Evolution Roadmap

Document Ref:	PEOPLE-EA_ER (Deliverable 19)
Version:	1.4
Contract No:	4000139263/22/I-AG
Creation Date:	2024-03-12
Last Modified:	2025-01-29

Submitted by

vito remote sensing	bc3	Ecountin	UNIVERSITY OF PATRAS ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

In collaboration with Early Adopters

Statistisk sentralbyrå Statistics Norway	cbs	ile Institute of Landscape Ecology Slovak Academy of Sciences	UNIVERSITY OF PATRAS ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ	Istat Istituto Nazionale di Statistica ISPRA
Norway	*Netherlands*	*Slovakia*	*Greece*	*Italy*

DOCUMENT RELEASE SHEET

Role	Name
Book Captain	Lars Hein (Ecounting)
Approval (consortium)	Bruno Smets (VITO)
Approval (ESA)	Marc Paganini (ESA)
Contributing Authors	Bruno Smets (VITO)
	PEOPLE-EA Early Adopters
	International Workshop participants
	PEOPLE-EA Advisory Board members
Distribution	Public

DOCUMENT CHANGE LOG

Issue	Issue date	Pages affected	Relevant information
0.1	2024/03/13	All	Submitted outline for review by ESA
0.2	2024/04/08	All	First draft (with some open sections) for internal review in consortium
0.3	2024/05/03	All	Final draft for internal review by consortium, Early Adopters and Advisory Board
0.4	2024/05/14	15-16, 30-32	Final draft as input for International Workshop Athens 22&23 May
1.0	2024/08/31	All	Integrated feedback from International Workshop
1.1	2024/09/12	43-47	Integrated feedback from Early Adopters validation results into recommendations
1.2	2024/10/07	23, 31-32, 47	Final version, feedback on recommendations from Early Adopters and Advisory Board members
1.3	2024/11/25	All	Final editing for public release, based on feedback EEA and ESA
1.4	2025/01/29	7, 9, 14, 21, 25, 27 & 29	Integrated final feedback (mainly editorial) from EEA for use in BIOSPACE25 conference

Table of Content

List of Figures

List of Tables

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 2, Revision 0, dated 27 October 2023
[AD 5]	PEOPLE-EA State-Of-Art Review, Issue 3, Revision 1, dated 22 December 2023 and available on https://esa-people-ea.org/sites/esapeopleea/files/downloads/PEOPLE-EA_D2-SAR_V3_1.pdf
[AD 6]	2022 Workshop on Earth Observation for Ecosystem Accounting, available on https://eo4ea-2022.esa.int/
Geller, 2023	CEOS Ecosystem Extent Task Team White Paper V1.0
Bulckaen, 2024	Ecosystem services overview, https://zenodo.org/records/10715892
[AD 7]	PEOPLE-EA International Workshop, 22-23 May 2024, Athens; and available on https://esa-people-ea.org/en/international-workshop-earth-observation-seea-compliant-natural-capital-accounting.

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 are provided at the end of the document.

1. Introduction

1.1 Project objectives and approach

Ecosystem accounts are inherently spatial accounts, with the implication that they strongly depend on the availability of spatially explicit datasets. The emergence of dense Earth observation (EO) data streams combined with advances in digital technologies offer new opportunities for countries to efficiently monitor the extent and condition of their ecosystems, determine ecosystem services and implement their ecosystem accounting. However, the use of EO data – at least for the part that can be covered - in ecosystem assessment and accounting is limited due to several conceptual and technical challenges.

The **main objective** of the PEOPLE Ecosystem Accounting project (PEOPLE-EA), contract N°4000139263/22/I-AG, is to **study** the **relevance** of **Earth observations for SEEA ecosystem accounts** and to **demonstrate** its use for terrestrial and freshwater ecosystems. To reach this main objective, the PEOPLE-EA project is considered a trailblazer project, hence aiming to demonstrate the value of EO data to prepare a roadmap for subsequent studies with a larger deployment in terms of both geographic regions and accounts.

In short, the PEOPLE-EA project works closely together with Early Adopters to achieve the following objectives:

1. Review and describe the added value of integrating Earth observation data for ecosystem accounting in terrestrial and freshwater ecosystems, expressed in physical terms for ecosystem extent, condition and ecosystem services.
2. Co-develop (pioneer and test) innovative high-quality EO-based ecosystem account models according to the FAIR principle following an agile method.
3. Showcase and validate several selected demonstrators to prove the value of integrating EO in national ecosystem accounting in a regular and consistent manner through the appliance of a cloud-based tool (ARIES-INCA Tier2/3 platform) using open standardized interfaces (OpenEO).
4. Contribute to the international collaborative efforts to advance the use of EO in ecosystem accounting and support countries developing their national ecosystem accounts.
5. Prepare an outlook (R&D roadmap) to further scale-up the use of EO in ecosystem accounting.

1.2 Purpose of the document

The Evolution Roadmap (D19) is a deliverable of the project. The roadmap has been developed as guidance for identifying future studies with a larger deployment in terms of both the geographic region and user communities, hence objective 5 described above.

This document proposes a roadmap to support the enhanced integration of Earth observation data in the generation of ecosystem accounts in a broad sense. The roadmap assesses the adequacy of the proposed approach to respond to the accounting needs of the Early Adopters, identifying the areas that still need further development and those that are ready for integration withing the Early Adopter systems and processes on ecosystem accounting. The roadmap is not limited to the demonstrator accounts as developed within the project in collaboration with the Early Adopters but goes beyond taking the opportunities and bottlenecks as identified during the State-Of-Art review [AD5] and the lessons learned during the 2022 Workshop on Earth Observation for Ecosystem Accounting [AD6].

Its objective is to define a research agenda to tackle the critical areas to integrate Earth Observation for ecosystem accounting and serves as input for the European Space Agency, as well as potential use by European institutions, UN Technical Committee on the SEEA Ecosystem Accounting (EA) and Group of Earth Observation (GEO). As such the roadmap defines the necessary steps to further evolve the developed (and other) innovative products/indicators/methods, including optical, radar and upcoming new satellite missions, and to scale-up to a global scale (e.g., algorithms/methods limitations with suggested approaches for improvements, future processing needs, non-EO data integration needs, advancements of forecasting analysis). The roadmap considers that not all spatial data relevant for ecosystem accounting can be derived from EO data (such as essential biodiversity variables and indicators reflecting the use of several ecosystem services) – but focusses on the key indicators that can be derived from EO data.

The roadmap benefited from discussions and input provided during the International Workshop (IWS) on the use of Earth Observation data for Ecosystem Accounting, hosted by the PEOPLE-EA project on 22 and 23 May 2024 in Athens, Greece [AD7]. The project wants to express special thanks to the European Environment Agency (Jan-Erik Petersen and Pavel Milenov) to feedback valuable comments. However, it represents the view of the project team and encourages the SEEA EA Technical Committee to organize a broader review in the community.

1.3 Content of the document

This document is structured as follows:

- Chapter 2 describes the user perspective relevant for the roadmap.
- Chapter 3 describes the roadmap from technical perspective, zooming in on the various accounts.
- Chapter 4 describes technical challenges and key elements for a roadmap from an overarching perspective of developing accounts and ensuring that institutional collaboration to connect EO and other spatial data to accounts is in place.
- Chapter 5 summarizes the recommendation for future R&D programs.

2. User and reporting needs

2.1 Introduction

SEEA Ecosystem accounting is increasingly applied to produce statistics on the use and state of ecosystems and the services they provide. At the same time, policy makers are faced with limited resources when supporting initiatives such as ecosystem accounting and tend to prioritize the compilation of accounts that are most policy relevant, i.e., can be expected to be of particular use to stakeholders in environmental and resource management. Whereas policy relevance may not be the only criterion for supporting EO data use in ecosystem accounting, this section nevertheless will propose several considerations that can be relevant for the implementation of a roadmap in support of EO application for ecosystem accounting. The section is organized by user group, and we will briefly discuss potential accounts (core and thematic) and data of interest to the user groups, and the potential use of EO data in this context zooming in on required temporal and spatial resolution and timeliness of the accounts.

2.2 National Statistical Offices and other institutes preparing SEEA Ecosystem Accounts

Now that, as of 2021, the SEEA EA is a global statistical standard, there is an increase in the compilation of SEEA EA accounts by National Statistical Offices (NSOs) and other national bodies preparing SEEA EA accounts. This interest is further enhanced by the revision of legislation pertaining to accounting in the EU (amendment to Regulation 691/2011 on European environmental economic accounts). This will make it mandatory to compile SEEA EA accounts including extent accounts, 7 ecosystem services and 9 condition indicators in the EU from the reporting year 2024 onwards. The United Kingdom statistical office and DEFRA[1] have a particularly strong tradition in natural capital accounting and is also applying SEEA EA to compile accounts for specific landscapes. The US White House has indicated to pursue natural capital accounts building upon SEEA EA, and the Japanese government is piloting SEEA EA accounts as well.

Worldwide there is an increasing interest in the compilation of ecosystem accounts. For instance, Colombia, Costa Rica, India, and Indonesia, Mexico, the Philippines, Rwanda, and Uganda, have produced accounts on either a regular or a pilot basis, and China has made progress in producing natural capital accounts with the Gross Ecosystem Product, which is similar in scope to the ecosystem accounts of the SEEA EA.

The degree of experience with spatial datasets in NSOs and other stakeholders varies; some have elaborate GIS units in-house, whereas others have less staff skilled in spatial data management. In general, the more staff, the more interest in spatial datasets, but also the more spatial datasets tend to be already available at national scale in the NSO (either produced by the NSO or by partnering organizations). In other words, the demand for spatial datasets, and the capacity to integrate these, differs substantially by NSOs, with the European NSOs likely to focus on the accounts and indicators included in the legal proposal, see the table below and the text below describing the ecosystem services included in the European Union legal amendment.

[1] Their strategic focus for future development can be found at https://www.ons.gov.uk/economy/environmentalaccounts/articles/naturalcapitalaccountsroadmap/2022#strategic-focus-for-future-development

Table 1. Condition indicators included in the EU legal proposal.

Ecosystem type	Indicator
settlements and other artificial areas	m^2 green areas in cities and adjacent towns and suburbs
	Concentration of particulate matter with a diameter up to 2.5 µm or 10 µm to be reported in µg/m^3 as a national average for the reporting period
croplands	Soil organic carbon content in topsoil shall be reported in tonne/ha, as a national average for the reporting period
grasslands	Soil organic carbon content in topsoil shall be reported in tonne/ha, as a national average for the reporting period
croplands and grasslands together	Common farmland bird index shall be reported as a national aggregate index for the reporting period
forests and woodlands	Dead wood shall be reported in m^3/ha, as a national average for the reporting period
	Tree cover density shall be reported in %, as a national average for the reporting period
	Common forest bird index shall be reported as a national aggregate index for the reporting period
coastal wetlands, beaches, and dunes	Artificial impervious area cover shall be reported in %, as a national average for the reporting period

Ecosystem services accounts record the supply and use of ecosystem services in the form of supply and use tables. The supply table records the supply of ecosystem services from ecosystems to society. The use table records the use of ecosystem services by institutional sectors. The supply table is underpinned by maps showing the spatial distribution of the supply. In the EU legal amendment, the supply and use tables shall be reported in physical units, including the following services:

- **Crop provision**, defined as the ecosystem contributions to the growth of cultivated plants that are harvested by economic units for various uses including food and fibre production, fodder and energy, shall be reported in tonnes of agricultural crops, by type of crop, and cover at least 90% of the utilised agricultural area. Crop types to be distinguished are: (i) arable crops, (ii) permanent crops and (iii) permanent grasslands.

- **Pollination**, defined as the ecosystem contributions by wild pollinators to the fertilisation of crops, shall be reported in tonnes of pollinator-dependent crops that can be attributed to wild pollinators, by type of crop for the main types of pollinator-dependent crops comprising fruit trees, berries, tomatoes, oilseeds and 'other'.

- **Timber provision**, defined as the ecosystem contributions to the growth of trees and other woody biomass in forest available for wood supply, shall be reported as net increment in thousand m^3 over bark.

- **Air filtration**, defined as ecosystem contributions to the filtering of air-borne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly trees, that mitigates the harmful effects of the pollutants, shall be reported in tonnes of fine particulate matter (PM2.5) absorbed.

- **Global climate regulation**, defined as the ecosystem contributions to reducing concentrations of greenhouse gases in the atmosphere through (i) the primary carbon sequestration (i.e. due to natural sequestration and emissions); (ii) net carbon sequestration (i.e., the net of natural sequestration and emissions and human-induced emissions such as due to peat drainage and anthropogenic land use change) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems. The contributions shall be reported in terms of tonnes of net sequestration of carbon and tonnes of carbon stored in ecosystems including above ground and below ground in the first 0.3 meter of the soil (including in peatlands).

- **Local climate regulation**, defined as the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) in urban areas through the presence of vegetation that improves the living conditions for people and supports economic production, shall be expressed, and reported as the reduction of temperature in cities during heat days or periods (with a temperature over 25 degrees C).

- **Recreation and tourism-related services**, defined as the ecosystem contributions, through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment, shall be reported in number of overnight stays in hotels, hostels, camping grounds, etc., that can be attributed to visits to ecosystems.

These seven ecosystem services also feature prominently in the UK natural capital accounts, and they are all included in the Netherlands SEEA EA accounts, for instance. Given that these are priority accounts for all EU member states soon, they can be of policy relevance at present (e.g. EU Nature Restoration Regulation, Common Agriculture Policy, Land Use Land Use Change and Forestry, etc.). We note that countries in the global south may have different priorities, related to specific environmental, economic or climate conditions they are facing. For example, many pilots in water scarce countries focus on water (e.g., water accounting in Namibia), whereas countries in monsoon climates may have a specific interest in flood control services of forests, or the rainfall maintenance service of forests (dependent upon the recycling of rainwater back into the atmosphere, over the year).

