Product Specification and Algorithm Theoretical Base Document: Coastal ecosystem condition account

Document Ref:	PEOPLE-EA_ATBD_D7_CoastalCondition
Version:	1.2
Contract No:	4000139263/22/I-AG
Creation Date:	2023-03-21
Last Modified:	2024-11-30

Submitted by

vito remote sensing	bc3	Ecounting	UNIVERSITY OF PATRAS ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

In collaboration with

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	Mathilde De Vroey (VITO)
Approval (consortium)	Bruno Smets (VITO)
Approval (ESA)	Marc Paganini (ESA)
Contributing Authors	Bruno Smets (VITO)
Distribution	Giuseppe Ottavianelli (ESA)
	Early Adopters
	Project Team

DOCUMENT CHANGE LOG

Issue	Issue date	Pages affected	Relevant information
1.0	2024/07/26	All	Initial version based on shared presentation to Early Adopters
1.1	2024/09/13	All	Initial release
1.2	2024/11/30	5	Added TRL level

Table of Content

1. Introduction

1.1 Report objectives and approach

The objective of this report is to detail the technical requirements of the selected accounting pilot demonstrators for the PEOPLE-EA project, and hence covers the results of tasks in WP2.1 and WP2.2.

The report first describes the technical specification of the platform, whereafter for each demonstrator account is described:

- the technical specification (e.g., selection of condition indicators and reference levels)
- an overview of potential algorithms to be evaluated during an agile iterative co-design round-robin benchmarking.
- test areas and input datasets necessary to perform the round-robin benchmarking.
- results of the benchmarking, and justification of the selected algorithm

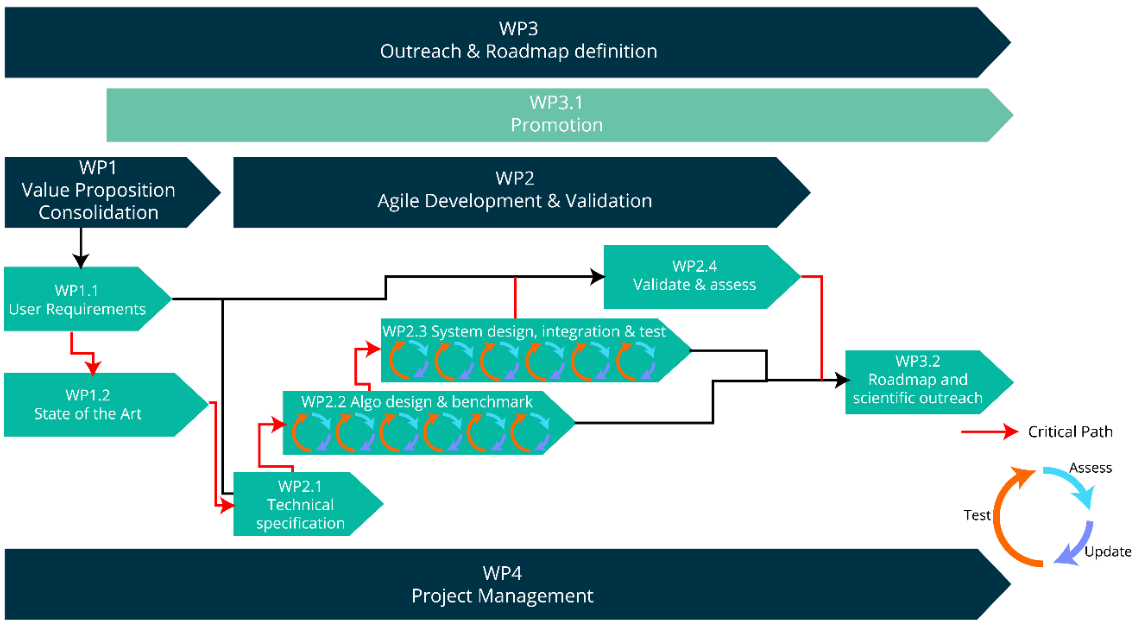

Figure 1: Overview of WP2 agile iterative co-design development cycle

1.2 Scope of work

Table 1 shows the selected pilot demonstrators, and the Early Adopters (countries) where a test-site will be selected to perform the round-robin benchmarking as a co-design activity.

Table 1: Overview of ecosystem account pilot demonstrators

Account	Country	Details / Indicator	Year	Round-robin
Condition - coastal	Greece	Artificial impervious area cover in coastal zone	(1945-) 2018 – 2022	X
	Italy	Artificial impervious area cover in coastal zone, at a resolution of not more than 10m	2019-2021	
	Netherlands	Artificial impervious area cover (temporal and permanent) in coastal zone	2020	X

Note that the workflow developed is still experimental and not operational, since it is considered to have reach TRL[1] Level-3. This level declares the technology is experimental proof of concept (in this context the demonstrations) and requires further R&D work as well as being made compliant to the European Statistics Code of Practice (CoP) before being used for official statistical reporting.

1.3 About ecosystem condition accounts

Ecosystem condition reflects the state or quality of an ecosystem type measured in terms of its abiotic, biotic and landscape characteristics. Measuring ecosystem condition over time provides insights in the development of the health of the ecosystem as a function of, for instance, human use, ecological variability, and climate change. The ecosystem condition itself is described by the combination of various ecosystem condition indicators which are derived from condition variables.

