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Applicable Documents

[AD 1]	The General Clauses and Conditions for ESA Contracts (herein referred to as GCC), reference ESA/REG/002, rev. 2 not attached hereto but known to both Parties and available on http://emits.sso.esa.int/emits/owa/emits.main) "reference documentation" – "administrative documents", as amended by the Draft Contract
[AD 1]	The Statement of Work, ref. ESA-EOP-SD-SOW-0251, Issue 1, Revision 1, dated 17 November 2021;
[AD 2]	The Standard Requirements for Management, Reporting, Meetings and Deliverables (rev 3: 2015-11) and its Annex A: Layout for Contract Closure Documentation (in its latest version)
[AD 3]	The Contractor's Proposal reference TAP/20289/280222, issue 1, Revision 1, dated 24 February 2022
[AD 4]	PEOPLE-EA Project Management Plan, issue 1, Revision 0, dated 30 September 2022
[VR-1]	PEOPLE-EA Validation and Assessment Report, Greece, V1.5, 6 November 2024 (restricted access)
[VR-2]	PEOPLE-EA Validation and Assessment Report, Italy, V1.2, 8 October 2024 (restricted access)
[VR-3]	PEOPLE-EA Validation and Assessment Report, Norway, V1.3, 8 October 2024 (restricted access)
[VR-4]	PEOPLE-EA Validation and Assessment Report, Slovakia, V1.2, 8 October 2024 (restricted access)
[VR-5]	PEOPLE-EA Validation presentation, Netherlands, 22 May 2024 (IWS presentation, public)

Reference Documents

For clarity all references used are in the text using the APA style. A bibliography is provided at the end of the document.

An acronyms and abbreviations list is provided at the end of the document.

1. Introduction

The European Space Agency (ESA) project “Pioneering Earth Observation Applications for the Environment – Ecosystem Accounting” (PEOPLE-EA) aims to demonstrate the relevance of Earth Observation (EO) for ecosystem accounting in terrestrial and freshwater ecosystems, but also put in place the best technological solutions that can facilitate the use of EO in Accounting for end-users.

1.1 Ecosystem Accounting

Decision- and policy- making often involve macroeconomic assessments, that use the national accounts. To date, national accounts produced under United Nations System of National Accounts (SNA) (United Nations, 2009), do not incorporate information about ecosystems, their extent and/or their condition, and how ecosystems contribute to economic activity (Comte et al. 2022). The economic consequences of ecosystem degradation are therefore not reflected in indicators produced with the national accounts, such as GDP.

The System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA) constitutes an integrated and comprehensive statistical framework for organizing data about habitats and landscapes, measuring the ecosystem services, tracking changes in ecosystem assets, and linking this information to economic and other human activity. The United Nations Statistical Commission adopted the SEEA Ecosystem Accounting in March 2021.

The SEEA EA[1] is built on five core accounts. These accounts are compiled using spatially explicit data and information about the functions of *ecosystem assets* and the *ecosystem services* they produce. The five ecosystem accounts, as shown in Figure 1, are:

1. **ECOSYSTEM EXTENT** accounts record the total area of each ecosystem, classified by type within a specified area (ecosystem accounting area). Ecosystem extent accounts are measured over time in ecosystem accounting areas (e.g., nation, province, river basin, protected area, etc.) by ecosystem type, thus illustrating the changes in extent from one ecosystem type to another over the accounting period.

2. **ECOSYSTEM CONDITION** accounts record the condition of ecosystem assets in terms of selected characteristics at specific points in time. Over time, they record the changes to their condition and provide valuable information on the health of ecosystems.

3.&4. **ECOSYSTEM SERVICES** flow accounts (physical and monetary) record the supply of ecosystem services by ecosystem assets and the use of those services by economic units, including households.

5. **MONETARY ECOSYSTEM ASSET** accounts record information on stocks and changes in stocks (additions and reductions) of ecosystem assets. This includes accounting for ecosystem degradation and enhancement.

[1] More information can be found at https://seea.un.org/ecosystem-accounting.

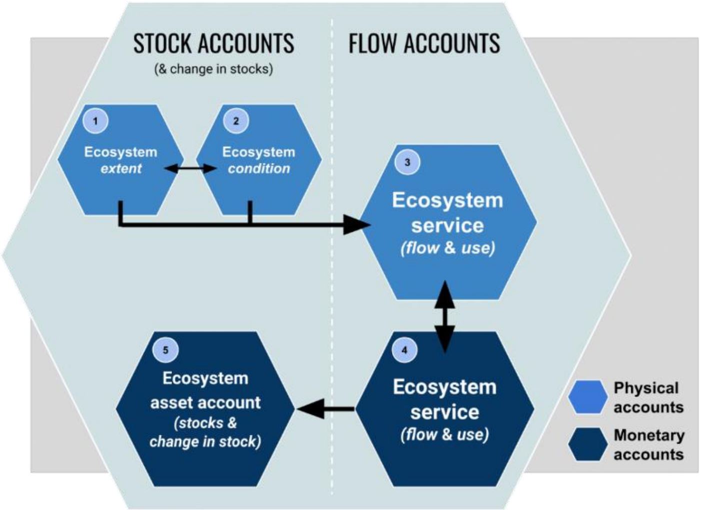


Figure 1. Ecosystem accounts and how they relate to each other (credit: UNSD)

The SEEA EA takes a spatial approach to accounting, as the benefits a society receives from ecosystems depend on where those assets are in the landscape in relation to the beneficiaries. In contrast, the SEEA Central Framework looks at individual environmental assets (resources), such as water or energy resources. This spatial focus identifies the location and size of ecosystem assets, the ecosystem services provided, and the location of beneficiaries (households, businesses and governments). For example, the beneficiaries of water filtration ecosystem services are likely located downstream of the ecosystem asset that provides that benefit (see Figure 2).

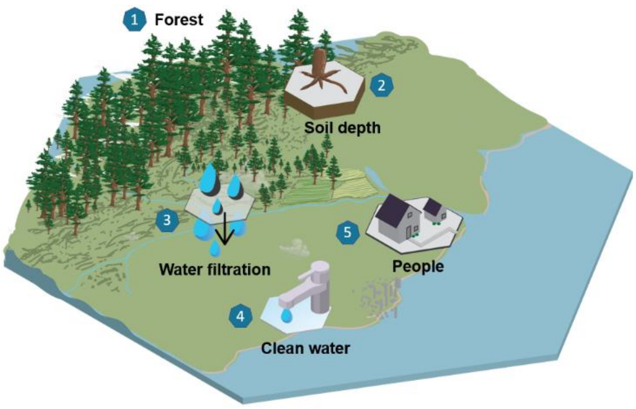


Figure 2. How ecosystem assets generate ecosystem services to beneficiaries in a spatial relationship (credit: UNSD)

As a result, ecosystem accounts are commonly presented using maps, bringing together geographical, environmental, ecological, and economic information in one place, as well as tables. The SEEA EA can be compiled at different spatial scales, including the subnational (state, river basin, protected area, urban, etc.), or national level and across terrestrial, freshwater and marine areas. The use of data from ecosystem extent and condition accounts has been used to monitor progress towards the United Nations Sustainable Development Goals and the strategic objectives of the United Nations Convention to Combat Desertification. Accounts will provide relevant information for monitoring the Post-2020 Global Biodiversity Framework.

In *Europe*, the European environmental accounts – a regulation being adopted in 2024 - underpin the supranational dimension of the environmental issues and provide a systematic approach and coverage across Member States and environmental topics that enable policy assessment and comparisons across Member States. A European task force, under lead of Eurostat, is developing guidance notes for ecosystem extent, condition and services. At the time of writing this document, Eurostat is conducting a number of voluntary data collection to prepare the collection of ecosystem accounts from 2026 onwards (reporting year is 2024). Biophysical service accounts have to be generated and submitted by the Member States annually, while extent accounts and condition accounts will be updated on maximum a 3-yearly cycle.

1.2 Earth Observation

Earth Observation (EO) is the gathering of information about the physical, chemical, and biological systems of the Earth. Space-based or remotely-sensed data is used to monitor and assess the status of and changes in natural and built environments from satellites. Remote sensing satellites observe and gather data from a distance, similar to a simple photography. Precisely, remote sensing by satellite will capture electromagnetic radiation on the microwave, ultraviolet, infrared and visible wavelengths radiated, scattered, or reflected from the Earth. A variety of types of sensors that image different parts of the electromagnetic spectrum exist. These sensors can be mounted on aircraft or carried by spacecrafts.

Optical sensors operate in the visible or near-infrared domain and capture the reflected solar radiation; or in the thermal infrared domain to capture the radiation from earth itself, as shown in Figure 3. Multi-spectral optical sensors have a limited number of bands and hence cannot capture the same details as hyper-spectral optical sensors. Despite the latter have a (more or less) continuous spectrum, they are more complex to process given the amount of data and the sensitivity of the bands to noise.

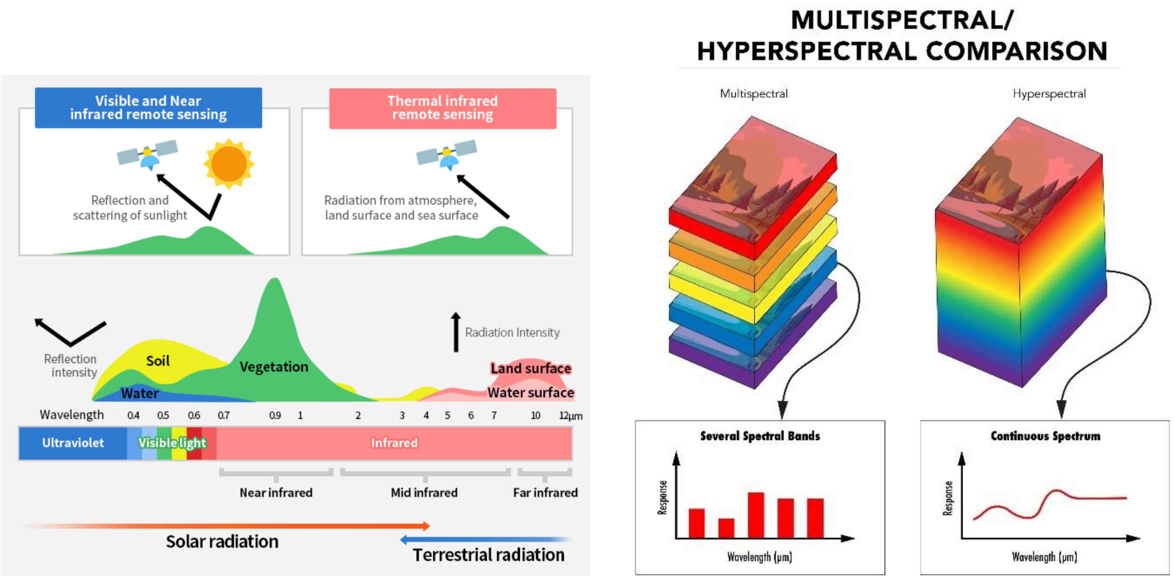


Figure 3. Optical remote sensing principles (left: difference between multi-spectral and thermal, right: difference between multi- and hyper-spectral). Credit left image: JAXA, Credit right image: Edmund Optics.

Synthetic Aperture Radar (SAR) uses radar frequencies to construct an image of the surface of the earth, which means that images can be acquired regardless of weather conditions and cloud cover, and at any time of day or night. SAR is known as an active data collection, where an instrument sends out a pulse of energy (signals) and the records the amount of that energy reflected back after it interacts with Earth.The difference in SAR signals is related to the penetration into the canopy, and hence what can be measured inside the visible top layer. Figure 4 shows a simplified figure on the different SAR signals.

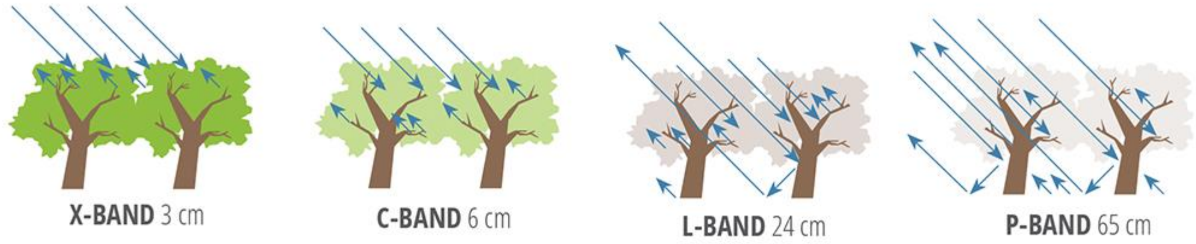


Figure 4. Sensitivity of SAR measurements to forest structure and penetration into the canopy at different wavelengths used for airborne or spaceborne remote sensing observations of the land surface[2]. Credit: NASA SAR Handbook.

LIDAR is a surveying method that measures the distance to a target by illuminating the target with laser light (ultraviolet, visible or near-infrared light). A pulsed laser is sent to an object and the distance is measured by measuring the time it takes for the reflected and scattered light to reach the optical sensor when the laser strikes the object, as shown in Figure 5.

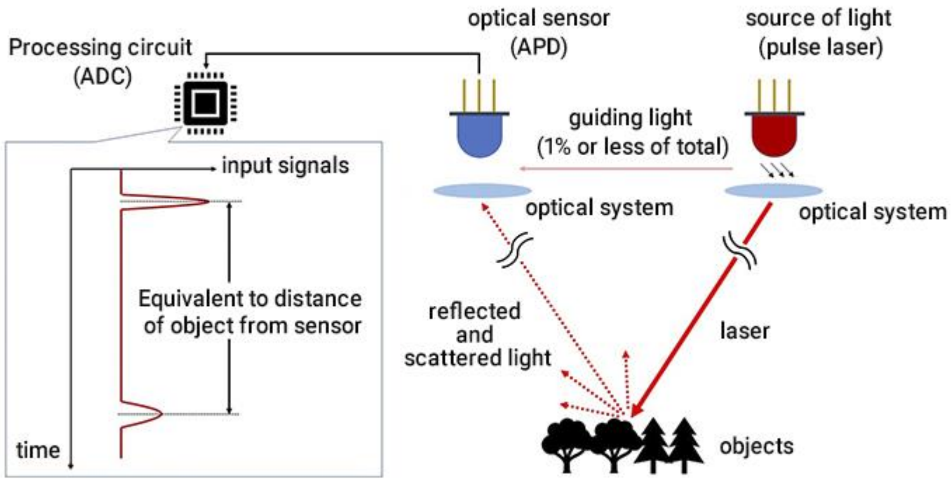


Figure 5. Laser principle. Credit: JAXA.

In Europe, Copernicus[3] is the Earth Observation component of the European Union's Space program. It provides accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security.

1.3 Earth Observation for Ecosystem Accounting

Earth observation has become an essential element in assessing and addressing challenges at local to global scale, providing synoptic overviews which can be used for situation assessment and change detection. Earth Observation (EO) data and EO products (e.g., land cover/land use and vegetation,

[2] More details can be found at https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar
[3] More details can be found at https://www.copernicus.eu/en

above ground biomass, climatic indices maps, etc.) can provide important information about the current state, as well as for changes of ecosystems and their services, in spatial and temporal terms.