2.3 Multilateral organizations including international finance organizations.

Multilateral organizations including international finance organizations have implemented several programs in the last decade aimed at supporting countries in the global south with the compilation of SEEA EA accounts. Prominent among these are, for instance, the UN Statistics Division programs that have supported a range of countries with compiling ecosystem accounts, and the World Bank Global Program on Sustainability. Also, the Interamerican Development Bank has invested in testing SEEA ecosystem accounting, driven by well-defined accounting needs from its member countries. Furthermore, experiences with using EO data to compile SEEA EA accounts are also of interest to the Global Biodiversity Framework, that promotes the monitoring of biodiversity including with (but not limited to) indicators that can be measured from space.

To the best knowledge of the authors, SEEA EA is yet not used to inform decision making or investment planning in the multilateral organizations themselves, but targeted to inform global frameworks such as SDGs, GBF, etc. At first instance, this may be related to the SEEA EA being a system developed to be applied at national level (or for a specific state or province, or e.g., watershed). When compiling accounts across countries, the issue of data comparability will frequently occur as countries may use different methods or metrics to quantify datasets needed to compile ecosystem accounts. Note the SEEA EA provides a statistical framework that allows countries to use a range of different datasets and methods. At the same time, some of the datasets, particularly those that can be retrieved with EO data (since data comparability issues will be much less of an issue, given that similar inputs datasets are used across countries) could potentially be relevant to inform project design or strategy formulation in international organisations including international financing institutions. For example, detailed, accurate and up to date datasets on pasture condition (degraded versus under-grazed areas) tailored to capture the relevant information within an ecological region as derived from EO data, coupled with local data from field experiments, can support the design of rangeland management and pastoral livelihood projects. Likewise, data on carbon, water resources, and potentially land use and ecosystem changes can be highly relevant for multilaterals, provided that the data is up-to-date, accurate, well explained and easily accessible.

2.4 Private and financial sector

Several mechanisms trigger the increasing interest of the private sector in natural capital accounting in general, noting that the private sector is highly diverse and information needs vary considerably between companies, including Small and Medium Enterprises (SME). As general drivers for information needs the following can be considered: (i) a need to better understand environmental impacts to inform internal decision making; (ii) a need to understand changes in natural resources relevant for the supply chain of the company (including effects of climate change); (iii) a need for reporting – that may or may not be entirely or partly driven by policy regulations such as the EU No deforestation regulation and the EU non-financial disclosure directive (for large companies, with over 400 staff in the EU, only). Furthermore, there is an increasing interest in carbon stocks and sequestration related for a part to the voluntary carbon market and companies' interest in offsetting residual GHG emissions. And finally, there is a starting interest in biodiversity data, with potentially a development of a biodiversity offset market underway (assurance, if possible, of the quality or benefits of such a biodiversity market needs further scrutiny but is not the topic of this report).

Interests in specific datasets will always be driven by the company's specific needs, but carbon stands out, whereas multiple companies have taken an interest in water resources, in recognition of the increasing pressure on water resources in many parts of the globe. Furthermore, there is an increasing interest in the private sector in biodiversity accounts, with several companies exploring the idea of biodiversity offsets (i.e., compensating negative biodiversity impacts through restoring biodiversity elsewhere). It is noted that this is not yet a generally accepted approach, and that it remains difficult to express biodiversity in common indicators that are representative of biodiversity in different types of ecosystems and contexts.

The Taskforce on Nature-related Financial Disclosures (TNFD) integrates in its recommendations the SEEA, particularly Ecosystem Accounting, ensuring that the definitions of ecosystem extent, condition, and ecosystem services and assets are used by corporations and embedded within the TNFD's the LEAP approach. This approach facilitates the identification and assessment of nature-related issues, with the TNFD recommending the application of SEEA for measuring impact drivers in nature-related issues.

Finally, some companies may have an interest in the ecosystem accounts to understand environmental risks and climate change risks to which they are exposed. For example, companies may be interested in learning about changes in water availability to their production sites, or the risks of climate change (e.g., increases in flood risks in coastal areas) - noting that to date the SEEA EA accounts are not designed to capture risks of climate change.

2.5 Other stakeholders (NGOs, scientists, and citizens)

Furthermore, environmental NGOs and citizen groups may use data from the accounts. However, some of them may specifically need very localized data, e.g., to show the societal benefits of certain farming practices, or the negative impacts of the construction of a new road. Environmental NGOS, as well as scientists, may have specific information needs for instance related to carbon stocks or emissions from ecosystems, biodiversity or specific condition or ecosystem service indicators (e.g., on urban air quality). The applicability of data will depend entirely on its accuracy and timeliness, and it is hard to predict which indicators will be most relevant to this diverse group of stakeholders.

3. Methodological perspective

The SEEA EA standard describes the 'what' of ecosystem accounting including the components, structure, and contents of the accounts. The 'how', i.e., how to to compile accounts, is not described as much in the SEEA EA itself, but the UNSD Biophysical Modelling for Ecosystem Accounting handbook and the Eurostat guidance notes provide further guidance. It should be noted that this work remains in progress, and it is expected that more and more practical guidelines will become available, e.g., through the work programme of the Technical Committee on SEEA Ecosystem accounting and via several Ad-hoc Technical Expert workgroups (e.g., agro-ecosystems, carbon accounts, etc.). Producing accounts requires many datasets and models that are geo-spatial explicit. This chapter analyses per ecosystem account type (extent, condition, services) the main data and modelling gaps to integrate EO data and then proposes potential R&D tasks to fill these gaps.

Before starting the analysis per ecosystem account type, an overview of the main EO datasets to be considered as input for ecosystem accounting is provided. It should be noted that these datasets require sufficient ground-truth (in-situ data) to train or calibrate satellite data products or validate modelling outputs, as further explained in section 3.3. The models also benefit further on the availability of other auxiliary datasets (e.g., rainfall, soil, etc.) that are not further detailed in this document.

3.1 Terminology

Both the Ecosystem Accounting community and the Earth Observation community have their terminology, so first a table is created to explain the major concepts and terminology used throughout this document. The terminology is made consistent with the SEEA EA (UN, 2021).

Table 2: Terminology

Concept/Term	Abbrev.	Description
Aries for SEEA Explorer		An integrated, open-source modelling platform for environmental sustainability, used to produced rapid, standardized, scalable and customizable ecosystem accounts consistent with SEEA EA
Cultural services		Experiential and intangible ecosystems services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits.
Earth Observation	EO	Gathering of information about the physical, chemical, and biological systems of the planet Earth from space. In this document we refer to Level-3 data which is gridded geophysical parameter data, averaged, gridded and rectified or composed in time and space.
Ecosystem		A dynamic complex of plant, animal and microorganism communities and the abiotic environment, interacting as a functional unit
Ecosystem Accounting	EA	An integrated and comprehensive statistical framework to organize data on habitats and landscapes, measure ecosystem services, tracking changes in ecosystem assets and link this information to economic and other human activity.
Ecosystem Accounting Area	EAA	The geographical territory for which an ecosystem account is compiled.
Ecosystem Account Ready dataset	AccoRD	Pre-packaged and pre-processed bundles of EO data products that make the archive more accessible and easier to use for

Concept/Term	Abbrev.	Description
		accounting purposes. E.g. EO Level-3 data products are typically delivered as 10-day temporal images in a tiling grid. AccoRD will aggregate these images into an annual data product, projected to the grid to perform best statistical operations.
Ecosystem Assessment		The interpretation of scientific results/evidence in non-monetary terms and other form of information that is intelligible and meaningful for policy and decision making.
Ecosystem assets	EAs	Contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions.
Ecosystem Type	ET	Recurrent classified discrete units (e.g., deciduous forests) that represent complexes of organisms and their associated physical environment within an area, based on one or more dominant features (Keith et al., 2015, based on Tansley, 1935).
Ecosystem extent		The size of an ecosystem asset in terms of spatial area.
Ecosystem condition		The quality of an ecosystem measured in terms of its biotic (e.g., structural, functional and composition) and abiotic characteristics (e.g., chemical and physical)
Ecosystem condition index		Aggregate a number of ecosystem condition indicators into a single dimensionless value (0-1). The actual aggregation function (e.g., arithmetic mean, geometric mean, quantiles, etc.) is to be chosen.
Ecosystem condition indicator		A rescaled ecosystem condition variable towards a dimensionless scale (0-1). Rescaling is performed by comparing past/present/future measured values to some reference.
Ecosystem condition typology	ECT	A hierarchical typology for organizing data on ecosystem condition characteristics
Ecosystem condition variable		The representation of a single ecosystem characteristic within one of the ECT categories.
Ecosystem services	ESs	The contributions of ecosystems to benefits used in economic and human activity.
Findable, Accessible, Interoperable and Reusable	FAIR	The FAIR principles emphasize machine-actionability. The first step in (re)using data is to find them. Once found, they need to know how to access it. The data usually needs to interoperate with workflows. The goal is to optimize the reuse of data and models.
Integrated Natural Capital Accounting	INCA	A project implemented at EU level compliant with the SEEA EA to build ecosystem accounts.
Natural Capital Accounting	NCA	A process of quantifying and valuing the stocks and flows of natural resources and ecosystem services in economic terms. It is a broader concept that encompasses the valuation of all natural resources.
Open Earth Observation	OPENEO	An interface that targets the processing and analysis of Earth Observation (EO) data in the context of open-source software (Apache 2.0)
Provisioning services		Those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems.
Regulating services		Those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence

Concept/Term	Abbrev.	Description
		climate, hydrological and biochemical cycles and thereby maintain environmental conditions beneficial to individuals and society

3.2 EO datasets

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. The former is typically used for some specific field campaign, hence cover only a limited area and time-period[2], while the latter provides a continuous data stream of observations across the globe. This analysis is limited to spacecraft sensors only, as to ensure scalability across the European continent and the entire globe.

As explained by Geller et.al, 2023 [AD05], there is a multitude of different EO data types already applicable for use by ecosystem accounting, as shown in Table 3. This number of EO datasets continues to grow in the upcoming years and provide a long-preserved lifetime, however, requires the EO community to step up to prepare these datasets as to create value-added products, combine data from different sensors, provide the FAIR principles, deal with multi-scale aspects and improve the availability of good reference data for training and validation.

We can mainly see in the near-future, ecosystem accounting workflows can take benefit of the more spectral bands for optical sensors (hyperspectral) and the diversity of synthetic radar aperture (SAR) signals.

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 1. 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.

[2] Some national programs exist to provide country wide and regular aerial surveys, however the regularity in this case should be understood as a campaign covering several days (weeks) to capture once the entire area within one or several years.

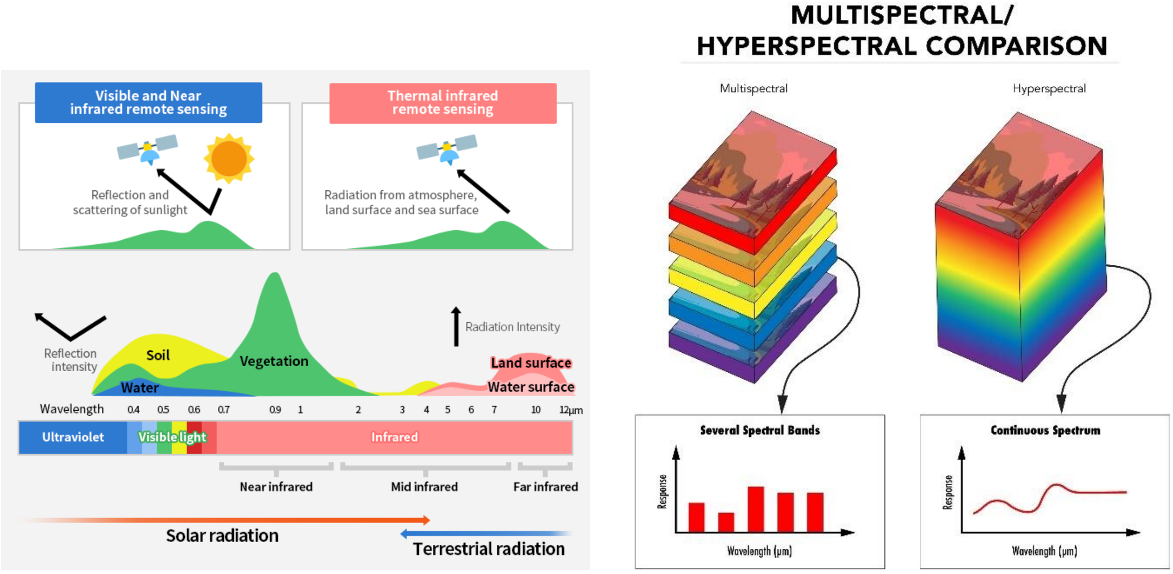

Figure 1. Optical remote sensing principles (left: difference between multi-spectral and thermal, right: difference between multi- and hyper-spectral). Credit left image: JAXA, Credit right image: Edmund Optics.

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 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 2 shows a simplified figure on the different SAR signals.

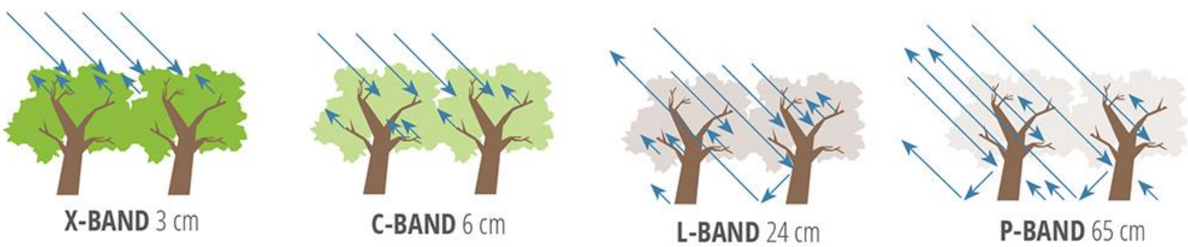

Figure 2. Sensitivity of SAR measurements to forest structure and penetration into the canopy at different wavelengths used for airborne or spaceborne remote sensing observations of the land surface[3]. Credit: NASA SAR Handbook.

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 3.