Ecosystem condition variables are quantitative metrics describing individual properties or characteristics of an ecosystem asset. In SEEA EA ecosystem characteristics are structured along a standard Ecosystem Condition Typology (ECT). The ECT is first organized by Groups of characteristics: Abiotic (A), Biotic (B), and Landscape level (C), thereafter subdivided into a second level. For each ecosystem type, one or more variables for each of the SEEA EA ECT classes should be measured to provide a comprehensive assessment of ecosystem condition.

	SEEA Ecosystem condition typology	Key ecosystem attributes (Society of Ecosystem Restoration)	MAES pressures and ecosystem condition typology
	Not included (can be covered by other classes)	**Absence of threats** (Direct threats to the ecosystem such as overutilization, contamination, or invasive species are absent)	**Pressures** (e.g. habitat conversion and degradation, invasive alien species, pollution)
Group A: **Abiotic ecosystem characteristics**	Class A1. **Physical state characteristics**: physical descriptors of the abiotic components of the ecosystem (e.g. soil structure, water availability)	**Physical conditions** (Environmental conditions, including the physical and chemical conditions of soil and water, and topography, required to sustain the target ecosystem are present)	**Environmental quality** (physical and chemical)
	Class A2. **Chemical state characteristics**: chemical composition of abiotic ecosystem compartments (e.g. soil nutrient levels, water quality, air pollutant concentrations)		
Group B: **Biotic ecosystem characteristics**	Class B1. **Compositional state characteristics**: composition / diversity of ecological communities at a given location and time (e.g. presence/abundance of key species, diversity of relevant species groups)	**Species composition** (Native species characteristic of the appropriate reference ecosystem are present, whereas undesirable species are absent)	**Structural ecosystem attributes** (incl. species diversity and abundance & soil attributes)
	Class B2. **Structural state characteristics**: aggregate properties (e.g. mass, density) of the whole ecosystem or its main biotic components (e.g. total biomass, canopy coverage, annual maximum NDVI)	**Structural diversity** (Appropriate diversity of key structural components, including demographic stages, trophic levels, vegetation strata and spatial habitat diversity are present)	
	Class B3. **Functional state characteristics**: summary statistics (e.g. frequency, intensity) of the biological, chemical, and physical interactions between the main ecosystem compartments (e.g. primary productivity, community age, disturbance frequency)	**Ecosystem function** (Appropriate levels of growth and productivity, nutrient cycling, decomposition, species interactions, and rates of disturbance)	**Functional ecosystem attributes** (incl. soil attributes)
Group C: **Landscape level characteris-tics**	Class C1. **Landscape and seascape characteristics**: metrics describing mosaics of ecosystem types at coarse (landscape, seascape) spatial scales (e.g. landscape diversity, connectivity, fragmentation)	**External exchanges** (The ecosystem is appropriately integrated into its larger landscape or aquatic context through abiotic and biotic flows and exchanges, facilitated by connectivity)	**Landscape mosaic**

Figure 2: Ecosystem Condition Typology (ECT) of the SEEA-EA (adapted from Vallecillo et al. (2022)

The definition of an ecosystem condition reference state by setting condition indicator baselines allows monitoring. Therefore, good ecosystem condition will be considered when it presents good physical, chemical, and biological condition, or good physical, chemical and biological quality with self-reproduction or self-restoration capability, in which species composition, ecosystem structure and ecological functions are not impaired (cf. definition of the Taxonomy Regulation (EU) 2020/8528).

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

2. Coastal ecosystem condition accounts

Coastal zones rank among the most productive regions, offering a diverse array of valuable habitats and ecosystem services that have consistently drawn human presence and activities. Their beauty and richness have made them popular for settlements, tourism, business, and transport. This intensive use places significant pressures on coastal ecosystems, leading to biodiversity loss, habitat destruction, and space congestion. The EU coastline stretches 68,000 km, encompassing 24 EEA coastal countries and representing 13% of their total land mass. Despite there is little to no specific measures, pressures are mostly reported through the Habitats directive and the conservation status is considered poor.

To compute the accounts, the coastal zone is defined by a 1 km buffer landwards of those Corine Land Cover (CLC) classes that are characterized as being under the influence of sea water (either as sea water bodies or areas regularly flooded in tidal environments, up to the high-tide line). These CLC classes include 521 Coastal lagoon, 522 Estuaries, 423 Intertidal flats, 523 Sea and ocean, and selected pixels from 421 Salt marshes and 422 Salines (isolated polygons inland are excluded). The coastal area includes ecosystem types of coastal beaches, dunes, and wetlands.

For the coastal ecosystems, the focus is on the one and only mandatory condition indicator from the EU Legislation: *the share of artificial impervious area cover*, in %, as a national average for the reporting period. The substitution of the original (semi-) natural land cover or water surface in coastal areas with an artificial, impervious cover is an indicator for ecosystem condition degradation, reflecting the encroachment of built-up land in the coastal zone (e.g., roads, residential development, holiday houses).