Subsequently, this information can be used to quantify and monitor changes and identify trends of the related ecosystem services. By this, the integration of EO data and EO products into the SEEA EA is considered a valuable tool to be combined with other socio-economic and ground truth ecosystem reference datasets to generate information that considers both economic and environmental aspects in the decision-making process.

Recent outcomes of the Group on Earth Observations (GEO) – Earth Observations for Ecosystem Accounting Initiative (EO4EA) point out the importance of EO data and products in ecosystem accounting, e.g., the Copernicus land monitoring services can provide long-term support to ecosystem accounting in Europe, mainly via the Corine Land Cover products. Moreover, EO enables much of the approach, feasibility, and options for standardization of ecosystem accounting.

In *Europe*, the 55th meeting[4] of the European Statistical System Committee (February 2024) has declared in their work program (2024-2028) to explore new data sources (Objective 4). One example of new data source is Earth observation, which has a lot of potential for ecosystem accounts (extent, condition, services) and for forest accounts.

1.4 Aries4SEEA

ARIES is an open-source artificial intelligence (AI)-powered modelling platform aimed at contributing timely and relevant information to address major environmental sustainability challenges. It enables researchers globally to contribute data and models (i.e. knowledge resources) to a humanly curated semantic web. ARIES employs a semantic-driven approach to modelling, using consistently labelled, machine-actionable data and models that can be automatically assembled from web services. The semantic-first approach involves annotating data and models using shared ontologies, composable in logical expressions, which facilitate machine-actionable synthesis and integration of diverse sources.

ARIES utilises the open-source k.LAB (Knowledge Laboratory) software stack (https://docs.integratedmodelling.org/technote/index.html), enabling (1) data and model developers to expose and maintain knowledge resources as open web services; (2) consistent semantic annotation practices for developing modular models with proper documentation and reuse conditions; and (3) a distributed peer-to-peer network hosting interoperable data and model resources made accessible via a web browser and dedicated user interfaces (i.e., ARIES apps).

The most widely used app of this kind is the ARIES for SEEA Explorer (https://seea.un.org/content/aries-for-seea), which allows users anywhere in the world to produce rapid, standardised, scalable and customizable ecosystem accounts for their area of interest that are consistent with the SEEA Ecosystem Accounting framework. ARIES for SEEA is available on the UN Global Platform, a cloud-service platform supporting international collaboration in the development of official statistics using new data sources and innovative methods.

The ARIES for SEEA application provides a user-friendly interface to compute accounts consistent with the SEEA framework, based on the most updated and fully transparent information available in the ARIES ecosystem and its network. Any user can access the application for free, and very quickly and easily obtain results by selecting with a simple click one or more of the accounts available in the panel on the left for a geographic region of interest, over a specific period of time, also intuitively selected from the same panel. This enables any country on earth to jump-start the compilation of SEEA-EA

[4] See https://ec.europa.eu/eurostat/documents/1798247/6191525/European+Strategy+for+Environmental+Accounts/.

without input from their national agencies, which is very important for most of the areas in the world (especially the Global South) with no data availability or lack of experience and capacities to develop this information. Many areas of the world lack the resources to do so, and those are in many cases the region most in need of taking decisions to mitigate and adapt to the climate crisis challenges that the SEEA EA tries to address.

The ARIES for SEEA application allows them to obtain results quickly and for free, which should only be revised and endorsed by the NSO before being used for reporting. But the results, which are obtained more easily and quickly, can also be more easily customized. While clearly the information currently present in the ARIES system is crucial and some cases the only viable way to produce results where data and/or technical capacity are scarce, countries with available local data and a greater experience in generating accounts following their national guidelines, are also favored by the use of ARIES. Indeed, they can more easily use their information to produce accounts consistent with the official SEEA-EA requirements and generate results that are both comparable with other countries and useful for designing effective policymaking at national level. Moreover, since any information used in ARIES can be more easily reapplied in a different context, when more advanced models or better data are introduced in ARIES, they can help other countries to improve their results too, so reducing the gaps between more advanced and less-experienced SEEA-EA users.

ARIES was not developed with the only or main goal to simplify and democratize access to SEEA-EA accounts everywhere on earth. There are far more applications of the ARIES technology, and more will be implemented over time, since the main goal of this project is to democratize scientific knowledge to tackle those issues related to the environment and the sustainability of our planet, our economy and the people.

1.5 INCA

The European Commission has supported the UN in the development of the SEEA EA framework with contributions from scientists, statisticians, and policymakers throughout the Knowledge Innovation Project on Integrated Natural Capital Accounting (INCA). The INCA project is jointly undertaken by European Commission services (Eurostat, the Joint Research Centre, DG Environment and DG Research and Innovation) and the European Environment Agency. INCA addresses key policy objectives of the EU. In the context of the European Green Deal, the EU Biodiversity Strategy for 2030 is calling for the establishment of an international natural capital accounting initiative.

INCA[5] has developed a series of applications based on an approach fully compliant with the SEEA EA. The approach provides an operational procedure to assess and value ecosystem services. Ecosystem service accounts from 2000 to 2021 were generated across the EU Member States, through the INCA tool. This INCA QGIS (Geographical Information System tool) plug-in contains service models for nine ecosystem services, written in python as open source in a modular way.

[5] More information can be found at https://ecosystem-accounts.jrc.ec.europa.eu/.

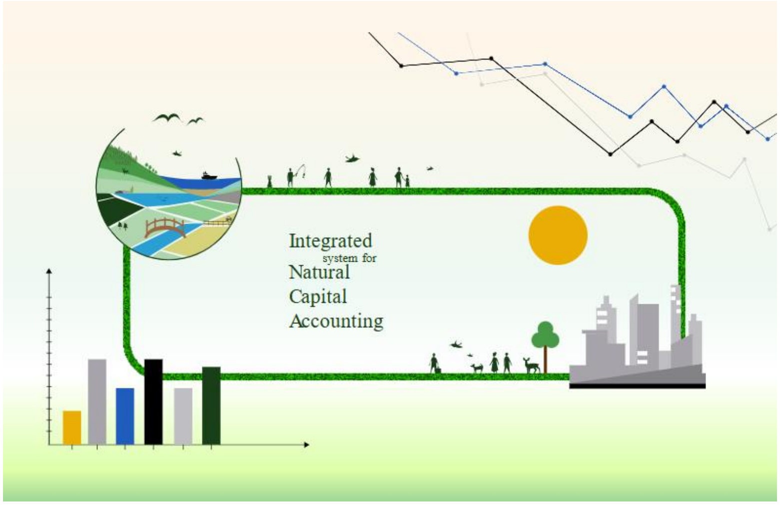


Figure 6.Integrated system for NCA in Europe (credit: JRC).

The European INCA accounts were generated with continental datasets made available and tailored to the European context. These datasets can be used as default inputs for the INCA-tool to generate one, or more, of the nine ecosystem service accounts. The pre-processing of data into these default datasets is done offline and the scripts are not available in the source repository.

1.6 OpenEO

OpenEO[6] offers standardized interfaces for easy access and processing of Earth Observation data. The interfaces are implemented in OpenEO platforms, amongst one is the Copernicus Data Space Ecosystem. These OpenEO platforms provide intuitive programming libraries to process a wide variety of earth observation datasets. With its versatile tools, one can effortlessly create new workflows or integrate them in existing ones and perform explorative research to large-scale production of EO-derived maps and information.

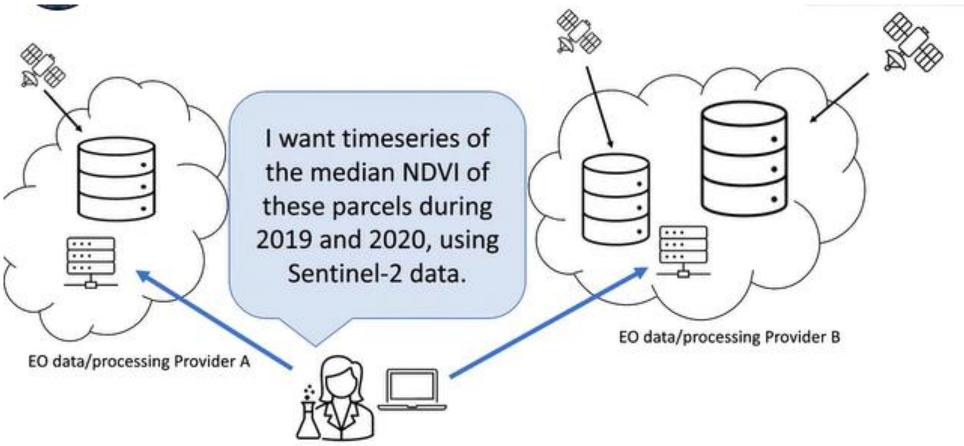


Figure 7. Request information from EO time-series through OpenEO (credit: Terrascope).

[6] See https://openeo.cloud/.

2. Case study

2.1 System-of-system approach

Based on the experience by the two technological project partners, VITO and the Basque Centre for Climate Change (BC3), their respective innovative solutions were capitalized by connecting different available systems seamlessly, therefore harnessing the power of their integration. The blueprint of the integrated architecture was then built with three main pieces in mind:

1. ARIES, as semantic front-end of the integrated system, powered by the k.LAB software stack;
2. OpenEO, as data and processing workflows supplying engine (via UDP/UDF[7] catalogues);
3. INCA, as dedicated NCA data preparation routines and models, according to EU standards.

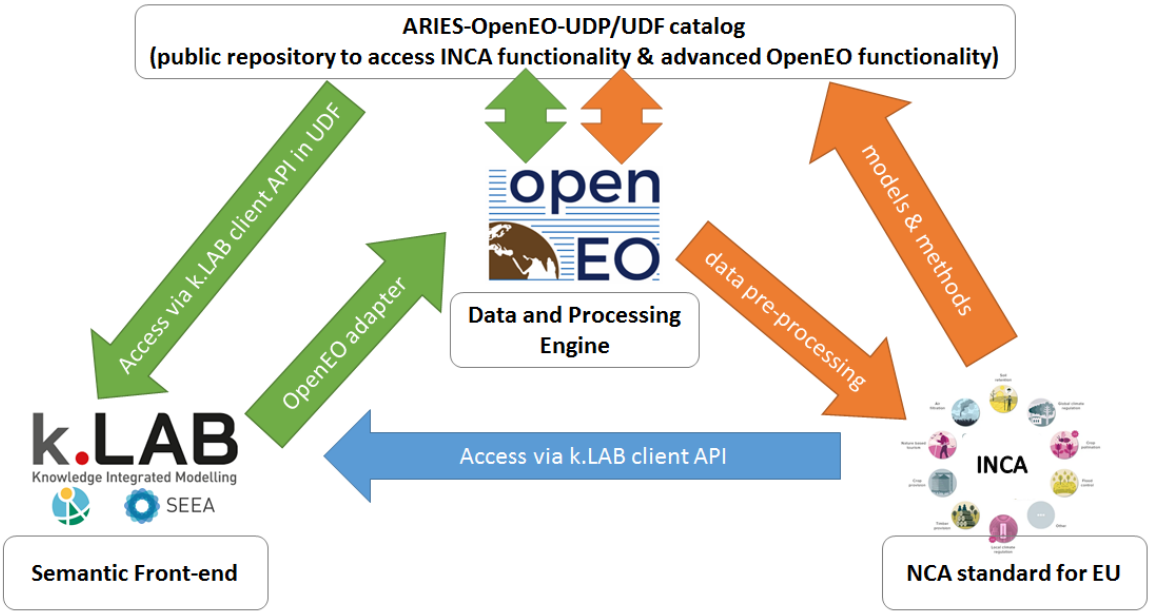


Figure 8: The system architecture triangle

The system, called the ARIES for PEOPLE, is an application developed to generate accounts focused on forest condition in Europe, obtained by integrating processed Earth Observation data from different cloud providers, a pioneering and state-of-the art implementation of data and model interoperability. The system also showcases the ability to integrate INCA ecosystem service models, as is demonstrated for the soil erosion service.

2.2 Pilot Accounts

Five Early Adopters (countries) did define their interest to explore the use of Earth Observation for different ecosystem accounts. Table 1 presents an overview of the accounts requested by the early adopters.

[7] User defined processes and user defined functions; see https://openeo.org/documentation/1.0/

Table 1. Pilot demonstrator accounts

Ecosystem account*	**Greece**	**Italy**	**Norway**	**Slovakia**	**the Netherlands**
Ecosystem extent	X		X**	X	
Forest ecosystem condition	X	X	X	X	X
Coastal ecosystem condition	X	X			X
Wood provision ecosystem service	X	X	X	X	
Nature-based tourism ecosystem service	X		X		

(*) The Global Climate Regulation ecosystem service was explored but demonstrator accounts could not be generated due to limitations found in the EO input datasets.
(**) The Ecosystem Extent account was explored for Norway, but a cross-referencing of vegetation plot data to the EUNIS habitat typology was not available in-time to create the accounts.

In accordance with the **Findable, Accessible, Interoperable, Reproducible (FAIR)** principles, and to enhance knowledge sharing, all algorithms and products from PEOPLE-EA are available on **publicly accessible** environments with transparent access conditions.

Table 2. Overview of available tools to generate ecosystem accounts.

	Tool	**Codebase**
hEUNIS (Ecosystem extent)	OpenEO	Github*
Aries4People (Forest condition)	People EA	Github
CoastC (Coastal condition)	Offline	On request
WoodP (Wood provision)	Offline	On request
RPM (Nature-based tourism)	INCA Tool	On request

(*) Upcoming

3. Aries4People

As explained in chapter 2.1, a new system was setup to ease the compilation of accounts taking benefits of the large wealth of EO datasets, named Aries4People application.

One of the flagship products available in this web application is an EO-based forest condition assessment for Europe based on the methods published in Maes et al. 2023, which computes a forest condition index on the fly using the latest EO products for key variables such as Net Difference Water Index (NDWI), Above-ground Biomass (AGB) and Net Primary Production (NPP). The application thus enables: (1) dynamic, low-latency re-computation of forest ecosystem condition accounts as new, semantically annotated data products become available or to extend existing time series, while using established methods, (2) the potential to apply similar methods outside of Europe, or to adjust weightings for the condition accounts as appropriate to national contexts within or beyond Europe, (3) the potential to extend the approach to support dynamic, flexible, and rapidly compliable ecosystem condition accounting for other ecosystem types for which needed ecosystem condition indicator data are available, such as grasslands, wetlands, or coastal systems.

The application is tested by the Project Team and the Early Adopters, and is targeted to be open and publicly available. A video tutorial is available at https://www.youtube.com/watch?v=fvChjWO5IN8 (link at https://esa-people-ea.org/en/results/deliverables).

Despite its first version, this "system of systems" already supports retrieval and processing of data from satellite EO programs like ESA Sentinel and NASA/USGS Landsat. This architecture also facilitates the creation of integrated models composed of distributed building blocks. It is designed to delineate a clear separation between the building blocks themselves (i.e., data and models) and semantics (used to precisely define their content), with each being uniquely identified and peer reviewed. Semantics orchestrate these independently contributed resources, enabling dynamic creation and execution of computational workflows based on user queries. Should a critical mass of models contributed by the global scientific community be achieved, the potential for the rapid growth and uptake of ecosystem accounting globally is thus evident.