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

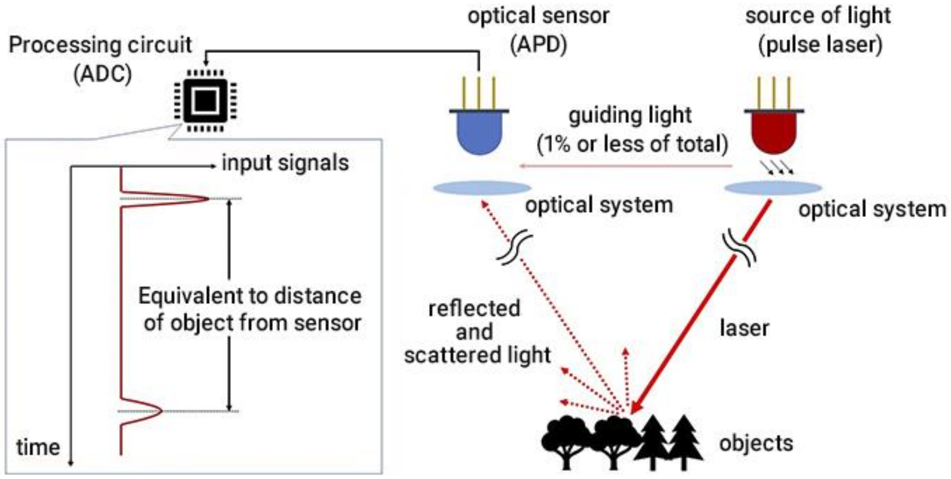

Figure 3. Laser principle. Credit: JAXA.

Table 3. The basic types of sensors and their applicability for ecosystem mapping and monitoring (adapted from Geller, 2023)

Sensor type	How it works	Benefits / Limitations
Optical – Multispectral	Passive sensor measuring reflected light in a limited number of spectral bands, typically in the visible, NIR and SWIR range	Benefits - Many platforms. - Historical time-series back to 1984. Limitations - Obscured by clouds. - Canopy surface only.
Optical – Hyperspectral	Passive sensor measuring reflected light in hundreds of narrow spectral bands	Benefits: - Enables biochemical plant analysis (“functional traits”). Limitations: - Newer modality, less historical record. - Same as multispectral.
Optical - Thermal	Passive sensors using infrared to measure land surface temperatures	Benefits: - Enables monitoring disturbance regimes (droughts, fires, …). Limitations: - Low temporal and/or spatial resolution.
VHR for Urban	Passive sensor measuring reflected light in a limited number of spectral bands	Benefits: - High spatial detail to detect urban features as roads, infrastructure, green spaces, etc. - Enable detection of subtle changes to monitor ecosystem dynamics (if sufficiently revisited). Limitations: - Limited temporal coverage. - Cost to acquire imagery. - Cost to process imagery.
Synthetic Aperture Radar – C-band	Active sensor that emits microware signals	Benefits: - Enables vegetation, soil and terrain structural analysis (short wavelengths

Sensor type	How it works	Benefits / Limitations
		sensitive to canopy structure, long wavelengths sensitive to trunk and branch structure). - penetrates clouds, haze, and smoke. - can image during both day and night. - historical data since 1990's. Limitations: - initially challenging for ecosystem scientists to utilize.
Synthetic Aperture Radar – L-band	Active sensor that emits microwave signals	Benefits: - penetrates dense canopy. - all weather and day-night observations. Limitations: - coarser spatial resolution and limited spectral information. - complex processing.
Synthetic Aperture Radar – P-band	Active sensor that emits microwave signals	Benefits: - penetrates deeper into vegetation canopies and soil layers. - better spatial resolution than L-band, enable detection of fine-scale ecosystem features and subtle changes in soil properties. - all weather and day-night observations. Limitations: - limited availability. - complex processing. - regulatory constraints due to interference with other radio-frequency systems.
Lidar	Active sensor that emits laser pulses	Benefits: - Enables structural forest measurements, such as canopy height and profile. Limitations: - point-based sampling. - few space-based platforms. - limited historical data.

Table 4 provides an overview of the main EO platforms and sensors and some of their characteristics. The overview did not include datasets with a limited lifetime (e.g., Earth Explorer missions), with unclear data policies (e.g., Gaofen, Jilin). It should also be noted that for the Urban Ecosystems, a specific group is added that deal with the high spatial diversity of these ecosystems that require a specific EO data-stream that is limited in spatial coverage but extended in spatial resolution. Another nice overview can also be found at https://www.itc.nl/facilities/satellite-sensor-database/.

Table 4. Overview of main available and upcoming EO platforms and sensors (based on Geller, 2023)

Sensor type	Platform/sensor	Data characteristics
Optical – Multispectral	Landsat-series (NASA)	From 1984, 30-60m 8 spectral bands (1 thermal) 16-daily global 8-daily global (Landsat 8/9)
	Landsat-Next (NASA)	From 2030, 10-60m 23 spectral bands (5 thermal) 6-daily global
	Sentinel-2 (ESA)	From 2017, 10-20m 13 spectral bands 2-5 daily global
	Planetlabs	From 2009, 3.7m 4 spectral bands Daily global
	MODIS (NASA)	From 2000, 250-500m 36 spectral bands Daily global
	SPOT-VGT/Proba-V/Sentinel-3 (ESA)	From 1998, 100m-1km 4 to 21 spectral bands Daily global
Optical – Hyperspectral	CHIME (and pre-cursors[4])	From 2028, 30m 200 spectral bands 25-day global (11 days with 2 sats)
	SBG	From 2027
	Planetlabs	From 2023 Small narrow bands (5nm)
Optical - Thermal	Landsat-series (NASA)	From 1984, 30m-60m 1 thermal channel 16-daily global
	Landsat-Next (NASA)	From 2030 5 thermal channels 6-daily global
	Trishna (CNES)	From 2024
	LSTM (ESA)	From 2028, 50m 1-2 daily global
VHR for Urban	e.g. WorldView, SkySAT, Pleiades, etc.	
Synthetic Aperture Radar – C-band	Sentinel-1	from 2016, 10m Daily global
Synthetic Aperture Radar – L-band	ALOS, ALOS-2, JERS1	
	ALOS-4 Palsar-3 (JAXA)	From 2024
	NISAR (NASA/ISRO)	From 2024 12 daily global
	ROSE-L (ESA)	From 2028, 5-10m
Synthetic Aperture Radar – P-band	Biomass (ESA)	From 2024
	FLEX (ESA)	From 2025 27-day global
Lidar	GEDI	2018-2023, 25m Several images per year up to 55°N
	MOLI (JAXA)	From 2026

[4] Pre-cursors as PRISMA (ASI), DESIS (DLR), EnMAP (DLR) and EMIT (NASA) can help in the preparation of these signals in the workflows for the continued upcoming missions.

3.3 Importance of in-situ data

In-situ data provides ground-truth information and is either manually collected and checked by human experts or through a network of capturing devices that collect geo-tagged data in a semi-automated way (e.g. flux towers, camera traps, etc.). Such data are essential for nearly all applications of space-based Earth Observation to calibrate the sensor signal to meaningful information and to apply machine learning techniques on the EO large datasets, as well as to monitor the quality (validation) of the EO data. In particular, in-situ data is essential for establishing the relation between EO data (satellite signal or derived product) and the observed phenomenon / ecological characteristic on the ground. Despite the importance of these databases (e.g., EVA, BIEN, TRY, iNaturalist, etc.), in situ data are often the limiting factor in interpreting EO data. This also limits taking full benefits of state-of-the-art Artificial Intelligence techniques and reduces our ability to understand and monitor ecosystems.

The availability of in situ data differs considerably between countries and ecosystem types, and there is no European (or globally) institution responsible for gathering or making these data available. The landscape is very scattered and (mostly) not sufficiently harmonized which hampers scaling-up the EO workflows. Since collecting in situ data has a price tag, it is important that available in-situ data are standardized, shared, and made available open access, where legally and practically possible. An example of an open access system is the Global Biodiversity Information Facility (GBIF). Identified gaps (in all aspects, e.g. spatial, temporal and species) in in-situ data need to be discussed and aligned between the EO and in-situ communities to define protocols (e.g., accuracy of geo-location, which information to gather where, etc.) to fill these gaps in a cost-efficient manner and optimize their use for EO applications. Improving the availability, quality, and quantity of such databases in a harmonized and interoperable way should be a key component of any national monitoring that aims to optimise its use of satellite infrastructure investment for ecosystem monitoring (and beyond), especially in view of the tremendous potential upcoming new sensors. Distinguishing specific campaigns for essential satellite data calibration (one off campaign) and repeated surveys to monitor the quality of the calibrated EO datasets is important as they come with different price tags.

Another bottleneck, next to the availability of in situ data, is the coverage and amount of data points, especially with the new Artificial Intelligence (AI) techniques, such as Deep Learning. Contrary to the AI-based solutions in other domains, such as text or face recognition, where learning models could count on abundant structured and labelled training data, the mapping of ecosystems through machine learning suffers greatly from deficiency of training data. This is not only due to the scarcity of produced in-situ datasets, but also because certain ecosystem phenomena are either rare or very difficult to formalize in the digital domain. There are simply not enough features in the real world to use as training samples for the current AI-models (mostly neural network based). For example, the most abundant CLC class (342) has little bit less than 250 000 spatial features in the 2018 CLC. This means that for certain ecosystem the automated EO-based method will be of limited use, and the classical methods of manual photointerpretation (national orthophoto combined with ancillary in-situ data to derive the interpretation keys), will be the appropriate one. The recent development in the use of embeddings to express and represent complex land phenomena and allow machine learning (ML) and artificial intelligence (AI) systems to understand it like humans do, is a promising avenue to explore. However, it requires particular attention to the collection, structuring, and description of in-situ data, based on clear ecological-driven semantic logic.

It is clear that in-situ data and EO data should be seen as one system. To highlight the importance of in-situ data, an example is explained in the annex. The in-situ dataset (European Vegetation Archive in Annex) is of extreme importance to conduct amongst others habitat distribution mapping with EO, which is an important input to account for EU ecosystem extent at its highest level of detail. Combining the results of the EO modelling techniques with other ‘direct’ mapping techniques can be beneficial to better delineate or provide information on habitat types which are hard or impossible to see from space (e.g. understory).

It should be noted that these in-situ datasets can also be used for direct spatial modelling and hence provide additional information on the spatial extent of individual ecosystems (e.g., fauna breeding sites).

3.4 Extent accounts

Analysis

Ecosystem extent accounts present, in maps and tables, the area covered by different ecosystem types, classified by national, supranational, or global typologies. UNSD requests countries to provide crosswalks of national typologies to the IUCN Global Ecosystem Typology in case countries do not use the IUCN GET as typology for their national SEEA EA accounts. To date, maps of extent accounts are only available for specific countries and years. There are several priorities with regards to extent accounting that need to be addressed to scale up extent accounting efforts. These are, first, testing how the IUCN GET can be better aligned or potentially extended (e.g., levels 4 to 6) to better account for ecosystems that are strongly modified by people, in the different continents. Second, this includes testing which part of the adjusted extent classification can be implemented using EO data. In principle, there is scope to test the mapping of classes within the European level-2 ecosystem typology (which is detailed, i.e., much more detailed than IUCN GET level-3 for terrestrial ecosystems) with currently, freely available EO data and automated workflows . It would be useful to have the same aim for the level-2 typology in other continents, given the challenges of mapping ecosystems on an annual basis with other means. Importantly, this means that development of the reporting classes for extent accounts needs to be done with simultaneous consideration of (i) accounting principles; (ii) IUCN GET; and (iii) the possibilities that EO, in combination with in-situ data, provides to map these ecosystem types. Third, the extended extent classification needs to be further aligned with other reporting initiatives, the global and intergovernmental conventions, and multilateral environmental agreements such as the GBF. It is also noted that continuation of the Corine Land Cover (CLC) program is of essential importance for supporting the ecosystem accounting efforts in the EU, including but not limited to harmonized mapping of ecosystem extent in the EU.

Another important aspect is the use of upcoming new satellite missions (e.g., hyperspectral, and thermal) to further distinguish ecosystem types with EO to move to European scale level-3 ecosystem typology mapping (level 3 is tightly linked to EUNIS). This level of detail is very important for biodiversity and carbon (tree species) accounting. Such Essential Biodiversity Variables (EBVs) could provide important information to further distinguish ecosystem types at the higher levels. ESA could consider supporting pilots on extent account classification feasibility towards this detailed level-3 using already datasets from the German Environmental Mapping and Analysis Program (EnMAP, see enmap.org), and other explorer missions.

Ecosystem extent is the base of ecosystem accounting, and hence its reliability (accuracy) and its standardization (common technical specification) is very important for the remainder of the accounting process. Special care should be taken to handle properly temporal variations in the extent, since this mostly forms the basis for policy decisions. Handling change, even on land cover, in an accurate manner is still a challenge and deserves special attention. Linking change to drivers of change, as being explored in biodiversity, could be an interesting new information source to be integrated in the generation of changes in extent. Next to facilitating the use of time-series analysis for extent change mapping, it is useful to explore ways to utilize EO to characterize ecosystem condition and its relationship to ecosystem extent.

In 2022, experts in Earth Observation and in ecosystem accounting were brought together in a workshop to address the use of Earth Observation and ecosystem accounts in all realms. Figure 4 depicts the conclusion for ecosystem extent accounts.