This mandatory indicator represents the *Abiotic / Physical state* condition type and should be complemented with other indicators representing other condition types to represent a true condition index. Some potential other indicators are beach litter (Abiotic/physical), percentage of coastal wetland species with good population status (biotic/compositional), percentage of coastal wetland birds with increasing or stable population trends (biotic/compositional), percentage of beaches with water quality for swimming (biotic/compositional).

There is no agreement yet on the other (voluntary) indicators and as shown above the potential indicators do not yet represent well the range of condition types. Therefore, this demonstration will only use the mandatory condition indicator (share of artificial impervious area cover) to generate the coastal condition account and hence the results could be biased to represent only the abiotic physical state. Reporting of the account is expected to be done every three years.

2.1 State of the art: existing products and challenges

Various studies have explored EO-based methods to map impervious surfaces, soil sealing, land consumption. Most studies however focus on mapping imperviousness at urban scale and on comparing methodologies, rather than developing approaches that are applicable to international policies (Peroni et al. 2022), Three existing (partially) EO-based products were considered for the coastal condition account (Table 2).

The Copernicus Land Monitoring Service (CLMS) HRL Imperviousness Density products capture the spatial distribution and change over time of artificial impervious surfaces over Europe. These layers were produced every three years with a 20 m spatial resolution from 2006 to 2015. An enhanced version with a 10 m resolution was generated in 2018 using Sentinel-1 and Sentinel-2 images. The 2018 HRL Imperviousness Density map is based on a supervised classification of sealed/unsealed areas, followed by visual refinement of the classification results.

Within the sealed area mask, the degree of imperviousness (1-100%) is determined from yearly Sentinel-2 median composites of all spectral bands, the 90th percentile NDVI, and median composites of Sentinel-1 VV and VH backscatter.

The CLMS Coastal Zones Land Cover and Land Use product offers detailed LC/LU maps of Europe's coastal regions, extending 10 km inland, and updated every six years. Currently, two layers are available (2012 and 2018). The product is available in vector format with a minimum mapping unit (MMU) of 0.5 ha. The LC/LU maps are based on Very High Resolution (VHR) satellite data and ancillary data and distinguish 71 thematic classes derived from the Mapping and Assessment of Ecosystems and their Services (MAES) typology of ecosystems and CLC, adapted for coastal zones monitoring needs.

The World settlement footprint (WSF) is a 10m resolution binary mask outlining the global settlement extent. Two versions are currently available. WSF 2015 was derived from Sentinel-1 and Landsat-8 time series, while WSF 2019 was derived from Sentinel-1 and Sentinel-2. The settlement mask includes all built-up residential and commercial areas, excluding roads.

Table 2: Overview of available (partially) EO-based products that were considered for the coastal condition account.

Product	**CLMS HRL Imperviousness Density**	**CLMS Coastal Zones LC/LU**	**World settlement footprint**
Source	Sentinel-2, Sentinel-1 (+ manual corrections)	Very High Resolution (VHR) satellite data and other available data.	Sentinel-1, Sentinel-2, Landsat-8
Spatial coverage	Europe	Europe (10km coastal area + CLC seawards buffer)	Global
Temporal coverage	3-yearly, 2012, 2015 (20 m) 2018 (10 m)	6-yearly, 2012-2018	2015, 2019
Content	Per-pixel estimate of impermeable cover of soil as an index for the degree of imperviousness (0-100%)	LC/LU classes	Binary mask outlining the extent of human settlements.
Thematic coverage	-	MAES typology and CLC adapted to the specific needs of coastal zones monitoring (71 classes).	Settlements = built up residential or commercial areas. Excludes roads.
Format	Raster	Vector	Raster
Pixel size	10 m	-	10 m
MMU	10 m	≥ 0.5 ha (width ≥ 10m)	10 m

Although the CLMS HRL Imperviousness Density is currently available at 10 m resolution for only one year, it best meets the coastal condition account requirements in terms of spatial resolution, thematic coverage, and frequency. Therefore, it was used as the baseline for further development.

2.2 Test areas

The coastal condition account was tested and developed in three areas of interest situated in the Netherlands, Italy, and Greece (Figure 3). In the Netherlands, the whole country (NUTS-0) is considered, including five coastal NUTS-2 regions: NL34 (Zeeland), NL33 (Zuid-Holland), NL32 (Noord-Holland), NL12 (Friesland) and NL11 (Groningen). In Italy, the AOI includes all NUTS-2 along the Adriatic coastline: ITH3 (Veneto), ITH5 (Emilia-Romagna), ITI3 (Marche), ITF1 (Abruzzo), ITF2 (Molise), ITF4 (Puglia). Finally, in Greece the focus is on the Peloponnese peninsula, including five NUTS-3 regions: EL632 (Achaia), EL633 (Ileia), EL651 (Argolida, Arkadia), EL652 (Korinthia), EL653 (Lakonia, Messinia).

