
# Product Specification and Algorithm Theoretical Base Document: Ecosystem extent account

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# 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

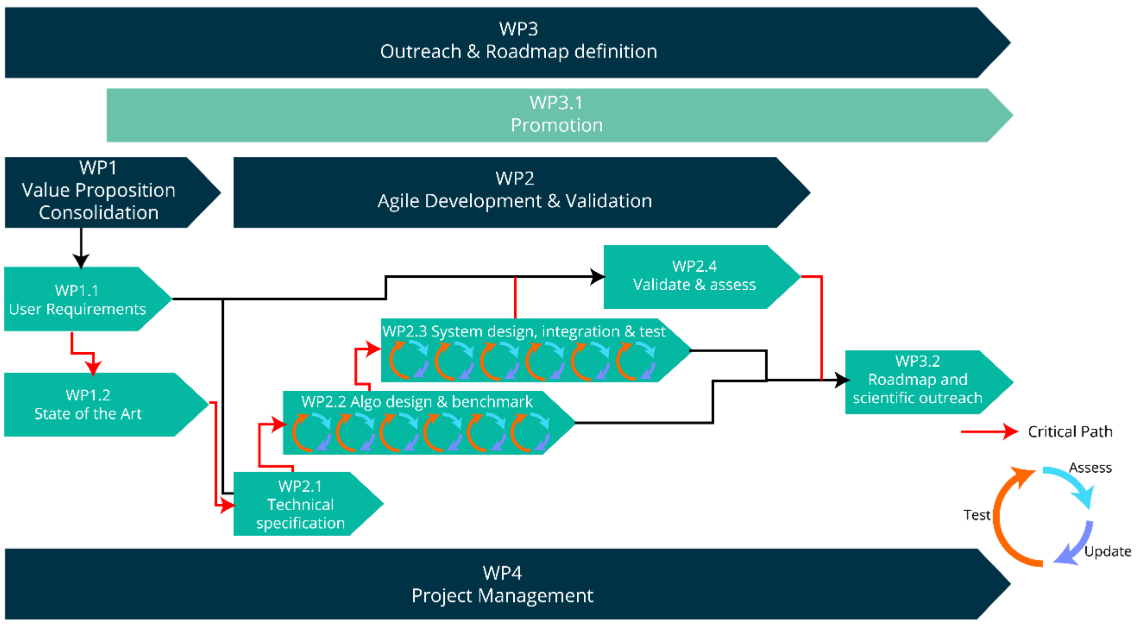



*Figure 1: Overview of WP2 agile iterative co-design development cycle*

The report will be updated regularly according to the agile development cycle as shown below.

## 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, see Table 2

*Table 1: Overview of ecosystem account pilot demonstrators*

| Account | Country | Details / Indicator | Year | Round-robin |
|---|---|---|---|---|
| **Extent** | Greece | Mapping habitat types at level 2 in the Peloponnesus, and at level 3 in the coastal zone of the Peloponnesus. | 2020 | X |
| | Netherlands | Habitat mapping: comparison of new habitat map and ecosystem type map of the Netherlands SEEA EA accounts | 2020 | |
| | Norway | Mapping rural ecosystem extent in 3 counties (tentatively Møre og Romsdal, Trøndelag, Oslo Og Viken[1];<br>Mapping urban and peri-urban extent | 2021 | |
| | Slovakia | Mapping ecosystem extent in the country | 2015-2022 | X |

*Table 2: Test-sites for round-robin algorithm development*

| Test site (NUTS) | Area size | Test account | Rationale |
|---|---|---|---|
| EL632, EL633, EL651, EL652, EL653<br>(West Peloponnesus) | 20 000 $km^2$ | • Extent (habitat changes) | Coastal zone (dunes, coastal forests, wetlands) |
| SK03 (Stredné Slovensko) | 16 000 $km^2$ | • Extent | Prime forest |

The remainder of the document will present the results for the round-robin test sites. After the methodology is finalized the extent accounts, as presented in Table 1, are generated and validated by the Early Adopters. The validation results will be described in a separate document.

Note that the workflow developed is still experimental and not operational, since it is considered to have reach TRL[2] Level-4. This level declares the technology is validated in the lab (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] Later to be determined if data are available to scale up.

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

# 2. Ecosystem extent account

The ecosystem extent account records the total area of each ecosystem, classified by type within a specified area (ecosystem accounting area). Ecosystem extent accounts are measured over time in ecosystem accounting areas (national, sub-national, basin, protected area, etc.) by ecosystem type and illustrate the changes in extent from one ecosystem type to another over the accounting period.

An ecosystem extent map is not to be confused with a land cover map. The difference can be explained by:

- **Ecosystem classification**: Land cover maps provide information about the physical characteristics of the land, such as vegetation types or urban areas. Land use maps depict how humans utilize and manage land, as residential areas, industrial zones, agricultural fields, transportation infrastructure, recreational and conservation areas. However, ecosystems are more than just land cover and land use types; they represent complex interactions between biotic (living) and abiotic (non-living) components. *To create an ecosystem extent map, you would need to classify and delineate ecosystems based on factors like vegetation composition, soil type, climate, hydrology, and other ecological parameters*.
- **Ecological data**: Land cover maps typically do not include detailed ecological data, such as species composition, biodiversity, or ecological processes. *Ecosystem extent maps require additional data on the presence and distribution of different species, ecological communities, and their interactions.* This information can be obtained through field surveys, remote sensing techniques, or existing ecological databases.
- **Spatial scale and resolution**: Land cover maps are often created at a specific spatial scale and resolution, which may not capture the full extent of ecosystems. *Ecosystems can vary in size, from small patches to large landscapes, and their boundaries may not align with administrative or geographical boundaries*. Generating an ecosystem extent map requires considering the appropriate scale and resolution that reflect the ecological processes and dynamics within the landscape.
- **Expert knowledge and interpretation**: Land cover maps are usually generated using automated classification techniques applied to remote sensing data. However, *accurately identifying ecosystems often requires expert knowledge and interpretation*. Ecologists and subject matter experts can provide valuable insights into ecosystem boundaries, transitions, and landscape patterns that might not be evident from land cover information alone.
- **Temporal dynamics**: Ecosystems are not static entities; they change over time due to natural and human-induced processes. Land cover maps capture a snapshot of land use and vegetation cover at a specific point in time. To *create an ecosystem extent map, you would need to consider temporal dynamics, such as vegetation phenology, successional stages, and land-use changes, to reflect the dynamic nature of ecosystems*.

To bridge the gap between a land cover map and an ecosystem extent map, integrating the missing components mentioned above is crucial. This involves combining land cover and land use data with ecological information, expert knowledge, and appropriate spatial and temporal considerations to delineate and classify ecosystems accurately. An ecosystem extent map represents the spatial distribution and boundaries of different ecosystems within a given area. Ecosystems are complex systems comprising living organisms, their physical environment, and the interactions between them.

Ecosystem extent maps typically integrate information from land cover, ecological data, and other relevant factors to delineate and classify ecosystems based on their ecological characteristics, processes, and functions. These maps provide a holistic view of the distribution and extent of various ecosystems, such as forests, grasslands, wetlands, deserts, and aquatic systems, enabling better understanding and management of ecological resources.

In summary, while land cover maps focus on the physical and biological characteristics of the land surface, land use maps highlight human activities and purposes for land utilization. Ecosystem extent maps go beyond land cover and land use, incorporating ecological information to delineate and classify ecosystems based on their ecological characteristics, interactions, and functions.

## 2.1 Technical specification

The EU Extent Typology is a hierarchical classification:

- Level 1 consists of 12 sub-types and is derived from the MAES (Mapping and Assessment of Ecosystem Services) ecosystem typology
- Level 2 consists of 47 sub-types and adds more Land Use information (i.e., Corine) and Habitat information (i.e., EUNIS level 2)
- Level 3 contains 137 sub-types) and adds more Crop Type information (i.e., HRVLCC) and Habitat information (i.e., EUNIS level 3)

The EU legislation mandates to report on Level-1 but recommends voluntary reporting on Level-2 or Level-3. Reporting is to be done every 3 years through (i) an accounting table (asset account, see Table 3), (ii) conversion matrix and (iii) underpinned by an ecosystem extent map representing the spatial distributions of ecosystems. The accounting table (and matrix) is following the EU Extent Typology and can be converted to the IUCN Global Ecosystem Typology using a crosswalk at Level-2.

*Table 3: Reporting table for ecosystem extent accounts at Level-1. Note this table is to be extended to comply to the Level-2 typology.*

| | | **Opening area** | **Additions** | **Reductions** | Net changes | **Closing area** |
|---|---|---|---|---|---|---|
| **1** | **Settlements and other artificial areas** | | | | | |
| **2** | **Cropland** | | | | | |
| **3** | **Grassland (pastures, semi-natural and natural grasslands)** | | | | | |
| **4** | **Forest and woodland** | | | | | |
| **5** | **Heathland and shrub** | | | | | |
| **6** | **Sparsely vegetated ecosystems** | | | | | |
| **7** | **Inland wetlands** | | | | | |
| **8** | **Rivers and canals** | | | | | |
| **9** | **Lakes and reservoirs** | | | | | |
| **10** | **Marine inlets and transitional waters** | | | | | |
| **11** | **Coastal beaches, dunes and wetlands** | | | | | |
| **12** | **Marine ecosystems (coastal waters, shelf and open ocean)** | | | | | |

At EU scale, the Corine Accounting Layers (CLCACC) are used to map to the ecosystem extent (100m spatial resolution) for the available Corine years (2000, 2006, 2012, 2018). This dataset however is not updated regularly and therefore the demonstrator accounts will explore the merging of different datasets excluding Corine.

The demonstrator accounts will include:

- Reports at EU Typology Level-2, and explore some Level-3 classes, using earth observation datasets for the countries as defined in the Table 4 below.
- MMU of 0.5 or 1.0 ha and MMW of 10m.
- Include uncertainty information.
- A conversion matrix, which requires 2 reporting years. According to the EU legislation the reporting should be done every three years. To enable reporting of a conversion matrix, and being compatible with European dataset, the reporting years chosen are 2018 and 2021.
- A report at IUCN-GET typology through applying a crosswalk from EU Typology reports.

*Table 4: Ecosystem extent accounts demonstrators.*

| **Country** | **Details / Indicator** | **Years (requested)** | **Co-design** |
|---|---|---|---|
| Greece | Mapping habitat types at level 2 in the Peloponnesus, and at level 3 in the coastal zone of the Peloponnesus. | 2020 (2020) | X |
| Netherlands | Habitat mapping: comparison of new habitat map and ecosystem type map of the Netherlands SEEA EA accounts | (2021) | |
| Norway | Mapping rural ecosystem extent in 3 counties (tentatively Møre og Romsdal, Trøndelag, Oslo Og Viken;<br>Mapping urban and peri-urban extent | (2021) | |
| Slovakia | Mapping ecosystem extent in the country | 2020 (2015-2022) | X |

## 2.2 Potential algorithms

### 2.2.1 Algorithm options

As explained above an ecosystem extent map is made of several components. The objective is to build a data-cube that combine features:

- Land cover characteristics (e.g., water/no-water), typically derived from land cover maps
- Land surface physical characteristics, such as geomorphological data (e.g., elevation, shoreline, soil type) and hydrological data (e.g., permanent/seasonal water, snow coverage)
- Vegetation properties, typically derived from habitat maps (e.g., EUNIS, see Chytry et.al, 2017)
- Land use information (e.g., managed versus non-managed grasslands)
- Environmental data (e.g., climate zone, precipitation, temperature)

We can identify three possible approaches:

1. Derive from Corine Land Cover, complemented with additional Copernicus Land Monitoring (CLMS) datasets and optionally applying some national corrections. This approach is explored by several countries (i.e., Ireland), the European Environment Agency (EEA), and is defined as the **Top-Down approach**.
2. Derive from national dataset(s) and crosswalk(/model) to the EU typology, optionally gap-filled with public datasets (i.e., CLMS). This approach is explored by several countries (i.e., Netherlands, Hungary, Germany) and is defined as the **Bottom-up approach**.
3. Derive from vegetation maps and land cover characteristics, complemented with additional land use and other information, and is defined as the **Veg-map approach**.

Most studies are based on ecosystem extent assessment and use this as the baseline for ecosystem services quantification or provide time-series with land use changes among different years (see Ramirez-Reyes at al. 2019). Regarding the studies related to ecosystem extent accounting limitations are noted, related to the use of diverse input data, accuracy variability over different areas and different classes, coarse update intervals and outdatedness in comparison to the real world. The development therefore of EO based workflows and pipelines specifically for ecosystem extent mapping and monitoring (e.g., Verde et al 2020) based on standardized class schemes would be beneficial for the wider uptake of such approaches. Further to this, upload availability of the classification models into open access repositories, would further promote the dissemination and uptake of the EO based approach. Several studies rely on dense time-series analysis for the quantification of changes in ecosystem extent and the accounting reports (i.e., Nguyen et al 2021, Lee et al. 2021a, Lee et al. 2021b). In these cases, medium and/or low spatial resolution data are used.

On the other hand, we identified studies that rely on existing EO products for bi-temporal change detection of ecosystem extent as in the case of Rodríguez-Rodríguez and Martínez-Vega (2017). Other studies also adopt the bi-temporal change detection approach but rely on primary EO data to generate temporal LULC or ecosystem type maps (Normyle et al. 2022). In the latter case, the methodological approaches range from simple, indices-based thresholding (Turpie et al. 2021) to machine learning based approaches (Nguyen et al. 2021).

Netherlands used the 'bottom-up' approach and uses following data sources to generate their ecosystem extent maps for 2006 and 2013:

| Data source | Owner | Version 2006 | Version 2013 |
|---|---|---|---|
| Digital Cadastral map | Cadastre | 2004 | 1 Jan. 2013 |
| Crop plots (BRP) | Netherlands Enterprise Agency | May 2006 | May 2012 |
| Statistics Netherlands Regiobase | Statistics Netherlands | 1 Jan–31 Dec 2006 | 1 Jan–31 Dec 2012 |
| Statistics Netherlands Dwelling register (WRG) | Statistics Netherlands | 1 Jan 2006 | – |
| Statistics Netherlands Addresses Geographical Base register (GBR) | Statistics Netherlands | Jan 2006 | – |
| Coupling Object-ID and coordinate | Statistics Netherlands | 1998–2016 | – |
| Base register Addresses en Buildings (BAG) | Dutch Communities | – | 1 Jan 2013 |
| Base register Topography / Top10vector (BRT/Top10vector) | Cadastre | 2003–2007 | 2011–2012 |
| Statistics Netherlands Land Use map (BBG) | Statistics Netherlands | 2006 | 2010 |
| Boundary dunes | | Natura2000 | Natura2000 |
| Ecological network | PBL; Netherland Environmental Assessment Agency | Nota Ruimte | SVIR |
| Boundary riverbed | PBL; Netherland Environmental Assessment Agency | BARRO 2011 | BARRO 2011 |

UK uses broad habitat classifications & land cover maps (see https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/habitatextentandconditionnaturalcapitaluk/2022).

## 2.2.2 Proposed workflow

We want to explore a more generic solution, hence the veg-map approach. The advantage from this approach is that it focuses on vegetation classes based on EUNIS typology that can directly be cross walked to the EU extent typology. The limitation is that we first need to have (or in our case generate) these EUNIS habitat maps. A second observation is that for land use classes we still require to complement the crosswalk with complementary data, preferably at continental scale but where needed with national data.

As shown in Figure 2, the extent account is built up by a 'base reference' map (i.e., 2018) and 'updates' (i.e., 2021) derived from the base reference map and change hotspots. The accounts are to be provided in both EU Typology as well as UCN Get Typology through using crosswalk tables and integrating climatic and environmental zone information.

The base map is composed of three important components: (i) land cover physical characteristics, typically derived from land cover maps, (ii) ecosystem or plant functional type characteristics, preferably according to the EUNIS typology and (iii) land use characteristics. The information of these three components will be combined to create an ecosystem extent map at Level-2 or Level-3.

Once the change hotspots are detecting, a similar mapping as done for the base map is to be applied to find the new ecosystem extent class.

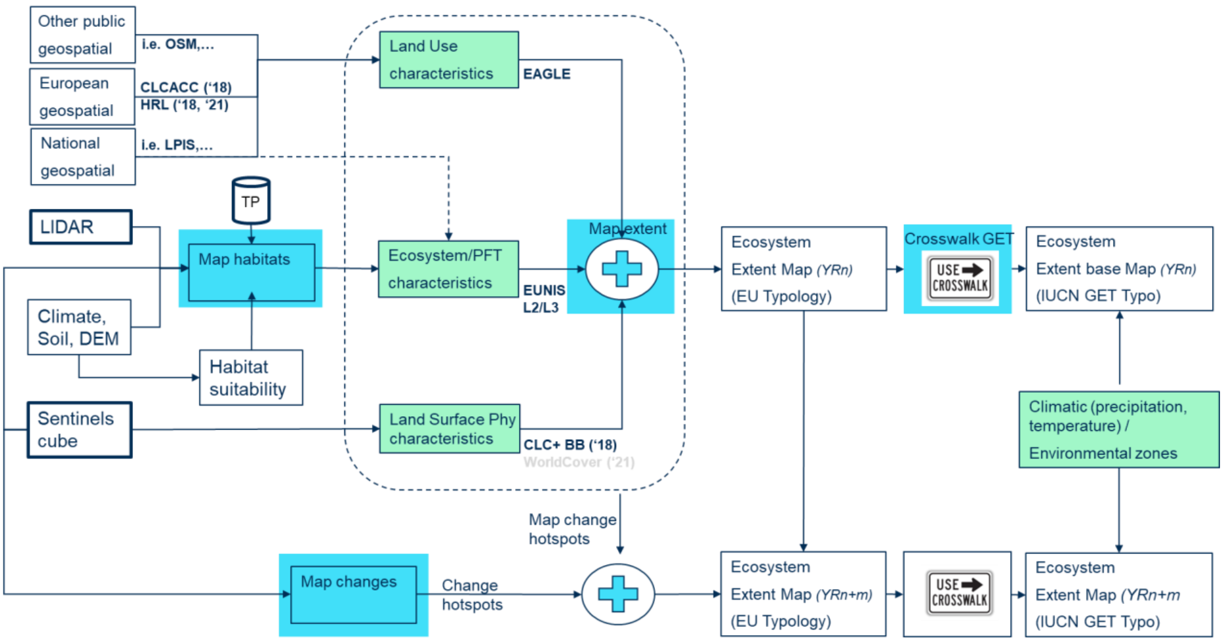



*Figure 2: Workflow diagram for EU extent accounts*

As shown in the diagram above, the EU extent account workflow consists of 4 major building blocks, described in the following sections:

1. Map habitats.
2. Map extent.
3. Map changes explored but no final solution available.
4. Crosswalk to IUCN GET, not further explored.

In the next chapters we'll provide more details on all 4 blocks. The workflow was developed in co-design with Slovakia (focus on forest extent) and Greece (focus on coastal extent).

## 2.2.3 Component Map habitats

### 2.2.3.1 Habitat mapping workflow

An automated state-of-art automated workflow was developed[3] to generate the EBV consisting of five modules, as shown in Figure 3:

1. **Feature Extraction**, preparing a set of predictors derived from remote sensing and other datasets.
2. **Feature Selection and Training Module**, using the input biodiversity data as training points and generate models using the extracted features.