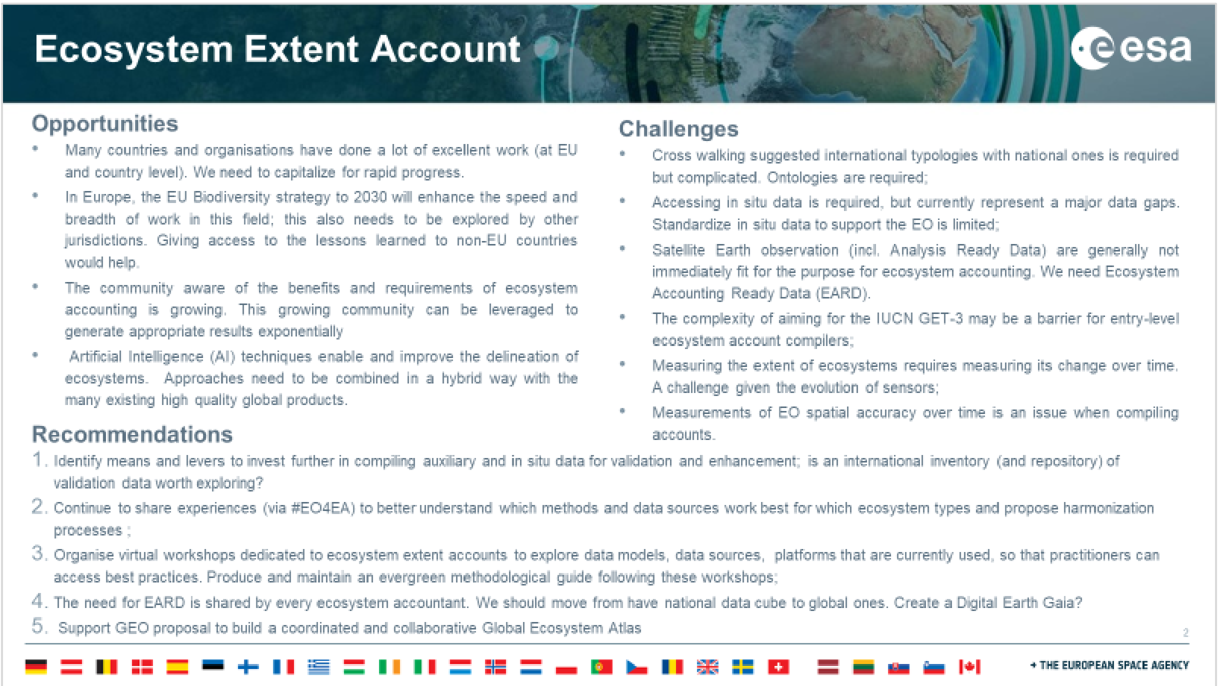

Figure 4. Conclusions of EO4EA 2022 workshop on ecosystem extent account (credit ESA).

Another highly useful manner for EO data to be applied in extent accounting is for reporting on the area covered by waterways. New approaches (e.g., the WaterMaskAnalyzer)[5] combining different EO data sources are now available and could be very helpful, since in many countries important parts of river stretches are only known in maps as linear features, whereas for extent accounting it is recommended to have these as areas. Similar approaches should be developed to use free EO datasets for other small linear landscape elements that are important for ecosystem extent delineation (e.g., hedgerows).

Wetlands protect against storms and store more carbon than the world's forests. However, information on wetland extent, wetland types, their ecosystem services and benefits are often scattered, hard to find and difficult to link to human services (e.g., Nature-based Solutions). Several wetland inventories are put in place to protect, manage, and restore wetlands. These inventories include developing technologies using EO data to monitor the wetlands more efficiently and regularly, and hence can be an important input for extent accounting.

Urban ecosystems have unique characteristics and challenges, being highly influenced by anthropogenic activities, and hence include a large and small-scale diversity. Higher resolution imagery enables better discrimination of different urban features, such as buildings, roads, parks, and green spaces. Next to fusion of optical and synthetic aperture radar data, techniques to integrate LiDAR and 3D mapping enable to accurately measure the vertical structure of urban vegetation,

[5] https://www.mdpi.com/2072-4292/14/18/4485

including trees and green roofs, and provide information about the height and density of vegetation. Also, the integration of Object-Based Image Analysis (OBIA) allows for the segmentation of images into meaningful urban objects, such as buildings, roads, and vegetation patches and as such can improve the accuracy of ecosystem extent accounting. The urban ecosystem is also very suitable to engage citizens in collecting and validating EO data related to urban ecosystems through crowdsourcing and citizen science initiatives to improve areas with complex land use patterns.

There are several initiatives to the ecosystem extent accounting and given the complexity and urgency such task these initiatives should be harmonized and made interoperable as much as possible such that countries can not only benefit quickly from these outcomes but also to avoid confusing countries which solution to choose. At least the proper characteristics, limitations and accuracy information from an independent validation is to be provided such that countries do not require to assess each solution themselves. Some of these initiatives are (i) the Global Ecosystems Atlas (Group of Earth Observation) which will bring together high-quality global, regional and national ecosystem maps into a single, open, online resource; (ii) the World Ecosystem Extent Dynamics (European Space Agency) which will develop a globally applicable open-source toolbox, leveraging existing datasets and tools while applying creative and novel methods using Earth Observation and deal with temporal variations according to different ecosystem typologies; (iii) Ecosystem Extent Task Team (Committee on Earth Observation Satellites) which explore the opportunities to use Space-based Earth Observation for Ecosystem Extent; the World Terrestrial Ecosystems Explorer (WTEE) and various regional ecosystem mapping efforts. Since these initiatives will produce new insights and datasets as time moves on, communication and collaboration is essential. Where relevant, protocols for harmonizing data from different sources to ensure consistency and comparability can be developed.

Proposed R&D

For the extent accounts, therefore, the main R&D topics are as synthesized in Table 6. Note the table is based on the Global Ecosystem Typology (at the biome level), and is limited to the Terrestrial and Freshwater realms, and their Transitions to Marine. The Marine and Subterrain ecosystems are not included.

Table 5. R&D priorities for extent accounts

Ecosystem biome	R&D priority	Comments
All ecosystems	High-Resolution Data Inclusion: Prioritize the inclusion of very high-resolution data in extent accounts to accurately map land-use features and threatened habitat types. Ensure that these data are regularly updated and validated.	High-resolution data should be used preferentially for spatially the most diverse ecosystems including typically urban ecosystems (e.g., to identify tree lines and green and blue elements).
	Combining data from different types of sensors	This involves the use high-resolution imagery and machine learning techniques to identify and classify small landscape elements.
	Improve the availability (quantity and quality) of reference data for training and validation	Integration of local in-situ data is a key aspect for using EO datasets. The EO and in-situ community must further align the needs and expected quality of these datasets.
	Disentangle ecosystem extent and condition factors to improve the delineation of ecosystems and deal with heterogeneous ecosystems. **This is considered a high priority based on feedback on the draft Roadmap.**	Approaches need to be defined by ecosystem type, but, for instance, for agroforestry systems this involves developing specific categories for different agroforestry practices such as alley cropping, traditional silvipastoral systems, and or modern agro-forestry methods using a combination of EO data and field surveys
	Deal with difference in required resolution to analyse different ecosystem types and landscape ecologies[6].	Urban ecosystems could require a higher spatial resolution (less than 10m), compared to other ecosystems.
	Handle robust detection of change and quantify their accuracies; differentiate between changes in ecosystem extent due to bias, errors, or uncertainties versus real changes. **This is considered a top priority based on feedback on the draft Roadmap.**	Focus first on abrupt changes, thereafter, disentangle ecosystem condition to characterize gradual changes
	Deal with varying capacities amongst countries, and ensure that countries have ownership	

[6] https://doi.org/10.1007/s10980-019-00820-z

	Enable comparability and interoperability across countries despite different typologies	Applying standard ontologies and meta-languages can be beneficial.
Tropical-subtropical forests		
Temperate-boreal forests and woodlands		
Shrubland and shrubby woodlands	Integrate fire regimes and water deficits	
Savannas and grasslands	Integrate fire and climate data to distinguish different savanna types (dry, moist, pyrrhic, trophic).	
Deserts and semi-deserts biomes	Integrate probability of fog information to distinguish cold and hot deserts	
Polar/alpine (cryogenic) biomes		
Intensive land-use biome	Integration of higher resolution EO datasets and use of object-based segmentation	
Rivers and streams	Apply new multi-sensor methodologies to distinguish linear features	
Lakes		
Artificial wetlands		
Palustrine wetlands		
Shorelines		
Tidal biomes		

3.5 Condition accounts

Analysis

Earth Observation plays a critical role in supporting ecosystem accounting by providing timely, accurate, and spatially explicit information and contribute to the measurement of the status and trends of ecosystems. There is a significant share of condition variables that can be measured with EO, and with many of these variables there is already a lot of experience (e.g., estimating NPP based on NDVI). In terms of terminology, the SEEA EA uses the term variable and indicator in a specific manner in the context of condition accounts. A variable is the ecosystem property that is measured, e.g., NPP or standing biomass. When this variable is compared to a reference condition, and where needed scaled to reflect relative values indicating poor or good ecosystem condition, the variable is turned into an indicator. However, this nomenclature is not generally applied in ecology or environmental sciences, and the EU legal proposal does not involve comparing measured ecosystem properties to a reference condition (noting that such reference conditions are particularly difficult to establish in much of Europe where there fully natural conditions may not have existed in climatic conditions comparable to the present since the last ice age). In this document, the term indicator is therefore used more broadly: i.e., indicators may or may not be scaled and compared to a reference condition.

There is a variety of options for assessing biodiversity and ecosystem attributes, relevant to the different parts of the SEEA-EA Ecosystem Condition Typology (ECT). It is important to harmonize the selection of these options with frameworks already in place (e.g., MAES in Europe, GBF, etc.) and linked to the needs of the policies (e.g., Nature-Restoration Law in Europe). Special attention should be given to emerging indicators to monitor and assess biodiversity variables (EBVs).

Preferably for every ecosystem type, at least one indicator per condition class (ECT) should be made available hence six indicators per ecosystem type. Within Europe the Ecosystem Accounting regulation mandates less indicators, but a list of complementary voluntary indicators – aligned with ecosystem assessment – is in preparation. For some ecosystems, e.g., forests, such indicators are well established and numerous indicators are already derived from EO. For other ecosystems, e.g., urban or coastal, such indicators are less established and require further work.

In 2022, experts in Earth Observation and in Ecosystem Accounting were brought together in a workshop to address the use of Earth Observation and ecosystem accounts in all realms. Figure 5 depicts the conclusion for ecosystem condition accounts.

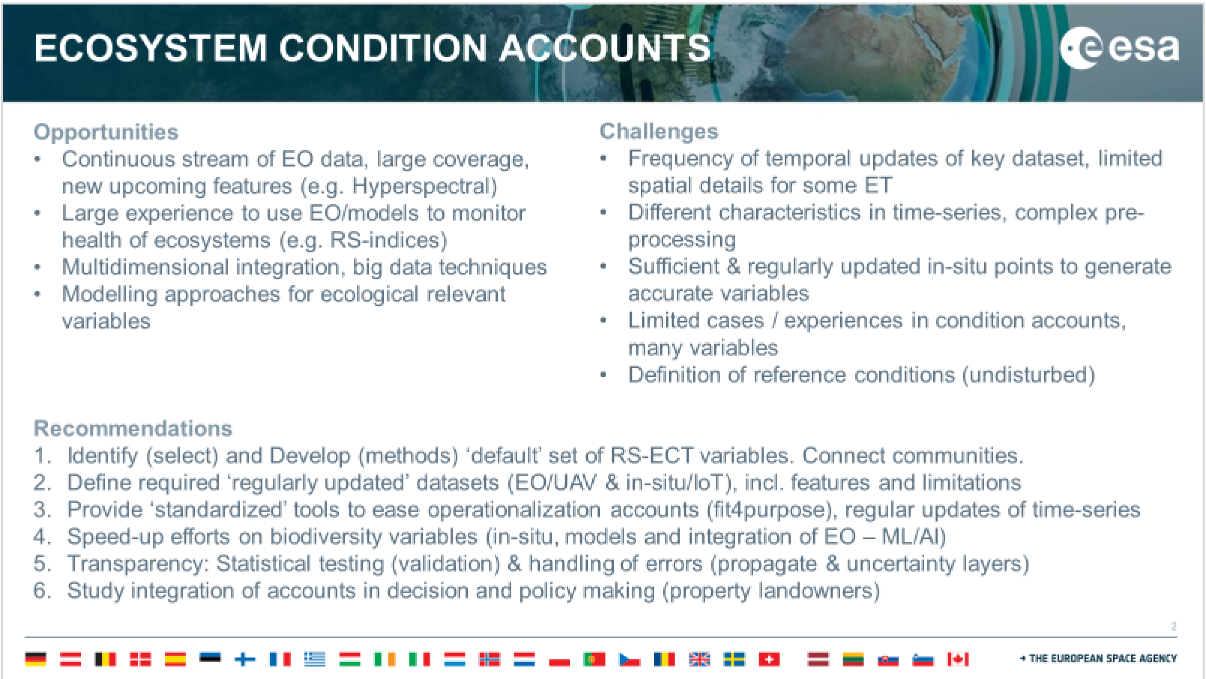

Figure 5. Conclusions of EO4EA 2022 workshop on ecosystem condition account (credit ESA).

More work is needed to test how impervious surfaces can be measured with EO, including in coastal zones (where reporting on this condition indicator is mandatory in the legal proposal). A challenge is that some of these impervious areas may be relatively small or narrow, yet widespread. Other potentially relevant condition indicators that can be measured with EO data and models are for which some further testing may be warranted are (i) greenspace and bluespace in urban areas; (ii) tree lines in urban areas; (iii) diversity of species with different landscapes like grasslands or forests.

Proposed R&D

For the condition accounts, therefore, the main R&D topics are as synthesized in Table 6. Note the table is based on the Global Ecosystem Typology (at the biome level), and is limited to the Terrestrial and Freshwater realms, and their Transitions to Marine.