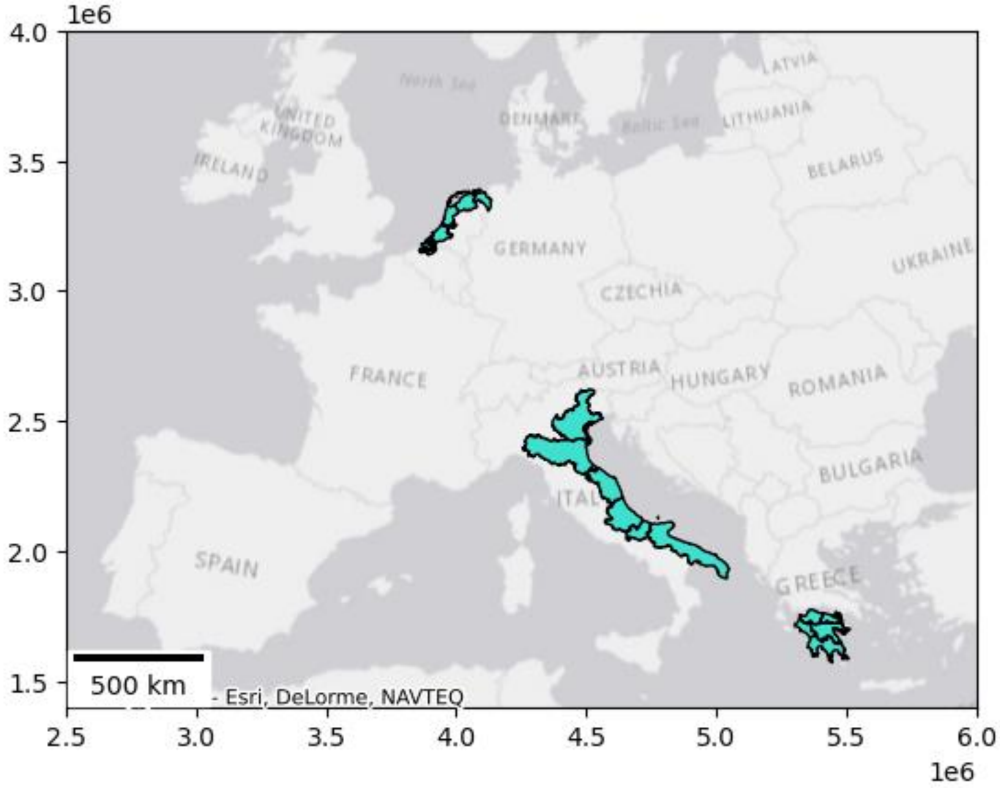

Figure 3: Location of the test areas for the coastal condition accounts. NUTS-2 in the Netherlands and Italy, NUTS-3 in Greece.

2.3 Method development and co-design

The coastal condition index was developed in two phases and in co-design with the early adopters. Initially, existing products were evaluated and compared to a local reference product in the Italian test site. Based on the gaps identified during this first phase, and in coordination with the early adopters, the subsequent development steps were planned. The focus was on distinguishing between temporary and permanent imperviousness on one hand and assessing annual imperviousness and changes over time on the other.

2.3.1 Evaluation and comparison of existing products

Existing products (CLMS HRL Imperviousness Density and CLMS Coastal Zones LC/LU of 2018) were evaluated and compared in the region of Venice in Italy (ITH3). The products were assessed visually, compared with each other, and with a local reference layer: the 'Carta Nationale Consumo Suolo' or soil consumption map (ISPRA, 2018)[2].

The soil consumption map of Italy is a yearly 10 m raster product generated by ISPRA. The products provide a detailed classification of temporary and permanent soil consumption, including impervious and non-impervious surfaces contributing to soil depletion (e.g., unpaved parking, dumps, quarries…). The classification is based on semiautomatic classification of high-resolution remote sensing images (Sentinel-1 & Sentinel-2) and photointerpretation of very high-resolution images (national orthophotos and other HRL).

First, the coastal condition index was computed for ITH3 in 2018, based on the three products (Table 3). From the CLMS HRL Imperviousness Density, the aggregated imperviousness density was computed as well as the fraction of pixels classified as sealed. To allow a good comparison, the CLMS HRL Imperviousness Density inclusion and exclusion rules for sealed surfaces were used to compute the fraction of artificial impervious surfaces from the CLMS Coastal Zones LC/LU classes and the Consumo di Suolo classes.

Table 3: Comparison of the coastal condition index for ITH3 (Venice) in 2018, based on different products and calculation methods.

Product	Calculation method	Coastal condition index ITH3 2018
CLMS HRL IMD	Aggregation (mean) of imperviousness density	12,7 %
CLMS HRL IMD	Fraction of sealed pixels (IMD > 0%)	16,5 %
CLMS Coastal Zones LC/LU	Share of impervious LC/LU classes according to CLMS HRL IMD inclusion rules[1]	16,6 %
Consumo di Suolo	Share of impervious LC/LU classes according to CLMS HRL IMD inclusion rules[1]	19,6 %

[1] *Elements to be included/excluded in the HRL Imperviousness 2018 are described in the "CLMS HRL Lot1: Imperviousness 2018, Imperviousness Change 2015 – 2018 and Built-up 2018 User Manual".*

The share of artificial impervious area cover calculated for ITH3 range from 12,7% to 19,6%. The lowest share is obtained by averaging the CLMS HRL imperviousness density. The share of sealed pixels in the CLMS HRL IMD and the share of impervious LC/LU classes in the CLMS Coastal Zones LC/LU are very similar (16,5% and 16,6%). The share of impervious LC/LU classes in the Carta Nationale Consumo Suolo is the highest (19,6%). The CLMS HRL IMD has been shown to underestimate the overall share of impervious area cover in other areas (Strand et al., 2022), which could explain the lower value obtained here. On the other hand, the high value obtained based on the Carta Nationale Consumo Suolo may be an overestimation due to a lack of thematic detail in this product. From the pixels counted as impervious for the index calculation, 4,5% are classified as 'consumed soil' with no further differentiation and could correspond to actual imperviousness and other forms of soil disturbances.