The content and available accounts in the current version of the application are available in this guide[8], which explains step by step (i) how to access the application, (ii) select the spatiotemporal context to be analyzed, (iii) query a particular account or other results, (iv) visualize the results and (v) navigate the documentation automatically generated from the application whenever a particular computation, model or account is triggered to obtain the results required by the user. The guide also provides theoretical support to back-up the selection of the datasets used to represent each one of the main categories, called Ecosystem Typology Class in SEEA's jargon, to assess an ecosystem condition account consistent with this international framework. The representation of each ETC is relevant to make sure the condition is assessed considering all the different aspect that affects an ecosystem state, but each indicator was also weighted based on the quality and frequency of the underlying information. Such considerations are explained in detail in the documentation, as well as in the ARIES4PeopleEA guide.

Each input, intermediate and final component in the modeling workflow is transparently described providing the details of its original source, the manipulations or transformations required to fit the purpose of the analysis, and the combination of these components to get to the results (also represented in a graphic way, to clearly represent the strategy adopted by the AI to integrate such information). All results can be visualized online, as maps (to represent the spatial information in the

[8] See https://confluence.integratedmodelling.org/pages/viewpage.action?spaceKey=AFP&title=ARIES+for+PEOPLE-EA+Explorer+users+guide

context selected) or summarized as tables, and these output can be downloaded for further analysis outside the application, and used as input for additional analysis (comparison of results, methodology, assessment of the model and/or data fit for a specific purposes) or to facilitate the environmental reporting after revision and endorsement from the relevant department of a national or subnational agency. NSOs and other environmental or administrative entities interested in environmental analysis can use these outputs to facilitate their work. The use of the application help to jump start NCA analysis in those offices were there was no previous experience in a consistent generation of condition assessment result to monitor the status of the ecosystems. Since model and data can be re-used, if a better model is developed and integrated in the system, once endorsed its effectiveness in different context, can be easily re-used or more quickly re-adapted to reflect the specific characteristic of the new study, but without starting the analysis from scratch. Since all models and data are integrated in the system as modules, only those components that require to be adjusted should be changed, decreasing exponentially the time required to run an environmental analysis when compared against a NSO working in isolation (here isolation means developing results in a non-interoperable system).

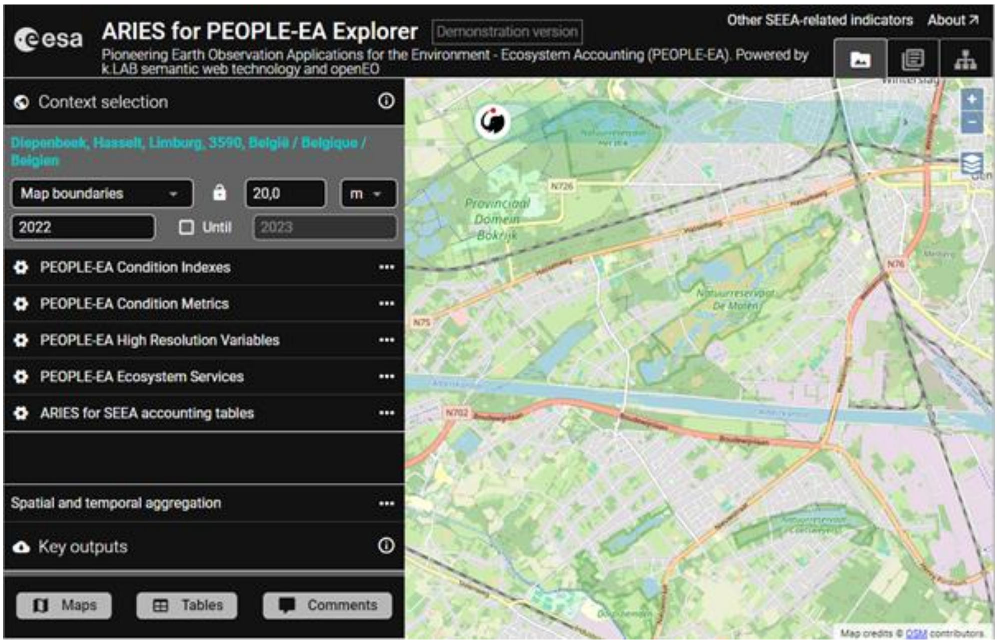


Figure 9. Aries4People application

Next to the EO-based forest condition account, the application has also integrated the INCA soil retention ecosystem service model. As such if users select a region in Europe, this model is used instead of the more generic global model. The European model has a more advanced C-factor, which is based on Fraction of Vegetation Cover time-series and agriculture management information compared to the generic global model. The latter model uses a simple Look-up Table for the land cover map for this C-factor. As a result the European model provides more accurate accounting results. The integration has shown that conceptually all available INCA models could be integrated into the new innovative system.

4. Results demonstrator accounts

Workflows were developed by the project team to generate the requested account for the Early Adopters. The Early Adopters have evaluated (validated) the accounts on a *best effort* base. The project team thanks all Early Adopters for their contributions during the co-design phase developing the workflows as well as assessing the results.

Note that the workflows developed are still experimental and not yet operational, represented by different TRL[9] Levels. Further R&D work is required as well as being made compliant to the European Statistics Code of Practice (CoP) before being used for official statistical reporting.

Table 3. Technical Readiness Level per demonstration account

Ecosystem account	TRL level	TRL description
Ecosystem extent	4	Technology validated in lab
Ecosystem coastal condition	3	Experimental proof of concept
Ecosystem forest condition	6	Technology demonstrated
Ecosystem wood provision service	3	Experimental proof of concept
Ecosystem global climate regulation service	1	Basic principles observed
Ecosystem nature based tourism service	4	Technology validated in lab

4.1 Ecosystem Extent account

4.1.1 Method

An existing habitat workflow (original developed in project Horizon EuropaBON) was enhanced to first generate EUNIS habitat maps, which are an important geospatial layer to distinguish natural ecosystem types at Level-2 and Level-3 of the EU extent typology. The workflow trains a machine learning model using the in-situ (or other) reference data points provided by the Early Adopters. The models are training in an hierarchical way, hence a model in each leaf of the EUNIS tree is created and applied (inferred) to the total ecosystem accounting area. The EUNIS habitat maps provide probabilities for each class in the tree branch, whereas a simple algorithm was developed to select the final EUNIS class. This EUNIS map is then combined with Land Cover and Land Use data in a simple rule-based model to generate the final extent maps at three different levels. The accounts are derived therefrom. Further detailed in the Algorithm Theoretical Base Document (ATBD).

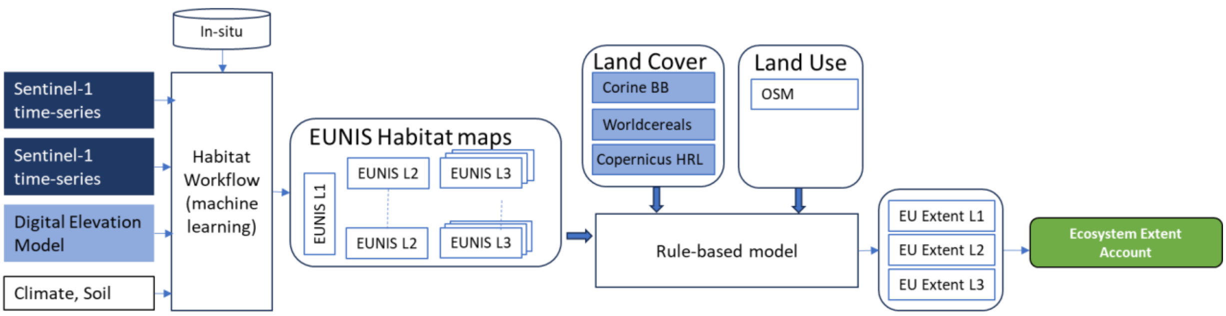


Figure 10. High-level workflow for ecosystem extent accounts.

[9] TRL defines the Technology Readiness Level ranging from 1 (basic principles observed) up to 9 (actual system proven in operational environment).

4.1.2 Results

Ecosystem Extent accounts were generated for Slovakia (entire country) and Greece (Peloponnese) for the year 2020, with focus on detailing up to Level-3 the forest & woodland and coastal ecosystem types. The results for Slovakia are shown in *Figure 11* and *Table 4*.

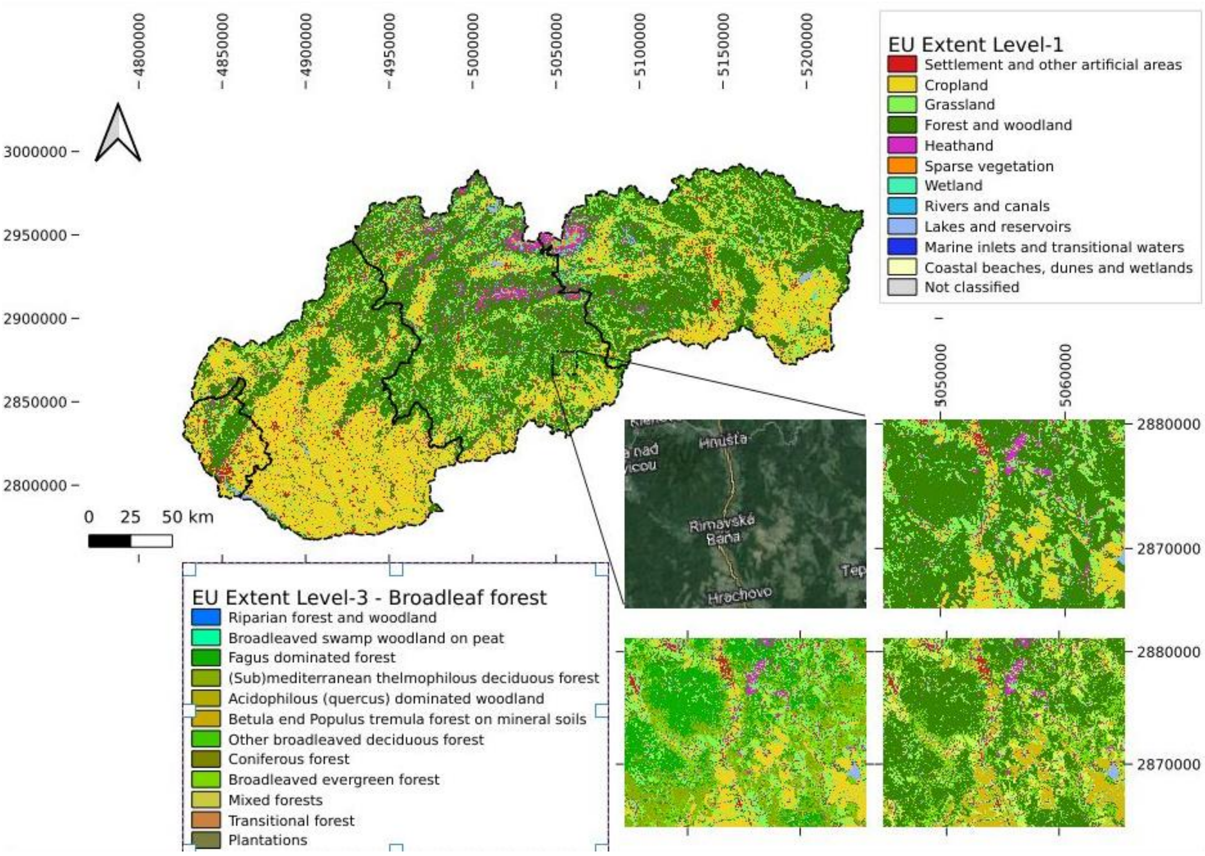


Figure 11. Ecosystem Extent map for Slovakia

Table 4. Ecosystem Extent Account for 2020 Slovakia (upper Level-1, lower Level-3 forest and woodland)

value	Ecosystem Type	Opening area (ha)	Additions	Reductions	Net changes	Closing area 2020 V3_1 (ha)	Share of closing area
0	outside accounting area						
1	Settlements and other artificial areas					156,141	3.17%
2	Cropland					1,499,487	30.47%
3	Grassland					773,421	15.72%
4	Forest and woodland					2,108,915	42.86%
5	Heathland and shrub					226,793	4.61%
6	Sparsely vegetated ecosystems					17,209	0.35%
7	Inland wetlands					52,902	1.08%
8	Rivers and Canals					48,928	0.99%
9	Lakes and reservoirs					37,208	0.76%
10	Marine inlets and transitional waters					0	0.00%
11	Coastal beaches, dunes, and wetlands					0	0.00%
12	Marine ecosystems					0	0.00%
	Total Ecosystem Accounting Area					**4,921,004**	

value	Ecosystem Type	Opening area (ha)	Additions	Reductions	Net changes	Closing area (ha)	Share of closing area
0	outside accounting area					1321837	
4	*Forest and woodland - Totals*					*2,108,915*	*42.86%*
4.0	*Unallocated L2*					*305,258*	*6.20%*
4.1	*Broadleaved deciduous forest - Subtotals*					*1,065,434*	*21.65%*
4.1.0	*Unallocated L3*					0	*0.00%*
4.1.1	Riparian forest and woodland					*8,795*	*0.18%*
4.1.2	Broadleaved swamp woodland on non-acid and acid peat					*205*	*0.00%*
4.1.3	Fagus dominated forest					*762,934*	*15.50%*
4.1.4	Submediterranean and Mediterranean thermophilous deciduous forest					*293,500*	*5.96%*
4.1.5	Acidophilous [Quercus]- dominated woodland					-	*0.00%*
4.1.6	Temperate and boreal and Southern European Betula and *Populus tremula* forest on mineral soils					-	*0.00%*
4.1.7	Other broadleaved deciduous forest, excluding highly-modified plantations					-	*0.00%*
4.1.8	Highly modified broadleaved deciduous forests including stands of non-native trees species that have long been established in European ecosystems stands					-	*0.00%*
4.2	*Coniferous forests - Subtotals*					*311,248*	*6.32%*
4.3	*Broadleaved evergreen forest - Subtotals*					*226,453*	*4.60%*
4.4	*Mixed forests - Subtotals*					*200,522*	*4.07%*
4.5	*Transitional forest - Subtotals*					-	
4.6	*Plantations - Subtotals*					-	