Table 6. R&D priorities for condition accounts

Ecosystem biome	R&D priority	Comments
All ecosystems	Selection/definition of key indicator(s) per ecosystem condition typology per ecosystem type	Needs to be aligned with policy initiatives including GBF Deal with scalability for each Tier (global, national, regional, local), and developed in partnership with the main expert teams (e.g., IUCN GET team). Note that critical condition indicators vary with ecosystem type.
	Selection of reference conditions. EO data can help in identifying the natural or reference conditions in condition accounts, where countries – as recommended in SEEA EA but not included in the EU legal proposal – decide to map condition vis-à-vis a reference condition. **This is considered a high priority based on feedback on the draft Roadmap.**	Reference conditions often are chosen to reflect natural/well conserved ecosystems. This poses challenges where there is large ecological diversity within natural ecosystems, or where a large proportion of ecosystems is disturbed due to human interference. It is noted that sometimes the management of ecosystems by humans may result in a healthy condition, e.g. fire landscape management by indigenous people. Traditional agricultural landscapes or extensively grazed areas can also harbour a rich biodiversity, contrary to intensive, large-scale agriculture.
	Use of (or generation of) value-added products as Essential Biodiversity Variables	
Tropical-subtropical forests	Selection of a set of key variables that may include level of past disturbance (e.g., logging history), fragmentation, productivity (NPP), fire occurrence, diversity of tree species, standing biomass.	Many variables (e.g., NPP) are routinely derived from EO data already, others can be derived using established procedures (e.g., fragmentation). There is however a need to better understand the occurrence of peatlands in these ecosystems[7]. Also, the analyses of standing biomass need to be enhanced, especially for high biomass, old growth forests.
Temperate-boreal forests and woodlands	Selection of a set of key variables that may include level of past disturbance (e.g., logging history), fragmentation,	Many variables (e.g., NPP) are routinely derived from EO data already, others can be derived using established

[7] The results of JRC SEPLA project are particularly relevant: https://wikis.ec.europa.eu/display/GUIDANCEANDTOOLSFORCAP/Climate+Action

	productivity (NPP), fire occurrence, diversity of tree species, length of growing season	procedures (e.g. fragmentation). There is however a need to better understand the occurrence of peatlands in these ecosystems.
Shrubland and shrubby woodlands	Selection of a set of key variables that may include level of past disturbance (e.g., fire), productivity (NPP), species diversity and fragmentation	
Savannas and grasslands	Selection of a set of key variables that may include Rain-use efficiency (in semi-arid and sub-humid grasslands), soil cover (throughout the year), productivity (NPP), water stress (NDWI)	There is a need to better understand the anthrophogenic impact on these ecosystems, including peatlands.
Deserts and semi-deserts biomes	Selection of a set of key variables that may include Rain-use efficiency, soil cover (throughout the year), productivity (NPP), water stress (NDWI)	Water stress is considered a permanent feature of these ecosystems, so its relationship as a condition indicator is to be further analysed.
Polar/alpine (cryogenic) biomes	Selection of a set of key variables that may include NPP, length of growing season, standing biomass.	There is a need to better understand the occurrence of peatlands in these ecosystems.
Intensive land-use biome	A key challenge here is dealing with the often-fragmented land use including mosaics of croplands, meadows, and more natural patches of vegetation. Grouping these in a class 'mosaic intensive land use' is helpful and may be the only practical way forward, but it hides potential large differences within such a class. Hence, condition indicators for such a mosaic class need to indicate proportions of natural versus managed land, as well as potentially variables for productivity (NPP), water stress (NDWI) and irrigation water use. **This is considered a top priority based on feedback on the draft Roadmap.**	It is important to assess and over time standardize which factors should be reflected in ecosystem extent maps and which in ecosystem condition maps. For example, linear landscape elements such as roads, rivers and hedgerows can be included as polygons or lines, and the widest hedgerows can be included as polygons in an extent account. However, the narrowest (say, 1 meter) hedgerows cannot be mapped in terms of surface and are most likely to be included as condition indicator (e.g., as in the Netherlands, length of hedgerows per square kilometer). Drawing the boundary between what is to be considered part of extent, and what part of condition is a topic for research that requires further testing of best practices as a function of map resolution and landscape properties.
Urban ecosystems	Detection of green spaces, tree lines, and PM concentrations (with PM concentration being an input for the modelling of	

	the air filtration service as well as an indicator for human health (but not necessarily linked to ecosystem in a country since PM emissions result from industry, traffic and domestic wood burning).	
Rivers and streams	For wetlands, with the presence of vegetation, a range of variables have been proposed that need further testing such as indicators for water stress (NDWI), productivity (NPP) and diversity of flora or vegetation heterogeneity. To date, most condition indicators for water-ecosystems such as rivers, lakes, and coastal zones are gathered through in-situ measurements. It needs to be examined if geospatial EO-derived variables can be developed into account-ready indicators that indicate water levels/streamflows as well as water quality such as algae blooms.	
Lakes		
Artificial wetlands		
Palustrine wetlands		
Shorelines		
Tidal biomes		Despite the wealth of information that is typically available in the freshwater community, further linking with these freshwater ecologists is needed to integrate their knowledge into ecosystem accounts.

3.6 Service Accounts

EO offers great, yet still mostly unused potential to map ecosystem services (ES). Once the appropriate models are developed, they can be run at continental or at global scale or re-calibrated for the national scale, given the complexity of the algorithms. Of course, mapping ES requires ground truth data for as many countries as possible, hence this can only be done in collaborations with national data providers and experts. Potential priority services are (with the most relevant scales/areas indicated), in tentative order of relevance:

Analysis

In 2022, experts in Earth Observation and in Ecosystem Accounting were brought together in a workshop to address the use of Earth Observation and ecosystem accounts in all realms. Figure 6 depicts the conclusion for ecosystem service accounts.

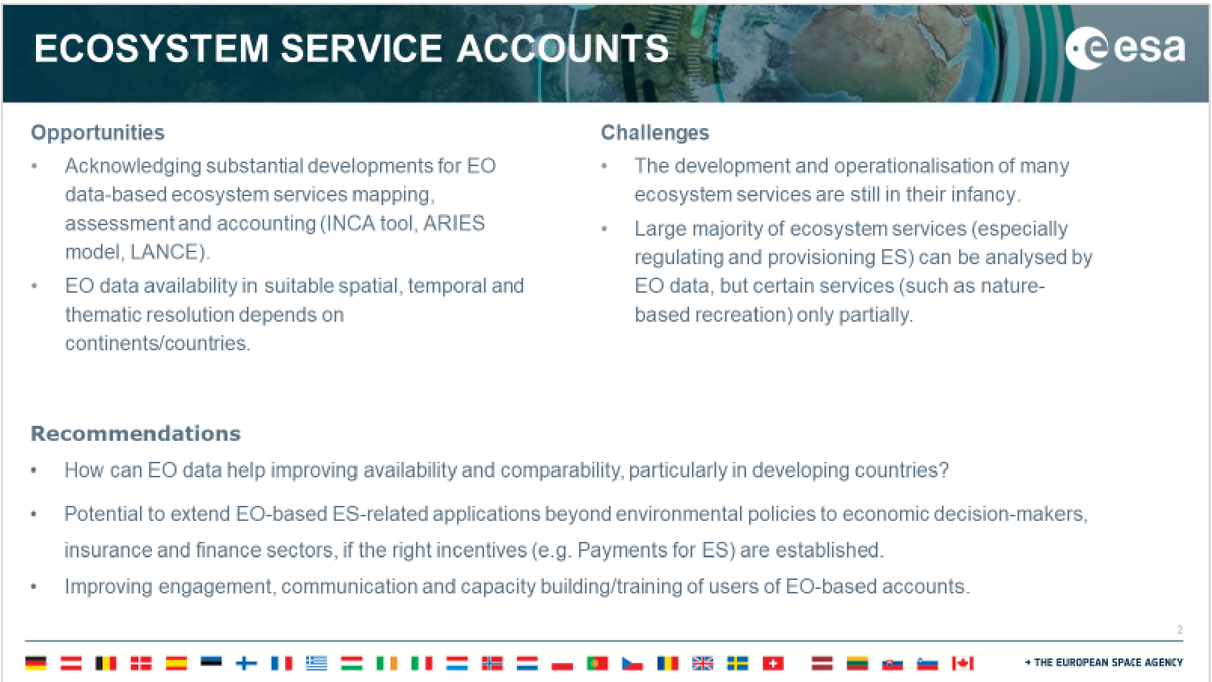

Figure 6. Conclusions of EO4EA 2022 workshop on ecosystem service account (credit ESA).

Carbon. In measuring the global climate regulation service, both stocks and net flows of carbon from ecosystems need to be measured. Carbon flows involve several processes and can be analysed in terms of net ecosystem production (i.e., net primary production – heterotrophic respiration), also termed primary carbon sequestration, or in terms of net carbon sequestration (i.e., primary carbon sequestration minus emissions from ecosystems due to human impacts such as land use change, peat drainage, wood harvest, and fire - noting that some fires are natural). Stocks include above ground (AGC) and below ground carbon (BGC), litter **(i.e., decaying leaves and other dead organic matter lying on top of the soil)** and deadwood and soil organic carbon. With EO, stocks of AGC can be estimated, and BGC, litter and deadwood can be modelled based on AGC and other parameters. Changes in stocks can be related to net sequestration. Alignment with the global climate regulation service for the different carbon pools as defined in the EU Regulation is recommended (living biomass, litter, deadwood, dead organic matter, mineral soils, organic soils, harvested wood products, catastrophic events).

Over the past decade, several global maps of above-ground biomass (AGB) have been produced, such as the ESA-CCI maps, WRI-Flux model, JPL time series, and SMOS-LVOD time series, and several updates or new maps are being planned. These maps have different resolutions and accuracies, and a remaining challenge is underestimating high biomass (saturation effect) and overestimating low biomass. Still, when AGB maps are combined with AGB estimates from a global collection of National Forest Inventories and research plots, increasingly accurate, high-resolution maps of AGB carbon stocks can be produced. Further work is needed to: (i) increase the accuracy of these maps; (ii) estimate Below Ground Biomass (BGB) using predictors specified by ecosystem type and correlated with EO data using Machine Learning (ML); (iii) test how carbon flows and retention can be estimated from the biomass maps. It is very likely that EO based estimates could, with marginal more investment in methodology development, provide complementary data to available country data for most countries. This will be the case when the BIOMAS and NISAR sensors will become operational.

Rainfall maintenance. Rainfall maintenance is a key ecosystem service, that is dependent upon the recycling of water back into the atmosphere by ecosystems, principally through evapotranspiration. Deforestation has been shown to cause reductions in the supply of this service, leading to climate change in the interior parts of LAC, Africa, Australia, and Kalimantan (see Duku and Hein, 2021[8] for an example).

This is potentially the most important ecosystem service provided by forests, however it seldomly shows up in ecosystem assessments because of the complexity of analysing this service. The service is recognised in the SEEA EA, and there is an urgent need to quantify this service and to start including it in accounts. This requires relatively complex algorithms that need to consider EO data on vegetation, rainfall, wind, temperature, and other factors at continental or even global[9] scale (i.e., the service cannot be analysed at national scale). There are also needs for further thinking on how this service can be included in accounts, because there may be large distances (crossing boundaries) between where the service is generated, and where it is used. Given the complexity of the service, this is not likely to be tackled by NSOs, and scientific support with analysing the service is required. Moreover, in one model, the service can be analysed for all countries on a continent, hence it is more efficient to do this centralised rather than by country.

Local climate regulation. Local climate regulation relates to the cooling effect of vegetation and is especially relevant in urban environments (where it may counteract the urban heat island effect). It is related to both shading provided by trees, and evapotranspiration provided by all vegetation. The effect is measurable up to several 100m for green spaces in cities. With the ongoing climate change, this is an increasingly important service, that has also been included in the proposed EU legal module on ecosystem accounting. The default approach is to analyse the service with a spatial regression model, where the influence of vegetation on local temperature is singled out. Various EO data are used (vegetation, tree cover, land surface temperature, distance to the sea, wind speeds, etc.), and could be improved by adding more information on urban context (e.g. building density, type of urban fabric) and fragmentation. Next, the model can be applied without vegetation to assess the cooling effect of vegetation. Whereas several models have been applied, especially in Europe, there is a need to refine the model. Potentially, datasets and models can be made available to NSOs, or incorporated into ARIES, to support NSO to run this model. A key limitation in the modelling at present is insufficient coverage of land surface temperature (now available only once in 8 days with LandSat overpass).

[8] https://iopscience.iop.org/article/10.1088/1748-9326/abfcfb/meta
[9] https://doi.org/10.1016/j.gloenvcha.2020.102051

Air filtration. Vegetation is filtering air pollutants, in particular particulate matter, thereby reducing incidence of various air pollution-related diseases. Satellite data from the Copernicus programme (i.e. Sentinel-5P) and the Copernicus Atmosphere Monitoring Service's (CAMS) European air quality forecast results in wall-to-wall maps of key air pollutants such as particulate matter (PM) and NO_2. The proposal legal module focusses on PM filtration by vegetation. The amount of PM filtered is a function of leaf area index (LAI), wind speed, and PM concentrations. Whereas the basic model exist, further refinement is needed, also in the EU, on how to compile an account for this service.

Flood control services. This service, in the SEEA EA, comprises both coastal protection and river flood mitigation. The service can be derived from EO data on bathymetry, wave action, DEM, coastal (e.g., mangroves) and riparian vegetation. Process based or regression modelling is required to analyse the mitigating effect of vegetation on floods. To date, there are several examples world-wide where this service has been mapped, however there has as yet not been a concerted effort to assess how EO data can be used to map this service across a range of environmental and infrastructure contexts. In Europe such context should be mapped to the flood risk management plans, as required by the Water Framework Directive.

Water regulation. Water regulation services are provided by, in particular, forests in upper parts of watersheds. Forests act as buffers, absorbing water during high rainfall events and gradually releasing water over the year. Currently, the service is typically mapped with detailed hydrological models such as SWAT or with simple modules such as in InVEST. Hydrological models are often too data and computationally intensive to be used for national scale accounting and InVEST is too inaccurate. Hence, it needs to be tested if there are alternative, intermediate (and scalable) approaches, based on ML. EO data is helpful to assess the forest cover in the watershed.

Wood provisioning. Potentially, there is scope to assess if advances with mapping biomass and carbon stocks can be used to inform or enhance statistics on wood provisioning. However, this will in most cases require linkages to local forest and harvest data, for instance to reveal harvest of different qualities and types of wood. The service is included in the legal proposal, and even though many if not all EU countries will have the forestry statistics to be able to report on the use of this ecosystem service, there is scope to test how EO can be used in this context.

Crop provisioning. To date, accurate maps derived from EO of which crops are grown where are mostly lacking, even though EO models themselves have become fairly accurate over time now reaching over 90% accuracy in some pilots (depending upon number of crops, types of crops and varieties, and size of the parcels). This information would be very important for monitoring crops, crop damages due to storm and floods and related farm compensation, and to feed into the SEEA EA accounts. It would also be critical information for monitoring the pollination service.