[3] This workflow was developed in collaboration with the EuropaBON project. The EuropaBON project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003553.

3. **Inference Module**, generating the full wall-2-wall habitat maps at different hierarchical levels applying the models from the previous step.
4. **Post-Processing Module**, selecting the best fit pixel from the hierarchical habitat maps in combination with external data (e.g., habitat suitability maps).
5. **Change Detection Module**, using a time series of remote sensing data to identify changes in the habitat.

Each module is further described in detail below the figure.

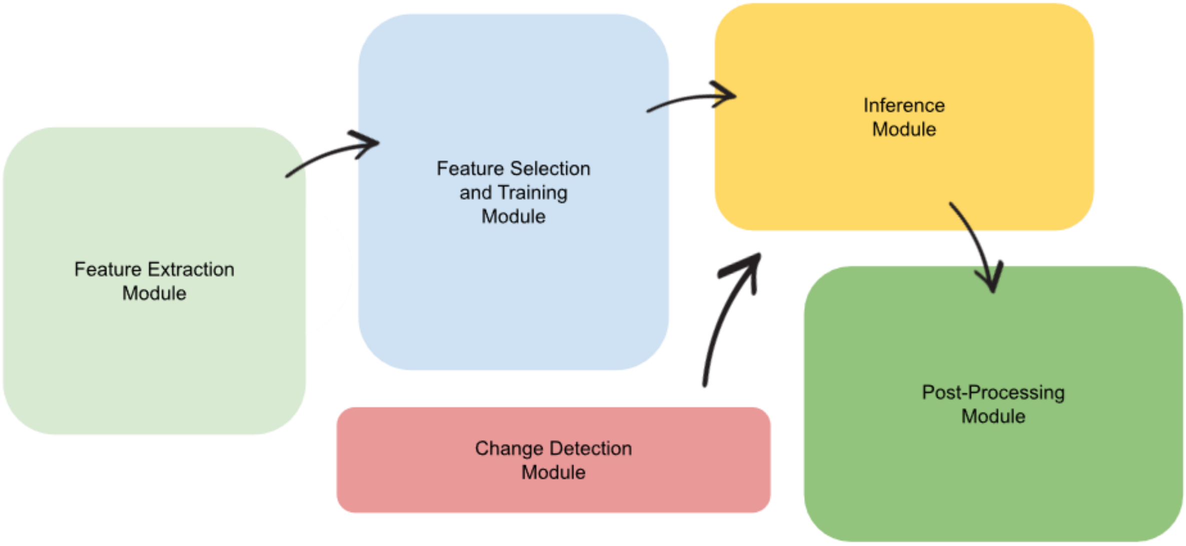



*Figure 3: Terrestrial habitat mapping workflow*

The **Feature Extraction Module** is responsible for preparing geospatial data (raster data) that provide information on the characteristics of the habitats. The characteristics are categorized into four different feature sets providing a total of 154 features (aka model predictors), as shown in Fig. 14:

- 8 Horizontal features, derived from Digital Elevation Model data (altitude and slope, topographic position index), LIDAR data (vegetation height) and distance to fresh water.
- 25 Scalar features derived from climate data (snow covered days, mean temperature during growing season, number of growing days above 5°C, precipitation in growing season, annual precipitation), soil data (bulk density, citation exchange capacity, coarse fragments, organic carbon concentration, sand texture, clay texture, pH) and other data sources (distance to inland water, inundation occurrence, population density, vegetation phenological parameters).
- 150 Spatial-temporal features, capturing both spatial and temporal information from optical (Sentinel-2) and radar (Sentinel-1) earth observation data, as is the 10$^{th}$, 50$^{th}$ and 90$^{th}$ percentile and inter-quantile range of spectral bands and a number of derived indices using a temporal series of 1 year of input data, plus a harmonics time-series for the Normalized Difference Vegetation Index.
- 16 Context features, capturing the spatial landscape information from the habitat derived from optical (Sentinel-2) earth observation data through an Artificial Intelligence (Conventional Neural Network or CNN) model.

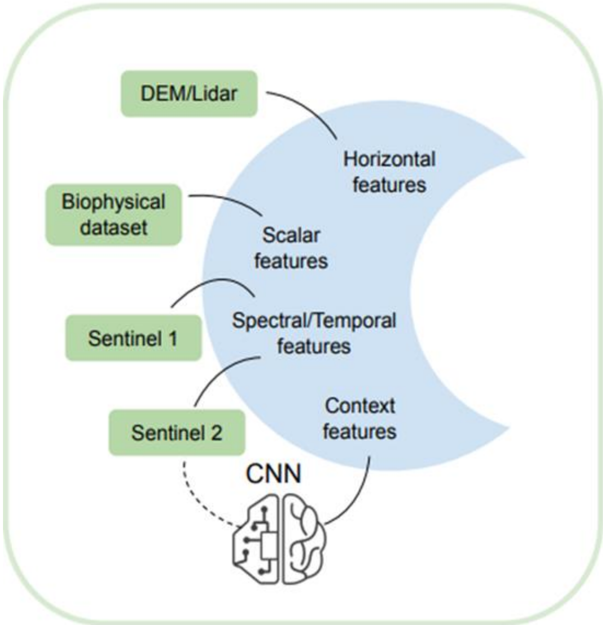



*Fig. 14: Terrestrial habitat map workflow - Feature Extraction Module*

The **Feature Selection and Training Module** uses reference data to train models per EUNIS level on the extracted features (see previous section). For each hierarchical level the best features (to distinguish the habitats) are selected through a Machine Learning approach using a five-folded Catboost model (Figure 4). This model is an improved version of the well-known Random Forest model and provides a gradient boosting framework (Dorogush et al., 2017) to solve categorical features using a permutation driven alternative compared to classical algorithms.

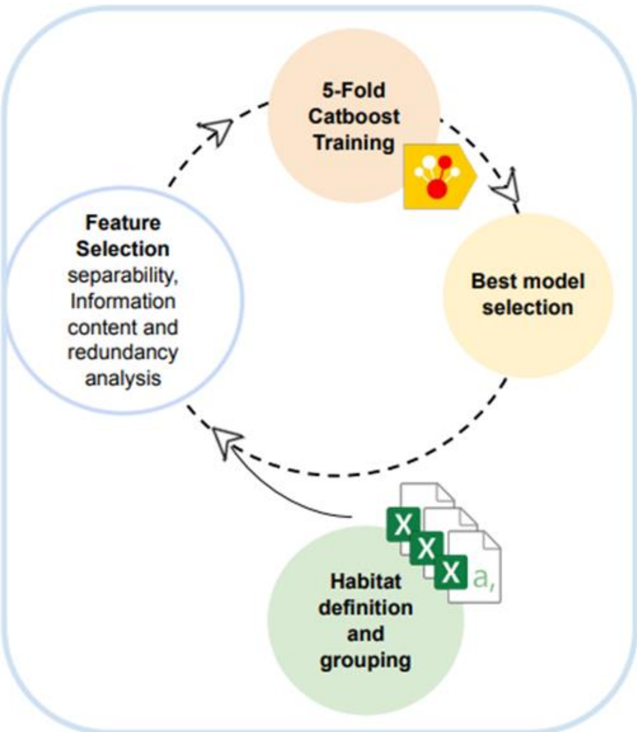



*Figure 4: Terrestrial habitat map workflow - Feature Selection and Training Module*

The **Inference Module** will perform the hierarchical habitat classification and generate wall-2-wall maps at 10m spatial resolution (Figure 5). Every hierarchical level (for Slovakia this results in 19 separate models across the three levels) is represented by a specific trained model and the best selected features (see Feature Selection and Training Model).

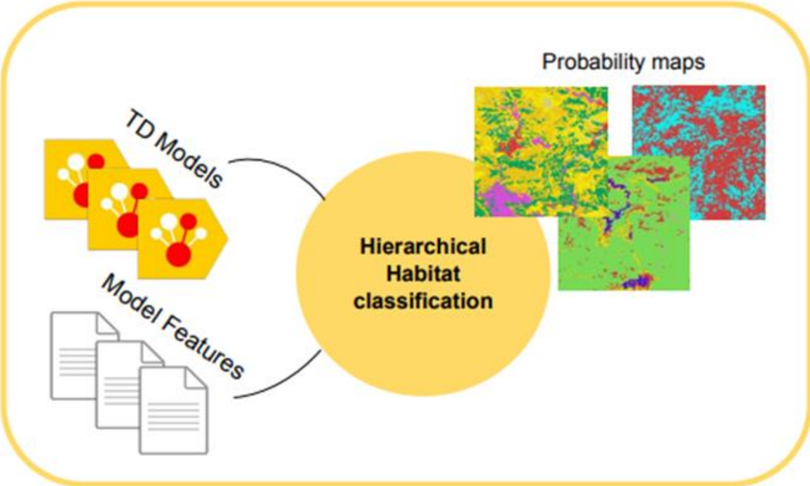



*Figure 5: Terrestrial habitat map workflow - Inference Module*

Finally, the Post-processing Module joins all hierarchical probability maps (output from the inference module) and produces a categorical EUNIS Habitat map with an accompanying quality layer. The selection of the final categorical class can be combined with the availability of habitat suitability layers. The latter layers are typically generated by species distribution models and identify the location where a habitat can appear (its suitability).

More information on the workflow can be found in EuropaBON Deliverable 5.2 (Past-to-present EBV modelled datasets and status indicator for selected terrestrial habitats in the Habitats Directive), available through https://riojournal.com/topical_collection/145/.

As explained above, the workflow is based on Artificial Intelligence, hence the training of the models is an, if not utmost, important aspect to generate high accurate Habitat maps. Therefore, special attention was given to the sampling of the training reference data, as described in the sections below.

### 2.2.3.2 Reference data preparation for Slovakia

For Slovakia, a national habitat map was provided up to EUNIS2012[4] Level 2 or 3 classification. Since a previous attempt at creating a detailed habitat map of Slovakia with our habitat mapping workflow had pointed out that our habitat map seemed to be a lot more accurate than the national (provided) habitat map when comparing the two maps to Google Satellite images, we decided to derive a confidence map of the national habitat map at EUNIS2012 Level 1 (Figure 6). This confidence map has an assigned value for each pixel within the national habitat map, based on certain decision rules. The national habitat map at Level 1 was compared with the CLC+ Backbone layer, the CORINE Land Cover map, the JRC Cropmap, the High-Resolution Water and Wetness layer, the High Resolution Grassland layer, the High Resolution Impervious Built-up layer and the High Resolution Forest Type layer. We identified which pixel values of the previously mentioned reference layers correspond to the unique Level 1 classes within the national habitat map. Then, we checked per pixel the match with either 2 or 3 of these reference maps. If the Level 1 class of the national habitat map matched with all reference layers, the confidence was assigned "Highest confidence".

[4] A crosswalk to the EUNIS terrestrial habitat classification 2021 can be found in Annex 4.

If two out of three reference layers matched, the confidence was set as “High confidence”. A “Medium confidence” was assigned if one reference layer matched, and if none reference layers matched, the pixel had a “Low confidence” in classification on the national habitat map. Regarding the pixels with class “X” (i.e., ‘Habitat complexes’), no confidence was derived (since no clear decision rule can be applied).

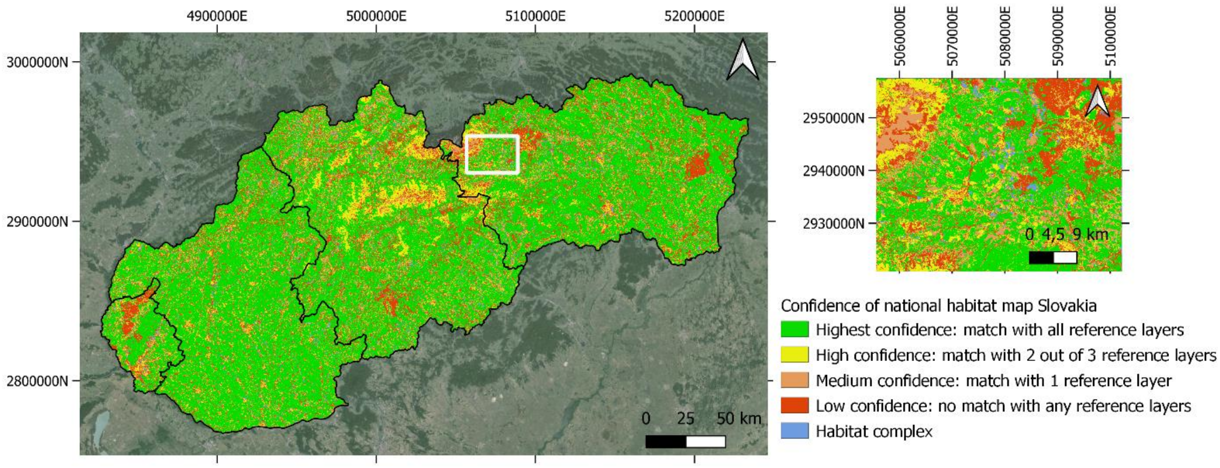



*Figure 6: Generated confidence map to assign confidence in classification of national habitat map of Slovakia.*

The pixels of the national habitat map with a classification up to Level 2 were reclassified into a non-existing Level 3 class by adding an ‘X’ to their label. The raster map was vectorized, so area per Level 3 class could be derived. Then, the fraction of Level 3 class area against total area was calculated as a weight for finding the desired proportional area-wise sample size per Level 3 habitat class, with the goal of a total amount of 50.000 sample points (Total area of 49.023.886.039 m^2, 4.902.388,6039 sample points for one point per grid cell in 100mx100m grid over the area, 1% of all points equals ~50.000). For some rare classes, where the area-weighted desired sample size turned out to be lower than 50 sample points, the sample size was set to a minimum of 200 (to create some buffer when selecting points with minimum distance and confidence criterion). This resulted in a total number of 75.000 sample points at the start of the selection process.

The European Vegetation Archive (EVA) database was used as the initial input for training point selection. We selected the EVA datapoints for which the location uncertainty was zero or less than 10%, that contained a ‘highest’/’high’/’medium’ confidence on the confidence map and for which the habitat classification at Level 2 matched the Level 2 classification of the national habitat map. This resulted in a selection of 5496 points out of the initial set of 7375 available points in the region. Next, the selected points were filtered again based on a minimum distance threshold of 250 meters. Lastly, the EVA points were removed that did not contain a habitat classification up to Level 3. This resulted in a final set of 1193 remaining EVA points.

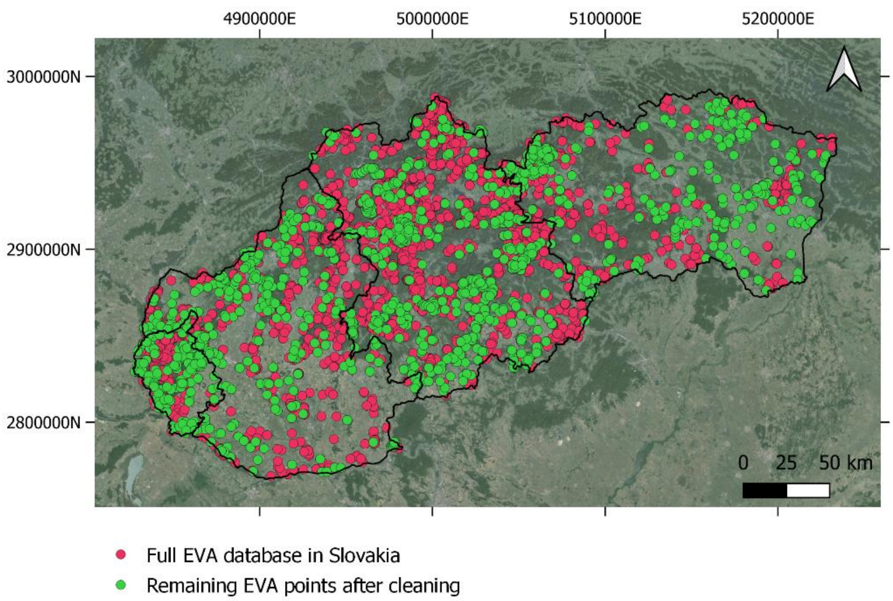



*Figure 7: Visualization of full EVA database in Slovakia (red) and EVA datapoints left after filtering on location uncertainty, confidence level, classification match with national habitat map and minimum distance threshold (green).*

Since the remaining set of EVA points only covered the desired total sample size for a small fraction, additional training points had to be selected from another source. In QGIS, we aimed at extracting the desired sample size per Level 3 habitat class from the national (provided) habitat map with the "Random Points In Polygons" research tool, and a specified inter-points minimum distance of 50 meters. If not enough points per habitat class were selected, we ran a random sampling for that class as a standalone vector and added these selected points to the dataset. Next, the confidence of these selected points was assessed and based on the number of points per Level 1 class in each confidence category, we only kept the points within selected categories (Table 5).

*Table 5: Overview of selected points from national habitat map within various confidence levels highlighted in light green.*

| Confidence Level | C | D | E | F | G | H | I | J | X |
|---|---|---|---|---|---|---|---|---|---|
| **Highest** | 216.3895 | 3.736 | 33 660.963 | 9.173 | 162 351.747 | 0 | 110 005.005 | 51.816 | 11 281.326 |
| **High** | 253.953 | 18.995 | 14 889.410 | 1 441.527 | 20 264.181 | 78.119 | 14 704.708 | 7 823.049 | |
| **Medium** | 333.402 | 1 063.279 | 12 285.771 | 5 451.788 | 7 421.431 | 109.403 | 14 484.984 | 4 215.774 | |
| **Low** | 378.9947 | 813.903 | 40 108.690 | 3 384.975 | 5 241.427 | 1 317.595 | 851.898 | 10 764.888 | |

The two datasets of selected points (EVA datapoints and points from national habitat map within selected confidence levels) were combined and filtered once again with a minimum distance threshold of 50 meters. In this filter process, we aimed at removing points that were selected from the national habitat map since the habitat classification of the EVA datapoints contain a higher credibility than the classification in the national habitat mapping. In case the resulting dataset still contained too many points, we randomly removed points selected from the national habitat map per class, until a dataset of more or less the desired amount of training points was reached. The combined set of all selected training points by this described method resulted in a total set of 45.249 training points (Figure 8).

The originally set desired total amount of training points (i.e., 50.000 points) was not reached, mainly due to the minimum distance criterion. Table 6 shows how many points per habitat class were selected, as also if the training points of a particular class were used in the hierarchical habitat mapping at Level 1, 2 or 3. Since our habitat mapping is hierarchical (i.e., Level 2 mapped classes are merged into Level 1 habitat maps and Level 3 mapped classes are merged into the hierarchically merged Level 2 maps), it is not always necessary to create habitat models for all classes. For habitat mapping at Level 1, all training points are evidently used. Since all Level 1 classes contain at minimum two Level 2 classes, all points are also used for habitat mapping at Level 2. At Level 3, it gets a bit more complicated. Here, we will leave out training points of a certain Level 3 class if that is the only Level 3 class that will be merged into a Level 2 class (i.e., the hierarchical merge can only assign one other class to that area). This explains for example why the training points for classes D2.2 and E6.2 are not used in habitat mapping at Level 3. Note that the 'X' after the dot indicates that these points were not classified to Level 3, therefore they do not provide useful information for habitat mapping at Level 3. For all J-classes at Level 3, the training points were removed from habitat mapping at Level 3 since we also didn't have intention to map J-classes any further than Level 2.