The results for Greece (Peloponnese) are shown in Figure 12and Table 5

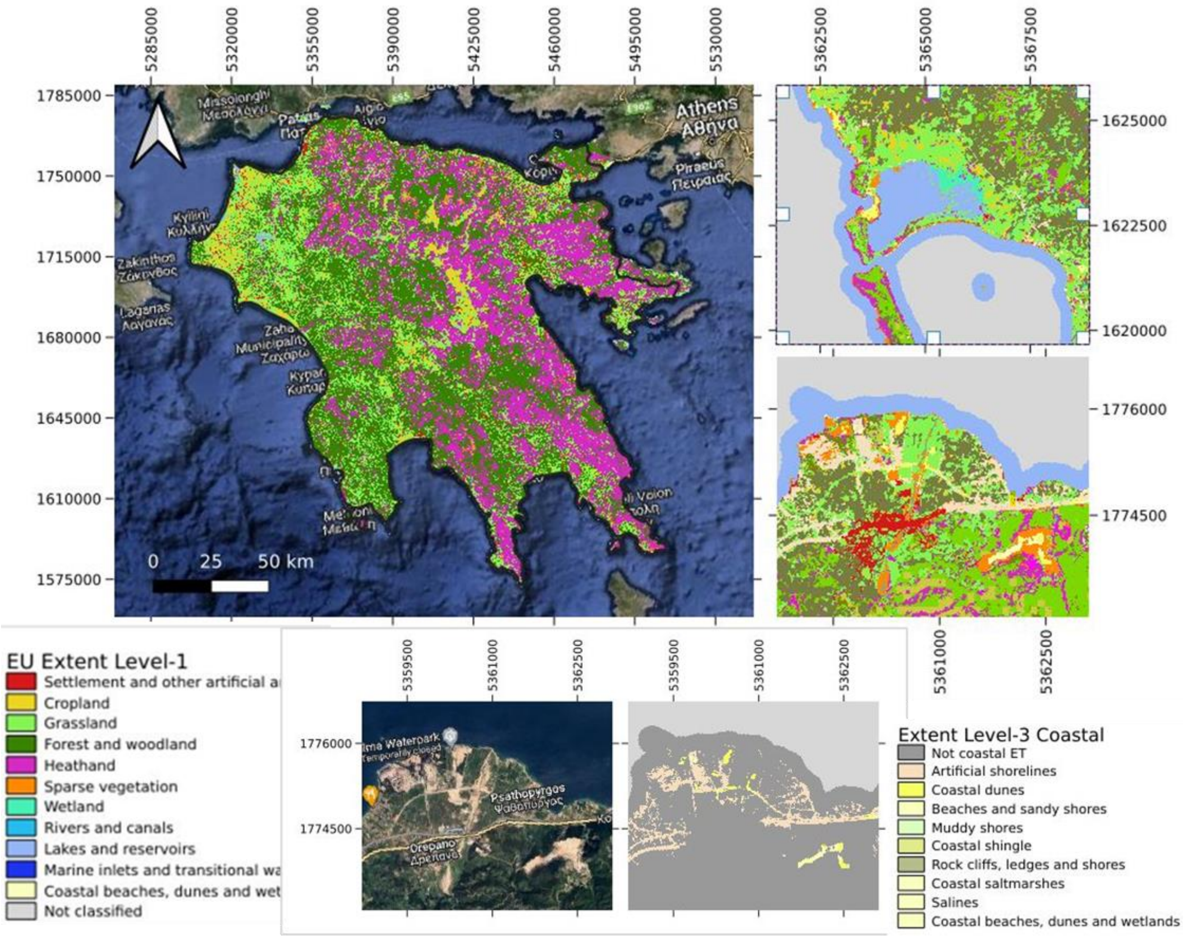


Figure 12. Ecosystem Extent map for Peloponnese (Greece)

Table 5. Ecosystem Extent Account for 2020 Peloponnese (upper Level-1, lower Level-3 coastal ecosystem type)

value	Ecosystem Type	Opening area (ha)	Additions	Reductions	Net changes	Closing area 2020 V3_1 (ha)	Share of closing area
0	outside accounting area						
1	Settlements and other artificial areas					35,784	1.6%
2	Cropland					96,318	4.3%
3	Grassland					467,716	20.6%
4	Forest and woodland					875,869	38.7%
5	Heathland and shrub					689,007	30.4%
6	Sparsely vegetated ecosystems					30,539	1.3%
7	Inland wetlands					1,806	0.1%
8	Rivers and Canals					5,621	0.2%
9	Lakes and reservoirs					49,726	2.2%
10	Marine inlets and transitional waters					-	-
11	Coastal beaches, dunes, and wetlands					13,452	0.6%
12	Marine ecosystems					-	-
	Total Ecosystem Accounting Area					**2,265,838**	

value	Ecosystem Type	Opening area (ha)	Additions	Reductions	Net changes	Closing area (ha)	Share of closing area
0	outside accounting area					1321837	
11	*Coastal beaches, dunes, and wetlands - Totals*					*13,452*	*0.59%*
11.0	*Unallocated L2*					-	*0.00%*
11.1	*Artificial shorelines*					*9,867*	*0.44%*
11.1.0	*Unallocated L3*					-	*0.00%*
11.1.1	Artificial shorelines					9,867	*0.44%*
11.2	*Coastal dunes, beaches and sandy and muddy shores*					*3,445*	*0.15%*
11.2.0	*Unallocated L3*					801	*0.04%*
11.2.1	Coastal dunes					2,214	*0.10%*
11.2.2	Beaches and sandy shores					429	*0.02%*
11.2.3	Muddy shores					-	*0.00%*
11.3	*Coastal rocky shores*					*140*	*0.01%*
11.3.0	*Unallocated L3*					140	*0.01%*
11.3.1	Coastal shingle					-	*0.00%*
11.3.2	Rock cliffs, ledges and shores					-	*0.00%*
11.4	*Coastal saltmarshes and salines*					*0*	*0.00%*
11.4.0	*Unallocated L3*					-	*0.00%*
11.4.1	Coastal saltmarshes					-	*0.00%*
11.4.2	Salines					-	*0.00%*

4.1.3 Validation

The EUNIS habitat maps were validated by Slovakia (Slovak Karst National Park en Devin Lake) by comparing with ground-truth data assembled in 2024 [VR-4]. The result show for Karst National Park an overlap and spatial match as shown in Table below.

Table 6. Accuracy results ecosystem extent maps in two study areas in Slovakia

Ecosystem Extent layer	Karst National Park		Devin Lake	
	Overlap Area (ha)	% of Study Area	Overlap Area (ha)	% of Study Area
Level 1	7221,16	91,18	803,27	63,82
Level 2	7136,83	90,12	801,36	63,67
Level 3	4852,48	61,27	796,65	63,29

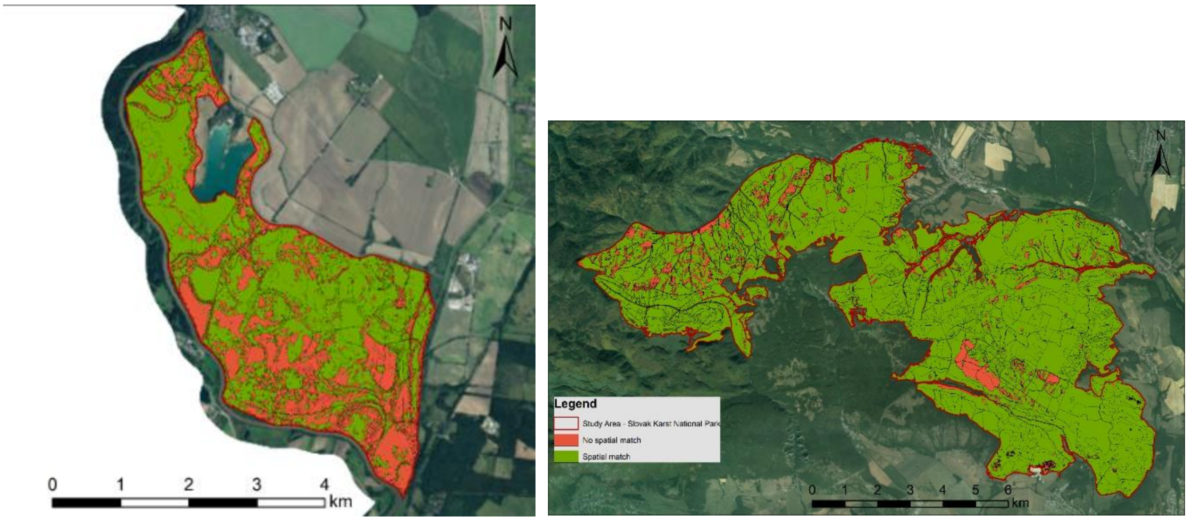


Figure 13. Matching Ecosystem extent classes (level-1) with study areas (left: Devin lake, right: Karst National Park)

Despite these first results are found very valuable and are an important step forward for Slovakia in ecosystem extent mapping, also including the use of the detailed delineations in several policy applications, several recommendations were listed for further improvements:

- Improvement of wetland ecosystem detection
- Focused refinement on riparian forest ecosystems
- Addressing ecosystem types with low or zero overlap (e.g. hay meadows)
- Enhance forest habitat classification at level-3 (especially ravine (T1F) and Carpinus and Quercus mesic deciduous forest (T1E).

For Greece an evaluation was done based on expert judgement visual interpretation with a focus on well-known areas by the early adopter's excerpts, alongside information retrieved from (sub)-national datasets [VR-1]. The evaluation concludes the developed, baseline ecosystem extent values allow for future accounting using a standardized approach to capture future changes. New training data, that are periodically (e.g. via the Habitat Directive reporting projects) or scattered (e.g. environmental studies, research for Diploma, MSc or PhD thesis) collected can be integrated to the model and support future mapping and accounts.

4.2 Ecosystem Condition accounts

4.2.1 Ecosystem Forest Condition account

4.2.1.1 Method

The five early adopters have used the Aries4People web applications to generate forest condition accounts. A workflow was developed, as shown in Figure 14, to calculate 13 condition variables using the SEEA EA Ecosystem Condition Typology (ECT) across different groups and characteristics:

- Abiotic ecosystem characteristics
    - Physical state
    - Chemical state
- Biotic ecosystem characteristics
    - Compositional state
    - Structural state
    - Functional state
- Landscape level characteristics
    - Landscape and seascape

The workflow is implemented in OpenEO and integrated in the ARIES4People application. Users can select to run the workflow at Tier-1 (national scale) or Tier-2 (regional scale). Due to data availability, different variables are integrated in the condition accounts, as shown in

Table 7. Three flavors of weighting and averaging are available to calculate the final index and hence account.

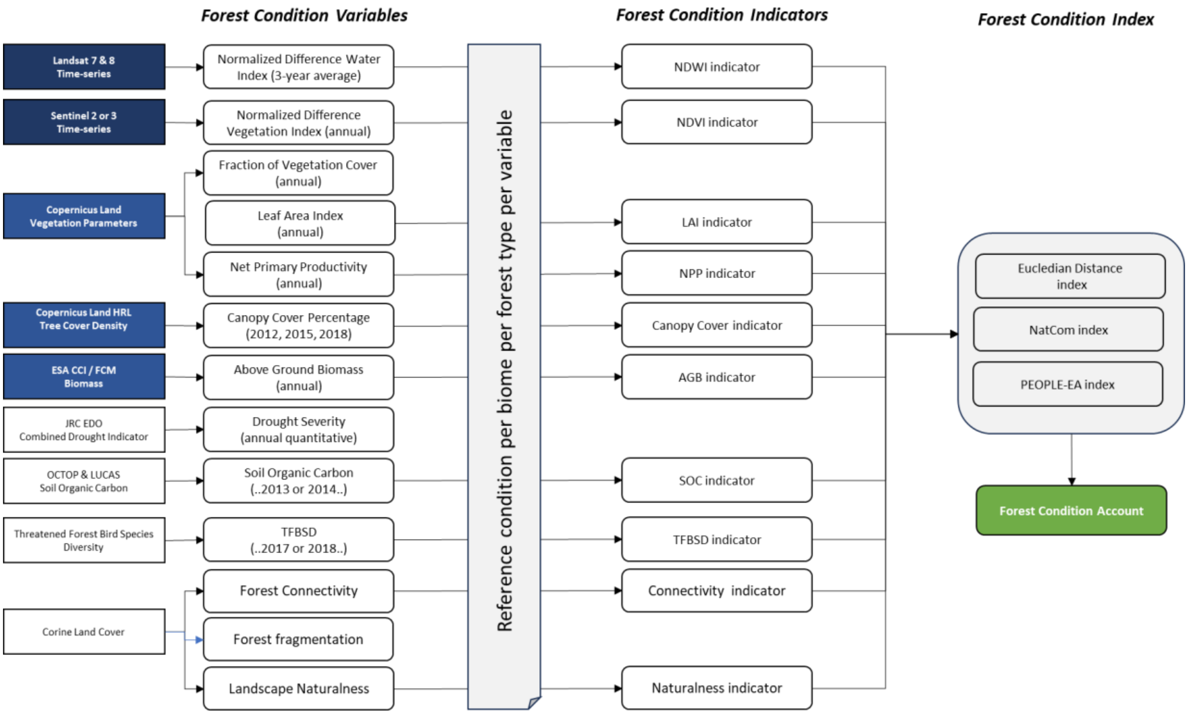


Figure 14. Forest Condition account workflow

Table 7. Mapping table for Forest Condition accounts at Tier-1 and Tier-2

Variable	Tier level	Variable Data	Conversion to indicator	PEOPLE-EA index	NatCom index	Euclidean Distance index
NDWI	1	X	X	X	X	X
SOC	1	X	X	X	X	X
Threatened Forest Bird Species	1	X	X	X	X	X
AGB	1	X	X	X	-	X
AGB	2	X	-	-	-	-
LAI	1	X	X	-	-	-
LAI	2	X	-	-	-	-
PPI	2	X	-	-	-	-
Tree cover density	1	X	X	-	X	-
NPP	1	X	X	X	-	X
FCOVER	1	X	Planned	-	-	-
FCOVER	2	X	-	-	-	-
FAPAR	2	X	-	-	-	-
Drought resistance	1	X	Planned	-	-	-
NDVI	1	X	X	-	X	-
NDVI	2	X	-	-	-	-
Forest connectivity	1	X	X	X	X	X
Landscape naturalness	1	X	X	-	X	-
Forest fragmentation	1	X	-	-	-	-

Further detailed in the Algorithm Theoretical Base Document (ATBD).

4.2.1.2 Results

The Early Adopters have used the ARIES4People web application to generate their own forest condition accounts. Below, see Figure 15 and Table 8, you can find results generated for the year 2022. The accounts were generated with the Corine Forest types combined with the Biogeographic region types in Europe. It should be noted that there were some issues generating the final account for Norway, hence only the forest condition variables were generated and not further shown in this chapter.