[2] https://www.isprambiente.gov.it/en/publications/reports/soil-consumption-territorial-dynamics-and-ecosystem-services-2018-edition

Second, a more detailed comparison was performed, between the Consumo di Suolo classes and CLMS HRL imperviousness density categories. A random stratified sampling approach was applied on the Carta Nationale Consumo Suolo to build a confusion matrix between both products (Figure 4). Overall, given the inclusion rules of CLMS HRL IMD sealed area mask, there is a relatively good agreement with the local reference layer. Especially the unsealed classes (landfills, reversible consumption and non-consumed) seem to be mostly identified as unsealed (0%) by the CLMS HRL IMD product. In the sealed classes, paved roads cause the most confusion, with a majority identified as unsealed by the CLMS HRL IMD product. The higher-level classes of 'Consumed soil' and 'Permanent land consumption', which include both sealed and unsealed surfaces show a consistent distribution between imperviousness categories.

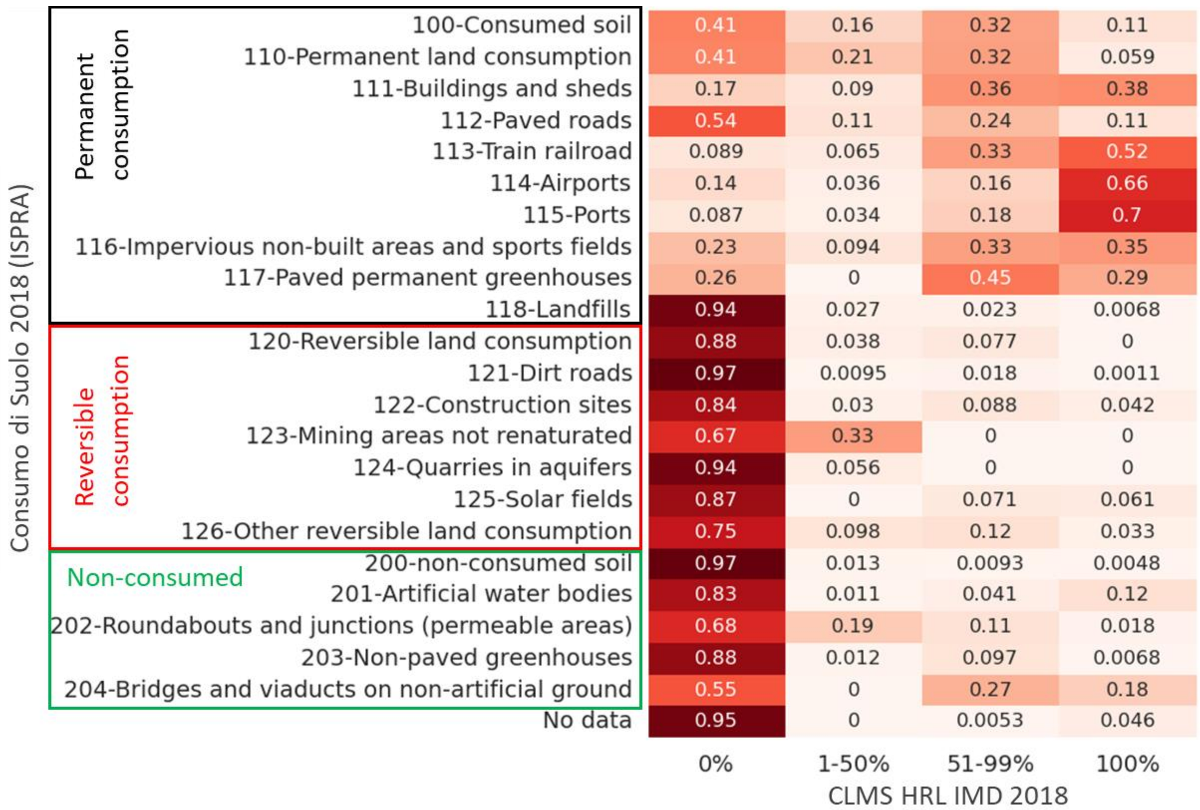

Figure 4: Confusion matrix between CLMS HRL IMD and Consumo di Suolo classes, based on a random stratified sampling of the Consumo di Suolo classes.

This initial evaluation, comparison complemented with a visual assessment allowed to identify the main shortcomings of the CLMS HRL Imperviousness Density product regarding the requirements for the coastal condition account and to set the focus for the calculation of the share of artificial impervious surfaces in coastal areas.