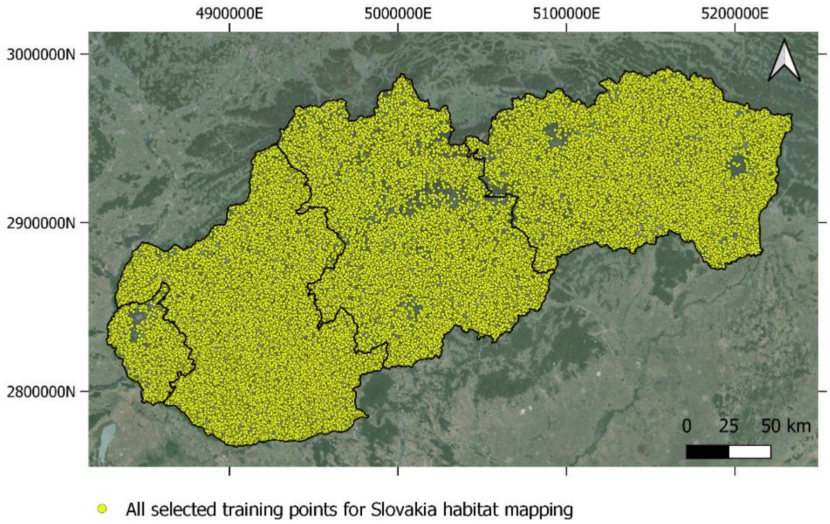



*Figure 8: Overview of final training data generated for habitat mapping in Slovakia.*

*Table 6: Overview of unique habitat classes within training data, their amount of training points for that particular class and clarification if these points are used for hierarchical mapping at level 1, 2 or 3.*

| EUNIS2007 habitat class | Number of training points | Used in Level 1 habitat mapping | Used in Level 2 habitat mapping | Used in Level 3 habitat mapping |
|---|---|---|---|---|
| C1.1 | 12 | True | True | True |
| C1.2 | 67 | True | True | True |
| C1.3 | 51 | True | True | True |
| C1.4 | 32 | True | True | True |
| C1.X | 191 | True | True | False |
| C2.1 | 50 | True | True | False |
| C2.X | 55 | True | True | False |
| C3.2 | 53 | True | True | True |
| C3.4 | 55 | True | True | True |
| C3.5 | 70 | True | True | True |

| EUNIS2007 habitat class | Number of training points | Used in Level 1 habitat mapping | Used in Level 2 habitat mapping | Used in Level 3 habitat mapping |
|---|---|---|---|---|
| C3.X | 25 | True | True | False |
| D1.1 | 55 | True | True | False |
| D1.X | 55 | True | True | False |
| D2.2 | 61 | True | True | False |
| D4.1 | 79 | True | True | False |
| D5.2 | 33 | True | True | False |
| E1.1 | 49 | True | True | True |
| E1.2 | 151 | True | True | True |
| E1.X | 22 | True | True | False |
| E2.1 | 416 | True | True | True |
| E2.2 | 1633 | True | True | True |
| E2.3 | 32 | True | True | True |
| E2.6 | 26 | True | True | True |
| E2.X | 2482 | True | True | False |
| E3.4 | 175 | True | True | True |
| E3.5 | 22 | True | True | True |
| E3.X | 30 | True | True | False |
| E4.3 | 47 | True | True | True |
| E4.4 | 34 | True | True | True |
| E4.X | 24 | True | True | False |
| E5.4 | 288 | True | True | True |
| E5.5 | 21 | True | True | True |
| E5.X | 241 | True | True | False |
| E6.2 | 20 | True | True | False |
| F2.2 | 77 | True | True | True |
| F2.3 | 21 | True | True | True |
| F2.4 | 186 | True | True | True |
| F3.1 | 39 | True | True | True |
| F3.2 | 55 | True | True | True |
| F4.2 | 37 | True | True | False |
| F4.X | 38 | True | True | False |
| F9.1 | 91 | True | True | False |
| FB.4 | 710 | True | True | False |
| FB.X | 50 | True | True | False |
| G1.1 | 44 | True | True | True |
| G1.2 | 384 | True | True | True |
| G1.4 | 78 | True | True | True |
| G1.5 | 66 | True | True | True |
| G1.6 | 13500 | True | True | True |
| G1.7 | 780 | True | True | True |
| G1.8 | 230 | True | True | True |
| G1.A | 3100 | True | True | True |
| G1.D | 28 | True | True | True |

| EUNIS2007 habitat class | Number of training points | Used in Level 1 habitat mapping | Used in Level 2 habitat mapping | Used in Level 3 habitat mapping |
|---|---|---|---|---|
| G1.X | 55 | True | True | False |
| G2.X | 459 | True | True | False |
| G3.1 | 342 | True | True | True |
| G3.2 | 53 | True | True | True |
| G3.4 | 312 | True | True | True |
| G3.E | 55 | True | True | True |
| G3.X | 158 | True | True | False |
| G4.X | 266 | True | True | False |
| H2.3 | 68 | True | True | True |
| H2.4 | 25 | True | True | True |
| H2.6 | 27 | True | True | True |
| H2.X | 49 | True | True | False |
| H3.1 | 57 | True | True | True |
| H3.2 | 56 | True | True | True |
| H3.6 | 54 | True | True | True |
| H5.X | 47 | True | True | False |
| I1.X | 14000 | True | True | False |
| I2.X | 29 | True | True | False |
| J1.6 | 26 | True | True | False |
| J1.7 | 24 | True | True | False |
| J1.X | 22 | True | True | False |
| J2.1 | 1011 | True | True | False |
| J2.X | 94 | True | True | False |
| J3.X | 18 | True | True | False |
| J4.2 | 15 | True | True | False |
| J4.3 | 2 | True | True | False |
| J4.4 | 22 | True | True | False |
| J4.5 | 14 | True | True | False |
| J4.X | 28 | True | True | False |
| J6.X | 14 | True | True | False |
| X04.X | 54 | True | True | False |
| X07.X | 745 | True | True | False |
| X09.X | 215 | True | True | False |
| X10.X | 607 | True | True | False |
| X25.X | 55 | True | True | False |

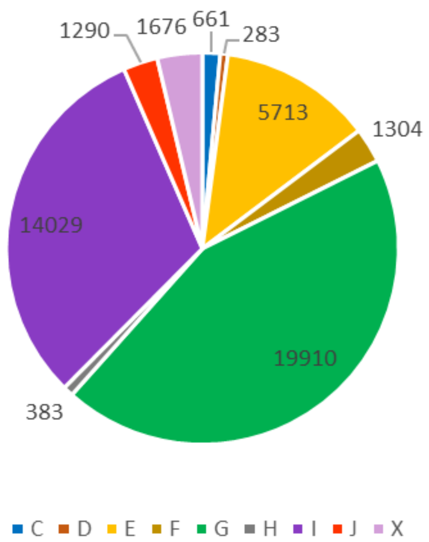



*Figure 9: Overview of collected training points for Slovakia habitat mapping per EUNIS2007 Level 1 habitat class.*

### 2.2.3.3 Reference data preparation for Greece

The MAES map was used to retrieve the area distribution of EUNIS2021 Level 1 habitat classes over Peloponnese. The MAES map has its own LIFE-IP classification typology, that was translated into EUNIS2021 Level 1 classes. Since the current EUNIS2021 habitat typology does not cover urban or industrial areas, we added the class 'J' from the EUNIS2007 habitat typology to provide a wall-to-wall habitat mapping. A proportional area-wise desired sample size was calculated per EUNIS2021 Level 1 habitat class, with the goal of a total amount of 20.000 sample points (Table 7).

*Table 7: Translation LIFE-IP classes of MAES map to EUNIS2021 Level 1, with associated desired sample size per Level 1 class.*

| EUNIS2021 Level 1 habitat class | MAES: LIFE-IP classes contained in EUNIS class | Desired sample size |
|---|---|---|
| J | 1, 2, 23, 24 | 551 |
| M | 21 | 111 |
| N | 16 | 50 |
| Q | 18, 19, 20 | 50 |
| R | 12 | 479 |
| S | 13, 14 | 8803 |
| T | 5, 6, 7, 8, 9, 10, 11, 31 | 3275 |
| U | 15, 17, 22 | 230 |
| V | 3, 4, 30 | 6538 |

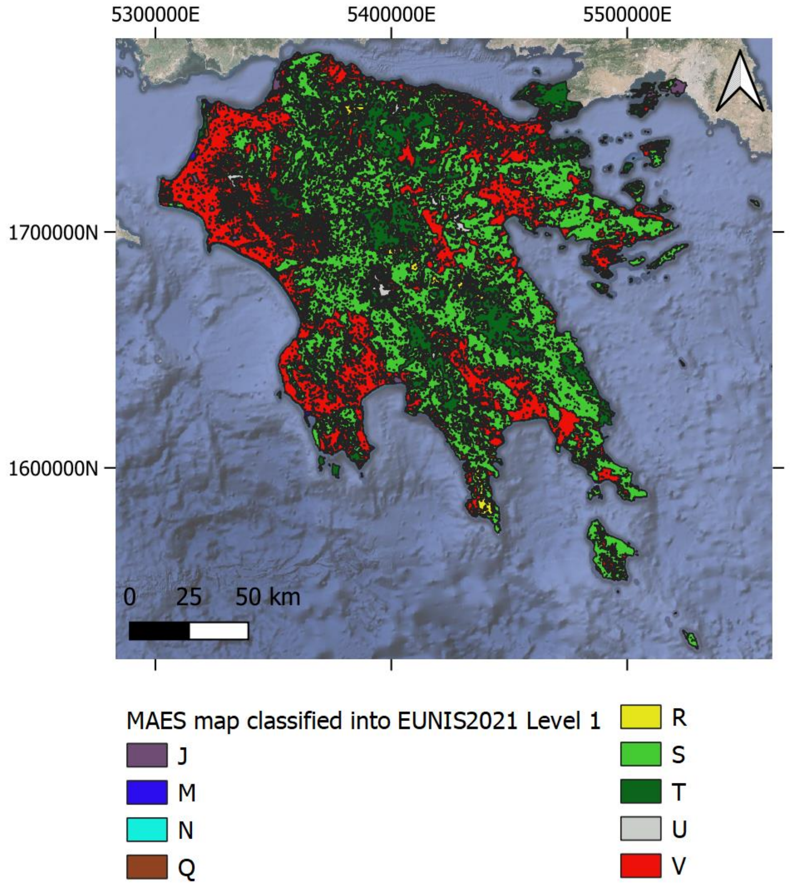
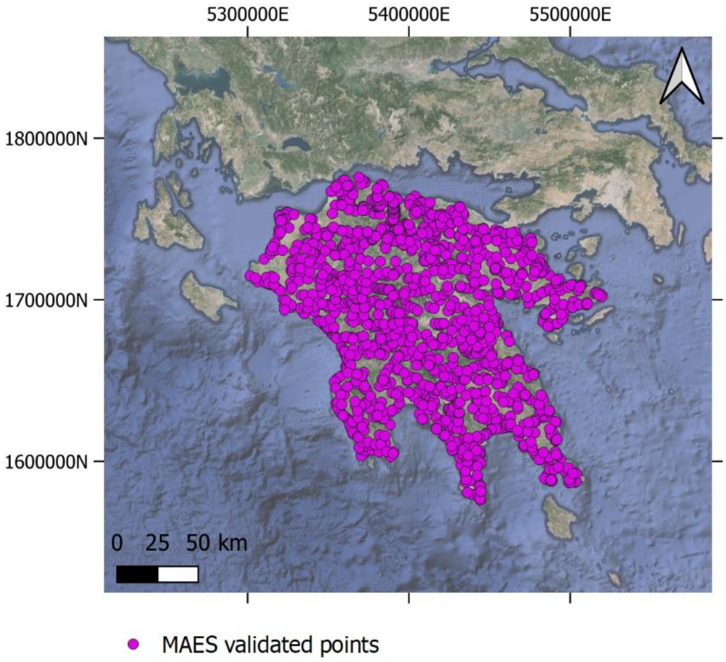
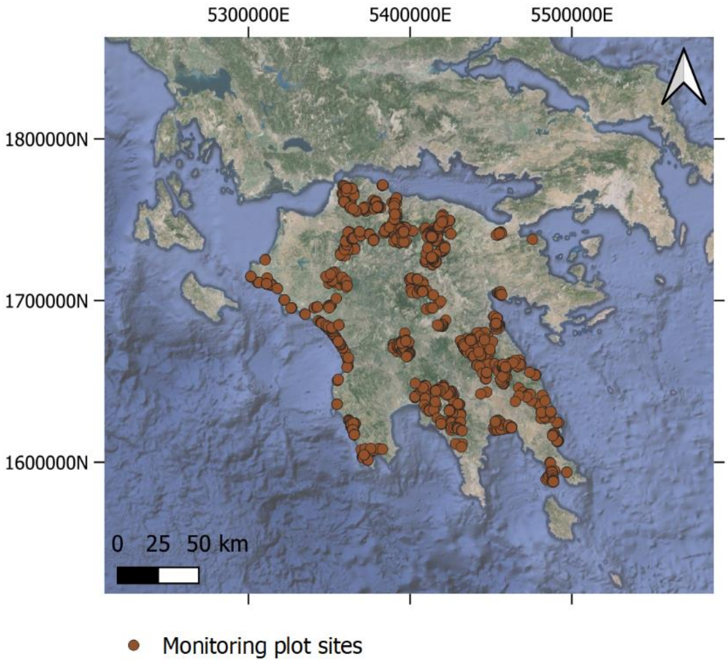


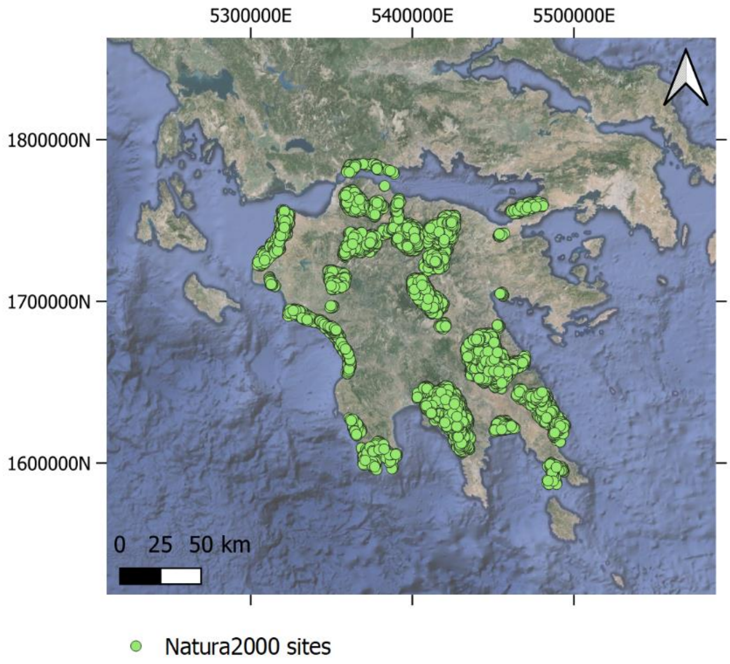
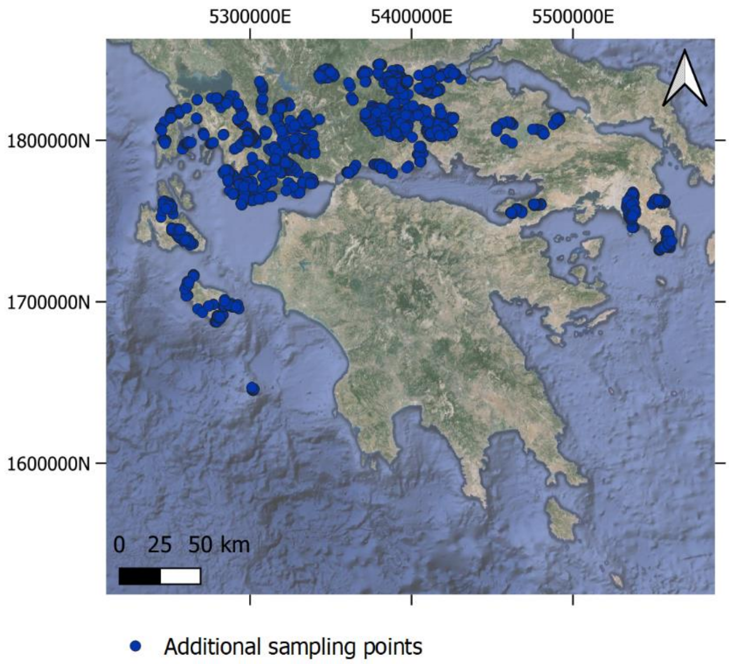

*Figure 10: MAES map with LIPE-IP classes clustered into EUNIS2021 Level 1, for Peloponnese region.*

The data as input for training point selection for the Peloponnese test site consisted of 4 datasets (

Table 8). These point locations were classified into habitat classes according to the Annex-I typology. The classes were translated into EUNIS2021 habitat classes by expert knowledge.

*Table 8: Overview of provided input data for training point selection.*

| Dataset (point vectors) | Description |
|---|---|
| Validated points of MAES map | Validated in the field during LIFE-IP (LIFE Integrated Project)<br>Original classification in Annex I format<br><br> |
| Monitoring plot sites | Situated mainly within and near Natura2000 sites<br>Original classification in Annex-I format<br><br> |

| | |
|---|---|
| Natura2000 sites | Selected and validated points of Natura2000 polygon map<br>Original classification in Annex-I format<br><br> |
| Additional sampling points | Additional validated point vector dataset, covering surrounding Greek domain around Peloponnese, to add training input for coastal zones, grassland and shrub type habitats<br>Original classification in Annex-I format<br><br> |

The 4 datasets were combined and counts per unique EUNIS2021 Level 3 habitat class were extracted. Then all Level 3 classes for the same Level 1 class were summed up and the fraction of each Level 3 habitat class in its associated Level 1 class was calculated. Then, this fraction was multiplied with the desired sample size per EUNIS2021 Level 1 habitat class, in Table 7.

As a result, the proportional area-wise amount of sample points for each EUNIS2021 Level 3 habitat class was found. This amount was raised to a minimum amount of 20 points if the resulting amount for the Level 3 class was under 20.

Next, a random sample point selection was run to extract for each Level 3 habitat class the desired number of points, considering a minimum distance of 100 meters between all selected points (not only between points within one habitat class but also between points of different habitat classes). For Level 1 classes R, S and V not enough training points were selected, due to the criterion of minimum distance between the points. For classes R and S this was not a substantial amount, so it was decided to neglect the lack of training points. However, for class V still many points were missing, to create a representative area sample for the region. Also, the 4 datasets did not contain data on classes J and M. Therefore, the remaining necessary points for classes J, M and V were extracted from the MAES map (Figure 10), considering a minimum distance of 100 meters between all selected points (also considering the previously selected training points).

The combined set of all selected training points by this described method resulted in a total set of 17.400 training points (Figure 11, Figure 12). The originally set desired total amount of training points (i.e., 20.000 points) was not reached, due to the minimum distance criterion. Table 9 shows how many points per habitat class were selected, as also if the training points of a particular class were used in the hierarchical habitat mapping at Level 1, 2 or 3. For habitat mapping at Level 1, all training points are evidently used. At Level 2, training points for classes J, M and V are left out since they were extracted from the MAES map and are mapped up to Level 1. Furthermore, we did not have the intention to map classes J and M further than Level 1. For all V-classes at Level 3, the training points were removed from habitat mapping at Level 3 since we also didn't have intention to map V-classes any further than Level 2.