Crop pollination. A service which requires by default several spatial datasets, linking pollination species, climate conditions, suitable habitats, and agriculture crop information. Simple models have been developed as INCA/Aries and InVEST. However, in most cases the suitable habitats rely on basic ecosystem maps, while no actual species information is included. Also at crop side, currently crop type maps mostly provide information for the main crops. More information is required on pollinator-dependent crop types, nutrient cycles, etc. Integrating more EO can contribute to further details on suitable nesting sites, including integration in species distribution models, as well as agriculture field information (including management practises) to further enhance these services. There is also a strong link between these services and biodiversity. In terms of EO data, this service requires high resolution data with which small landscape elements such as hedgerows that provide a habitat for pollinators can be mapped.

Proposed R&D

For the ecosystem services accounts, therefore, the main R&D topics are as synthesized in Table 7. It is noted that the table focuses on R&D priorities that have an important EO / spatial modelling component. The SEEA EA present more (broader) R&D topics, with a crosswalk[10] to CICES, NESCS, TEEB and IPBES reporting classes. The following services are excluded from the table below, as they require more investigation if and how EO can contribute:

- Provisioning services
    - Aquaculture
    - Wild fish and other natural aquatic products
    - Wild animals, plants, and other biomass products
    - Genetic material services
    - Water supply
    - Other provisioning services
- Regulating and maintenance services
    - Soil quality
    - Water purification (nutrients and other pollutants)
    - Storm mitigation
    - Other regulating services (e.g., fire protection, seed dispersal, etc.)
- Cultural services
    - Education, scientific and research
    - Spiritual, artistic, and symbolic
    - Ecosystem and species appreciation
    - Other cultural services

A recent analysis provides a comprehensive overview of candidate models, data sources, and SEEA-compatible valuation methods for ecosystem service assessments. Despite this analysis did not focus on the use of EO, it is a valuable source [Bulckaen et.al., 2024].

The authors want to stress again the importance of in-situ measurements, as described in section 3.3. The table does not specifically refer to these measurements, but its importance is of utmost priority to calibrate or validate the service models for regional or national use.

[10] See https://seea.un.org/sites/seea.un.org/files/documents/EA/seea_ea_online_supplement_ecosystem_services_reference_list_crosswalk.xlsx.

Table 7. R&D priorities for ecosystem service accounts

Service	R&D priority
1. Provisioning services	
Crop	Wall-2-wall maps of crops, annually updated, would be of high interest as complementary information to the European Common Agriculture Policy payments (IACS) to support implementation of the European legal module on SEEA EA accounting. **This is considered a high priority based on feedback on the draft Roadmap.**
Wood	At the point that Above Ground Biomass estimates become accurate enough to be interpreted in individual parcels or combined with national forest inventories, EO data can be used to estimate wood harvests, either through clearcut and/or selective harvesting.
Non-timber forest products	EO data could be used as a proxy for some services (wild animals, plants, etc.), based on available in-situ datasets and regression.
Livestock / grazed biomass	Rangeland productivity, seasonal or annually, would be required to link to livestock statistics. EO data can be used to estimate this productivity, although mowing is easier to detect than grazing.
….	
2. Regulating and maintenance services	
Global climate regulation (carbon)	Integrating radar data, from the upcoming NISAR and BIOMASS satellites to enhance estimates of AGB including dealing with saturation effect
	Enhancing the models of SOC, root-shoot ratios, litter, and deadwood to have wall-to-wall carbon stock maps. **This is considered a top priority based on feedback on the draft Roadmap.**
Rainfall maintenance	Enhancing models of the service based on EO data and AI algorithms to establish the functioning of this highly important but as yet not sufficiently understood service
	Integrating this service into SEEA EA accounts (since no case studies exit yet)
	Monetary valuation of the service (which requires complex modelling of the linkages between rainfall patterns and water use including for rainfed and irrigated cropping.
Water regulation	Modelling the effect of vegetation on water flows is time consuming and data intensive, requiring hydrological models such as SWAT. EO data cannot solve this issue, but EO data can be used in potential new AI driven models that aim to establish the water regulation service of forests. However, this is to date a not proven approach, and it is recommended to wait until further modelling efforts in this direction are published.
Flood control	EO data can assess the amount (length, density, width) of vegetation that is present in buffer zones along the coast (e.g., mangroves) or rivers (riparian forest). When this information is combined with bathymetry/elevation data, the flood

Service	R&D priority
	control service can be derived. However, a challenge at present is that the globally available DEMs are relatively course, both horizontally and vertically). A more accurate global DEM, the European Ground Motion Service or similar InSAR-based dataset would allow more accurate modelling of this service (as well as a range of other effects such as soil subsidence in drained peatlands or areas where water extraction is leading to subsidence.
Local climate regulation	EO data depicting small scale urban greenspaces including lines of trees. **This is considered a high priority based on feedback on the draft Roadmap given importance for the EU legal proposal.**
	Providing daily data on land surface temperature.
	Develop Object-based methods to detect and qualify the different types of urban fabric. Enhance spatial models for the local climate regulation service.
Air filtration	Providing data on ground level PM2.5 concentration (as PM2.5 is a more accurate prediction of health effects than PM10), and relevant for health effects is the concentration to which people are exposed, i.e., at ground level.
	Better models of the filtration of PM2.5 by vegetation – based on wind speed, leaf area index, and resuspension of PM2.5 including calibration and validation of such models
Flood control	More accurate models, and approaches to scale up these models, of flood mitigating impacts of mangrove and riparian forests are required to facilitate incorporating this service in SEEA EA accounts. EO data is needed to understand the vegetation flood barriers itself (length, height, bathymetry/geomorphology) as well as human assets (houses, infrastructure, etc.) in the zone at risk from flooding. **A much more accurate global DEM compared to what is currently available with specifically a high horizontal, vertical, and temporal resolution for peatlands is a top priority based on feedback on the Draft Roadmap.**
Water regulation	A wide range of hydrological models is available, however scaling up from one watershed to the next is cumbersome. AI models may be developed that allow easier scaling up to analyse this service at national scale. Further testing of AI models is required.
Soil erosion and landslide mitigation	RUSLE is a basic simple approach, however more complex models that incorporate other types of erosion (landslides, gully, etc.) are also available. Several input factors as dynamic vegetation cover, but also erodibility can be derived from EO.
Coastal protection	Different models exist for various types of coastal ecosystems. The service is linked to flood control, but protection by vegetation is another important component. EO data can help detecting the vegetation type and their condition to protect coastal areas.
Pollination	Pollination models require maps of crops (so that crops requiring pollination can be identified spatially) and detailed maps of pollinator habitat including small landscape elements.

Service	R&D priority
Pest and disease control	EO and climatic data can help by improving the predictions about where potential agriculture pests and diseases may be a threat. Spatial modelling techniques with EO data can also help to create special maps with risk surveillance and assessments that can be used also for vector-borne diseases.
Fresh water aquaculture services	Aquaculture can be monitored with Sentinel-1 (e.g., effect of oil pollution in terms of smoothing waves) and Sentinel-2 (e.g., colour differences to detect algae blooms) or combined to mapping aquaculture facilities.
Nursery and habitat maintenance services	Ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy can be expressed as the presence of suitable ecological conditions (habitats) and of species and hence evaluate the risks to which these habitats and species are exposed (hotspots at risk). EO can contribute to measure migration patterns, fragmentation, diversity, etc., which has to be complemented by other species information (e.g., genetic). These services should be further detailed in separate sub-services to support habitat maintenance and restoration programs.
….	
3. Cultural services	
Recreation-related	EO in combination with social media can provide spatiotemporal contributions to cultural ecosystem services
Visual amenity	EO data can measure the greenness and other landscape elements of importance, both in urban and rural areas
….	

3.7 Thematic accounts

Carbon. The carbon stock account covers all relevant carbon stocks and changes in stocks across all stores of carbon at a national or sub-national level covering both managed and unmanaged areas. In this sense, the account is complementary to the LULUCF part of the national GHG inventories: the carbon account includes also unmanaged lands, and it includes both stocks and flows (whereas the focus of the GHG inventories is on changes in flows). The measurement of stocks and flows of carbon can support discussion of policy relevant issues such as the analysis of greenhouse gas emissions, deforestation and land use change, loss of productivity and biomass, and sources and sinks of carbon emissions. The carbon account also covers methane emissions from ecosystems (such as paddy fields), and the CO2 equivalent of nitrogen dioxide emissions from ecosystems may also be added.

EO data is relevant for compiling carbon accounts, for the measurement of stocks and changes in stocks of above ground carbon (AGC). Carbon sequestration or emissions may be derived from changes in stocks, provided that AGC estimates can be translated using appropriate algorithms. This information is well aligned with the scope of SEEA EA carbon accounting since EO data covers all ecosystems, managed and unmanaged. Two main points of research are translating AGC to the other carbon pools (below ground carbon, litter, deadwood, harvested wood products, and soil organic carbon for mineral and organic soils) and better understanding stocks of carbon in peatlands and emissions from peatlands due to fire and drainage. The data compilation should support the reporting for the new LULUCF regulation, requiring geo-spatial information. Sentinel-1 imagery using inSAR techniques (e.g. APSIS© of TerraMotion) may be well placed to assess soil subsidence in peatlands given its frequent overpass. The problem with using Lidar images, though more accurate in terms of measurement, is that a one-off measurement of elevation, or once a year measurement, is not an accurate reflection of soil dynamics given the swelling and shrinking of peat due to rainfall (which can cause peat to swell or shrink by several centimetres, which may exceed annual subsidence rates). Using Sentinel 1 images – or combining Sentinel-1 and LiDAR images may help dealing with the swelling and shrinking of peat. In all the main priority for the C accounting is in the peatlands, because peatlands are a very large store and source of carbon especially when drained. At the same time, despite several activities are ongoing[11] there is still much unknown in terms of exactly where peatlands occur and to what degree they are being drained.

Biodiversity. The definition of biodiversity comprises three levels – ecosystems, species, and genes – as reflected in the CBD definition of biodiversity being "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 a part; this includes diversity within species, between species and of ecosystems." The purpose in accounting for biodiversity includes informing conservation actions and the enhancement of biodiversity as an environmental management objective, as well as discussion about securing ecosystem services supply, and about various policy responses that may be relevant, such as biodiversity finance (SEEA EA 13.17).

It is noted that the species component of biodiversity can also be used to compile condition indicators, where these indicators inform on the condition/health of ecosystems (such as indicator species, e.g., species that only occur in unpolluted environments). The purpose of the accounting for biodiversity is somewhat differently: to inform on biodiversity as such, including those aspects of biodiversity that are of relevance for people (e.g., occurrence of endangered species) but that do not necessarily reflect ecosystem condition.

[11] See https://op.europa.eu/en/publication-detail/-/publication/386bbfb4-35a7-11ee-800c-01aa75ed71a1/language-en and https://www.greifswaldmoor.de/global-peatland-database-en.html.

To date, there are only limited options to observe biodiversity with EO data. One entry point is monitoring tree diversity (which can also be used as condition indicator), however this indicator may not reveal the presence of particularly rare trees, for example. Hence, whereas EO data can be used as inputs into models for biodiversity (e.g., Maxent habitat suitability models), observing biodiversity itself with EO data is at present not realistic.

Urban. Urban ecosystem accounts are not fundamentally different from other ecosystem accounts, in the sense that they may include, for urban zones, extent accounts, condition accounts, service accounts, etc. Only the zooming in on urban lands, with a different proportion built-up versus non-built-up land is different.

In terms of using EO data, the main difference is the need for higher resolution imagery, since urban areas are typically more fragmented, and ecosystems (or natural elements such as tree lines) may be smaller in extent. A main question for research, therefore, is to what degree open access satellite data can be used (e.g., Sentinel) and to what degree very high resolution (<3 meter) commercial data are needed, e.g., to map tree lines.

In 2022, experts in Earth Observation and in Ecosystem Accounting were brought together in a workshop to address the use of Earth Observation and ecosystem accounts in all realms. Figure 7 depicts the conclusion for urban ecosystem accounts.

Figure 7. Conclusions of EO4EA 2022 workshop on urban ecosystem account (credit ESA).

Ocean. Ocean accounts enables monitoring several critical trends: (i) changes in ocean ecosystem extent and condition, and in associated flows of ecosystem services; (ii) changes in ocean wealth, including produced assets (e.g., ports) and non-produced assets (e.g., mangroves, coral reefs); (iii) ocean-related income and welfare for different groups of people—e.g., income from fisheries for local communities; (iv) ocean based economic production—e.g., GDP from sectors deemed to be ocean-related; (v) changes in how oceans are governed and managed—e.g., ocean zoning, regulatory rules and responsibilities, and social circumstances (SEEA EA 13.81). There are several new initiatives to compile ecosystem accounts for oceans, with some coordination taking place by the Global Ocean Accounting Partnership (GOAP) and the SEEA EA Oceans Working Group.

In ocean accounting, a main challenge lies in reflecting depth in addition to area and accurately capturing changes in condition across these depths. In ocean accounting, as in aquatic systems in general, there are often sets of interlinked causes, as in pollution causing eutrophication causing increased turbidity causing changes in bottom-dwelling plants causing changes in fish species. Inserting these links in the accounts is a general challenge, whereas some of the condition indicators may be observable with EO data (such as turbidity or algal blooms). Further research is needed to see which indicators relevant for ocean accounting (such as turbidity, oil spills, fishing boat activity and algal bloom presence) can be used as inputs into the accounts. EO data obviously has a limited applicability below certain (quite shallow- depth thresholds, so it’s use can be mainly seen to shallow inshore marine ecosystems. Furthermore, specific challenges apply to correct reflectance for waves, etc.

4. Technical perspective

4.1 Data management

Ecosystem accounting provides a statistical framework to handle large and diverse datasets. Time-series analysis, geospatial data cubes at difference spatial scales, and artificial intelligence are important tools for ecosystem accounting. With the upcoming EO datasets (e.g., hyperspectral data), the data to be processed will keep growing exponentially. For users to be able to handle such data and tools, technical capacities need to be developed that make both the data (EO and in-situ measurements) as well as the models Findable, Accessible, Interoperable and Reusable (FAIR). Interoperability requires shared conventions across the globe in the field of ecosystem services that are not yet widely embraced despite some ongoing initiatives (e.g., IUCN Global Ecosystem Typology) and hence require further collaboration between the organizations. It should also strive to make the data and models machine-actionable and semantically enriched to operationalize accounting. These are listed in Table 8.