The main identified challenges and shortcomings are:

- Omission of narrow paved roads and small isolated buildings,
- Commission errors on beaches and other bare surfaces,
- Inconsistent detection of temporary imperviousness and no differentiation from permanent imperviousness, and
- Currently available for only one year (2018) at 10 m resolution

For further development, the focus was set on (1) distinguishing between temporary and permanent imperviousness and (2) consistently mapping and quantifying annual imperviousness and changes over time.

2.3.2 Temporary imperviousness

Most artificial impervious surfaces such as buildings, roads and other paved elements are permanent, in the sense that, once constructed, they remain throughout the year(s). Some artificial impervious surfaces however cover natural surfaces only temporarily, or seasonally. In coastal areas particularly, temporary impervious surfaces, such as camping grounds or leisure infrastructures on beaches can be common. While temporary impervious surfaces have an impact on the coastal ecosystems condition, this impact is small compared to permanent impervious surfaces. Therefore, it would be valuable to differentiate these two types of imperviousness.

The detection of temporary imperviousness however comes with several additional challenges. Mainly, temporary imperviousness is often caused by very small objects, such as camping cars, caravans, beach cabins etc., which could most probably not be detected at the spatial resolution of Sentrinel-1 and Sentinel-2. Because of the temporary aspect, a combination of very high spatial and temporal resolution would be needed. Finally, since temporary impervious surfaces are much less common, gathering reference data represents an additional challenge.

Given these challenges, in the frame of this project, the focus was further set on the consistent mapping annual imperviousness and change. Further efforts should investigate the feasibility of differentiating temporary imperviousness, using very high-resolution images.

2.3.3 Annual imperviousness and change

The coastal condition account is expected to be reported on every three years. Consistent mapping of imperviousness and its changes over time is essential for this purpose. To achieve this, a workflow was developed to produce yearly imperviousness density maps using features derived from Sentinel-1 and Sentinel-2, with the 2018 CLMS HRL Imperviousness Density map serving as the baseline and reference. This workflow was initially tested and developed in Veneto, Italy (ITH3) for 2018, and subsequently expanded to other test regions and years.

The developed workflow (Figure 5) closely mirrors that of the CLMS HRL IMD 2018 and involves two primary steps. First, a binary classification based on Sentinel-1 and Sentinel-2 data is performed to create a sealed surfaces mask. Then, within this mask, the imperviousness density (1-100%) is estimated using Sentinel-2 features.

The reference dataset for training and validation was collected through stratified random sampling of the 2018 CLMS HRL IMD product. In Italy, stratification was based on the Carta Nazionale Consumo Suolo to represent various types of sealed and unsealed surfaces. For each point, reference imperviousness density values were extracted from the 2018 CLMS HRL IMD product.

Image collection, preprocessing, and feature calculations were conducted using openEO. Input features for binary classification and imperviousness density estimation included yearly median composites of Sentinel-2 spectral bands (blue, NIR, and SWIR1), normalized built-up area index (NBAI), the 90th percentile normalized difference vegetation index (NDVI), and median Sentinel-1 VV and VH sigma0 backscatter.

To create the binary sealed surfaces mask, a random forest classifier was iteratively trained for each region. A first model is trained and applied to generate a mask, which is then visually evaluated. Additional training points are added in areas of confusion, and a new classifier is trained with the enhanced dataset. This cycle continues until no notable improvements are observed. The final masks were validated with independent datasets.

Sealed surface pixels were further differentiated by imperviousness density using the 90th percentile NDVI and median NBAI. First, a threshold 90th percentile NDVI (0,25) value was established to identify 100% impervious pixels. The imperviousness density for the remaining pixels (1-99%) was determined through linear regression of the 90th percentile NDVI and median NBAI.

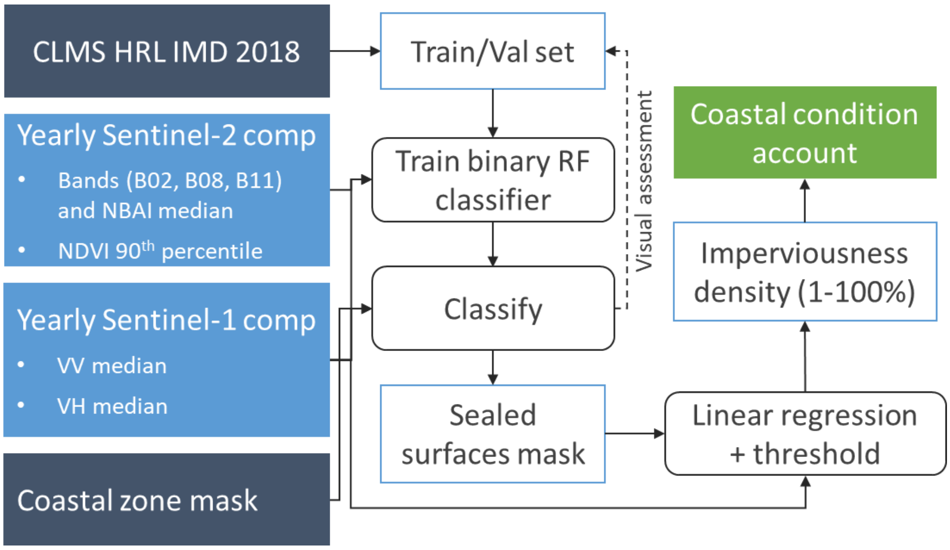

Figure 5: Workflow for a yearly imperviousness density map

2.4 Results and uncertainty estimation

In each test area, the sealed surfaces mask generated for 2018 was validated using the CLMS HRL Imperviousness Density 2018 product as the reference. The evaluation metrics comparing the two sealed surfaces masks are presented in Table 4. Additionally, Table 5compares the share of artificial sealed surfaces, calculated as the fraction of sealed pixels in both products.