*Table 9: Overview of unique habitat classes within training data, their amount of training points for that class and clarification if these points are used for hierarchical mapping at level 1, 2 or 3.*

| EUNIS2021 habitat class | Number of training points | Used in Level 1 habitat mapping | Used in Level 2 habitat mapping | Used in Level 3 habitat mapping |
|---|---|---|---|---|
| J | 551 | True | False | False |
| M | 96 | True | False | False |
| N12 | 20 | True | True | True |
| N14 | 50 | True | True | True |
| N16 | 20 | True | True | True |
| N1B | 20 | True | True | True |
| N1G | 15 | True | True | True |
| N1J | 20 | True | True | True |
| N35 | 20 | True | True | False |
| Q23 | 15 | True | True | False |
| Q53 | 43 | True | True | False |
| Q63 | 12 | True | True | False |
| R1D | 85 | True | True | True |
| R1E | 15 | True | True | True |
| R1K | 73 | True | True | True |
| R61 | 28 | True | True | False |

| EUNIS2021 habitat class | Number of training points | Used in Level 1 habitat mapping | Used in Level 2 habitat mapping | Used in Level 3 habitat mapping |
|---|---|---|---|---|
| S24 | 13 | True | True | False |
| S51 | 564 | True | True | True |
| S52 | 10 | True | True | True |
| S54 | 45 | True | True | True |
| S62 | 3378 | True | True | False |
| S72 | 816 | True | True | True |
| S75 | 1234 | True | True | True |
| S93 | 92 | True | True | False |
| T14 | 202 | True | True | True |
| T19 | 231 | True | True | True |
| T1A | 23 | True | True | True |
| T21 | 259 | True | True | True |
| T24 | 285 | True | True | True |
| T2B | 254 | True | True | True |
| T36 | 317 | True | True | True |
| T3A | 273 | True | True | True |
| T3D | 83 | True | True | True |
| T3N | 27 | True | True | True |
| T3P | 1320 | True | True | True |
| U29 | 31 | True | True | False |
| U38 | 169 | True | True | False |
| U5 | 19 | True | True | False |
| U72 | 11 | True | True | False |
| V | 5063 | True | False | False |
| V11 | 41 | True | True | False |
| V13 | 221 | True | True | False |
| V16 | 11 | True | True | False |
| V17 | 344 | True | True | False |
| V31 | 8 | True | True | False |
| V54 | 61 | True | True | False |
| V55 | 19 | True | True | False |
| V61 | 50 | True | True | False |
| V62 | 345 | True | True | False |
| V67 | 196 | True | True | False |
| V68 | 302 | True | True | False |

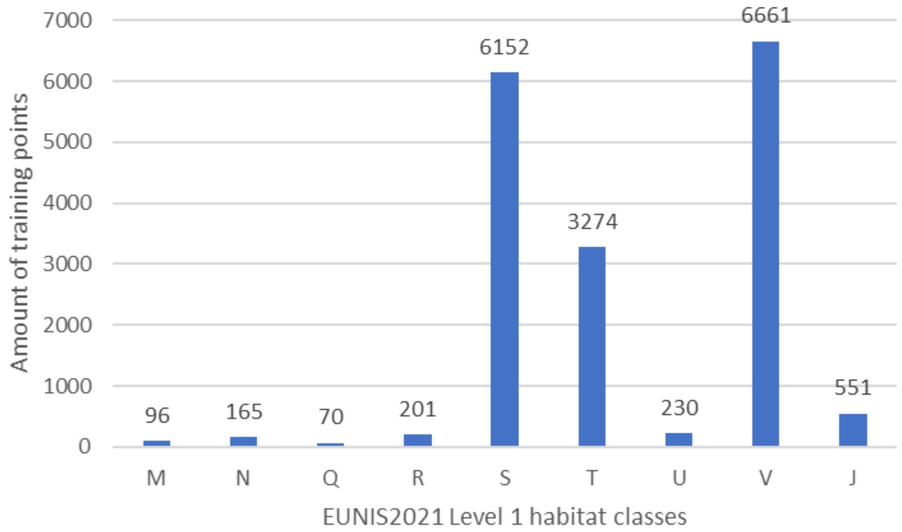



*Figure 11: Overview of collected training points for Peloponnese habitat mapping per EUNIS2021 Level 1 habitat class.*

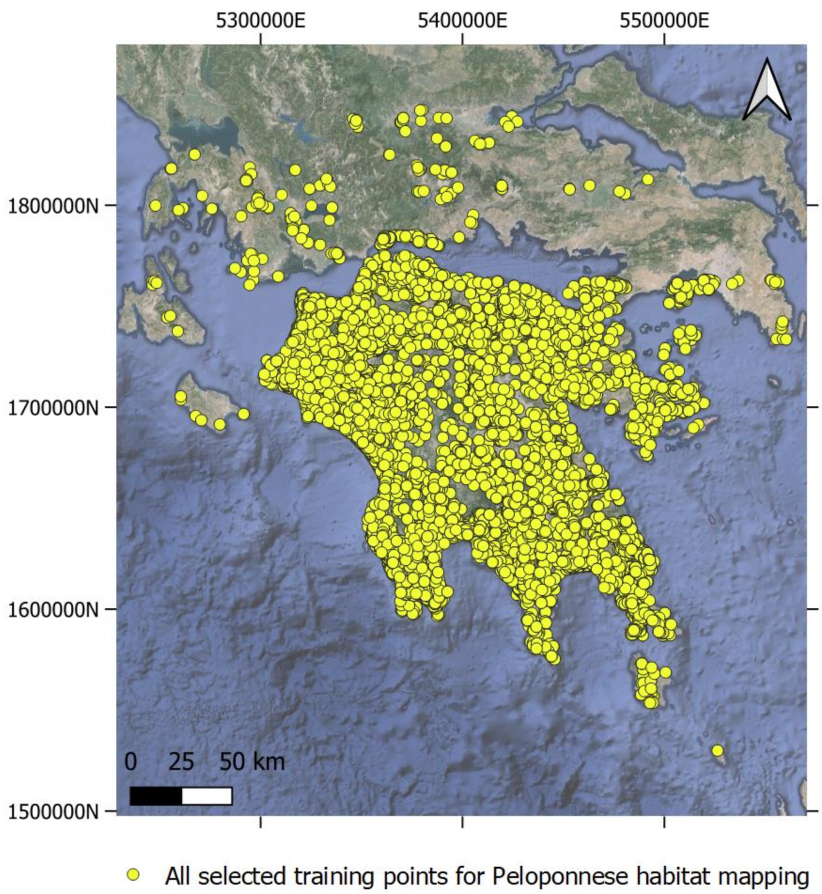



*Figure 12: Overview of final training data generated for habitat mapping in Peloponnese.*

## 2.2.4 Component Extent mapping

The current version of extent mapping is based on some simple rules based on three important inputs, as shown in Figure 2: land surface characteristics, habitat/vegetation characteristics, land use characteristics.

### 2.2.4.1 Level-1 mapping

The first step is mapping at EU Typology level 1, which is closely related to land surface characteristics. Therefore, the rules are based on using primarily land surface characteristics for non-vegetated classes and habitat maps for vegetated classes.

More details on the rules for level-1 mapping are shown in Table 10. Column B shows the ecosystem extent class, columns E, H and I show the three input sources. The extent rule is shown in column L and the final extent map value in column M. It is important to notice that the extent rules are executed in a specific order and this order defines also the mutual exclusive class of the extent map. The order of the rules is shown with the number in brackets (x) before the actual extent rule. Column J shows a potential secondary data source which is not included in the rule itself but used for the Quality flag. If both the primary source and the secondary source have the same information, then the level of the quality is raised.

Some observations / limitations:

- CLC+ backbone layer, used as input for land surface characteristics has no cropland class, therefore the global WorldCover map (ESA) is used. The former layer is from 2018, while the latter is for 2020 which could cause some errors if land is converted from/to cropland within this period.
- CLC+ backbone layer has a single class for water, so the OpenStreetMap layer is used to distinguish rivers & canals (ecosystem type 8) to lakes and reservoirs (ecosystem type 9). The OpenStreetMap layer is currently used to generalize the mapping across full Europe, however, can be replaced by national layers.
- The EUNIS 2012 typology includes a complex class (X), which combines different vegetation types outside the R, S, T classes. If we would not crosswalk them, some pixels would remain unclassified at Level-1. Therefore, specific rules are added to map these complex classes using the land cover characteristics (CLC+ backbone layer).
- The EUNIS 2021 typology includes a human man-made class (V), which is typically mapped to cropland. At level-1 this EUNIS input is not required.

*Table 10: EU extent mapping protocol – level 1*

| B | E | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|
| EU ecosystem typology: level 1 | Habitat maps | EU/Global data sources for augmentation | National data soruces for augmentation | Data sources to confirm (raise confidence) | | Extent RULE | Raster value |
| 1. Settlements and other artificial areas | J | CLC+ backbone (sealed=1) | | EUNIS is J | | (1) CLC+ backbone is sealed or (13) EUNIS = J | 1000 |
| 2. Cropland | | ESA worldcover (crop= ), future HRL_crop | | EUNIS is V | | (4) ESA worldcover is cropland | 2000 |
| 3. Grassland (pastures, semi- | R, X | | | CLC+ backbone is permanent grassland | | (7) EUNIS is class R or CLC+ is period grassland or (14) EUNIS=X and CLC+ is grassland | 3000 |
| 4. Forest and woodlands | T, X | | | CLC+ backbone woody trees (2,3,4) | | (5) EUNIS is class T or (16) EUNIS=X and CLC+ is forest | 4000 |
| 5. Heathland and shrub | S, X | | | low-growing woody plants (5) | | (8) EUNIS is class S or (15) EUNIS=X and CLC+ is woody plants | 5000 |
| 6. Sparsely vegetated | U | CLC+ backbone is non or sparse vegetated (9) or lichen and mosses | | EUNIS is U | | (11) CLC+ backbone is sparse or lichen/mosses | 6000 |
| 7. Inland wetlands | Q | | | CLC+ backbone is periodical grassland | | (6) EUNIS is class Q | 7000 |
| 8. Rivers and canals | | CLC+ backbone (water = 10) | OpenStreetmap (river=8101, stream=8102, canal=8103) | EUNIS is U | | (3) CLC+ backbone is water or OpenStreetMap_waterways is canal, river or stream | 8000 |
| 9. Lakes and reservoirs | | CLC+ backbone (water = 10) | | EUNIS is U | | (2) CLC+ backbone is water | 9000 |
| 10. Marine inlets and transitional waters | | | | | | skipped | 10000 |
| 11. Coastal beaches, dunes and wetlands | N | Continental coastal zone mask (1km) | | | | (9) EUNIS is class N and within coastal zone or (10) ET=settlement and other artificial areas within coastal zone mask | 11000 |
| 12. Marine ecosystems | | | | | | skipped | 12000 |

### 2.2.4.2 Level-2 mapping

After applying the rules at Level-1, a set of rules are defined to decompose every (except artificial) ecosystem extent pixel to Level-2. The rules are shown in Table 11.

Some observations / limitations:

- Detect L2 classes for settlements and other artificial areas was not further explored. To distinguish settlement areas and infrastructure areas, the HRL impervious layer can be used following the protocol as defined in Corine. The urban greenspace can be detected with the combination of the Copernicus VPP layers.
- Rice fields were not further investigated and mapped, as they were not occurring in our test areas.
- The distinction of agro-forestry and other farmland is currently dependent on EUNIS, however is a vegetation man-made class which is harder to distinguish from EO. Hence it is advised to explore further integration of land use information.
- The detection of small linear features as hedgerows and tree rows in cropland or grassland was not further tested, however Copernicus provides a small woody feature layer that could be explored to be integrated.
- Transitional forest and woodland shrub are currently derived from EUNIS V6. As with agro-forestry, this is a Vegetation man-made class and further investigation is required to potentially use other EUNIS classes for clear-felling and/or transitional woodland.
- Plantations is derived from some specific EUNIS T classes but requires further validation to check its consistency. Complementing with land-use information could improve its accuracy.
- To distinct rivers from canals/ditches and lakes from artificial reservoirs, the Open Street Map layer was used. This layer can be used for entire continent, but its accuracy needs to be evaluated. Furthermore, the vector layer is currently rasterized at the 10m pixel level, while some further selection is required especially for rivers and canals (some are larger while others are smaller). Adding complementary land use (or cadastre) information can improve.
- Ice sheets, glaciers and perennial snowfields were not further explored, as they were not occurring in our test areas.
- Marine inlets and transitional waters were not explored, as well as Marine ecosystems.

*Table 11: EU extent mapping protocol – level 2*

| EU ecosystem typology: level 1 | EU ecosystem typology level 2 | Habitat maps | EU/Global data sources for augmentation | National data soruces for augmentation | Data sources to confirm (raise confidence) | | Extent RULE | Raster value |
|---|---|---|---|---|---|---|---|---|
| 2. Cropland | 2.1 Annual cropland | | CLMS_HRL_TCD (<30%) | | | | CLMS_HRL_TCD <30% | 2100 |
| | 2.2 Rice fields | | | | | | | 2200 |
| | 2.3 Permanent crops | | CLMS_HRL_TCD (>70%) | | | | CLMS_HRL_TCD (>70%) | 2300 |
| | 2.4 Agro-forestry areas | V5 | ?? | | | | EUNIS is class V5 | 2400 |
| | 2.5 Mixed farmland | | CLMS_HRL_TCD (30%<70%) | | | | CLMS_HRL_TCD (30%<70%) | 2500 |
| | 2.6 Other farmland | V1 | ?? | | | | EUNIS is class VV1 | 2600 |
| | 2.7 Hedgerows and tree rows in cropland | | | | | | next version, test future HRL_SWF | 2700 |
| 3. Grassland (pastures, semi-natural and natural grasslands) | 3.1 Sown pastures and fields (modified | R1, R2 | | OpenStreetmap (landuse=meadows) | | | EUNIS is class R2 or (R1 if OSM is meadows) | 3100 |
| | 3.2 Natural and semi-natural grasslands | R1, R3 to R7 | | | | | EUNIS is R3 to R7 or R1 if OSM is not meadows | 3200 |
| | 3.3 Hedgerows and tree rows in grassland | | | | | | next version, test future HRL_SWF | 3300 |
| 4. Forest and woodlands | 4.1 Broadleaved deciduous forest | T1 | | | CLC+ BB woody broadleaved decidious (3)<br>HRL dominant leaf type (1) | | EUNIS is class T1 minus (T1H, T1K) minus mixed (FTY) | 4100 |
| | 4.2 Coniferous forests | T3 | | | CLC+ BB woody needleleaf (3)<br>HRL dominant leaf type (2) | | EUNIS is class T3 minus (T3M,T3N) minus mixed (FTY) | 4200 |
| | 4.3 Broadleaved evergreen forest | T2 | | | CLC+ BB woody broadleaf evergreen (4)<br>HRL dominant leaf type (1) | | EUNIS is class T2 minus (T29, T2A) | 4300 |
| | 4.4 Mixed forests | | HRL_FTY | | | | FTY at 100m = 3 (mixed) | 4400 |
| | 4.5 Transitional forest and | V6 | | | check eunis on clear-felling and/or | | EUNIS is V6 | 4500 |
| | 4.6 Plantations | T* | | | | | EUNIS is one of class (T1K, T29, T2A, T3M, T3N) | 4600 |
| 5. Heathland and shrub | 5.1 Tundra | S1 | | | | | EUNIS is S1 | 5100 |
| | 5.2 Heathland and (sub-) | S2 to S4 | | | | | EUNIS is S2, S3 or S4 | 5200 |
| | 5.3 Sclerophyllous vegetation | S5 to S8 | | | | | EUNIS is S5, S6, S7 or S8 | 5300 |

| EU ecosystem typology: level 1 | EU ecosystem typology level 2 | Habitat maps | EU/Global data sources for augmentation | National data soruces for augmentation | Data sources to confirm (raise confidence) | | Extent RULE | Raster value |
|---|---|---|---|---|---|---|---|---|
| 6. Sparsely vegetated ecosystems | 6.1 Bare rocks | H2, H3 | | | | | EUNIS is H2 or H3 | 6100 |
| | 6.2 Semi-desert, desert and other sparsely | H5 | | | | | EUNIS is H5 | 6200 |
| | 6.3 Ice sheets, glaciers and perennial snowfields | | | | snow and ice (11) | | | 6300 |
| 7. Inland wetlands | 7.1 Inland marshes on | D6 | | | | | EUNIS is D5 or D6 | 7100 |
| | 7.2 Mires, bogs and fens | D1 to D4 | | | | | EUNIS is D1 or D2 or D3 or D4 | 7200 |
| 8. Rivers and canals | 8.1 Rivers | | | OSM = 8103 or 8104 | | | OSM_waterways is river or stream | 8100 |
| | 8.2 Canals, ditches and drains | | | OSM = 8101 | | | OSM_waterways is canal | 8200 |
| 9. Lakes and reservoirs | 9.1 Lakes | | | OpenStreetmap OSM=8101 | | | OSM_water is not reservoir | 9100 |
| | 9.2 Artificial reservoirs | | | | | | OSM_water is reservoir | 9200 |
| | 9.3 Geothermal pools and wetlands (Iceland) | | | | | | | 9300 |
| 11. Coastal beaches, dunes and wetlands | 11.1 Artificial shorelines | | CLC+ Backbone (sealed), Coastal mask | | | | CLC+ backbone is sealed and ET coastal mask is true | 11100 |
| | 11.2 Coastal dunes, beaches and sandy and | N1 | Coastal mask | | | | EUNIS is N1 and ET coastal mask is true | 11200 |
| | 11.3 Rocky shores | N3 | Coastal mask | | | | EUNIS iS N3 and ET coastal mask is True | 11300 |
| | 11.4 Coastal saltmarshes and salines | | | | | | | 11400 |

### 2.2.4.3 Level-3 mapping

After applying the rules at Level-2, a set of rules are defined to decompose the forest and woodlands, and coastal beaches dunes and wetlands ecosystem extent to Level-3. The rules are shown in Table 12. Further work is required to define the rules to decompose also other ecosystem types to Level-3.

Some observations / limitations:

- EUNIS (level-3) maps provide a very high thematic detail and can be used easily to be crosswalk to EU typology. This was expected since the EU typology is derived from EUNIS at L3. Furthermore, several EUNIS classes need to be grouped for this mapping, hence the EUNIS maps have an additional value to provide more details compared to the EU extent maps, and hence can be positioned as complementary. Countries could use this to further split some L3 classes according to their needs, which is still in line with the EU guidance.
- The highly modified deciduous forest class was not detected, as no training data was available for this class. Note the highly modified coniferous and broadleaved evergreen were classified, but further investigation is required in their accuracy.
- Mixed forests class is currently based on the Copernicus HRL Forest Type (FTY) dataset. This dataset is only provided at 100m resolution and confuses especially the detailed delineation of forests. Therefore, it is suggested to add a ‘moving box’ filter approach in the workflow to make this distinction.
- As explained in L2 mapping, the mapping of plantations was unreliable, hence we did not further distinct plantations into L3.
- The distinction of coastal L3 classes is highly dependent (as other ecosystem types) on the availability of EUNIS training data. We were only able to distinct coastal dunes, beaches and sandy and muddy shores. Special care should be taken to gather also training data for rocky shores and coastal saltmarshes and salines.

