperature annual range (BIO07), Temperature seasonality (BIO04), Volumetric soil water layer 1 annual mean, Volumetric soil water layer 1 coldest quarter, Volumetric soil water layer 1 driest quarter, Volumetric soil water layer 1 warmest quarter, Volumetric soil water layer 1 wettest quarter, Water vapour pressure, Wind speed, Zonal wind speed.

Name	Description	Variables in the dataset
sis-biodiversity-cmip5-global	This dataset provides global bioclimatic indicators derived from CMIP5 climate projections. These bioclimatic indicators describe how the climate affects ecosystems, the services ecosystems deliver and nature's biodiversity. They are specifically relevant for applications within the biodiversity and ecosystem community. The 78 indicators cover bioclimatic variables for both land and marine environments characterising surface energy, drought, soil moisture and the (near-)surface climate including wind as well as Essential Climate Variables (ECV). The selection of indicators is based on user requirements and consultation with stakeholders, in order to facilitate the direct use of climate information in screening analyses or in diverse downstream applications. The indicators calculated based on daily CMIP5 climate projections from 10 Global Circulation Models for two future climate scenarios, Representative Concentration Pathway (RCP) 4.5 & RCP 8.5. The data have been additionally bias-adjusted against ERA5 reanalysis data. The temporal resolution differs depending on the indicator, varying between monthly, annual and multi-annual averages. This dataset was produced on behalf of the Copernicus Climate Change Service.	Annual mean temperature (BIO01), Annual precipitation (BIO12), Aridity annual mean, Aridity coldest quarter, Aridity driest quarter, Aridity warmest quarter, Aridity wettest quarter, Cloud cover, Dry days, Evaporative fraction annual mean, Evaporative fraction coldest quarter, Evaporative fraction driest quarter, Evaporative fraction warmest quarter, Evaporative fraction wettest quarter, Frost days, Growing degree days, Growing degree days during growing season length, Growing season end of season, Growing season length, Growing season start of season, Isothermality (BIO03), Koeppen-Geiger class, Maximum 2m temperature, Maximum length of dry spells, Maximum precipitation, Maximum temperature of the warmest month (BIO05), Mean diurnal range (BIO02), Mean intensity of dry spells, Mean length of dry spells, Mean precipitation, Mean temperature of coldest quarter (BIO11), Mean temperature of driest quarter (BIO09), Mean temperature of warmest quarter (BIO10), Mean temperature of wettest quarter (BIO08), Meridional wind speed, Minimum temperature, Minimum temperature of the coldest month (BIO06), Number of dry spells, Potential evaporation annual mean, Potential evaporation coldest quarter, Potential evaporation driest quarter, Potential evaporation warmest quarter, Potential evaporation wettest quarter, Precipitation in coldest quarter (BIO19), Precipitation in driest quarter (BIO17), Precipitation in warmest quarter (BIO18), Precipitation in wettest quarter (BIO16), Precipitation of driest month (BIO14), Precipitation of wettest month (BIO13), Precipitation seasonality (BIO15), Sea ice concentration, Sea surface temperature, Summer days, Surface latent heat flux annual mean, Surface latent heat flux coldest quarter, Surface latent heat flux driest quarter, Surface latent heat flux warmest quarter, Surface latent heat flux wettest quarter, Surface sensible heat flux annual mean, Surface sensible heat flux coldest quarter, Surface sensible heat flux driest quarter, Surface sensible heat flux warmest quarter, Surface sensible heat flux wettest quarter, Temperature annual range (BIO07), Temperature seasonality (BIO04), Volumetric soil water layer 1 annual mean, Volumetric soil water layer 1 coldest quarter, Volumetric soil water layer 1 driest quarter, Volumetric soil water layer 1 warmest quarter, Volumetric soil water layer 1 wettest quarter, Water vapor pressure, Wind speed, Zonal wind speed