Table 8. Forest Condition account results, 2022 per forest ecosystem type

	Year 2022	Year 2022	Year 2022	Year 2022
	Greece	Italy	Slovakia	the Nether
Coniferous forest, Mediterranean	0.61	0.54		
Coniferous forest, Alpine	0.67	0.54	0.57	
Coniferous forest, Continental	0.66	0.47	0.53	
Coniferous forest, Atlantic				0.60
Coniferous forest, Pannonian			0.63	
Broadleaf forest, Mediterranean	0.63	0.60		
Broadleaf forest, Alpine	0.69	0.50	0.60	
Broadleaf forest, Continental	0.68	0.54	0.58	0.50
Broadleaf forest, Atlantic				0.51
Broadleaf forest, Pannonian			0.56	
Mixed forest, Mediterranean	0.59	0.59		
Mixed forest, Alpine	0.73	0.52	0.59	
Mixed forest, Continental	0.72	0.50	0.63	0.38
Mixed forest, Atlantic				0.55
Mixed forest, Pannonian			0.59	
Transitional woodland scrub, Mediterranea	0.59	0.60		
Transitional woodland scrub, Alpine	0.55	0.53	0.69	
Transitional woodland scrub, Continental	0.58	0.48	0.73	
Transitional woodland scrub, Atlantic				0.48
Transitional woodland scrub, Pannonian			0.61	

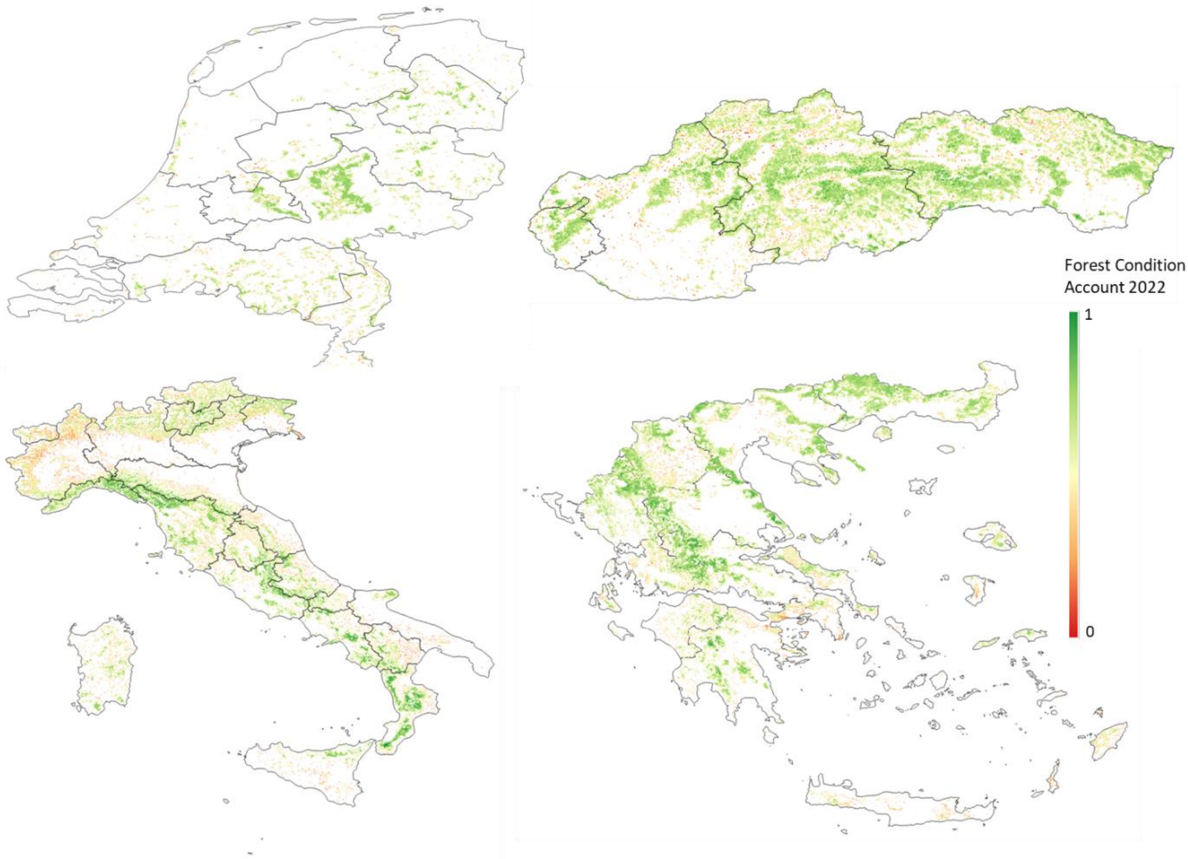


Figure 15. Forest Condition Account 2022: the Netherlands (upper left), Slovakia (upper right), Italy (lower left), Greece (lower right)

4.2.1.3 Validation

Slovakia selected a study area of Čierny Balog (Central Slovakia) [VR-4]. The overall usability of the tool developed within the project is very good, considering many parameters, and the tool can be currently used for a comprehensive assessment of the state of forest ecosystems. The tool has also shown sufficient sensitivity to predict changes such as lycopod calamities and can therefore also be used as a prevention tool. Main recommendations for improvement:

- CLC inaccuracy (30 m) in defining forest and forest type, therefore we recommend to use CLC+ with 10 m resolution data or newly prepared ecosystem extend map/ alternatively other EO based datasets for better deliniation of forest borders can be used
- bird index can be linked to information on art. 12 distribution data and CES (common effort sites) = more precise model
- If possible and where data is available, it's important to recalibrate reference areas and percentile-based thresholds to fit the specific region and scale. This ensures that the selected upper and lower bounds accurately represent local forest conditions and ecological characteristics. Utilizing national datasets (e.g., protected areas or forest typologies) can further refine boundaries, providing more precise and ecologically relevant condition assessments tailored to the local context.
- We recommend shifting from annual temporal composites to a seasonal composite approach (e.g., April to October) to address the limitations of optical data and improve the reliability of spectral indices like NDVI. By recomputing raw variables based on the growing season, the data would better reflect forest health, reducing noise from non-growing periods and providing more stable, meaningful condition indicators.

The Italian forest heritage is characterized by a wide diversity of specific composition. In the last National Forest Inventory (INFC, 2015) a total of about 180 different species were recorded in 23 forest typologies, of which 20 for tree formations and 3 for shrublands [VR-2]. For Forest Condition, it was found possible to detect a decreasing trend in case of forest disturbance, however it is difficult to assess the cases of increasing trend in the condition values, because of lack of reference data and no visible change from photointerpretation. Also, the spatial definition of forest and the spatial resolution often don't include small patches of forest and can cause outliers in boundary pixels such as near the border of rivers.

Norway verified the Standing Biomass (or Above Ground Biomass) forest condition variable through comparing with the national statistics for the Nordland County for the period 2015-2022 for three forest categories: Spruce, Pine and Broadleaf, since the statistics does not distinguish between Atlantic and Alpine forest areas [VR-3]. The average standing biomass in tonnes per hectare for Spruce (46.55), Pine (44.88) and Broadleaf forests (23.91) calculated by Norway differ significantly from the PEOPLE-EA-modelled numbers but are of the same magnitude. This can be traced back to the differences in forest categories in national statistics and the PEOPLE-EA-model, and differences in density factors. The methodology must be further developed and tested.

Greece used field data from forest management studies (where available and spatially explicit), habitat directive monitoring (local conservation degree), MAES national project (LIFE IP 4 NATURA) field surveys and results for ecosystem condition, expert judgment on well-studied forests, and information from local authorities regarding forests and their status, have been used to evaluate the results provided in the ARIES for PEOPLE EA Explorer [VR-2]. The evaluation of the different provided indicators via the ARIES for PEOPLE EA Explorer, documents that forest ecosystem condition in well captured, given the constrains in the fine scale differentiations among forest types. For instance,

- the above ground biomass indicator captures real life conditions, however not always in absolute numbers, i.e. higher indicator values correspond to forest areas with high aboveground biomass, but the indicator value and the real value may be different.
- the forest connectivity percentage indicator, higher values correspond to areas where the local conservation degree for the forest habitats is registered as "good" (in "bad, poor, good" scale) and as assessed by the Dir. 92/43/EEC monitoring project. More precisely, higher values (reddish cells) are found mostly in mountainous areas, and inside Natura 2000 protected areas, where forests (especially Pinus nigra and Abies cephalonica forests) were also assessed with good conservation degree.

The Netherlands have verified the generated accounts with national datasets, as is the naturalness from their ecosystem maps, the forest types and threatened bird species ([VR-5]. As a conclusion, earth observation data products are useful, but gaps exists compared to national mapped data so independent checks with ground truths is needed. For biodiversity related indicators, a rigourous validation against monitoring data is required.

4.2.2 Ecosystem Coastal Condition account

4.2.2.1 Method

A workflow was developed to generate coastal condition accounts based on the Copernicus Imperviousness layer (IMD) – also derived from Earth Observation, and both optical (Sentinel-2) and radar (Sentinel-1) time-series, as shown in Figure 16 and further detailed in the Algorithm Theoretical Base Document (ATBD).

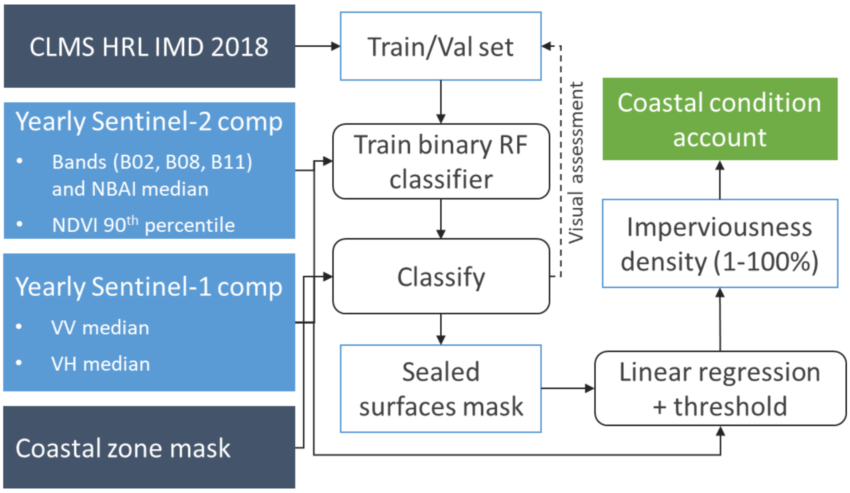


Figure 16. Coastal Condition account workflow

4.2.2.2 Results

The python workflow was used to generate offline the ecosystem accounts for the three requested countries, namely specified coastal regions in Italy, Greece, and the Netherlands, for the years 2018 and 2021. The workflow is scalable as it does not require any specific national parameters. The results of the accounts are shown inTable 9.

Table 9: Annual coastal condition accounts (2018 and 2022) computed for each country's AOI and per NUTS-2 (NUTS-3 for GR). The accounts are given based on two calculation methods: the fraction of sealed pixels (IMD > 0%) and the aggregated mean IMD%.

		SEALED PIXELS %		MEAN IMD%	
NUTS	**NAME**	**2018**	**2022**	**2018**	**2022**
Peloponnese (GR)		**12,4%**	**12,4%**	**8,6%**	**8,9%**
EL632	Achaia	24,5%	24,9%	17,5%	18,3%
EL633	Ileia	9,1%	7,8%	6,3%	5,5%
EL651	Argolida, Arkadia	9,9%	9,4%	6,5%	6,5%
EL652	Korinthia	24,6%	24,4%	17,1%	18,3%
EL653	Lakonia, Messinia	7,5%	7,9%	5,0%	5,4%
Italian Adriatic coast (IT)		**14,2%**	**14,6%**	**12,0%**	**12,5%**
ITH3	Veneto	11,6%	12,0%	9,9%	10,4%
ITH5	Emilia-Romagna	17,0%	17,8%	13,7%	14,5%
ITI3	Marche	24,7%	25,0%	21,2%	21,2%
ITF1	Abruzzo	25,5%	26,2%	21,8%	22,4%
ITF2	Molise	10,1%	10,7%	8,9%	9,5%
ITF4	Puglia	11,3%	11,5%	9,7%	10,1%
Netherlands (NL)		**13,0%**	**13,5%**	**7,9%**	**8,2%**
NL34	Zeeland	19,0%	18,6%	10,8%	10,6%
NL33	Zuid-Holland	17,4%	19,1%	11,3%	13,2%
NL32	Noord-Holland	11,2%	11,8%	7,1%	7,3%
NL12	Friesland	4,9%	6,5%	2,8%	3,6%
NL11	Groningen	11,6%	11,9%	7,6%	7,8%

4.2.2.3 Validation

In Italy, ISPRA has compared the coastal condition for the period 2018-2022, with the land consumption maps of Italy, generated by ISPRA/SNPA [VR-2]. The latter maps are published annually since 2014 and is a first level satellite-based semi-automated classification followed by a manual photo interpretation. The map represents the official reference at national level for information on land consumption, according to Law 132/2016.

Table 10. Error matrix coastal condition account 2022

	SC ISPRA				
Coastal condition IMD	**Non sealed (number of pixels)**	**Sealed (number of pixels)**	**Total (number of pixels)**	**User's accuracy (%)**	**Commission error (%)**
Non sealed (number of pixels)	13,140,715	2,033,532	15,174,247	86.6	13.4
Sealed (number of pixels)	237,185	2,380,081	2,617,266	90.9	9.1
Total (number of pixels)	13,377,900	4,413,613	17,791,513		
Producer's accuracy (%)	98.2	53.9			
Omission error (%)	1.8	46.1			

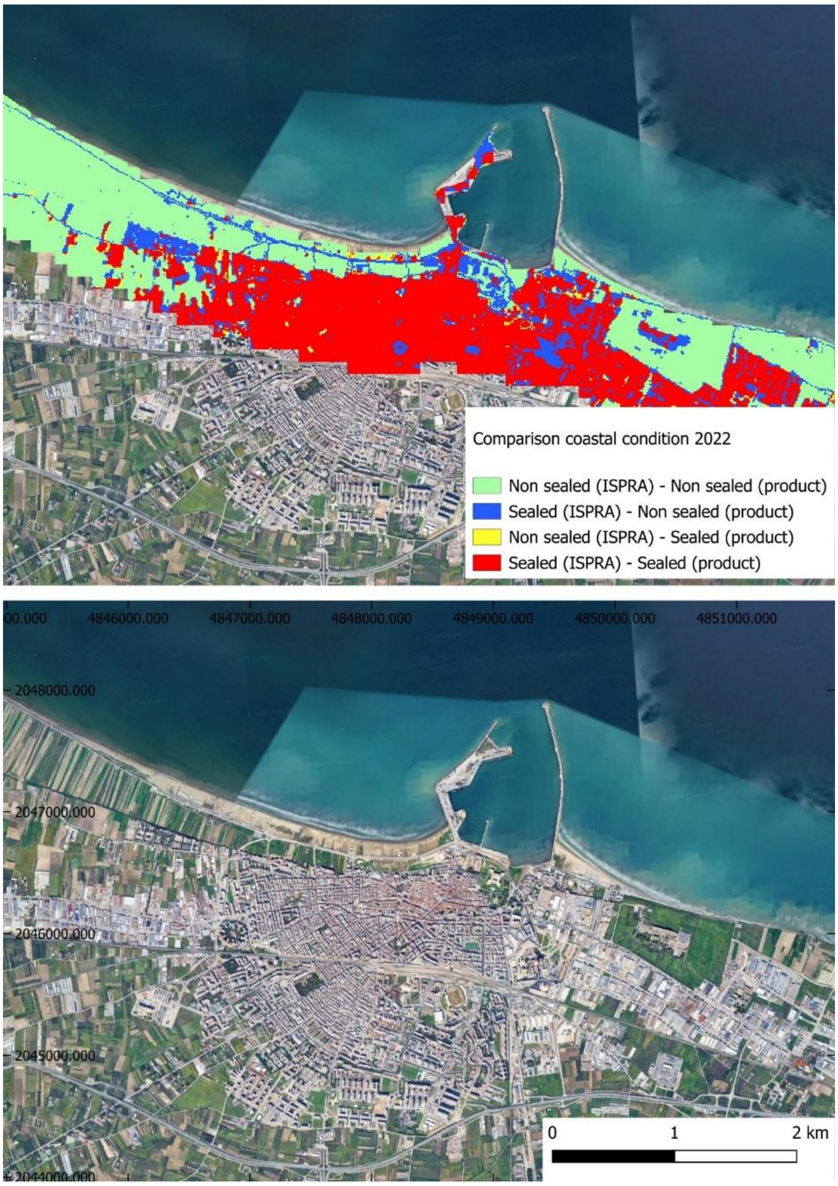


Figure 17. example of comparison between land consumption maps (ISPRA/SNPA) and coastal_condition_IMD_2022_IT (upper image) and Google satellite image (lower image); omission errors are mapped in blue, commission errors in yellow. The green and red areas show agreement.