*Table 12: EU extent mapping protocol – level 3*

| Level | EU ecosystem typology: level 1 | EU ecosystem typology level 2 | EU Ecosystem typology level 3 | Habitat maps | EU/Global data sources for augmentation | National data soruces for augmentation | Data sources to confirm (raise confidence) | | Extent RULE | Raster value |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 4. Forest and woodlands | 4.1 Broadleaved deciduous forest | 4.1.1 Riparian forest and woodland | T11 to T14 | | | | | EUNIS is T11 to T14 | 4101 |
| 3 | | | 4.1.2 Broadleaved swamp woodland on non-acid and acid peat | T15 to T16 | | | | | EUNIS is T15 or T16 | 4102 |
| 3 | | | 4.1.3 Fagus dominated forest | T17 to T18 | | | | | EUNIS is T17 or T18 | 4103 |
| 3 | | | 4.1.4 Submediterranean and Mediterranean thermophilous deciduous forest | T19A to T1A | | | | | EUNIS is T19 or T1A | 4104 |
| 3 | | | 4.1.5 Acidophilous [Quercus]- dominated woodland | T1B | | | | | EUNIS is T1B | 4105 |
| 3 | | | 4.1.6 Temperate and boreal and Southern European Betula and *Populus tremula* forest on mineral soils | T1C to T1D | | | | | EUNIS is T1C or T1C | 4106 |
| 3 | | | 4.1.7 Other broadleaved deciduous forest, excluding highly-modified plantations | T1E to T1K | | | | | EUNIS is T1E to T1K | 4107 |
| 3 | | | 4.1.8 Highly modified broadleaved deciduous forests including stands of non-native trees species that have long been established in European ecosystems stands | | | | | | ? | 4108 |

| A | B | C | D | E | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|
| Level | EU ecosystem typology: level 1 | EU ecosystem typology level 2 | EU Ecosystem typology level 3 | Habitat maps | EU/Global data sources for augmentation | National data soruces for augmentation | Data sources to confirm (raise confidence) | | Extent RULE | Raster value |
| 3 | | 4.2 Coniferous forests | 4.2.1 Boreal and temperate fir and spruce forest | T32 to T33 | EnvZ_Metzger | | | | if EUNIS old, add envZ to split 4.2.1 and 4.2.2 | 4201 |
| 3 | | | 4.2.2 Mediterranean mountain fir and spruce forest | T32 to T33 | EnvZ_Metzger | | | | EUNIS is T32 or T33 | 4202 |
| 3 | | | 4.2.3 Temperate subalpine Larix, *Pinus cembra* and *Pinus uncinata* forest | T34 | | | | | EUNIS is T34 | 4203 |
| 3 | | | 4.2.4 Pine forest, excluding mires, non-thermophilous | T35 to T39 | | | | | EUNIS is T35, T36, T37, T38 or T39 | 4204 |
| 3 | | | 4.2.5 Mediterranean thermophilous lowland pine forest | T3A | | | | | EUNIS is T3A | 4205 |
| 3 | | | 4.2.6 Spruce, pine and larch mire forest | T3K, T3J | | | | | EUNIS is T3K or T3J | 4206 |
| 3 | | | 4.2.7 Taiga forests | T3F to T3H | | | | | EUNIS is T3F, T3G or T3H | 4207 |
| 3 | | | 4.2.8 Other coniferous forests, excluding plantations | T28 or T3B to T3D or T3L | | | | | EUNIS is T38, T3B, T3C or T3D or T3L | 4208 |
| 3 | | | 4.2.9 Highly modified coniferous forests including stands of non-native trees species that have long been established in European ecosystems stands | T3M to T3N | | | | | EUNIS is T3M or T3N | 4209 |

| A | B | C | D | E | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|
| Level | EU ecosystem typology: level 1 | EU ecosystem typology level 2 | EU Ecosystem typology level 3 | Habitat maps | EU/Global data sources for augmentation | National data soruces for augmentation | Data sources to confirm (raise confidence) | | Extent RULE | Raster value |
| 3 | | 4.3 Broadleaved evergreen forest | 4.3.1 Mediterranean evergreen Quercus forest | T21 | | | | | EUNIS is T21 | 4301 |
| 3 | | | 4.3.2 Mainland laurophyllous forest | T22 | | | | | EUNIS is T22 | 4302 |
| 3 | | | 4.3.3 Macaronesian laurophyllous forest | T23 | | | | | EUNIS is T23 | 4303 |
| 3 | | | 4.3.4 Olea europaea-Ceratonia siliqua forest | T24 | | | | | EUNIS is T24 | 4304 |
| 3 | | | 4.3.5 Palm groves | T25 to T26 | | | | | EUNIS is T25 or T26 | 4305 |
| 3 | | | 4.3.6 Other broadleaved evergreen forests | T27 to T28 | | | | | EUNIS is T27 or T28 | 4306 |
| 3 | | | 4.3.7 Highly modified broadleaved evergreen forests including stands of non-native trees species that have long been established in European ecosystems stands | T2A | | | | | EUNIS is T2A | 4307 |
| 3 | | 4.4 Mixed forests | 4.4.1 Mixed forests dominated by coniferous species | | FTY is mixed | | | | ET level-2 is coniferous AND FTY is mixed | 4401 |
| 3 | | | 4.4.2 Mixed forests dominated by broadleaved species | | FTY is mixed | | | | ET level-2 is deciduous AND FTY is mixed | 4402 |
| 3 | | | 4.4.3 Other mixed forests including stands of non-native trees species that have long been established in European ecosystems stands | | FTY is mixed | | | | ET level-2 is evergreen AND FTY is mixed | 4403 |

| A | B | C | D | E | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|
| Level | EU ecosystem typology: level 1 | EU ecosystem typology level 2 | EU Ecosystem typology level 3 | Habitat maps | EU/Global data sources for augmentation | National data soruces for augmentation | Data sources to confirm (raise confidence) | | Extent RULE | Raster value |
| 3 | | 4.5 Transitional forest and woodland shrub | 4.5.1 Transitional woodland/forest land including recently felled or clear-cut, burnt, replanted or newly afforested | | | | | | | 4501 |
| 3 | | 4.6 Plantations | 4.6.1 Monoculture plantations of non-native tree species (note: forest stands of single or mixed species consisting of native and/or non-native trees species that have long been established in European ecosystems and have diverse undergrowth typical for forest ecosystems should be classified as part of types 4.1 to 4.4) | | | | | | | 4601 |
| 3 | | | 4.6.2. Mixed plantations of a few species of non-European coniferous and broadleaved trees with underdeveloped undergrowth. Forest stands of single or mixed species consisting of native and/or non-native trees species that have long been established in European ecosystems and have diverse undergrowth typical for forest ecosystems should be classified as part of types 4.1 to 4.4) | | | | | | | 4602 |
| 3 | 11. Coastal beaches, dunes and wetlands | | 11.1.1 Artificial shorelines | | | | | | same as Level2 | |
| 3 | | | 11.2.1 Coastal dunes | N14, N16, N18 or N1G | | | | | EUNIS is N14 or N16 or N1B or N1G | 11201 |
| 3 | | | 11.2.2 Beaches and sandy shores | N12 | | | | | EUNIS is N12 | 11202 |
| 3 | | | 11.2.3 Muddy shores | N1J | | | | | EUNIS is N1J | 11203 |
| 3 | | | 11.3.1 Coastal shingle | | | | | | | |
| 3 | | | 11.3.2 Rock cliffs, ledges and shores | | | | | | | |
| 3 | | | 11.4.1 Coastal saltmarshes | | | | | | | |
| 3 | | | 11.4.2 Salines | | | | | | | |

### 2.2.4.4 Consistency update

Since some classes can only be disentangled at level-2 or level-3, at the end of the Level-3 mapping an extra processing step was added to the workflow to merge back the lower-level ecosystem extent map into the higher level. So, classes which move from e.g., forest and woodland ecosystem type to cropland ecosystem type going to the hierarchical mapping are made consistent at the upper layers and hence the result is consistent ecosystem maps at each of the three levels.

## 2.2.5 Component Change mapping

Habitats are not expected to change quickly; however, the current cycle of monitoring every six years is found to be too restrictive and mostly provides few details. To avoid regenerating each habitat map yearly, we try to identify target areas where a change was detected. Changes can be categorized in (i) abrupt changes (e.g., fires, harvested areas, deforestation, flooding) and (ii) gradual changes (e.g., due to climate change, invasive species, etc.). In this study, we focus on the detection of abrupt changes that might directly impact the distribution of the habitat. To this end, the time dimension must be considered, and regular (yearly) detection is required, which is facilitated using Earth Observation remote sensed data streams. Moreover, given that different remote sensing sensors can capture different characteristics of the observed area, it is beneficial to consider such multi-sensor information that might facilitate the detection of an abrupt change in different conditions.

In this test, we tried to develop a separate workflow applying state-of-art Deep Learning techniques to identify changes, as shown in Figure 13.

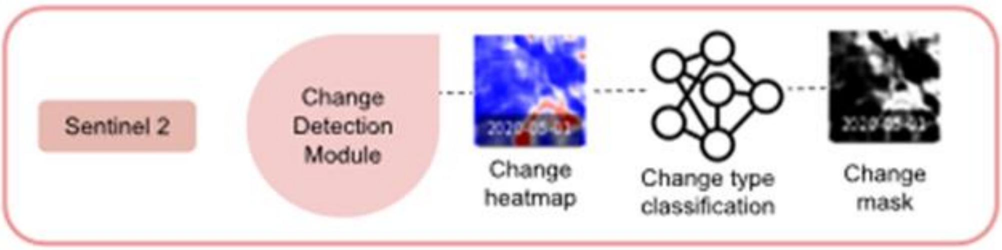



*Figure 13: Terrestrial habitat map workflow – Change Detection Module*

Two approaches were tested, as shown in Figure 14:

- Tile2Vec (Jean, et. al., 2019): an unsupervised, patch-based method that takes the context into account. The inputs are patches of remote sensing imagery, either monthly or yearly composites.
- Siamese Unet (Corley, et. al., 2024): a supervised method that was used with a synthetic dataset derived from landcover. The synthetic dataset was generated by taking patches from 'short' distance land covers and imprint them into the remote sensing dataset to generate 'fake' changes for training purposes. Each potential transition needs to be represented by a 'pair' of synthetic datasets. The pair represents the before and after.

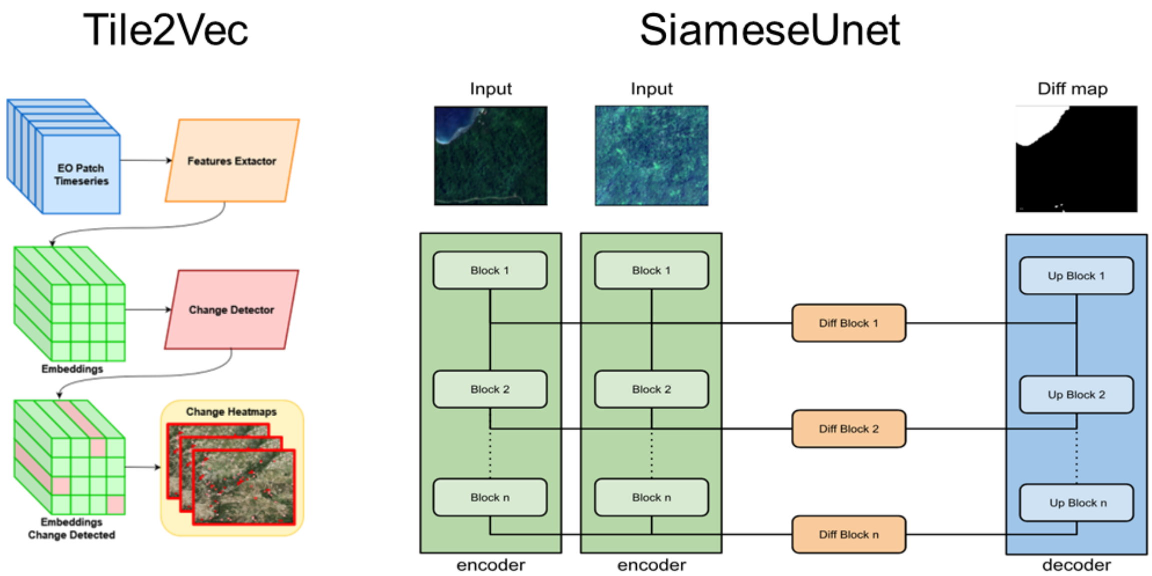



*Figure 14: Change detection methods, tested in the context to detect abrupt ecosystem changes*

The Tile2Vec approach was found that this approach was complex to build triplets for training, had issues with convergence of finding the hotspots of changes and provide a lower resolution (dependent on the context box).

The It was found that the Siamese Unet approach provided a better convergence and performance than the Tile2Vec method, however still some issues were remaining due to the model complexity and noisy results/false positives. Some results can be seen in Figure 15, with the upper right image showing the binary change maps (white is change detected).

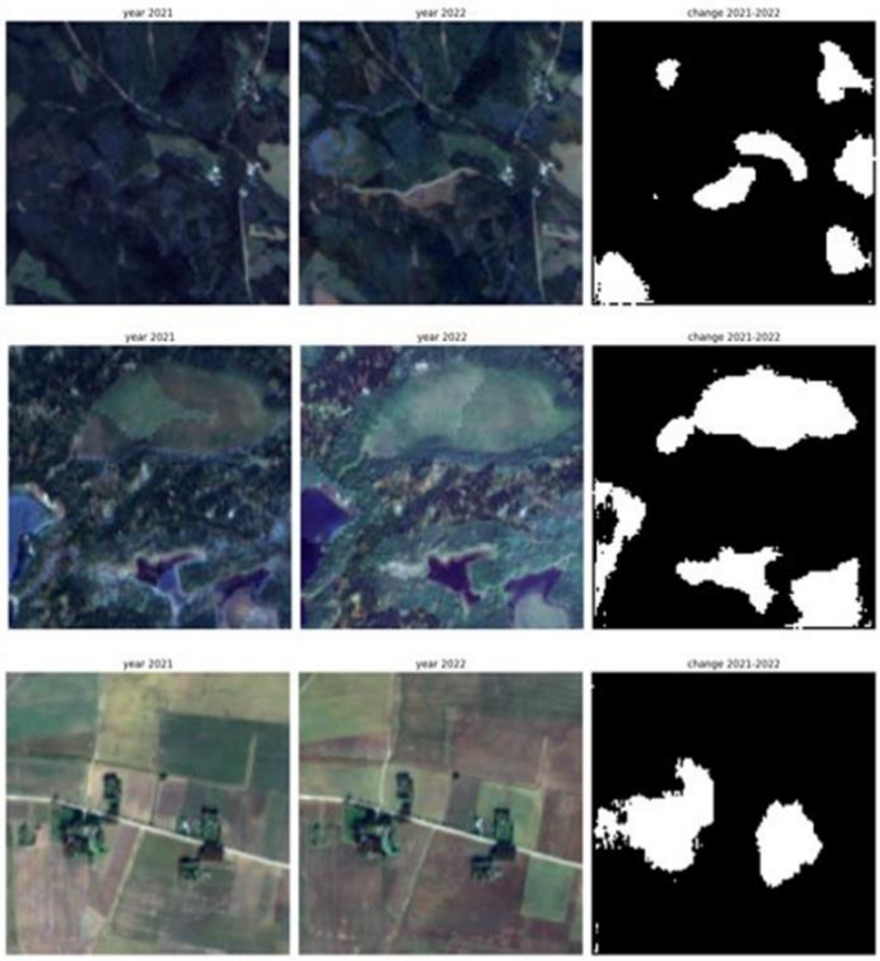



*Figure 15: Examples of change detection results using the Siamese Unet approach.*

Most deep learning models in literature are trained on RGB images and focus on detection of abrupt changes in imperviousness (mainly buildings). The Unet approach is considered a good way forward to detect abrupt ecosystem (land cover) changes. The number of different deep learning networks based on Unet is increasing quickly, and some of these networks (e.g., Early-Fusion Unet) already provide more realistic changes. It is therefore suggested to further explore the integration of such network in the workflow, but also to check more conventional approaches based on time-series break detection as BFAST, CCDC – typically require long time-series requiring the integration of Landsat -; or use of co-variance matrices – able to work with shorter time-series.

### 2.2.6 Component Crosswalk to IUCN GET

A crosswalk table is added in Annex 3, however was not further tested within the timeframe of this project.

## 2.3 Round-robin results

### 2.3.1 Test area and input dataset

Two regions, as shown in Figure 16 and Table 13, are selected to test different algorithm methods to generate ecosystem extent accounts at Level-2 and Level-3. These tests, known as round-robin, are done in close cooperation with Early Adopters in Slovakia and Greece and hence the two regions are in those countries.

Initially the rules were defined for Mid Slovakia (SK03) region, whereafter they were refined – with special attention to coastal – for Peloponnese in Greece.

*Table 13: Test-areas for extent account round-robin*

| Test site (NUTS) | Area size | Sentinel-2 tiles | Rationale |
|---|---|---|---|
| EL632, EL633, EL651, EL652, EL653 (West Peloponnesus) | 20 000 km² | 34SEF, 34SEG, 34SEH, 34SFF, 34SFG, 34SFH, 34SGG | Coastal zone (dunes, coastal forests, wetlands) |
| SK03 (Stredné Slovensko) | 16 000 km² | 33UYP, 33UYQ; 34UCV, 34UCU, 34UDV, 34UDU | Prime forest |

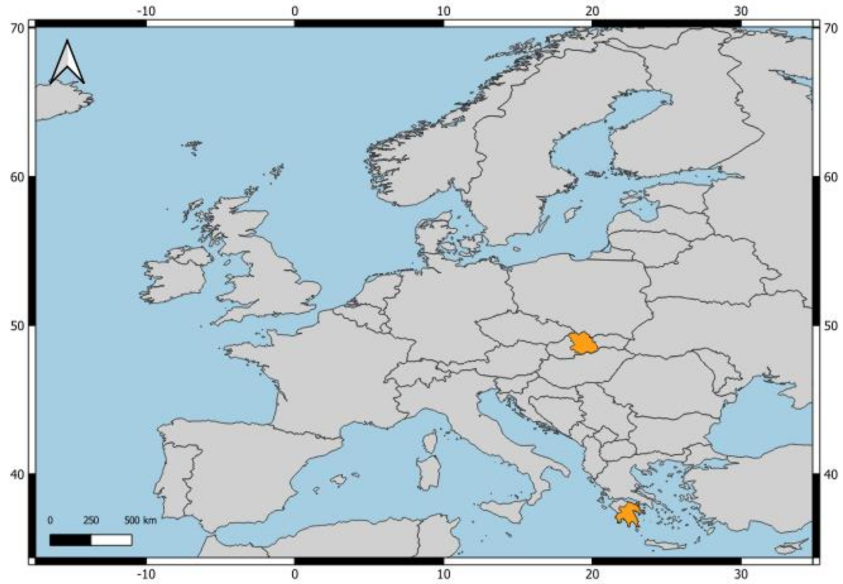



*Figure 16: Test-areas for extent account round-robin*

<u>Reference data Slovakia</u>

Slovakia has generated a geospatial ecosystem map[5] (> 1 million polygons) covering full Slovakia (~49000 km$^2$) and representing the year 2017-2018. The map was generated using GIS analytical tools, based on EUNIS 2017 typology level-3 (for some classes up to level-6), integrating several datasets into a geodatabase [Cernecky et al. 2019]. The more precise datasets were prioritized in overlapping areas and small features (< 10m$^2$ or < 10m width) were merged with larger adjacent polygons. Therefore about 80% of the territory was prepared at a scale 1:5000-1:10000. The map is composed of 9 ecosystem types at EUNIS L1, 20 types at EUNIS L2, 30 types at EUNIS L3 (consistency to be checked to new typology) and 62 types at EUNIS L4 or higher.