Table 8. Key data management considerations.

Consideration	Explanation
Interoperability	Ability of different data systems and platforms (e.g., ARIES and OpenEO) to communicate and exchange data in a consistent and meaningful way through machine2machine communication
Standardized	Set of uniform rules, formats, and procedures to ensure data is consistent, accurate and easily accessible
Uncertainties	Possible deviation of the result, the range of uncertainty indicates a confidence measure
Cost-efficient	Easy to use and low cost (price to be determined, e.g., 1 cent per km^2)
Flexibility	Integration of national or regional and non-EO datasets
Redundancy	Always on availability to the data and models
Security	Ability to replace standard datasets with national or regional datasets in a protected way, such these datasets cannot be accessed by others
Accuracy	Different types of accuracy apply, including spatial accuracy and thematic accuracy. Important is also to understand the accuracy of the produced maps and accounting tables derived from the maps.
Clearly defined and transparent analytical procedures	The EO products should be developed with clear and transparent procedures; where changes are made in models or data sources, if possible, time series should also be adjusted to allow for consistent accounting over time.

4.2 Institutional support

This section highlights some key institutional considerations relevant in a Roadmap for supporting EO data for ecosystem accounting. These are listed in Table 9.

Table 9. Key institutional considerations.

Consideration	Explanation
Timeliness	In the EU legal framework, accounts need to be published, the latest the end of the year after the reporting year (the first reporting year will be 2024, accounts to be submitted to the EU by the end of 2026. This means that spatial datasets should be available with a time delay of at most

	around 6 months to allow time for account compilation and further processing.
Authoritative source	There should be quality assurance processes and the organization publishing the maps should be recognized as an authoritative data source. Potentially a technical advisory committee could support the process.
Indicators aligned with SEEA EA	The SEEA EA has provided specific definitions for ecosystem services, and for seven of these (see chapter 2) these indicators have been worked out in more detail in the EU Guidance Notes published by Eurostat. These indicators should be considered when developing EO products to ensure easy uptake for account compilation.
Sustained production and consistency over time	For NSOs to engage in developing procedures to compile accounts based on EO data, it is important that they are certain that the data remains available long-term and enables a regular sustainable production.
Capacity building and training	Ecosystem account partners are not necessarily equipped to work with large EO datasets, and hence require to be supported and trained to avoid roadblocks in understanding the limits of EO data and using EO data in their accounting workflows.
Bridge communities	Capacity needs are required for partnerships between the EO and EA communities, as well as partnerships between the EO and in-situ communities.
Strengthening engagement with science community	Engagements and partnerships with the ecosystem science community will provide more insights in where to apply which model, avoid duplication and create models for remaining gaps.

Last, but not least, there is a strong need for involvement of stakeholders including key agencies such as UNSD to support the design of datasets and indicators. It should be noted that the operational (or institutional) implementation is not further detailed in this document, as it is considered outside the scope of this R&D agenda and should be tackled separately in parallel.

4.3 Ensuring easy access to account ready datasets

National Statistical Offices will not all have the technical capacity in the field of spatial modelling, and the budget and computing power to process EO data themselves. It is also much more efficient to process these datasets on a global or continental scale rather than that every country individually should do this, or at least provide an easy to access and easy to use platform which generates these datasets on their demand. Hence, as much as possible, they should be provided with account-ready datasets, covering relevant indicators related to extent, condition, and services. These datasets can then be combined with national datasets (e.g., on ecosystem use, or specific biodiversity variables) to compile ecosystem accounts.

In conclusion, therefore, several steps need to be taken:

1. Assessment and assembly of the relevant Earth Observation products for national statistical purposes and making these datasets available with a user friendly webtool.
2. Analysis and description of uncertainties and biases and their implications
3. Clear guidance on how to interpret, use and integrate different Earth Observation products in spatial models and accounts.

Several institutional models are available to ensure easy access to EO account ready datasets (AccoRD). Table 10 below shows overview of the major platforms, not targeted to be exhaustive and complete.

Table 10. Institutional models to access and process EO data.

Platform	**Description**	**Pros/Cons**
Google Earth Engine (GEE)	A cloud-based platform for planetary-scale environmental data analysis. It allows users to access a vast amount of satellite imagery and geospatial datasets, including pre-processed EO data	(+) Extensive library of EO data (+) Powerful computing resources, free use (-) User friendly API in Javascript or Python, but not standardized. (-) Limited hosting of own data
Copernicus Data Space Ecosystem (CDSE)	A cloud-based platform part of the Copernicus Programme by the European Union.	(+) Extensive library of EO data and other environmental datasets, including all Copernicus data (+) Powerful computing resources, User friendly and open standardized API (-) Need for credits to store and process data
Amazon Web Services (AWS)	A comprehensive cloud computing platform that offers a wide range of services, including powerful computing, storage, and other tools	(+) Access to large EO datasets (+) Scalable storage and flexible computing (-) No free of use, expensive data transfers
Planetary Computer (Microsoft)	A cloud platform focused on environmental sustainability	(+) Access to large environmental datasets (+) Collaboration environment for researchers (-) No free of use, existence in future not secured
ESRI ArcGIS	A cloud-based solution providing comprehensive tools for processing, analysing, and visualizing geospatial data	(+) Access to ESRI's extensive data catalogue (+) GIS based. (-) Expensive, only through ArcGIS license
Other national (e.g., Terrascope)	Other cloud-based solutions in Europe	(+) Flexible computing resources (-) EO datasets restricted in geospatial area, typically to country

5. Recommendations

5.1 Criteria

The following list of criteria was used to prioritize activities listed in this roadmap, see Table 11.

Table 11. Criteria for prioritizing

Number	Criteria	Comments
1	Added value of EO data	Including the accuracy and timeliness that can be reached with EO data, and the presence or absence of alternative data sources (national data) or complementary data (ground truth)
2	Policy relevance	Analysing EO data over large areas and at high resolution requires considerable resources (time, computing power, data capacity) and priority should be given to those datasets where it is easiest and most relevant to show the policy relevance
3	Feasibility of maintaining consistent time series over long time periods.	Accounting data requires consistent datasets maintained over time-period of decades. EO data that depend upon satellites that will be taken out of operation in the coming years and will not be replaced is not useful to support SEEA EA accounting
4	Representativeness / scope	Priority should be given to datasets that are relevant across many countries and/or ecosystem types.

5.2 Prioritized listing

The process followed including the literature review, the discussions with the early adopters and the discussions in the International Workshop with a broader stakeholder's community revealed a clear list of priorities for further integration of spatial data in ecosystem account compilation. This list does not include priorities for advancing the use of EO products in general terms such as increased attention for collecting and sharing in situ data for ground truthing, better integration of data from different sensors in models, etc., in line with the focus of the report.

A first point to note is the concern among the stakeholders related to the Corine Land Cover (CLC) program. The CLC data layers are critical to underpin the whole ecosystem account compilation efforts in Europe as required by the new legislation. In addition, they should be made available, with the current number of land cover classes (or more) every 3 years in the future, in line with the EU regulation that requires updating the extent account once per 3 years. Without CLC or an alternative continental solution, many EU countries will struggle to comply with the legislation on ecosystem accounting.

A second key point is that a system needs to be put in place giving easy access to account ready spatial data at high resolution (temporal and spatial) at continental to global scale. This data tool should provide NSOs and other stakeholders to account ready datasets (AccoRD) organised according to the SEEA EA. Besides making spatial data available, the tool should provide guidance on uncertainties and how to deal with these and provide support on applying the spatial data in models that can be used to generate the spatial data underlying the extent, condition, and services accounts. This webtool should be underpinned by detailed plans for the operational management of data. This includes IT resource needs, generation of account-ready data, creation of core EO datasets for accounting – as well as protocols for updating datasets and ensuring long-term consistency of datasets. Where relevant international standards should be applied to organise and analyse the spatial data in the tool (e.g., zonal statistics, threshold sensitivity analysis, etc.). This involves coordination of efforts to align methodologies and data across different countries and organizations.

Finally, focus should be set to organize local partnership and make available their ground-truth data as well as coordinate the community at global level by providing guidelines, capacity building and training.

A summary of these **generic R&D topics**, as well as some additional ones is summarized in Table 12.

Table 12. R&D priority topics for all account types (general topics)

All accounts (generic)	Comments
Make freely available Account Ready Data	Necessary (preferably web) tools or datasets need to be available to integrate EO data into accounts. NSOs should not be concerned about costs and computing power to do so. These datasets should be fit for purpose and include information on uncertainties and biases.
Standardize metadata and interfaces to make data and models readable by machines	Reduce the efforts to find and interpret data and models will help the community to advance more quickly.
Ensure regularly updated, timely available and consistent EO datasets	A consistent regular time series is needed to support the EU ecosystem accounting regulation, e.g., Corine Land Cover or other layers to compile ecosystem extent every three years.
Establish local partnerships, leverage citizens science and make budgets available to collect ground-truth data in a FAIR way	Sufficient and reliable in-situ measurements should be made available and used by EO dataflows to train and validate models or fill gaps in the mapping and monitoring processes. These datasets are also key to provide information on uncertainties and biases. Relevant institutions at EU and/or global level should consider that as their direct responsibility.
Establish global coordination to create community guidelines and, to perform capacity building and training	Coordination efforts are necessary to align communities (EO with EA, EO with in-situ, EO with ecological modelling, etc.) through leveraging existing efforts. These efforts should create clear guidance (or lessons learned) on how to deal with technological challenges (e.g., mix different geospatial layers to avoid biases and errors, which model to use in which circumstances). A knowledge sharing platform, regular reviews, a certification program, and feedback mechanisms are options to implement consistency checks.

Furthermore, there are **specific R&D topics** relevant for the different accounts, limited to terrestrial and freshwater ecosystems. A full overview of these is given in Tables 4 to 6 above, but the key priorities are listed in the Table below, based on a ranking of priorities by stakeholders according to the criteria in Table 9 above.

Table 13. R&D priority topics per account type

Extent account	Comments
Developing a protocol to map changes in ecosystem extent (assuring that only real changes are included in the accounts, not changes due to errors or biases in spatial data)	Changes in ecosystem extent are often more policy relevant that the areas themselves. At the same time, these trends may be unreal due to differences in datasets or methodologies, or due to uncertainties in the data. Such sources of change should be removed before statistically relevant trends are presented to the user.
Enhancing the use of EO data to monitor and analyse level 3 or other specific ecosystem types linked to Nature Based Solutions. E.g., peatlands (area, location, drainage, subsidence)	Globally critically relevant, for ecosystem accounting as well as for LULUCF analysis and reporting to UNFCCC as well as for biodiversity strategy and climate change mitigation efforts. Incorporating high resolution hyperspectral imaging and fully exploiting EO time-series can better differentiate detailed habitat types (e.g., forest types, clear cuts as grasslands, wetlands, etc.)
Mapping crop types, relevant for ecosystem services.	This important data layer is currently missing at EU scale or limited to some crop types, even though technically maps of crop type can be produced with EO data with high accuracy (>90% depending upon crop types, slopes, and field sizes). However, this is more challenging in case of smallholder holdings and intercropping practices, and mapping crops for specific ecosystem services as pollination. The potential of the upcoming hyperspectral missions could be investigated to fill this gap.
Mapping linear landscape elements, and developing protocols on whether to include these (e.g., hedgerows) in extent and/or in condition accounts	Linear landscape elements are critical landscape elements for biodiversity and several ecosystem services such as air filtration, local climate regulation and pollination, and capture diversity within smallholder and agroforestry systems. Their presence or absence needs to be covered in ecosystem accounts, but challenges remain given the diversity in width, length, and structure of these elements.
Dealing with the heterogeneity of urban and agricultural mixed landscapes.	Guidance and protocols need to be developed, based on best practices, on how to map fragmented landscapes, e.g., on the MMU to apply, and on how to aggregate classes. This is of relevance for spatially diverse urban and mixed agricultural landscapes. Where possible, localised high resolution EO data should be used in support of wall-to-wall EO datasets.
Condition account	
There is a general need to better understand which EO data can be used to measure ecosystem condition.	Development of indicators that are not measurable is not useful, and consideration of existing or potential new data sources is required for the identification of a suite of indicators that will together allow for accurate and cost-effective monitoring of ecosystem condition including overall functional properties and capacity to supply services. The indicators need to be made available at sufficient spatial resolution.

Trends on continuous datasets should be presented as statistically valid.	Both temporal and spatial autocorrelation should be accounted for to avoid false conclusions from the underlying data uncertainties.[12]
The need to develop algorithms to better deal with the saturation effect of measuring biomass, when BIOMASS and NISAR data become available,	This will reduce the saturation effect and greatly increase accuracy of biomass and carbon estimates. Further work is needed to better connect AGB to BGB and to better understand SOC and changes in SOC and how and where this can be measured (or not) with EO data.
The need to integrate a broader set of EO data sources such as satellite data on PM concentration, methane emissions, trackers of ship movement and oil spills (for the ocean accounts), etc.	SEEA EA is at present not entirely clear on how to include pressure indicators, partly because emissions are covered in the SEEA Central Framework. However, the SEEA CF is not spatial, and the added value of spatial data on emissions is increasingly becoming clear (e.g., on methane emissions). EO data increasingly reveals emissions and discharges, as well as concentrations of pollutants (e.g. PM). Further R&D is required to integrate these datasets into SEEA EA and SEEA CF.
Global DEM	Currently the global DEM has a horizontal resolution of 1 arc second (approximately 30 meter at the equator), and a vertical SD of 12 meter. In mountainous areas 12 m SD is for most purposes adequate, but for lowlands this is a bit course when waterways are modelled. A question for R&D is if, with LiDAR, much more accurate DEMs can be prepared on a regular basis, and be made available open access, for areas subject to soil subsidence such as peatlands and urban areas subject to soil compaction. Such data could also further improve the vegetation height characteristic and hence contribute to further discriminate habitats.
Services account	
Develop EO-based models to monitor crop yields and assess crop health, incorporating data on pest and disease outbreaks	These data are not only relevant for SEEA EA but have a wide range of applications depending upon context. Combining EO data and survey data will allow for the most accurate assessments of crop yields.
Global climate regulation	Better measurement of AGB (described above) will allow much better accounting for the GCR service, using the stock difference method.
Further R&D could reveal supply and use of services, such as wood harvesting, or crop yields.	In general, mapping ecosystem services requires models that integrate EO data with other datasets, however some types of use can, in principle, pending further R&D, be observed directly such as harvest of wood or crop yields at regional scale.
Multiple solutions and slow progress.	The R&D community has spent considerable effort last couple of years in providing just a few ecosystem service accounting models. Despite having several solutions is not bad, users need to be guided to use

[12] https://doi.org/10.1016/j.rse.2021.112678.

	which solution for which purpose. Furthermore, it hampers progress to provide solutions for other service accounts that are required by policy purposes.
Thematic accounts	
Biodiversity variables	It is currently not sufficiently known to what degree essential biodiversity variables, or biodiversity indicators more generally, can be derived from EO datasets and how they can be used for 'accounting for biodiversity'. Further testing is required, covering a broad set of ecosystems across the globe and including the new upcoming missions as the Hyperspectral missions and their linkage to environmental DNA. Biodiversity indicators can be used to complement the condition accounts and support the accounting for ecosystem services.