The change detection show from the total of land consumption change pixels (ISPRA/SNPA) a small number of pixels (651, about 1.4% of total changes) show decreasing soil sealing degree; a large number of pixels (33,176, about 70.7% of total changes) are not detected as changes in the PEOPLE-EA account; about 13,077 pixels of land consumption change (ISPRA/SNPA) are detected with increasing soil sealing values in the product PEOPLE-EA account.

In general, the products can detect the main changes related to soil sealing, but the detection of small changes is not accurate if compared to the land consumption maps by ISPRA/SNPA. This could cause an underestimation of real changes. It is worth mentioning that the ISPRA/SNPA land consumption maps are the result of a partially automatic process with an extensive phase of photointerpretation which allows for increasing the accuracy of detected changes. Therefore, the proposed products could be used as base for the photointerpretation of real changes, although this is time consuming.

For Greece, the coastal condition was assessed using the field survey sampling plot data from the Habitat's Directive monitoring project in Greece, alongside photointerpretation and local, expert knowledge from the early adopters [VR-1].

The outcomes in general are in line with the development growth in the tourism and in particular the construction sector in Peloponnisos. However, the recorded gain of natural vegetation (non-artificial impervious areas) in Korinthia Ileia, Argolida and Arcadia is probably mainly due to vegetation recovery after extensive forest fires occurred before 2018 in the region. This result demonstrates that the selected EO indicator can also capture a wider range of disturbances that affect coastal ecosystem condition.

4.3 Ecosystem Service accounts

4.3.1 Ecosystem Wood Provision Service account

4.3.1.1 Method

A workflow was developed to generate the wood provision service accounts based on Copernicus Land Monitoring Service (CLMS) data layers, Tree Cover Density and Gross Dry Matter Productivity. These datasets are derived from the Sentinel EO time-series. Further also the Global Forest Watch data layers are used, derived from the LandSAT EO time-series. Further detailed in the Algorithm Theoretical Base Document (ATBD).

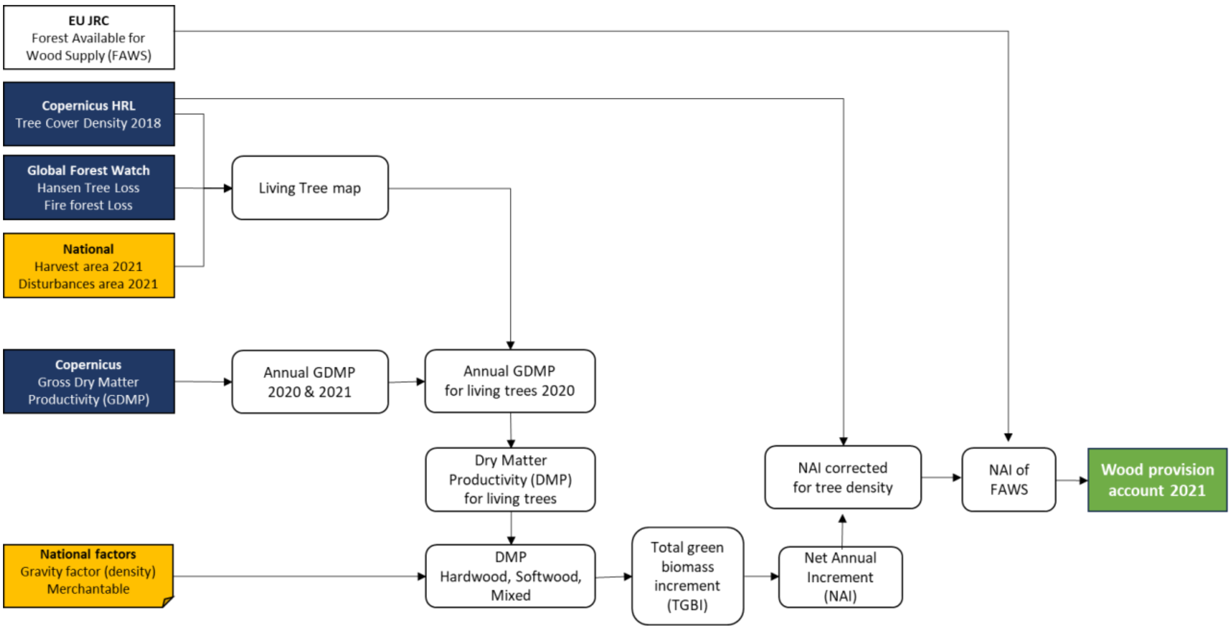


Figure 18. Wood Provision service account workflow

4.3.1.2 Results

The python workflow was used to generate offline the experimental ecosystem accounts for the four requested countries, namely specified coastal regions in Italy, Greece, Norway and Slovakia, for the year 2021. The workflow requires two national datasets: (1) national maps that provide areas of forest harvest and disturbance for the reporting year, (2) several national or sub-national factors for hardwood, softwood and mixed forest types. The results of the accounts are shown in *Table 11* and Figure 19.

Table 11: Experimental wood provision ecosystem service account for 2021.

NUTS_ID	NAME_LATN	NUTS_NAME	AREA [HA]	NAI [M3 OVER BARK]
EL62	Ionia Nisia	Ιόνια Νησιά	53,237	194,221
EL63	Dytiki Elláda	Δυτική Ελλάδα	321,733	1,177,433
EL41	Voreio Aigaio	Βόρειο Αιγαίο	86,868	556,816
EL42	Notio Aigaio	Νότιο Αιγαίο	21,835	163,934
EL51	Anatoliki Makedonia, Thraki	Ανατολική Μακεδονία, Θράκη	457,679	1,659,062
EL30	Attiki	Αττική	39,697	232,803
EL61	Thessalia	Θεσσαλία	358,730	1,423,050
EL65	Peloponnisos	Πελοπόννησος	409,747	2,019,442
EL43	Kriti	Κρήτη	88,190	247,241
EL52	Kentriki Makedonia	Κεντρική Μακεδονία	462,684	1,623,806
EL64	Sterea Elláda	Στερεά Ελλάδα	434,332	2,425,606
EL54	Ipeiros	Ήπειρος	354,564	1,378,013
EL53	Dytiki Makedonia	Δυτική Μακεδονία	243,679	865,016
GREECE			**3,332,976**	**13,966,444**
ITI4	Lazio	Lazio	499020	2449500
ITH2	Provincia Autonoma di Trento	Provincia Autonoma di Trento	258740	1038683
ITH3	Veneto	Veneto	316280	1201686
ITG1	Sicilia	Sicilia	247873	1266353
ITG2	Sardegna	Sardegna	571249	2757400
ITH1	Provincia Autonoma di Bolzano/Bozen	Provincia Autonoma di Bolzano/Bozen	185828	602839
ITC1	Piemonte	Piemonte	752781	2649279
ITI3	Marche	Marche	262677	1163696
ITF1	Abruzzo	Abruzzo	352611	1580463
ITC2	Valle d'Aosta/Vallée d'Aoste	Valle d'Aosta/Vallée d'Aoste	46525	107117
ITF2	Molise	Molise	129942	613251
ITC4	Lombardia	Lombardia	479033	1701635
ITF3	Campania	Campania	365857	1840346
ITI2	Umbria	Umbria	335004	1543902
ITI1	Toscana	Toscana	964553	4775373
ITH5	Emilia-Romagna	Emilia-Romagna	544193	2447877
ITH4	Friuli-Venezia Giulia	Friuli-Venezia Giulia	243107	865095
ITF4	Puglia	Puglia	140155	635369
ITF5	Basilicata	Basilicata	259411	1250871
ITF6	Calabria	Calabria	432194	2472018
ITC3	Liguria	Liguria	344828	1710270
ITALY			**7,731,861**	**34,673,022**
NO	Oslo and Viken	FMNO01	1,076,515	4,415,176
NO	Rogaland, Vestland and More og Romsdal	FMNO05	1,135,711	3,521,113
NO	Trøndelag	FMNO06	1,126,883	2,819,319
NO	Troms og Finnmark	FMNO08	861,044	1,155,342
NO	Innlandet	FMNO02	1,959,810	5,877,166
NO	Vestfold og Telemark	FMNO03	672,228	2,810,378
NO	Agder	FMNO04	626,072	2,574,535
NO	Nordland	FMNO07	662,814	1,266,325
NORWAY			**8,121,077**	**24,439,354**
SK01	Bratislavský kraj			556,000
SK02	Západné Slovensko			2,811,000

SK03	Stredné Slovensko	4,791,000
SK04	Východné Slovensko	4,568,000
SLOVAKIA		**12,726,000**

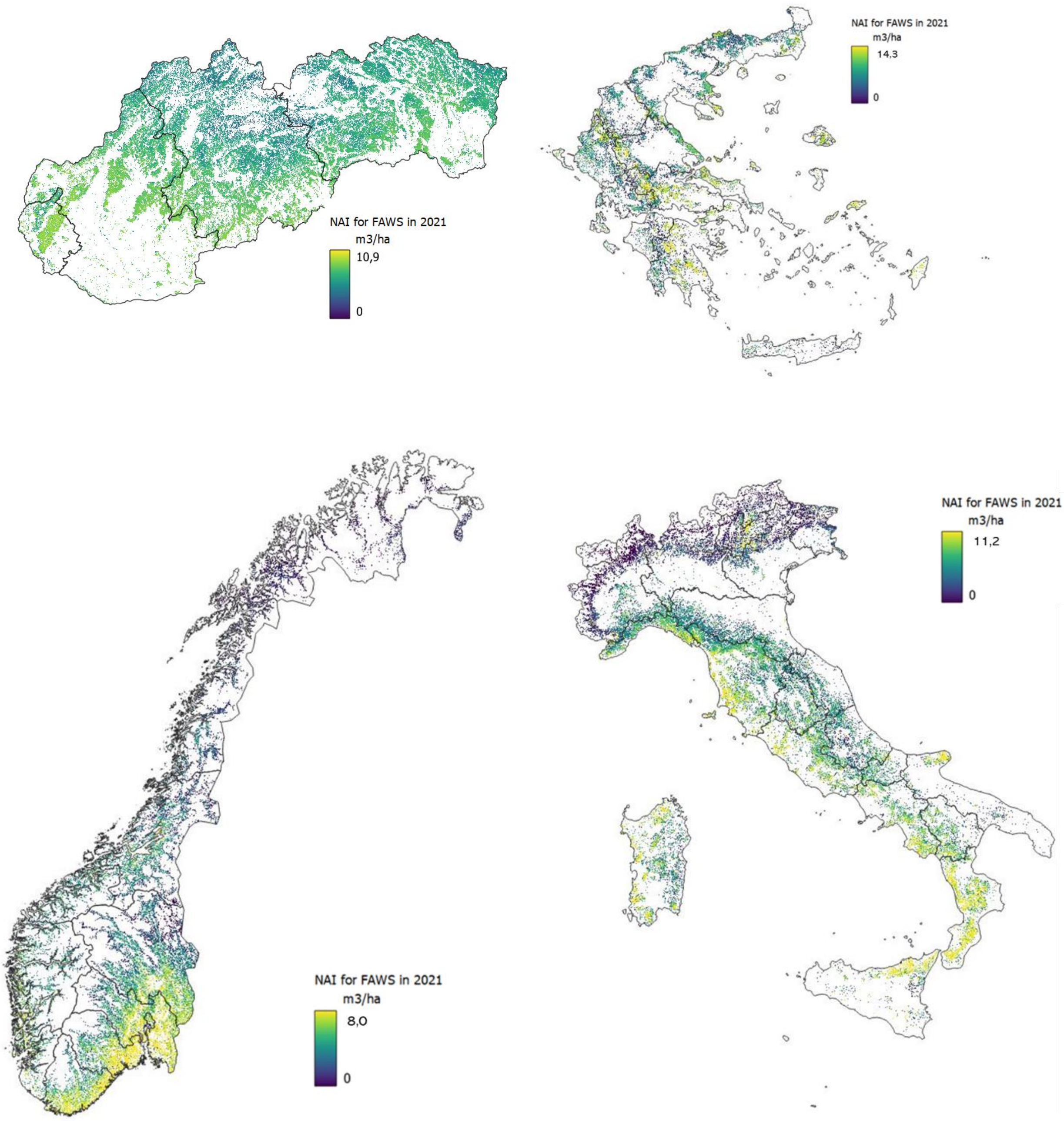


Figure 19. Net Annual Increment (NAI) for Forest Available for Wood Supply (FAWS) 2021, Slovakia (upper left), Greece (upper right), Norway (lower left), Italy (lower right)

4.3.1.3 Validation

Slovakia validated the Net Annual Increment (NAI) overbark, by comparing the results with the regular forest inventory in Slovakia, which is sourced from the governmental data portal [VR-4]. This inventory, known as the "Forest management plan", provides detailed forest stand characteristics such as forest type, age class, bonitated quality, and species composition. The dataset is comprehensive and updated in a 10-year cycle, with 1/10 of the total forest area inventoried annually. The NAI estimates used for validation were derived from these key forest attributes, making the dataset both robust and representative. For validation, the reference year was 2021, focusing on the predominant species in Slovakia: European Beech (hardwood) and Norway Spruce (softwood).

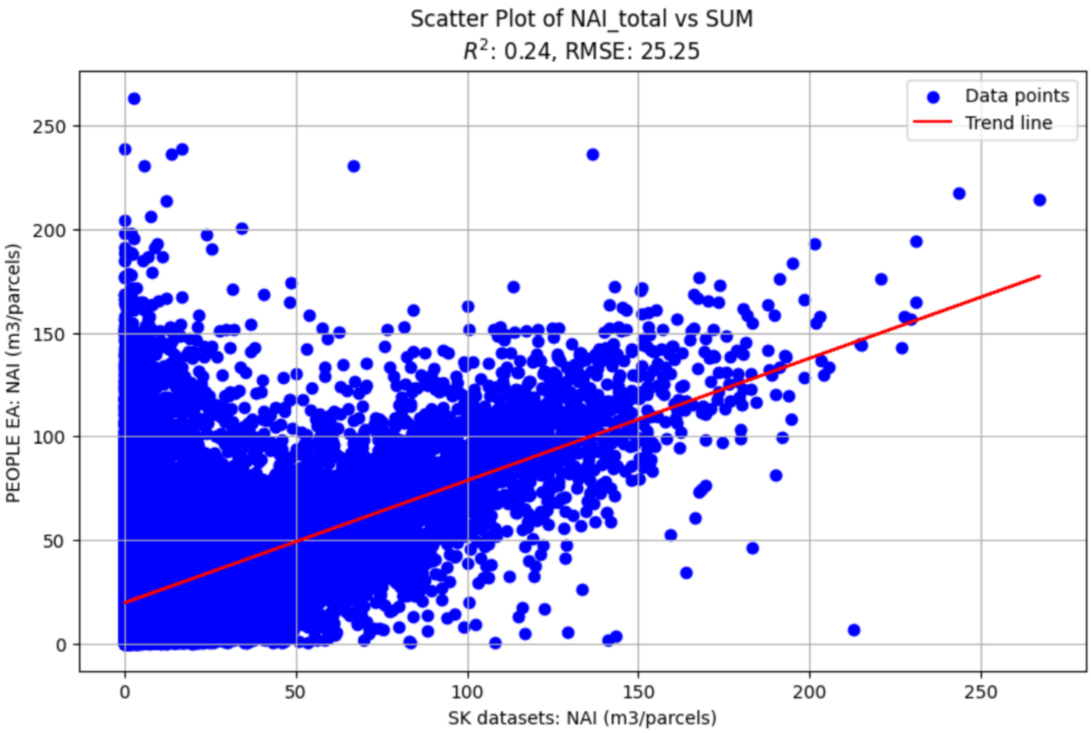


Figure 20. Parcel base comparison of NAI (Net annual increment) data aggregated ao parcel/forest stand level in Slovakia.