We also generated the ecosystem extent account based on the Corine Accounting Layer 2018 (CLCACC) at 100m which is defined as a reference at European scale. We identified some areas with major differences and investigated based on expert judgement by the Early Adopter.

[5] See https://maps.sopsr.sk/wms-ekosystemy?request=getCapabilities

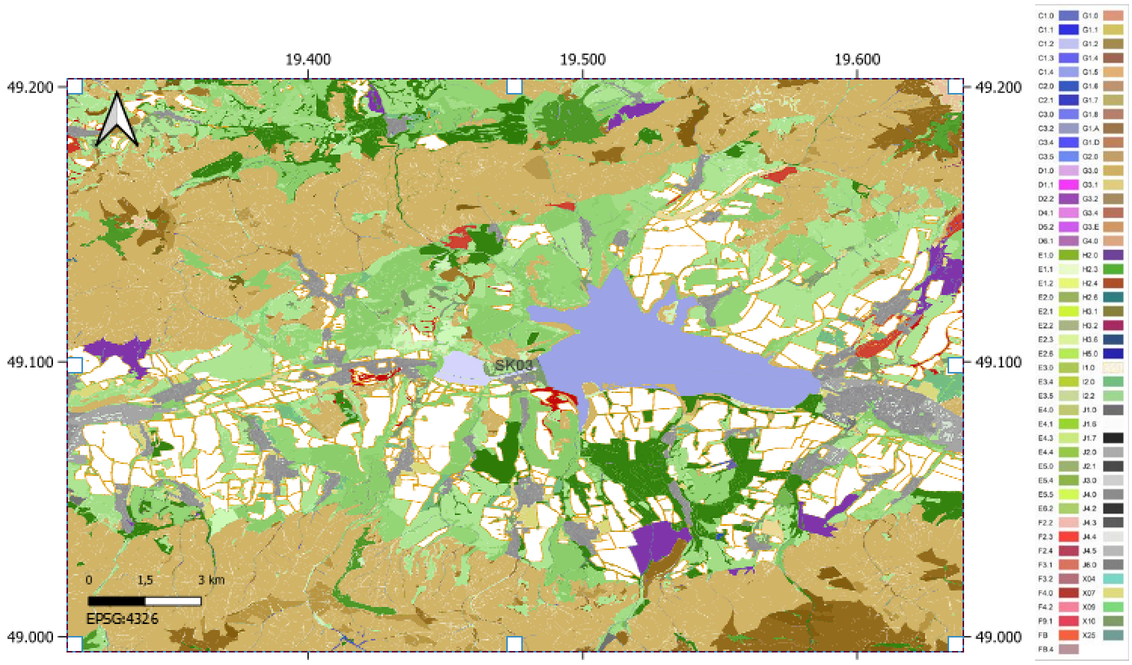



*Figure 17: Ecosystems EUNIS reference map Slovakia – zoom in on test zone (SK03). White areas are unclassified.*

Reference data Greece

Greece has generated a geospatial ecosystem map[5] (Verde et al., 2020) for the terrestrial territory of Greece (~132000 $km^2$, excluding islands) and representing the year 2018. The map was generated using seasonal and monthly EO information (Sentinel 1 + Sentinel 2) and a Random Forest classification with 84 to 168 input features. The training dataset was derived from different European and national datasets and the sampling scheme did include an object (simple non-iterative cluster) segmentation. The map was composed of MAES L3 typology (21 classes).

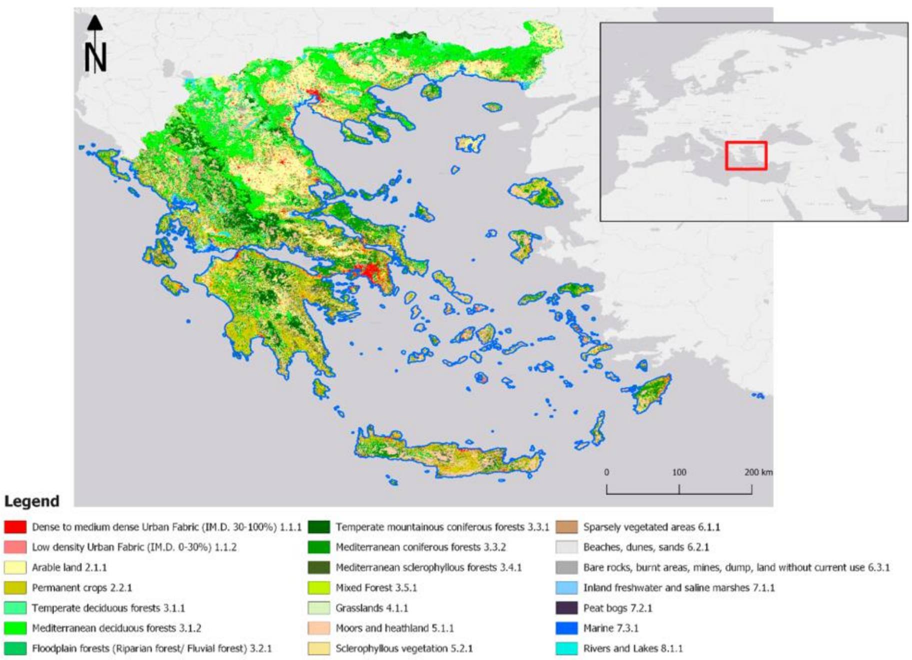



*Figure 18: Ecosystems MAES reference map Greece.*

<u>Iterative approach</u>

Several iterations were done in co-design with the Early Adopters. Initially the focus was on improving the habitat maps, mainly by adding or cleaning EUNIS training data. Thereafter the focus was on improving the extent rules.

## 2.3.2 Results Habitat maps

### 2.3.2.1 Slovakia

When comparing the provided national habitat map with the map generated by the habitat modeler at EUNIS2020 Level 1 habitat class (Figure 19) visually, the VITO habitat map contains a higher level of detail in the mapping. This is validated by comparing the VITO habitat map and the national habitat map to a satellite image (Figure 20). Considering the satellite image as a reference, the map generated by the modeler seems to delineate the habitats better than the national habitat map.

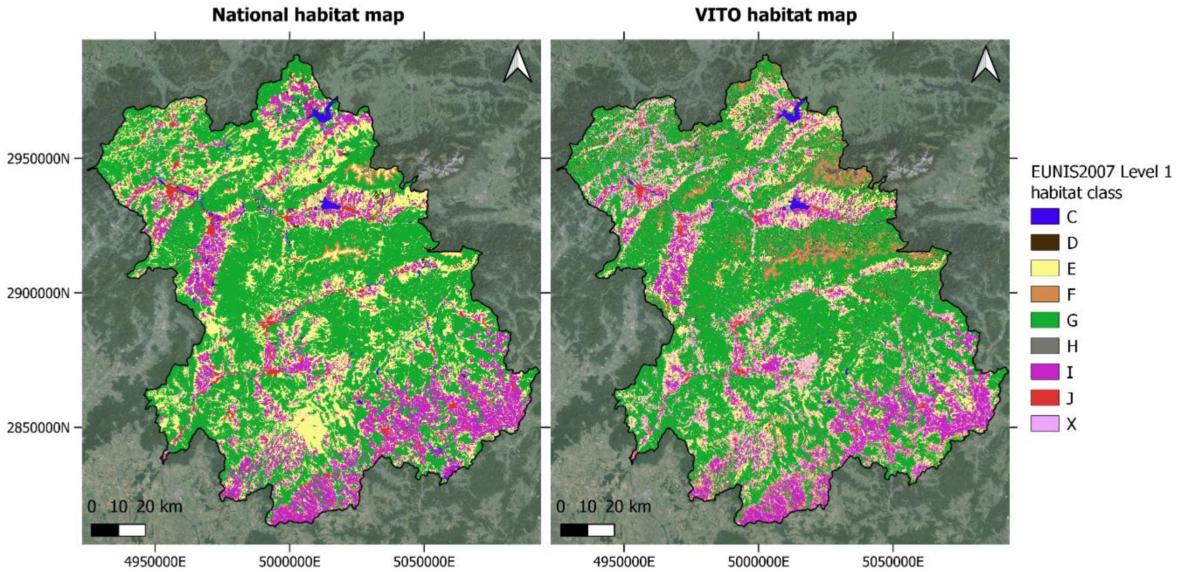



*Figure 19: Comparison of national habitat map and VITO habitat map at EUNIS2007 Level 1 for Stredné Slovensko (SK03).*

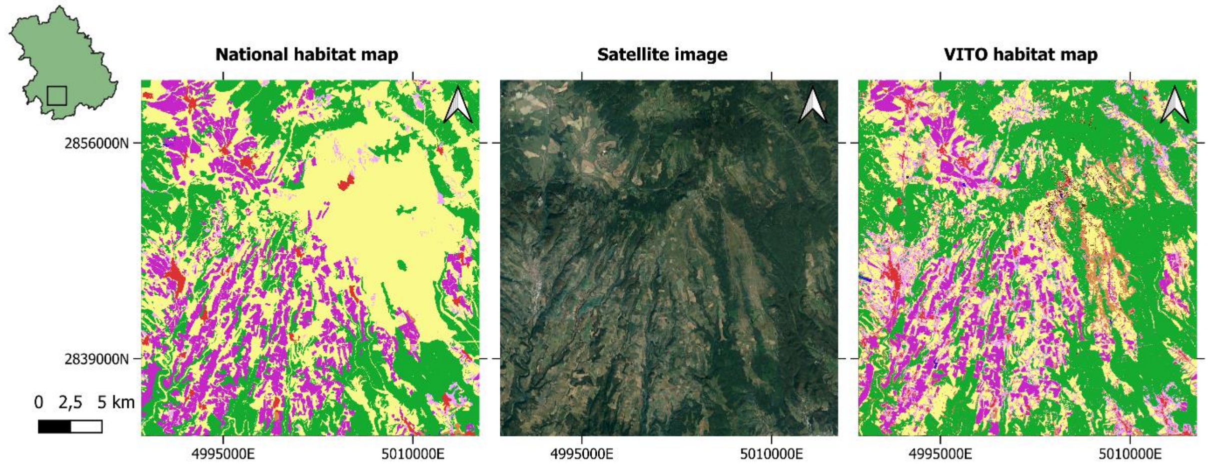



*Figure 20: Comparison between VITO habit map at EUNIS2007 Level 1 versus a satellite image (Google) and the national habitat map. Find the associated legend for EUNIS2007 Level 1 habitat class in Figure 19.*

The total area of Stredné Slovensko contains ca. 1 626.036 ha. Almost half of the area is occupied by forest or woodland (Figure 21). About a quarter is taken in by grassland, shrubland, scrubs and heathland. It seems like the portion of urban or industrial area is very limited and is often surrounded by large patches of agricultural land.

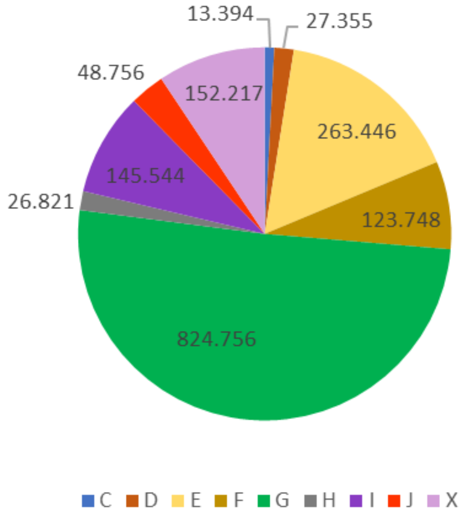



*Figure 21: Area distribution of EUNIS2007 Level 1 habitat classes in Stredné Slovensko, in hectare.*

The normalized confusion matrix for the Level 1 habitat modeler shows that the accuracy of mapping grassland, forest, agricultural land and industrial or urban area is very high (Figure 22). These classes are also represented in high amounts in the training data (Figure 8). Accuracy decreases when modelling water (C), peatlands (D), shrubland (F), sparse vegetation (H) and habitat complexes (X), which also related to the lower representation of these classes within the training data. We see that the modeler's biggest issue is related to misclassifying many pixels of sparse vegetation to forested areas. Overall, the modeler's accuracy of EUNIS2007 Level 1 habitat mapping is 89,34%.

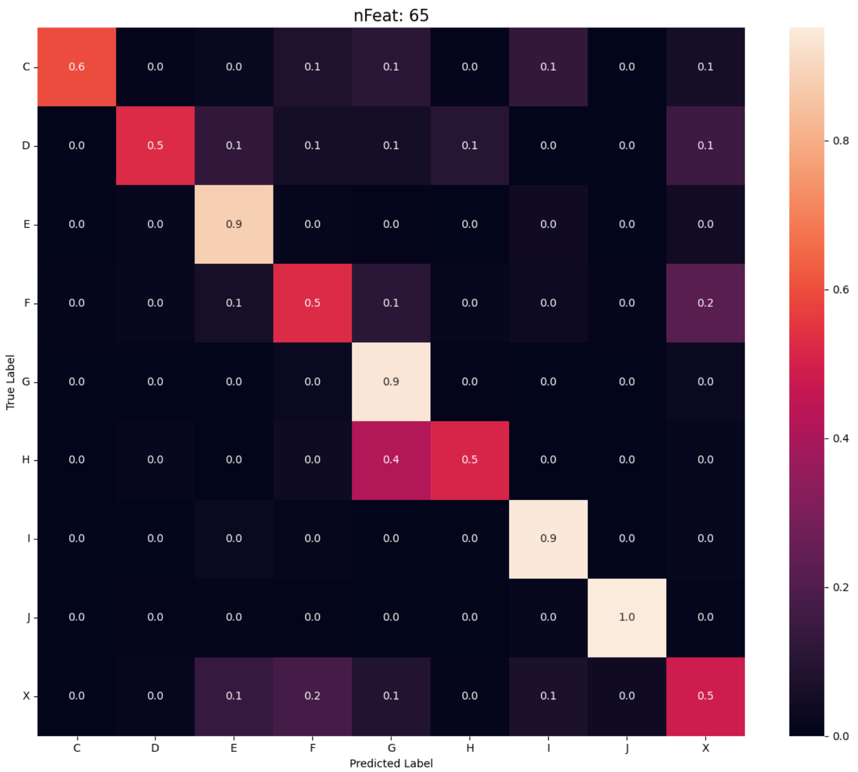



*Figure 22: Normalized confusion matrix of habitat mapping model at Level 1 for Stredné Slovensko.*

Figure 23 shows the modelled habitat map on EUNIS2007 Level 2, next to the provided national habitat map on Level 2. Here, the more detailed level of mapping of the modeler compared to the national habitat map becomes even more clear than on the Level 1 map.

An example is shown on Figure 24, where you can clearly see that the habitat modeler makes a realistic distinction in classification of forest patches in slopy areas, while the national habitat map considers all forest as similar.

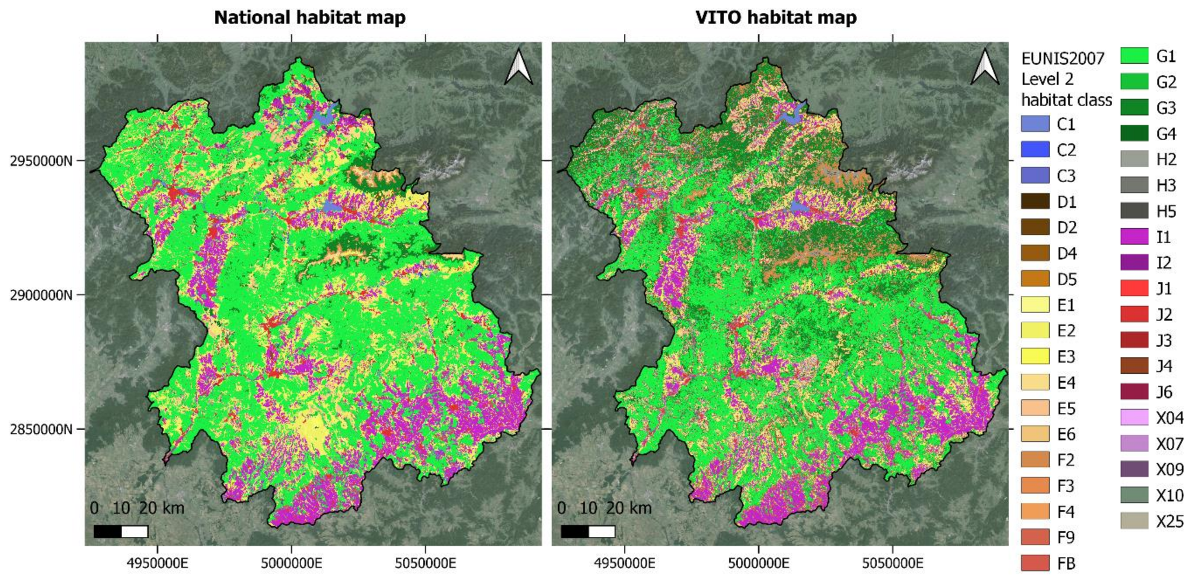



*Figure 23: Comparison of national habitat map and VITO habitat map at EUNIS2007 Level 2 for Stredné Slovensko.*

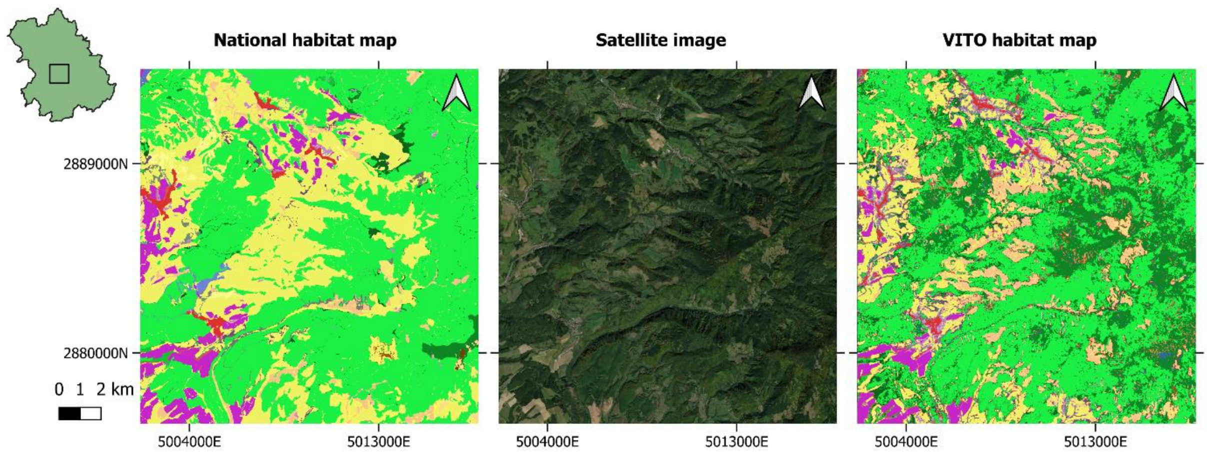
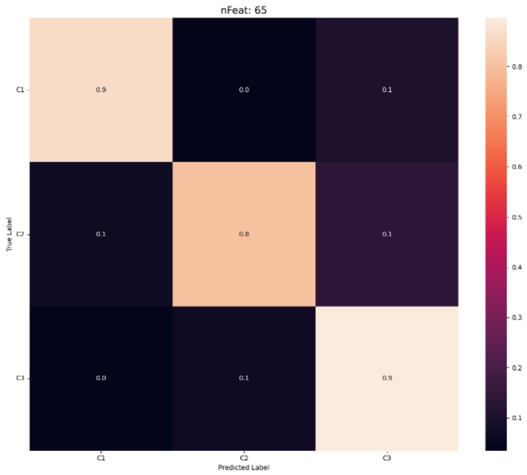


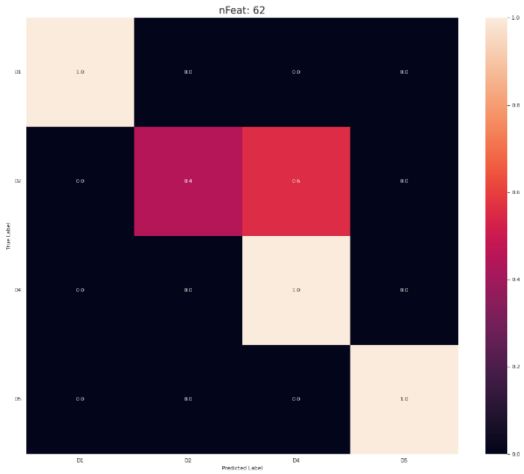

*Figure 24: Comparison between VITO habit map at EUNIS2007 Level 2 versus a satellite image (Google) and the national habitat map. Find the associated legend for EUNIS2007 Level 2 habitat class in Figure 23.*

In the next figure, the normalized confusion matrix for each modelled Level 2 class is shown. We see that even though class C had a lower prediction accuracy in Level 1 compared to some other classes, the Level 2 prediction within the class is very good. In contrast, the accuracy of Level 2 grassland mapping is more difficult. We notice many misclassifications of the modeler. This is likely due to the large amount of E2 sampling points within the training data, compared to a much lower amount for the other Level 2 grassland classes. Also, for class G, quite some misclassifications persist. Classes G2 and G4 both seemed to be mistaken often for class G1.