The validation results indicate a very high agreement (91% OA) between the PEOPLE and CLMS HRL sealed surfaces masks in the Italian test site. However, the share of artificial sealed surfaces (14,2%) is significantly lower than that in the CLMS HRL product (20,5%). This discrepancy is partly due to actual improvements, such as fewer commission errors on beaches, and partly due to more omissions of roads and other non-built-up artificial sealed surfaces.

In the Netherlands, the sealed surfaces mask also shows relatively high agreement with the CLMS HRL product (80% OA). The lower precision of sealed surfaces (0,63) is mainly due to commission errors on bare soil and dunes. Consequently, the share of artificial sealed surfaces (13,0%) is larger compared to the CLMS HRL product (10.4%).

In the Peloponnese, persistent commission errors on bare rocks, sparse vegetation, and steep slopes resulted in very low precision (0,39) for the sealed surfaces class and a relatively low overall accuracy (69%). Due to these issues, the share of artificial sealed surfaces is significantly overestimated (12,4%) compared to the CLMS HRL product (5,9%).

Table 4: Evaluation metrics obtained by comparing the sealed surfaces mask generated in this project to the CLMS HRL Imperviousness Density sealed surfaces

Site	CLASS	PRECISION	RECALL	F1-SCORE	OA
IT	**Unsealed**	0,91	0,90	0,91	91%
	Sealed	0,90	0,91	0,91	
NL	**Unsealed**	0,97	0,72	0,83	80%
	Sealed	0,63	0,95	0,76	
GR	**Unsealed**	0,99	0,62	0,76	69%
	Sealed	0,39	0,97	055	

Table 5: Coastal condition index calculated as the fraction of sealed pixels (IMD > 0%), based on the imperviousness layer generated in this project (PEOPLE) and on the CLMS HRL imperviousness Density product.

Site	*PEOPLE*	*CLMS HRL*
IT	14,2%	20,5%
NL	13,0%	10,4%
GR	12,4%	5,9%

Using the classification models and regression calibrated for 2018, yearly coastal imperviousness density maps were created for each test area from 2018 to 2022 (Figure 6). Additionally, imperviousness density change maps between 2018 and 2022 were produced. The results were visually evaluated using Google Earth imagery as a reference. Overall, many actual changes, such as new impervious surfaces, appear to be detected accurately and commission errors on rocks and bare soil remain relatively consistent across the years. However, some false detections of imperviousness changes occur with, for example, fire damage transforming vegetated areas into bare soil areas.