The comparison between the Slovak forest inventory datasets and EO-based wood provision accounts demonstrates a generally good spatial consistency, with the EO-based methodology effectively capturing broad patterns in forest growth. Though some discrepancies, particularly the overestimation of NAI in areas with older beech forest stands, were observed, the EO-based approach still holds significant value for assessing broad patterns in forest growth and wood provision. It is recommended that future work focus on addressing these discrepancies and enhancing the accuracy of the EO-based estimates, particularly by refining models for older forest stands and incorporating additional forest-specific parameters. The following recommendations were made for further improvements:

- Enhance the temporal consistency
- Address age-related growth dynamics
- Distinguish natural disturbances from standard regeneration
- Refine EO methodologies (incorporate additional environmental factors as soil, elevation and microclimate)

Greece assessed the thematic accuracy of the EO-based maps produced for the wood provision potential and for the year 2021 [VR-1], they gathered spatially explicit datasets related to wood provision (timber production, NAI etc). These data include:

(a) Boundaries and field survey data from forest management studies (Softwood),
(b) Field survey data from PhD Thesis (Hardwood),
(c) Overlap of forest fires with forest management areas,
(d) NAI for different forest types in Peloponnese (m3/ha) (updated by data from forest services),

The evaluation of the FAWS map revealed that the developed model corresponds almost identically to the officially designated areas for forestry (forest management area) in Peloponnisos. In hardwood dominated areas NAI EO product results are close to the expected NAI values from the area. However, this is not always for the softwood (i.e. *Abies cephalonica* and *Pinus nigra* forests). In softwood areas, NAI values are usually overestimated, and the EO model results are close to the expected values mainly at the forest edges. Forest fires and the subsequent clear-cutting to build constructions for the prevention of soil erosion and post-fire watershed management are in general well captured by the living tree model and the NAI in the NUTS2 level is adequately modelled and only the living trees areas were counted (the models spatial resolution excluded free, no-tree areas).

Italy compared with data from the National Forest Inventory (INFC 2015), which is the most up-to-date official source for Italy [VR-2]. The wood provision estimation model for Italy in 2021, based on INFC 2015, provided satisfactory results at the national level, with a NAI estimate very close to the official 2015 data. We note that despite some limitations in geographically more complex areas, the model demonstrated good reliability, particularly for central regions, and has the potential to be further improved with additional regional data and refinements in wood categorization. It is worth noting that for Italy we do not have complete and updated data on wood supply, therefore the validation could be unreliable and inaccurate.

Norway compared with data from the National Forest Institute [VR-3]. The national forest resource map SR16 was used for the delineation between productive and unproductive forest, applying the map layer for "bonitet" (SRRBONITET – translates into "site quality", "productivity class") from SR16. In addition, for best possible delineation of FAWS (Forest Areas for Wood Supply), Forest Management Plan data were applied where available (not all landowners have Forest Management Plans). *There is good external consistency:* The PEOPLE-EA account shows 8.12 million hectare of productive forest land which is only 1.5 per cent off the official number of 8.25 million hectare for the year 2021. The PEOPLE_EA account also shows a NAI of 24.4 million m^3 timber overbark for 2021 which is quite close to the official 24.5 million m^3 from the Statistics Norway Statbank (converting the numbers in m^3 under bark and into m^3 overbark). The NAI was predicted in the northernmost part of Norway; Troms og Finnmark County seems to be substantially overestimated. The same goes for Agder County which is the southernmost part of the country. Looking at the tree species dominating the forests in the three counties (and quite different parts of the country) mentioned above, we see from the table below that using one average model for hardwood, softwood and mixed wood for entire Norway most likely explains the error in the modelled NAI accounts.

4.3.2 Ecosystem Global Climate Regulation Service account

The current ecosystem account, as part of the INCA toolbox, is based on using LULUCF tabular statistics and distributing them through an EO-proxy to get a geospatial map. Aggregating these values back on a lower NUTS level, would reveal a lower accuracy. Therefore, in this PEOPLE-EA project, a workflow was designed to start from the Above Ground Biomass stock maps (difference between two years is the net removal) and thereafter apply corrections for wood harvest, disturbances, litter, land version and peat soil oxidation.

Five potential datasets for Above Ground Biomass were identified as potential candidates to calculate the net removal. After a first theoretical analysis, two datasets (ESA CCI Biomass V5 and ESA Forest biomass monitoring) were found to cover the minimum requirements, and were further evaluated for Slovakia using the years 2020 and 2021.

The CCI Biomass dataset was found a very valuable dataset for generating this account. The stock for 2020 was found within range of the statistics (applying the correct conversion from organic mass to carbon), but the consistency over time must be improved largely by reducing the area of improbable change (currently covering about 46% of forest area). Using the higher level of aggregated products (1 to 10km instead of 100m) did not reveal less improbable change. The project team understood that the ESA CCI Biomass team is working on an improved version 6 of this product and provided some recommendations.

Similar conclusions were found for the Forest Carbon Monitoring dataset, however the uncertainties are higher since the model is ran at 20m spatial resolution. Due to specificities in the model and data limitations for the calibration it is expected that the ESA CCI Biomass dataset could be more suitable for this service account.

As a final conclusion, despite the absolute stock values are within an ‘acceptable’ range, the uncertainties on stock changes are too high to be used for ecosystem accounting models at this time. Some further research and dataset improvements are ongoing, and it is suggested to re-evaluate these input datasets to further explore the design workflow model.

4.3.3 Ecosystem Nature-based tourism account

4.3.3.1 Method

The nature-based tourism service account is created in three steps: (i) collect tourism statistics, (ii) isolate the ecosystem contribution (nature visits), (iii) attribute to the ecosystem types.

The attribution to ecosystem types is done based on a Recreation Potential Map (RPM), which in INCA is generated by the Joint Research Center based on the model as shown in Figure 21. This workflow already uses some (limited) Earth Observation data as is for Riparian Zones (from Copernicus Land Monitoring service). The RPM maps however are updated every 6-years, co-exiting with the Corine maps. In PEOPLE-EA three workflows were developed to enhance the dynamics of the RPM maps (dRPM) using more earth observation data as is:

- Forest loss, which decreases the recreation potential, based on the Global Forest Change dataset providing annual loss.
- Water quality, to fill gaps in the current map, based on the Trophic State Index from the Copernicus Land Monitoring Service Lake Water Quality (100m and 300m) and Chlorophyll-a concentrations from the Copernicus Marine Environment Monitoring Service (HROC for North-West Shelf).
- Green leistures in cities, using the Copernicus High Resolution Vegetation Phenology and Productivity dataset.

Further detailed in the Algorithm Theoretical Base Document (ATBD).

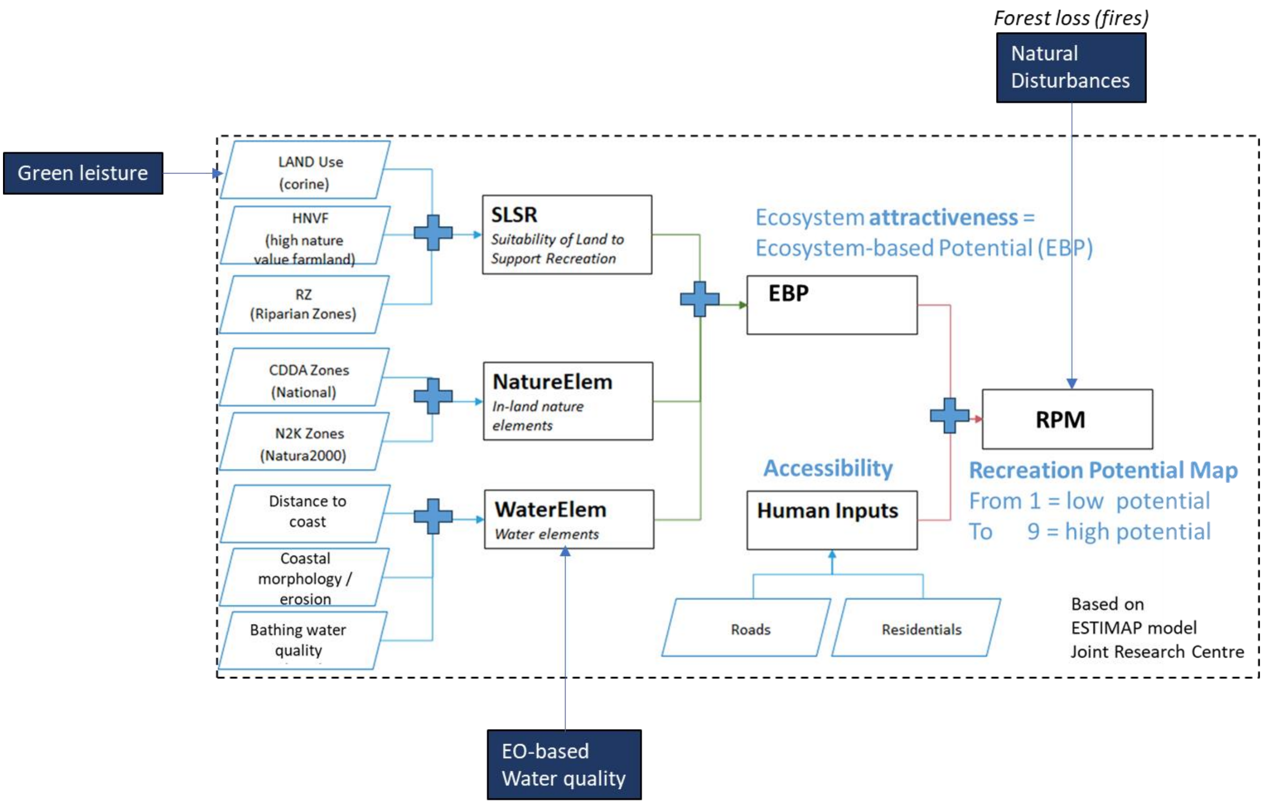
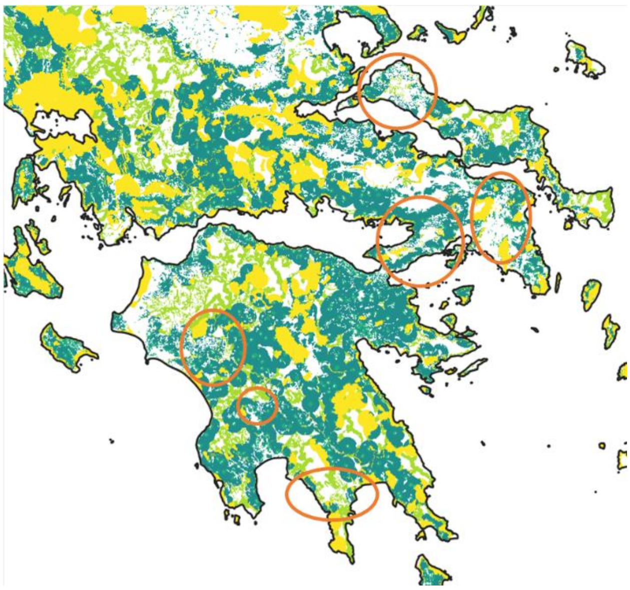
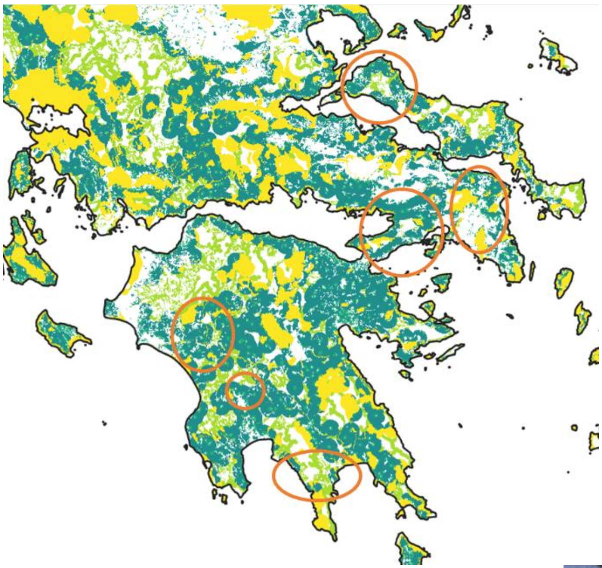


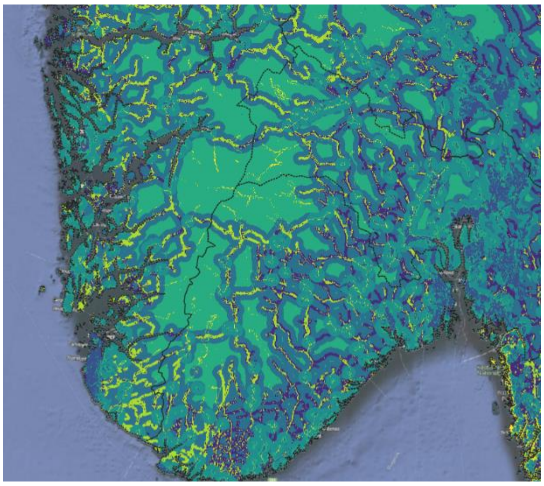
Figure 21. Nature Based tourism Recreation Potential map workflow (dashed box is original model from Joint Research Centre).

4.3.3.2 Results

The RPM map for 2021 were created for Norway and Greece, based on the original RPM map for 2018 (as provided by JRC), such they can be used as input layer for the INCA tool to calculate the nature-based tourism accounts.







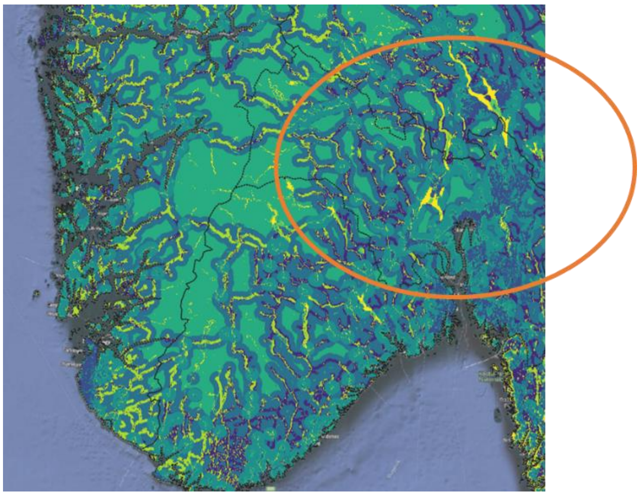


Figure 22. Recreation Potential Map for Greece (upper) and Norway (lower images). Left is the original RPM and right the dynamic RPM.

Table 12. Nature Based Tourism ecosystem service account for Greece using dynamic RPM, 2022. The last column shows the relative difference compared to the original RPM.