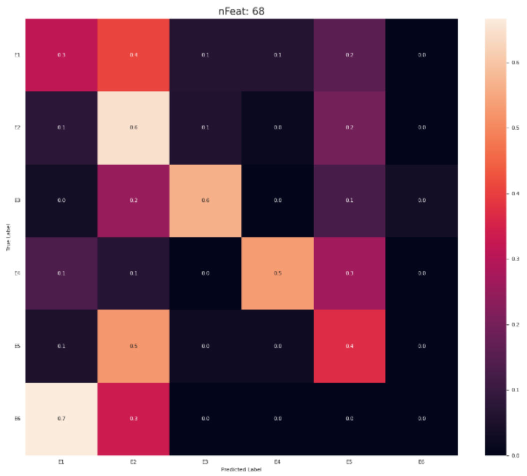
Similar to grasslands, class G1 has a dominant amount of training points within class G training data. Therefore, it may contain a high level of variation which might resemble the other classes. Within peatlands, there is a high level of misclassification of class D2 for class D4. Further, the Level 2 habitat mapping accuracy of the modeler for classes F and H area is also very good.



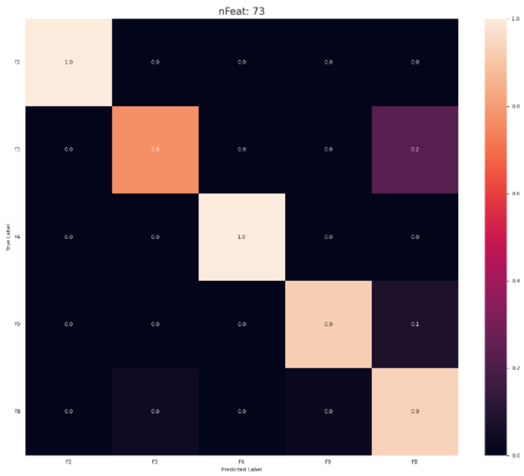

a)



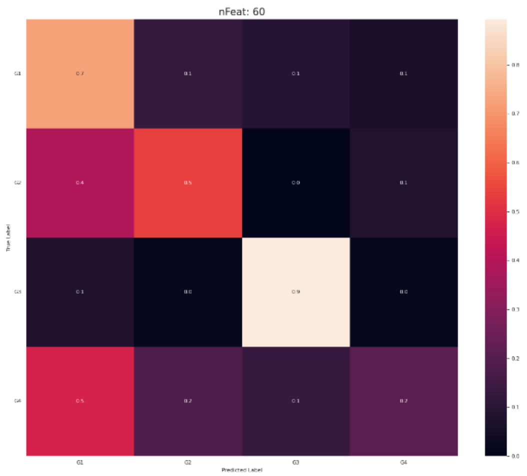

b)



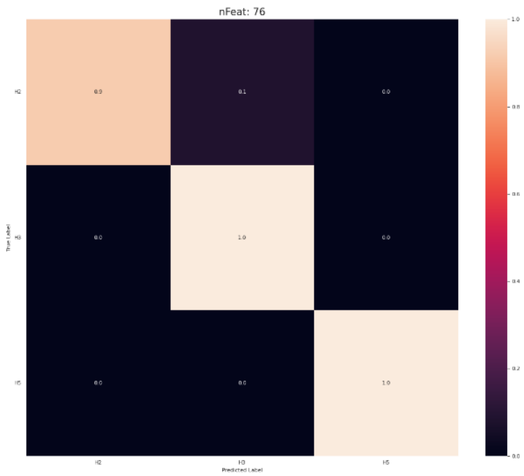

c)



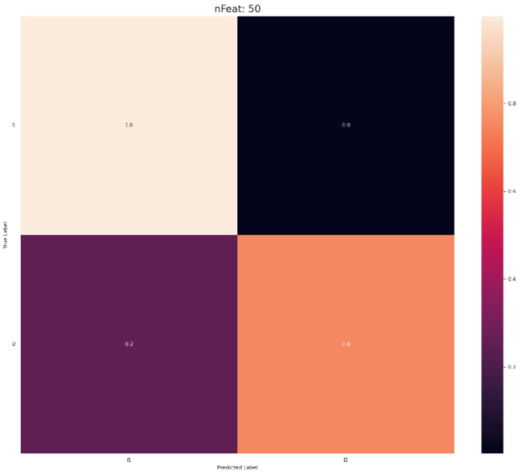

d)



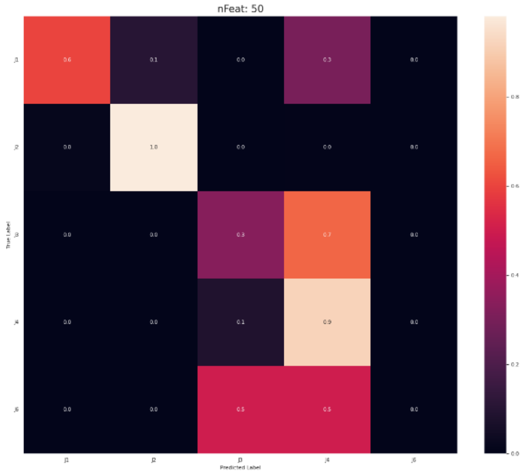

e)



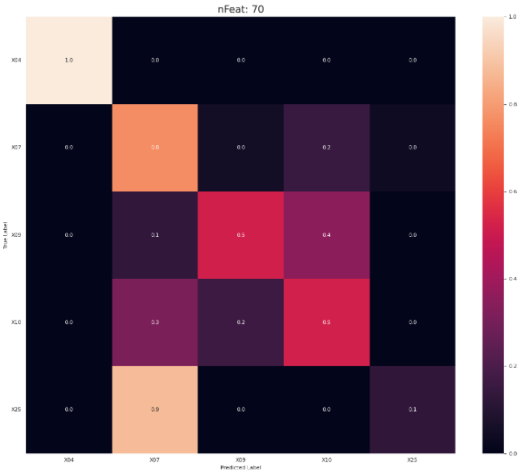

f)




g)




h)




i)

*Figure 25: Confusion matrices for modelled EUNIS2007 Level 2 habitat classes in: a) class C, b) class D, c) class E, d) class F, e) class G, f) class H, g) class I, h) class J & i) class X.*

In Figure 26, a comparison of VITO's habitat map with the national habitat map on EUNIS2007 Level 3 is shown. On both images, we masked out the areas for which the national habitat map did not provide a classification up to Level 3. Evidently, for these areas no comparison with the result of the habitat modeler on Level 3 is possible. A zoom-in on a mountainous area around the centre of the study area shows how the habitat modeler creates a detailed image of how the habitats evolve from forests on lower altitudes to sparse vegetation on higher altitudes (versus grasslands on higher altitudes on the national habitat map) (Figure 27).

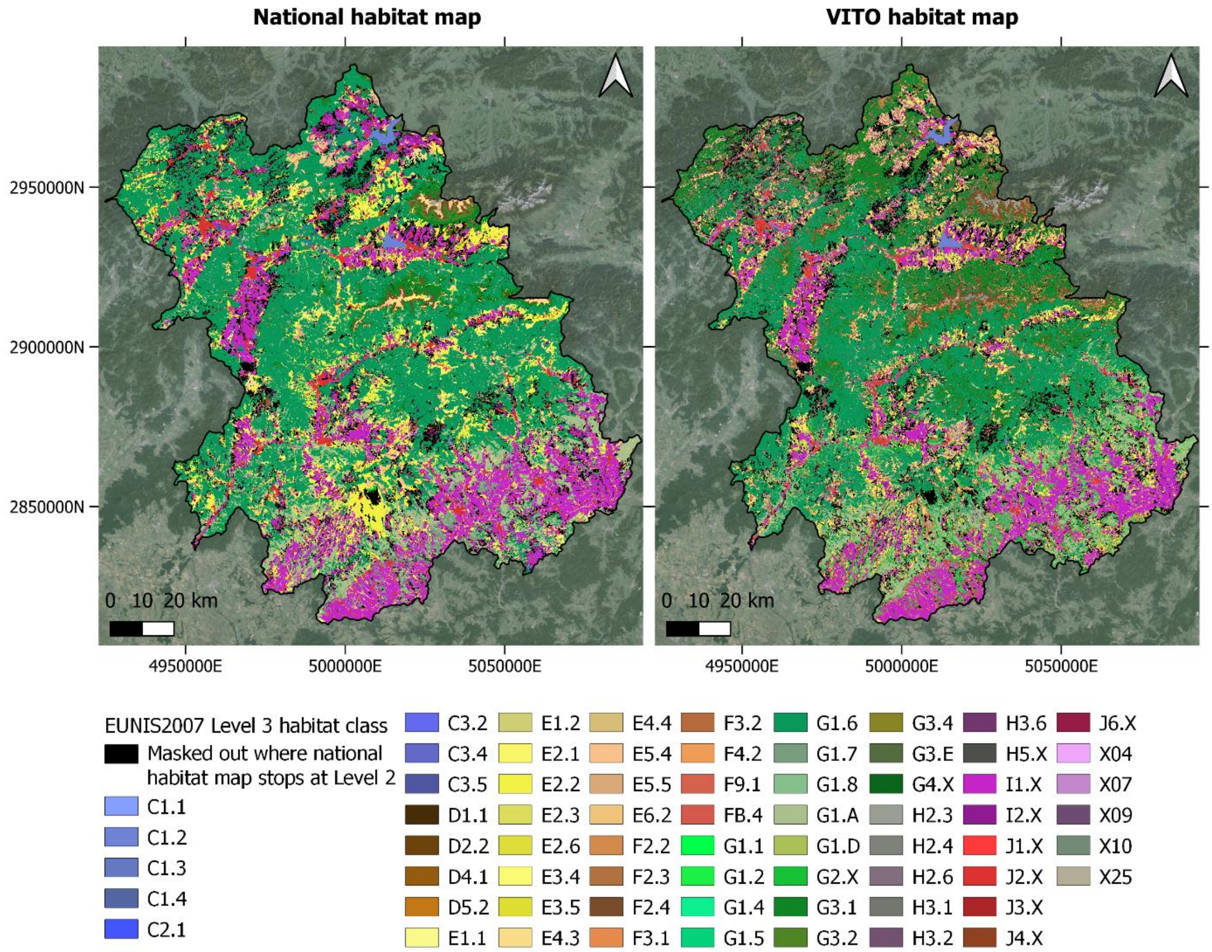



*Figure 26: Comparison of national habitat map and VITO habitat map at EUNIS2007 Level 3 for Stredné Slovensko.*

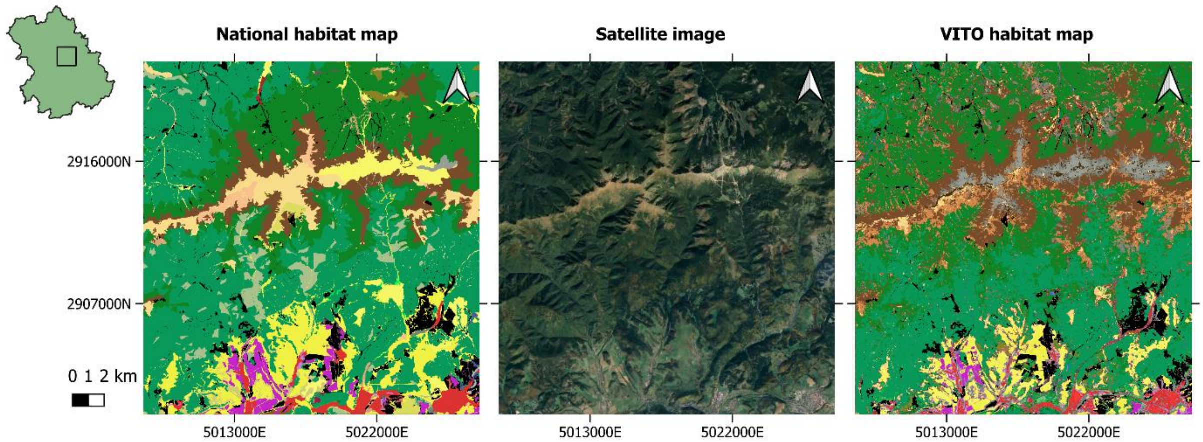
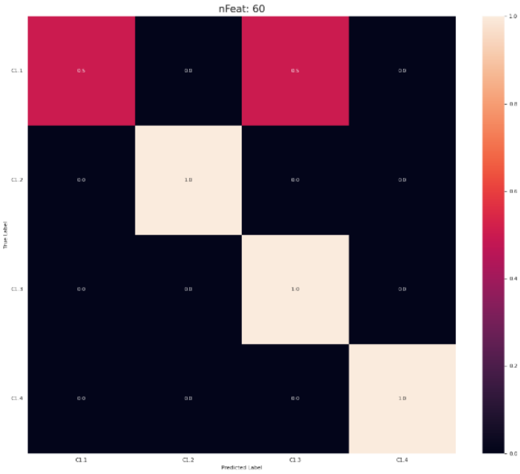
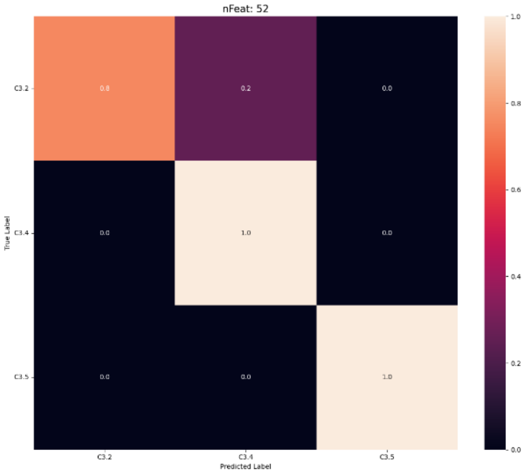


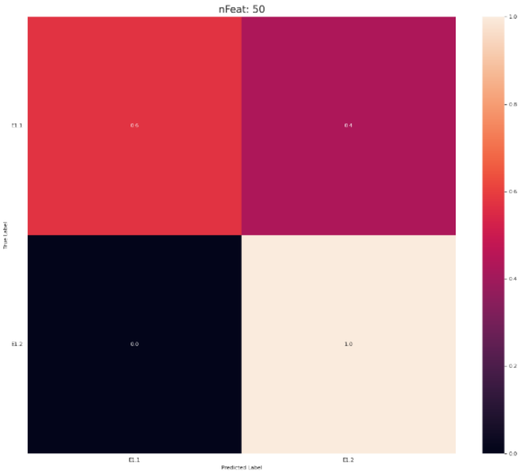

*Figure 27: Comparison between VITO habit map at EUNIS2007 Level 3 versus a satellite image (Google) and the national habitat map. Find the associated legend for EUNIS2007 Level 3 habitat class in Figure 26*


nFeat: 60

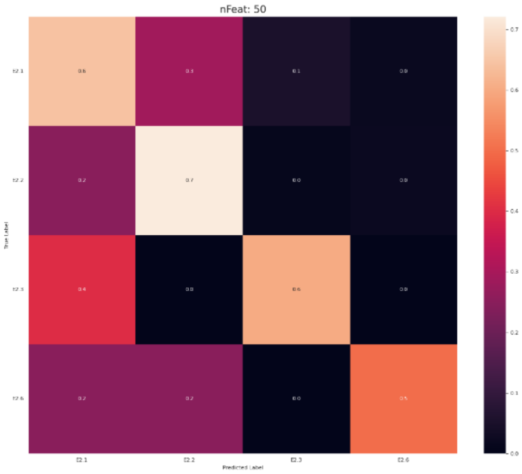
a)


nFeat: 52
C3.2
C3.4
C3.5
True Label
Predicted Label

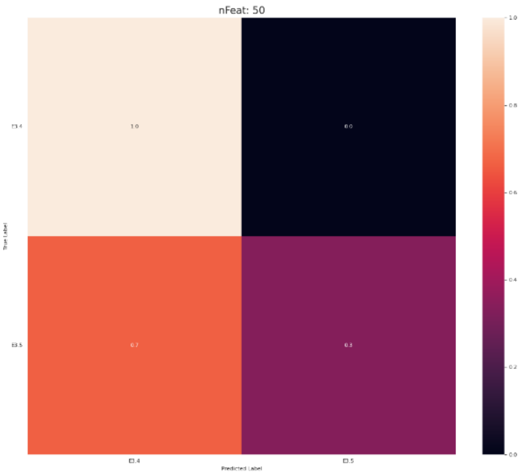
b)