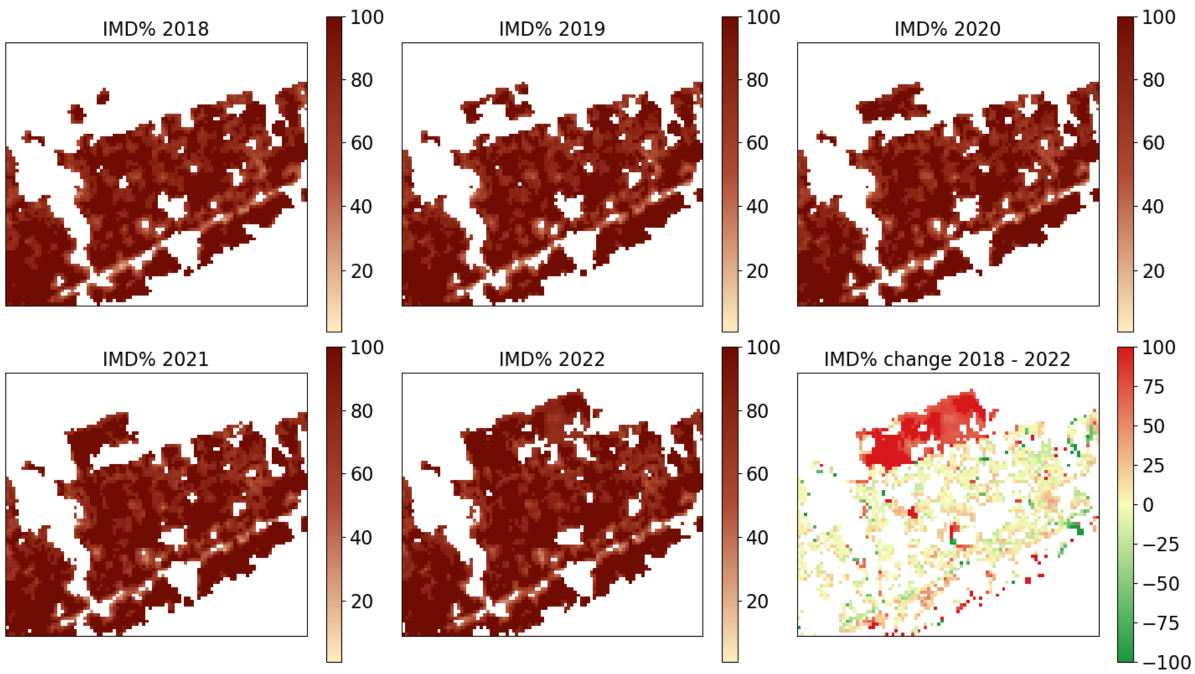

Figure 6: Yearly imperviousness density from 2018 to 2022 and change between 2018 and 2022 on a small extent in the region of Venice, Italy. The large red patch in the North of the extent, corresponds to actual change due to the installation of new impervious infrastructures.

2.5 Coastal condition accounts

The share of artificial sealed surfaces was calculated based on the yearly imperviousness density maps for a subset of each test area (Table 6). The accounts show overall increasing trends from 2018 to 2022. The irregularity in the NL subset trend could be linked to some local outliers and artefacts observed in the 90th percentile NDVI composite.

Table 6: Annual coastal condition accounts computed for a subset of each region's area of interest

AOI	2018	2019	2020	2021	2022
IT subset	10,6%	11,7%	11,6%	11,8%	12,4%
GR subset	15,0%	16,9%	16,9%	15,5%	15,4%
NL subset	22,4%	20,6%	21,3%	22,1%	22,8%

Finally, the coastal condition accounts for 2018 and 2022 were generated for each country's entire AOI and per NUTS-2 for Italy and the Netherlands and per NUTS-3 for Greece (Table 7). The accounts were generated based on two calculation methods, namely the fraction of sealed pixels (Sealed pixels %) and the aggregated mean imperviousness density (MEAN IMD%).

Table 7: Annual coastal condition accounts (2018 and 2022) computed for each country's AOI and per NUTS-2 (NUTS-3 for GR). The accounts are given based on two calculation methods: the fraction of sealed pixels (IMD > 0%) and the aggregated mean IMD%.

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

2.6 Conclusions and outlooks

Building on existing products and local reference layers and in co-design with the Early Adopters, a workflow was developed to map annual imperviousness degree at 10 m resolution. Through this workflow, sealed and unsealed surfaces are classified based on Sentinel-1 and Sentinel-2 yearly composites. The imperviousness degree of sealed surface pixels is then derived from Sentinel-2 90th percentile NDVI and median NBAI. Based on these imperviousness degree maps, the share of artificial impervious area cover can then be calculated, inside the defined coastal zone mask.

The workflow developed here allows to tackle one of the main issues with the existing CLMS HRL imperviousness degree product, which was the current lack of temporal coverage. Using this workflow, the coastal condition account, focusing on the share of artificial impervious area cover, can be computed on a yearly basis. Nevertheless, some shortcomings remain unsolved. Mainly, due to the confusion between artificial impervious areas and bare areas such as bare soil, rocks and sand, the indicator is overestimated in certain areas. Moreover, roads and other non-built-up artificial impervious elements are often omitted. These issues add uncertainty to the absolute value of the coastal condition indicator. However, given the consistency of these errors throughout the years, the estimation of change in share of artificial impervious area cover should be less impacted. The feasibility of differentiating temporary imperviousness was discussed but was not further investigated in the context of this project. Additional reference data and very high-resolution regularly imagery (below 10m) would be required to meet this goal.

Overall, EO-based methods allow to map artificial impervious surfaces relatively consistently. Some limitations remain and most existing products partially rely on visual and manual improvements to reach a high accuracy. The continuation of the CLMS HRL imperviousness density 10 m product on a 3 yearly basis would allow to meet the requirements related to the coastal condition account.

Finally, for this account, the focus was on one mandatory indicator, namely *the share of artificial impervious area cover*. This single indicator reflects only the physical and abiotic condition of coastal ecosystems. It should be complemented with other condition indicators to generate a completer and more accurate picture of coastal ecosystems condition.

3. References

Peroni, F. (2022). How to map soil sealing, land take and impervious surfaces, a systematic review. Environmental Research Lett.17 053005DOI 10.1088/1748-9326/ac6887

Strand, G. H. (2022). Accuracy of the Copernicus High-Resolution Layer Imperviousness Density (HRL IMD) assessed by point sampling within pixels. *Remote Sensing*, *14*(15), 3589.

Annex 1. National reference datasets

Country	Validation of:	Dataset	Source
Netherlands	Coastal condition	National ecosystem extent map; national annual 30cm resolution aerial photographs	https://www.cbs.nl/en-gb/society/nature-and-environment/natural-capital/themas/ecosystem-types
Italy	Artificial impervious area cover in coastal zone	SNPA soil consumption map (2006-2021) raster (10m resolution) and photo interpreted changes at very high resolution (<1m)	Available for the whole Italy https://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/consumo-di-suolo