NUTS co	NUTS name	total	Settlements and other artificial areas	Cropland	Grassland (pastures, semi-natural and natural grassland)	Forest and woodland	Heathland and shrub	Sparsely vegetated ecosystems	Inland wetlands	Rivers and canals	Lakes and reservoirs	Marine inlets and transitional waters	Coastal beaches, dunes and wetlands	Marine ecosystems (offshore coastal shelf and open ocean)	total difference RPM - dRPM
EL30	Αττική	6559728	1409091	1679286	170878	1522651	1401084	241779	11308	0	3230	539	119882	0	-4.20%
EL41	Βόρειο Αιγαίο	2075738	38829	801627	440073	451834	244740	71016	1239	0	872	2873	22635	0	-0.11%
EL42	Νότιο Αιγαίο	28148251	1040875	7569895	5755064	3088105	9494048	377111	1250	0	32345	0	789558	0	-0.10%
EL43	Κρήτη	24075500	537534	10313685	4382031	1794083	5845137	979235	0	0	21651	0	202144	0	-0.07%
EL51	Ανατολική Μακεδονία, Θράκη	1786333	43768	673979	100597	715822	180165	25305	8166	8441	8096	5649	16345	0	-0.09%
EL52	Κεντρική Μακεδονία	10233688	411459	5164417	445464	3006806	873345	81452	39262	47746	124164	1660	37913	0	-0.01%
EL53	Δυτική Μακεδονία	171523	5384	58172	20118	66142	10047	6938	339	435	3948	0	0	0	-0.06%
EL54	Ήπειρος	2330752	47111	526668	254455	944558	421928	88890	3608	2325	11906	7176	22127	0	-0.07%
EL61	Θεσσαλία	2173795	56781	913516	213833	562348	370323	34469	1734	6571	11486	0	2734	0	-0.11%
EL62	Ιόνια Νησιά	14612417	720143	6980522	934340	1888698	3705652	234796	5683	0	582	32546	109455	0	-0.01%
EL63	Δυτική Ελλάδα	1436586	30405	596789	61931	408027	253309	38512	4443	2621	27763	3979	8807	0	-0.68%
EL64	Στερεά Ελλάδα	1736865	46346	546682	85182	587829	420554	31497	886	1502	10634	73	5680	0	-2.05%
EL65	Πελοπόννησος	3772628	77530	1402692	277295	807897	1118739	75651	817	722	1973	1504	7808	0	-0.63%
all regions		99113804	4465256	37227930	13141261	15844800	24339071	2286651	78735	70363	258650	55999	1345088	0	-0.42%

Table 13. Nature Based Tourism ecosystem service account for Norway using dynamic RPM, 2021. The last column shows the relative difference compared to the original RPM.

NUTS code	NUTS name	total	Settlements and other artificial areas	Cropland	Grassland (pastures, semi-natural and natural grassland)	Forest and woodland	Heathland and shrub	Sparsely vegetated ecosystems	Inland wetlands	Rivers and canals	Lakes and reservoirs	Marine inlets and transitional waters	Coastal beaches, dunes and wetlands	Marine ecosystems (offshore coastal shelf and open ocean)		relative difference RPM - dRPM
NO02	Innlandet	1634457	11057	96927	406	760479	131827	399675	166627	3796	63654	0	9	0		0.60%
NO06	Trøndelag	1201163	6073	81920	23	401323	195529	270438	188570	1148	55886	253	0	0		0.00%
NO07	Nord-Norge	2113511	5469	40054	54	542360	313543	1012090	123271	2514	73035	841	280	0		-0.02%
NO08	Oslo og Viken	3584275	125088	438388	871	2041501	345373	301946	121257	14332	195179	340	0	0		1.09%
NO09	Agder og Sør-Østlandet	2293259	36280	111550	101	1268834	399745	283328	50724	2484	140088	125	0	0		0.46%
NO0A	Vestlandet	3922861	43622	274531	15226	977437	749712	1627036	91992	305	142695	208	97	0		0.25%
all regions		14749526	227589	1043370	16681	5991934	2135729	3894513	742441	24579	670537	1767	386	0		0.46%

4.3.3.3 Validation

Greece assessed the thematic accuracy of the PEOPLE-EA for the Nature-based recreation potential and for the year 2022, through spatially explicit datasets for recreation in nature or for recreation [VR-1]. These data include: (a) areas of organised bathing beaches ("blue-flag" beaches) (point data), (b) camping sites (point data), (c) mountain shelters (point data), (d) eBird hot spots (point data) (as ideal locations for birdwatching), (e) rafting and inland boating sites (point data for each route's starting point), (f) thermal springs (point data), (g) aesthetic forests (polygon data) (i.e., forests designated as protected for cultural, aesthetic, recreational and regulating purposes).

The evaluation recorded similar results (all areas covered by cells with the highest recreational value) for the nature-based recreation potential in mountainous areas, where most mountains of Peloponnisos are covered by mountain shelters, including trails and hiking routes that connect these shelters, and, three ski centres in operation at Mt Chelmos, Mt Ziria and Mt Menalo.

Regarding, the assessment at the designated as aesthetic forests' locations, the evaluation revealed that their vast majority is included in the highest value of the nature-based recreation potential. Only at Mt Panachaikon (NW Peloponnisos), two thirds of the aesthetic forests has a value of "7" and the rest of it is included in the highest value "9". For the EO model evaluation we also assessed where camping and eBird hotspots are located, i.e., sites that attract visitors for nature-related recreation. The majority of these locations are in areas where the EO model has the highest or high recreation potential value

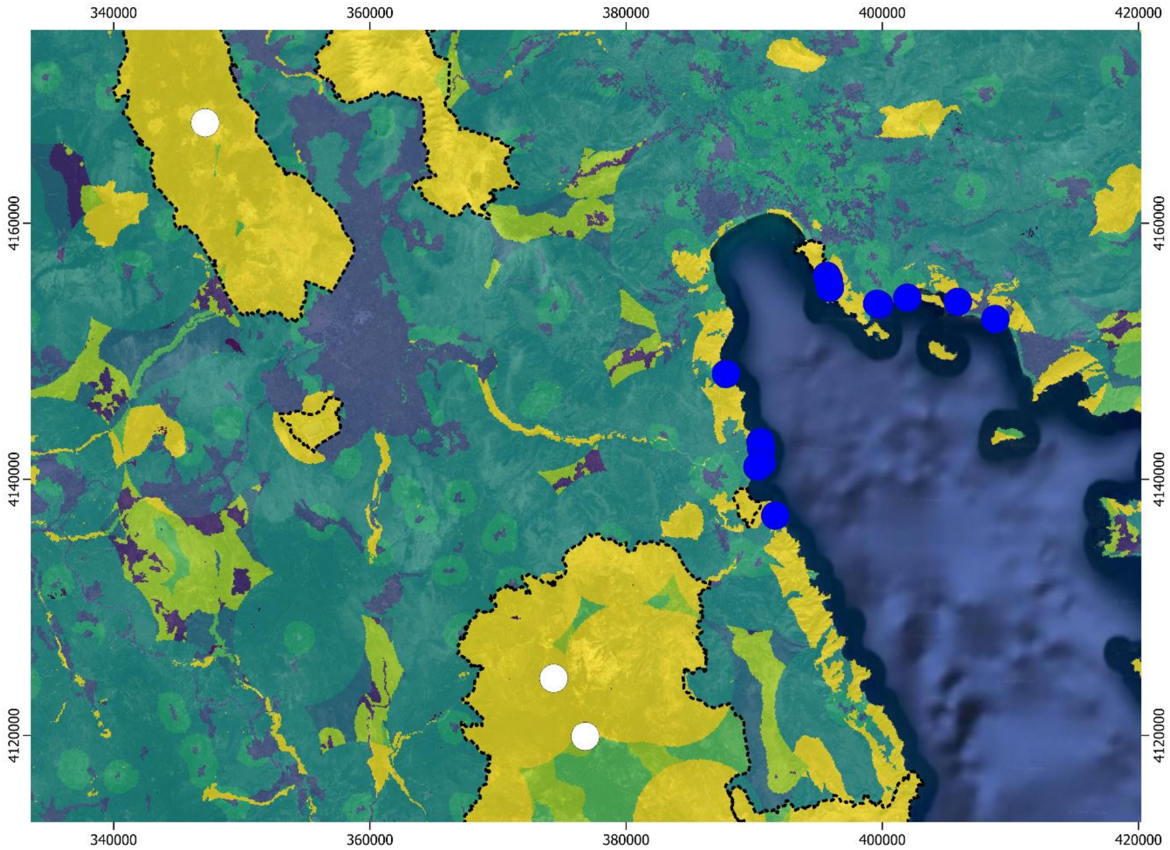


Figure 23. Thematic representation of sites (dots) with documented nature-based recreation use. White dots represent mountain shelters and blue dots the "blue-flag" beaches. Yellow cells represent highest recreation potential areas.

The evaluation also revealed that the EO model performs well on capturing nature-based recreation sites within the urban fabric. The EO model has correctly assigned the highest value in the cells that cover/represent this urban park. The assessment of the recreation potential in the rivers and major streams of the region, that have been captured by the EO model as areas with the highest value. In Peloponnisos there is only one major, permanent flowing river, the Alfios river. All other rivers are of temporary flow and their riverbed is not easily accessible. By this, we believe that the recreation potential throughout their riverbed / river routes is overestimated and only at major rivers the recreation is evident in the region.

<u>Norway</u> did a short visual interpretation on the dynamic Recreation Potential Map (dRPM), however the dataset was delivered too late to do a full qualitative or quantitative evaluation [VR-3]. In general the contributions from EO-data sources to the nature-based recreation account were put into practice. Missing water element input data was supplemented with three different EO datasets on water quality from the Copernicus services. This made a significant impact on the accounts, in the expected direction and for the expected geographic areas.

5. Roadmap

The project demonstrated the benefits and potential to integrate Earth Observation in ecosystem accounting workflows, however the demonstrations were limited in five accounts covering five European countries as shown in chapter 4. Therefore, a broader analysis was performed to analyze the potential of EO in ecosystem accounting which resulted in an Evolution Roadmap[10].

Following literature review, the discussions and experiences generating the demonstrator accounts with the early adopters, and discussions in an International Workshop with a broader stakeholder's community, a list of priorities was compiled that requires further R&D work to advance further in the integration of Earth Observation in ecosystem accounting. Note the view represents a limited view and still needs to be consulted further with the community experts.

Ecosystem extent accounts are the base of the accounting framework and many countries are still struggling with getting their first accounts, especially at a more detailed level which is required to be used within policy decisions. Major R&D topics detected are : detection of real changes, progress in habitat mapping to better discriminate habitats by both further optimize cooperations with in-situ data collections and exploring the use of high resolution hyperspectral imagery, improve the mapping of specific ecosystem types to support specific applications as LULUCF, Common Agriculture Policy, biodiversity (small linear landscape elements), and heterogeneity landscapes as urban and agriculture mixed landscapes.

Many biophysical variables (or indicators) are derived from EO with a potential to be used for ecosystem condition accounts. However these datasets should be meaningful, their limitations should be known and the best solutions should fit the ecosystem types. Major R&D topics detected are : make a set of EO-derived indicators available at sufficient spatial resolution per ecosystem type including the exploration of existing and potential new EO data sources, improve trends on continuous datasets through reducing uncertainties or at least avoid false conclusions, reduce saturation effects in some datasets as biomass and carbon estimates, integrate pressure indicators and improve digital elevation models potentially integrating high resolution LiDAR on a more regular base.

Ecosystem service accounts are the type of accounts where the integration of EO is at this moment less explored compared to the other types, so likely the potential is highest to improve service models by integrating more EO data. Major R&D topics detected are : more clearly describe the limitations and use conditions to guide users to select models and where possible prioritize adding new service models instead of duplicating model implementations, improve high attention models as crop, carbon, improve models by optimizing the integration of multiple data sources – EO and non-EO.

Two special domains of priority are to (i) further explore the use of EO for biodiversity accounts that can complement condition and service accounts, (ii) further explore the use for ecosystem accounts for corporate businesses which typically require more local scale and over-seas supply chain support.

Finally a number generic R&D topics were identified as : make the EO datasets more fit-for-purpose (Account Ready data) including regular and timely available, standardize and harmonize metadata and interfaces, establish local partnerships and leverage citizen science to optimize ground-truth data use, establish a global coordination for capacity building, and establish dialogues and partnerships with communities in corporate businesses, including Small-Medium enterprises.

[10] The evolution roadmap can be found in https://esa-people-ea.org/en/results/deliverables.

6. Acronyms and Abbreviations

ACCORD	Account Ready Datastack
AD	Applicable Document
ARIES	Artificial Intelligence for Environment & Sustainability
ATBD	Algorithm Theoretical Basis Document
BC3	Basque Centre for Climate Change
CAP	Common Agricultural Policy
CCI	Climate Change Initiative
CDB	Convention on Biological Diversity
CEOS	Committee on Earth Observation Satellites
CLC	Corine Land Cover
CLCACC	Corine Land Cover Accounting layers
CLMS	Copernicus Land Monitoring Service
DG	Director General
EA	Ecosystem Accounting
EAD	Early Adopter
EEA	European Environmental Agency
EU	European Union
EUNIS	European Nature Information System, a habitat classification scheme
EUROPABON	European Biodiversity Observation Network project
EO	Earth Observation
EO4EA	Earth Observation for Ecosystem Accounting
EOEP	Earth Observation Envelope Programme
EOEP-5	5th Earth Observation Envelope Programme (2017-2021)
ESA	European Space Agency
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reusable
FAO	Food and Agriculture Organization of the United Nations
FP7	7th Framework Programme
GEO	Group on Earth Observations
GEOBON	GEO Biodiversity Observation Network
GET	IUCN Global Ecosystem Typology
GIS	Geographic Information System
H2020	Horizon 2020
HR	High Resolution
HRL	Pan-European High-Resolution Layers
INCA	EU Integrated system of Natural Capital project
IPCC	International Panel on Climate Change
ITT	Invitation To Tender
IUCN	International Union for Conservation of Nature
JRC	Joint Research Center
LC	Land Cover
LCCS	LC Classification System
LDN	Land Degradation Neutrality
LIDAR	Light Detection And Ranging of Laser Imaging Detection And Ranging
LPIS	Land Parcel Identification System
LU	Land Use
LULUCF	Land Use, Land-Use Change and Forestry
MAIA	Mapping and Assessment for Integrated Ecosystem Accounting
MAES	Mapping and Assessment of Ecosystems and their Services
MMU	Minimum Mapping Unit

MoM	Minutes of Meeting
NOR	Network Of Resources
NSO	National Statistics Office
NUTS	Nomenclature of territorial units for statistics
OECD	Organization for Economic Co-operation and Development
OPENEO	Open Earth Observation interface/project
PEOPLE	Pioneer Earth Observation apPLications for the Environment
PM	Project Manager
PMP	Project Management Plan
PTM	Policy Traceability Matrix
PVP	Product Validation Plan
PVR	Product Validation Report
RB	Requirement Baseline
RD	Reference Document
SAR	Synthetic-Aperture Radar
SDGs	Sustainable Development Goals
SEEA	System of Environmental Economic Accounting
SEEA-EA	SEEA Ecosystem Accounting
SMEs	Small and medium-sized enterprises
SoW	Statement of Work
SPAM	Spatial Production Allocation Model
SSPE	Science for Society Programme Element
TDS	Test Data Set
TS	Technical Specification
UN	United Nations
UNCCD	UNCCD United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNSC	United Nations Statistical Commission
URD	User Requirement Document
URN	Uniform Resource Name
WBS	Work Breakdown Structure
WGCV	Working Group on Calibration and validation