Several reporting mechanisms are to be put in place for corporate businesses, including Small-Medium Enterprises. Several indicators require spatial information and hence the Ecosystem Accounts could support this process. To enable the use of biodiversity and ecosystem accounts using Earth Observation in the private sector, some additional **R&D topics** are required as explained in Table 14.

Table 14. R&D priority topics to enable use of accounts in the private sector.

All accounts (private sector)	**Comments**
Establish partnerships between EO, EA and the TNFD community	Ecosystem Accounts could support Corporate Sustainability Reporting to identify drivers of change, in state (assets) and in flow (services). A better alignment is needed to potentially use some accounts for specific metrics.
Establish partnerships between EO, EA and ESG reporting community	Ecosystem Accounts could support ESIMP Impact Measurement and Valuation protocols used by Small-Medium Enterprises. Support to emission data (country-sector matrices), impact pathways and digital solutions should be further evaluated and discussed.

Annex. Example of in-situ data

(text provided by the European Environment Agency)

The European Vegetation Archive (EVA; https://euroveg.org/eva-database/) is an initiative of the European Vegetation Survey Working Group, aimed at establishing and maintenance of a single data repository of vegetation-plot observations from Europe and adjacent areas (Chytrý et al. 2016). These data are for non-commercial purposes, mainly academic research and applications in nature conservation and ecological restoration. The archive currently comprises almost 2.4 million plot observations, including 260,000 resurvey plots (Figure 8). The EVA database is updated on a regular basis and more and more recent data, pinpoint with GPS coordinates. Analysis of these observations, however, was limited by the array of different species lists utilized by contributors that differed in nomenclature. An integrated crosswalk among the many different taxonomies (>40), makes analysis of large heterogeneous data sets feasible. For the dissemination of these data the EVA Data Property and Governance Rules are followed (https://euroveg.org/download/eva-rules.pdf).

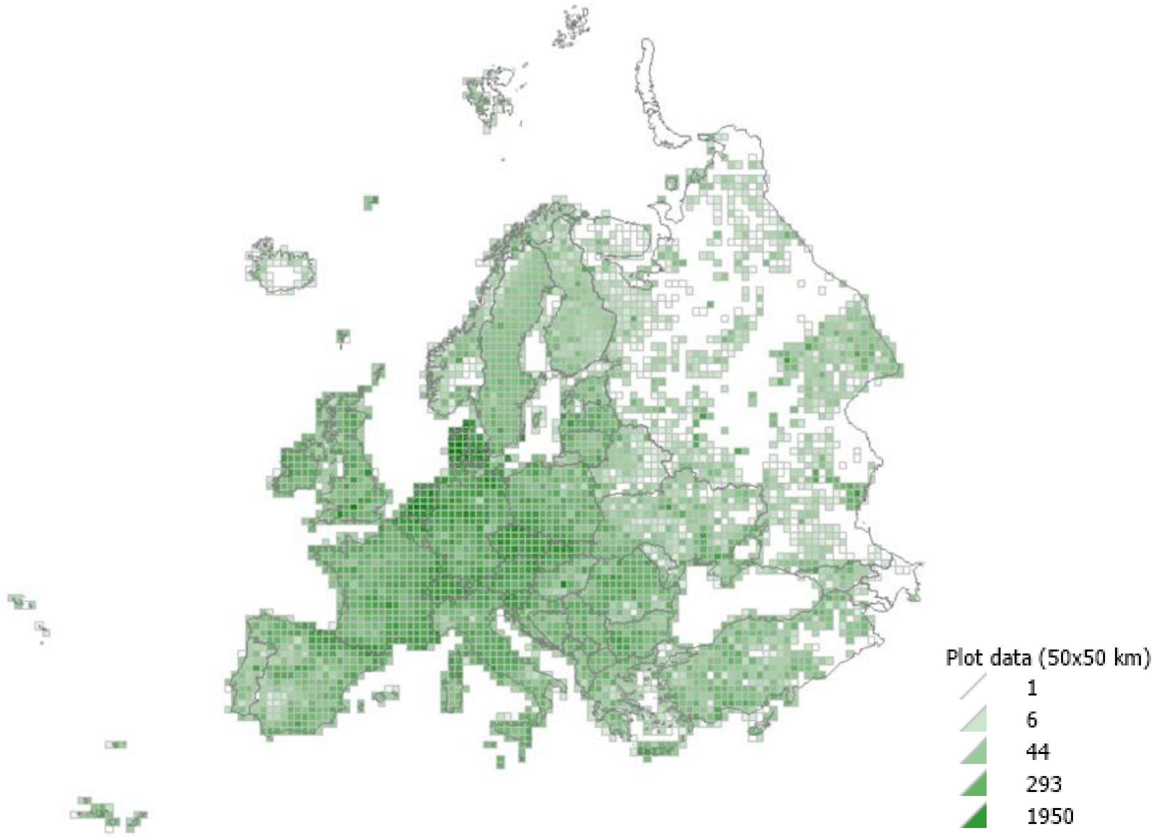

Figure 8. Density of georeferenced plots in EVA in 50 x 50 km grid cells (June 17 2023).

In-Situ Field Data for Training and Validation

While remote sensing provides a broad view of habitat mapping, field surveys play a pivotal role in both training and validating satellite-derived habitat data, substantially improving the reliability of habitat mapping. Field surveys are crucial in enhancing the accuracy and reliability of habitat mapping derived from both satellite imagery and modeling. These surveys provide real-world, ground-truth data that complements the broader-scale insights offered by remote sensing technology, strengthening the robustness of habitat mapping. Broad surveys systematically sample across environmental gradients and geographic areas, enabling a comprehensive characterization of the full diversity of EU biomes, within the limitations of the sample-based approach. Targeting under-sampled regions can strengthen data inputs for habitat distribution models, collectively reinforcing the accuracy of EU habitat mapping efforts. This expansion of standardized field surveys contributes to improved EU habitat mapping accuracy mainly in two ways: the in situ data resulting from field surveys provides critical (1) training and (2) validation points for habitat maps derived from satellite imagery and modeling.

Training

Field surveys play a fundamental role in training satellite data for automatic habitat classification or labeling through manual mapping using computer-assistance photo-interpretation (CAPI). The use of field surveys in the training process involves several key aspects:

- **Broad-Scale Insights**: Satellite imagery offers a broad view of habitat distribution patterns, such as forests, wetlands, and grasslands. However, to accurately categorize land cover, land use, or habitat types, detailed in-situ observations gathered during field surveys are crucial.
- **Calibrating Remote Sensing Data**: Field surveys provide the crucial ground truth data required to calibrate satellite imagery. This calibration process ensures that the spectral signatures of pixels accurately correspond to categorical habitat classes. Information gathered during field surveys, including vegetation plot data, species surveys, soil sampling, and other field observations, is used to inform and train machine learning algorithms applied to satellite imagery.
- **Enhancing Precision**: By integrating fine-grained, real-world information from field surveys into computational models, machine learning algorithms become more adept at distinguishing subtle differences in habitats. This ultimately improves the precision of satellite-derived habitat maps. The models become capable of recognizing and classifying habitat types more accurately, enhancing the overall quality of the maps.

Validation

Field surveys also serve as the benchmark for assessing the accuracy and reliability of satellite-derived habitat maps. This validation process is critical in ensuring that the maps accurately represent the real-world phenomenon, particularly in the context of conservation efforts. The key elements of validation with field surveys are:

- **Benchmark for Accuracy**: During the validation phase, field survey data is used to evaluate the consistency and precision of habitat classifications in satellite imagery. This comparison ensures that the satellite-derived maps align with the real-world conditions on the ground.
- **Identifying Disparities**: Field surveys are crucial for identifying any systematic disparities between the satellite-derived maps and real-world conditions. Discrepancies can be addressed and corrected based on the information gathered during field surveys.
- **Quantifying Confidence**: Validation is not only about verifying the accuracy of the habitat maps but also quantifying the level of confidence associated with them. This provides insights into potential errors and uncertainties within the satellite data, which is especially crucial in critical conservation efforts where precision is paramount.

While the European Vegetation Archive (EVA) comprises a substantial volume of vegetation-plot observations, it does have certain limitations that need to be considered. These limitations can affect the applicability of the data to specific purposes, including the classification into EUNIS habitats through EO and Machine Learning.

- **Incomplete Classification into EUNIS Habitats**: Out of the 2.4 million plots, only 1.6 million meet the criteria for classification into EUNIS habitats. These criteria can involve factors like plot size and specific habitat characteristics. As a result, a significant portion of the data does not meet the requirements for classification into EUNIS habitat types.

- **Spatial Limitation**: The coverage of EVA data across Europe is not uniform. There are regions, notably Scandinavia, Eastern Europe, and parts of Spain and Turkey, where the EVA database is underrepresented or lacks data. This spatial disparity can introduce gaps in our understanding of habitat distribution across the continent.
- **Temporal Limitation**: To effectively link plot observations as ground truth to remotely sensed data, up-to-date information is essential. However, only a portion of EVA's 2.4 million plots meets this requirement. Approximately 610,000 classified vegetation plots have been recorded from the year 2000, leaving gaps in recent data for habitat mapping.
- **Location Uncertainty**: Location uncertainty is a significant challenge in the EVA database, particularly when integrating it with remotely sensed data. A substantial portion of the plots (718,000 plots) lacks precise location information. While there are approximately 287,000 plots with a location uncertainty of 10 meters or less, factoring in the temporal constraint (recordings from the year 2000) further reduces this number to 217,000. These location uncertainties can affect the accuracy of habitat mapping.

These considerations underscore the need to carefully evaluate and contextualize in-situ data from field surveys, recognizing its strengths and limitations, to ensure its optimal utilization in various ecological and conservation applications.

Acronyms and Abbreviations

ACCORD	Account Ready Data-stack
AD	Applicable Document
AGB	Above Ground Biomass
AGC	Above Ground Carbon
AI	Artificial Intelligence
ARD	Analysis Ready Data-stack
ARIES	Artificial Intelligence for Environment & Sustainability
ATBD	Algorithm Theoretical Basis Document
BC3	Basque Centre for Climate Change
BGB	Below Ground Biomass
BGC	Below Ground Carbon
BIEN	Botanical Information and Ecology Network
CAMS	Copernicus Atmosphere Monitoring Service
CCI	Climate Change Initiative
CDB	Convention on Biological Diversity
CEOS	Committee on Earth Observation Satellites
CICES	Common International Classification of Ecosystem Services
CLC	Corine Land Cover
CLMS	Copernicus Land Monitoring Service
CNES	Centre National d'études spatiales
DG	Director General
DEM	Digital Elevation Model
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)
EA	Ecosystem Accounting
EAD	Early Adopter
EBV	Essential Biodiversity Variable
ECT	Ecosystem Condition Typology
EEA	European Environmental Agency
ER	Evolution Roadmap
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
ES	Ecosystem Service
ESA	European Space Agency
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reusable
FAO	Food and Agriculture Organization of the United Nations
GBF	Global Biodiversity Framework
GBIF	Global Biodiversity Information Facility
GDP	Gross Domestic Product
GEO	Group on Earth Observations
GEOBON	GEO Biodiversity Observation Network
GET	IUCN Global Ecosystem Typology
GIS	Geographic Information System
GOAP	Global Ocean Accounting Partnership
HR	High Resolution
HRL	Pan-European High-Resolution Layers

INCA	EU Integrated system of Natural Capital project
INVEST	Integrated Valuation of Ecosystem Services
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	International Panel on Climate Change
IUCN	International Union for Conservation of Nature
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory (NASA)
JRC	Joint Research Center
LAI	Leaf Area Index
LC	Land Cover
LCCS	LC Classification System
LDN	Land Degradation Neutrality
LEAP	Locate Evaluate Assess Prepare (TNFD)
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
ML	Machine Learning
MMU	Minimum Mapping Unit
NASA	National Aeronautics and Space Administration
NGO	Non Governmental Organization
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NESCS	National Ecosystem Services Classification System
NIR	Near Infra Red
NISAR	NASA and Indian Space Research Organization SAR mission
NO2	Nitrogen dioxide
NOR	Network Of Resources
NPP	Net Primary Productivity
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	Particular Matter
R&D	Research and Development
RD	Reference Document
RUSLE	Revised Universal Soil Loss Equation
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
SMOS	Soil Moisture and Ocean Salinity
SPAM	Spatial Production Allocation Model
SSPE	Science for Society Programme Element
SWAT	Soil Water Assessment Tool
SWIR	Shortwave Infra Red
TEEB	The Economics of Ecosystems and Biodiversity

TNFD	Taskforce on Nature-related Financial Disclosures
TRY	Plant Trait Database
UK	United Kingdom
UN	United Nations
UNCCD	UNCCD United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNSC	United Nations Statistics Commission
UNSD	United Nations Statistics Division
URD	User Requirement Document
URN	Uniform Resource Name
US	United states
VHR	Very High Resolution imagery
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
WBS	Work Breakdown Structure
WGCV	Working Group on Calibration and validation
WRI	World Resources Institute
WTEE	World Terrestrial Ecosystems Explorer