nFeat: 50

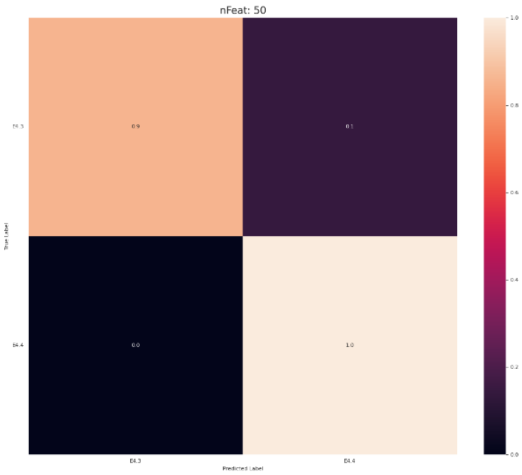
c)


nFeat: 50

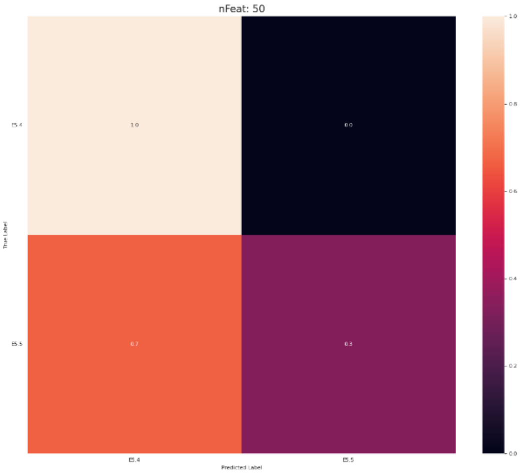
d)


nFeat: 50

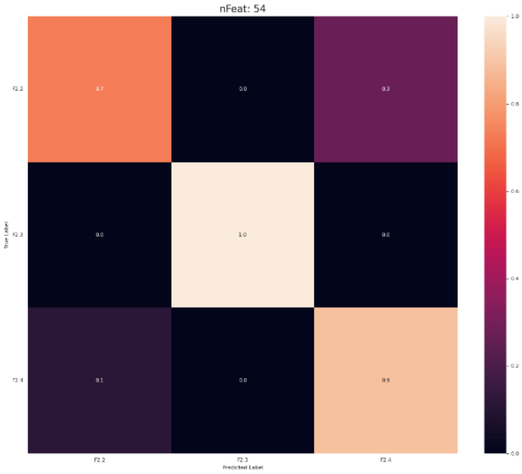
e)


nFeat: 50

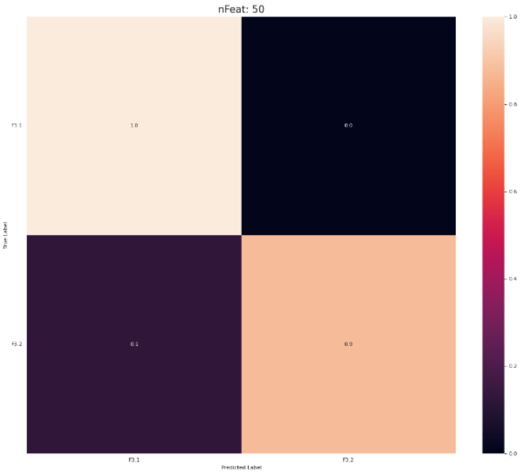
f)



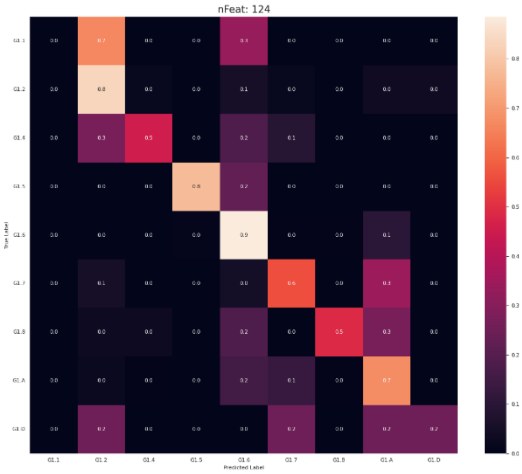

g)



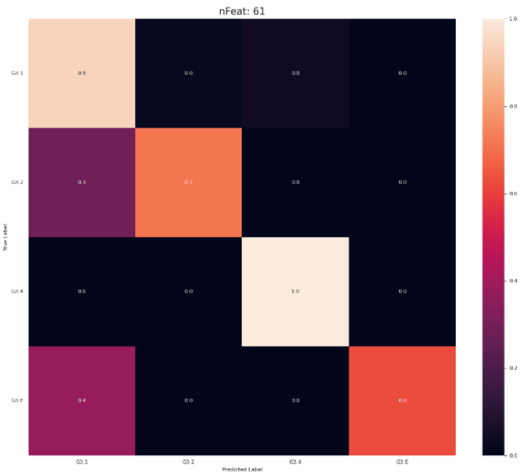

h)



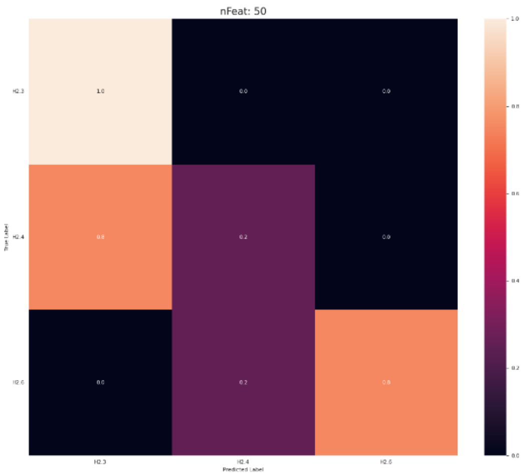

i)



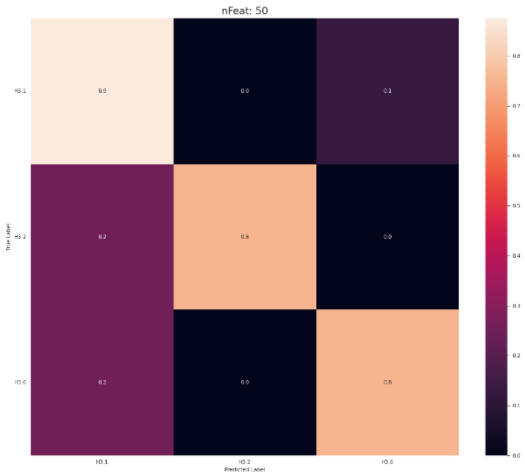

j)




k)




l)




m)

*Figure 28: Confusion matrices for modelled EUNIS2007 Level 3 habitat classes in: a) class C1, b) class C3, c) class E1, d) class E2, e) class E3, f) class E4, g) class E5, h) class F2, i) class F3, j) class G1, k) class G3, l) class H2 & m) class H3.*

**Error! Not a valid bookmark self-reference.** provides an overview of the modelling performance per hierarchical trained model.

*Table 14: Overview of modelling performances for EUNIS2012 hierarchical training in Slovakia*

| EUNIS code | EUNIS type | Model performance (%) |
|---|---|---|
| L1 | All level-1 types | 89.3 |
| L2 - C | In-land surface water types | 86 |
| L2 - D | Mires, bogs and fens types | 88 |
| L2 - E | Grassland and land dominated by forbs, mosses or lichens types | 60 |
| L2 - F | Heathland, scrub and tundra types | 94 |
| L2 - G | Woodland, forest and other woodland types | 72 |
| L2 - H | Inland unvegetated or sparse vegetation types | 96 |
| L2 - I | Regularly or recently cultivated agriculture types | 98 |
| L2 - J | Constructed, industrial or other Artificial types | 93 |
| L2 - X | Complex types | 63 |
| L3 – E1 | Dry grassland types | 90 |
| L3 – E2 | Mesic grassland types | 70 |
| L3 - E3 | Seasonal wet and Wet grassland types | 93 |
| L3 – E4 | Alpine and subalpine grassland types | 92 |
| L3 - E5 | Woodland fringes and clearings and tall forb stands grassland types | 96 |
| L3 - F2 | Alpine and subalpine scrubs types | 85 |
| L3 – F3 | Temperate and Mediterranean-montane scrub types | 93 |
| L3 – G1 | Broadleaved deciduous woodland types | 82 |
| L3 – G3 | Coniferous woodland types | 93 |

## 2.3.2.2 Greece

Figure 29 shows the wall-to-wall habitat mapping for Peloponnese at EUNIS2021 Level 1. According to the habitat map, Peloponnese (total area of 2 234.561 ha) is dominated land for agriculture (Figure 30). Within lay large patches of forest and shrubland area (Figure 29).

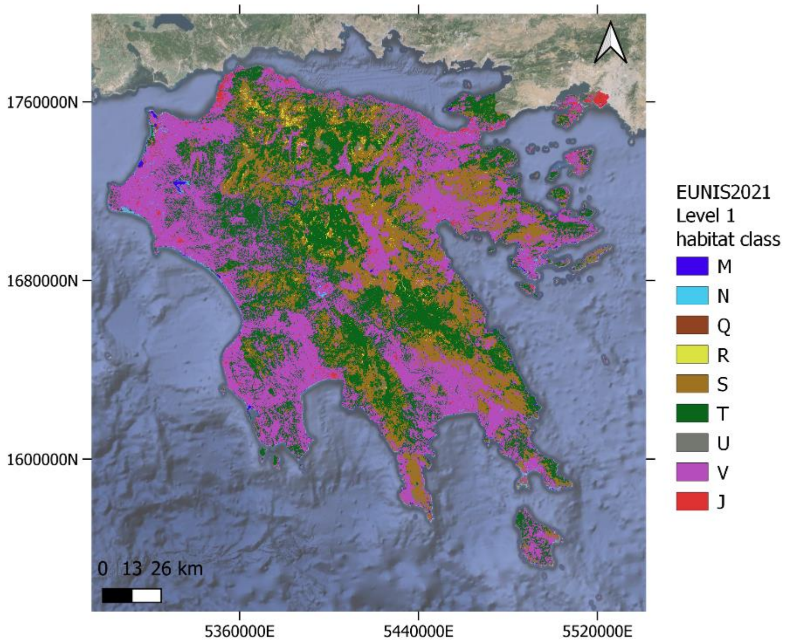



*Figure 29: VITO habitat map at EUNIS2021 Level 1 for Peloponnese.*

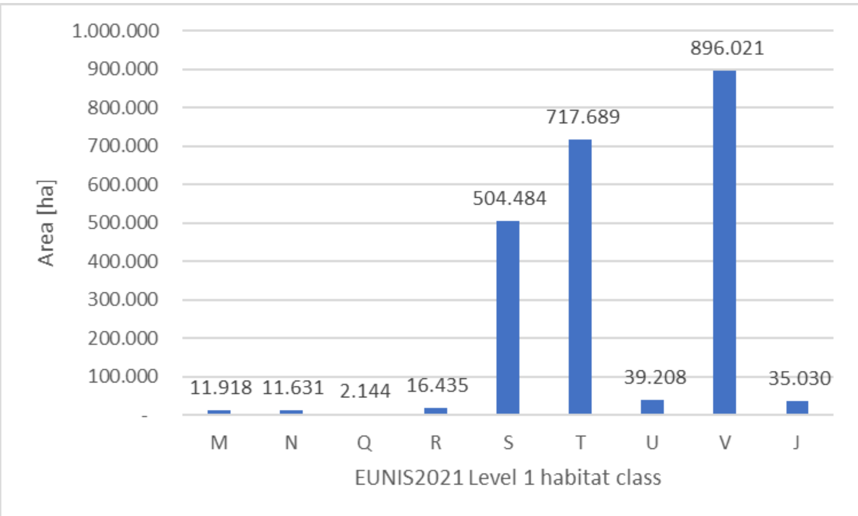



*Figure 30: Area distribution of EUNIS2021 Level 1 habitat classes in Peloponnese, in hectare.*

The normalized confusion matrix for the Level 1 habitat modeler shows that the accuracy of mapping for all classes is very good, though the accuracy of mapping peatlands and sparse vegetation is lower (Figure 31). Classes Q and U were represented in small amounts in the training data; however, peatlands do not occur largely in Peloponnese and adequate training data on class U was limited. Overall, the modeler’s accuracy of EUNIS2007 Level 1 habitat mapping is 83,27 %.

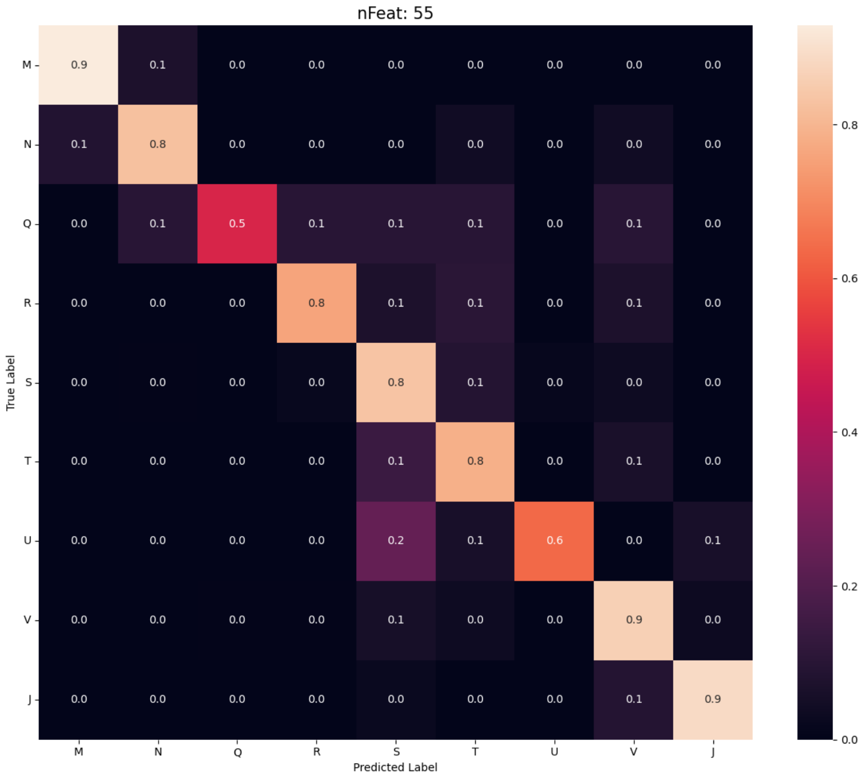



*Figure 31: Normalized confusion matrix of habitat mapping model at Level 1 for Peloponnese.*

On Figure 32, the result of the habitat modeler at EUNIS2021 Level 2 is shown. Further differentiation within class V results mainly in classification to V1 and V6. Regarding forest, type T3 is mostly common.

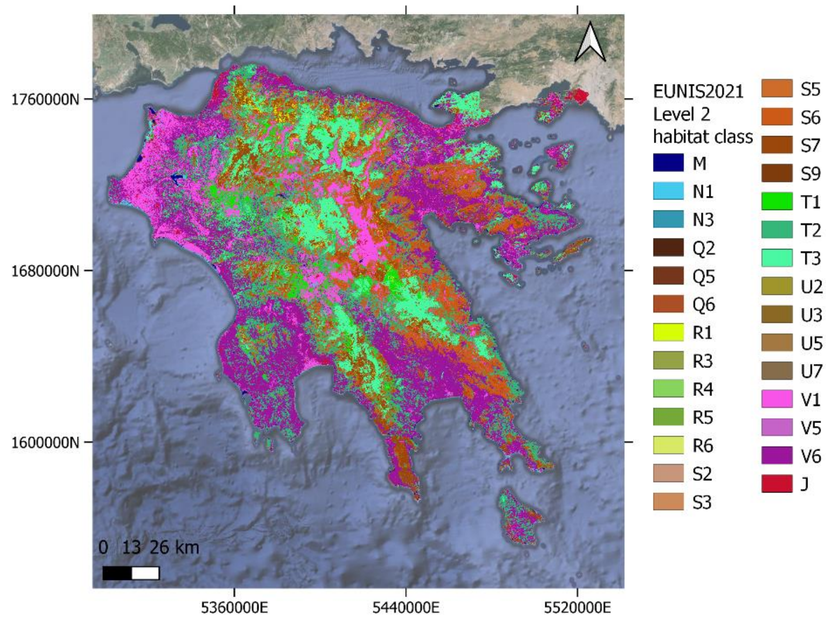
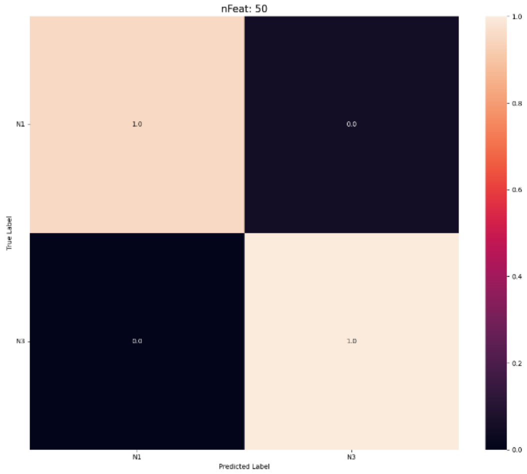
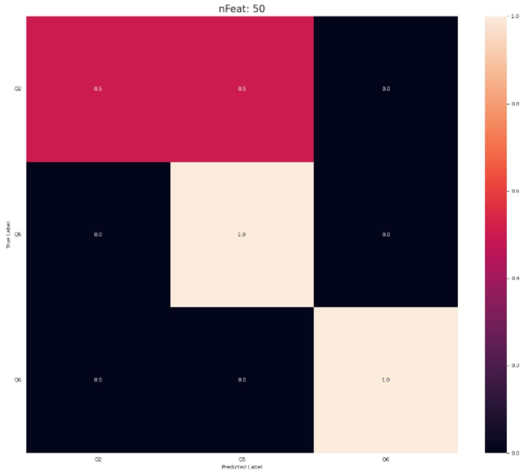
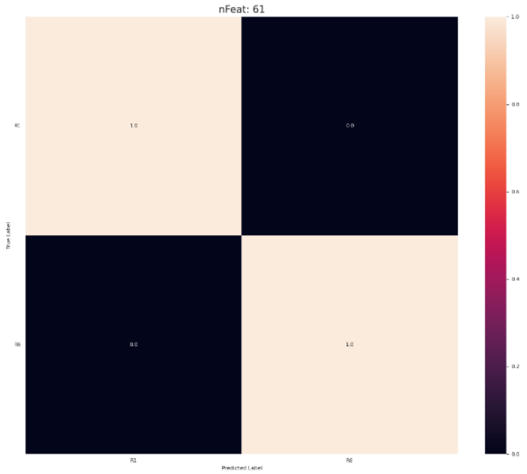


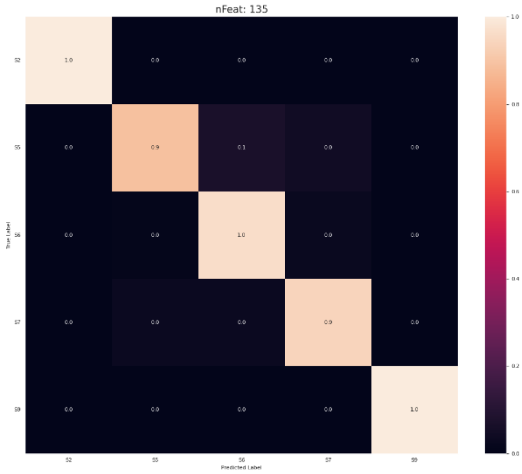

*Figure 32: VITO habitat map at EUNIS2021 Level 2 for Peloponnese.*

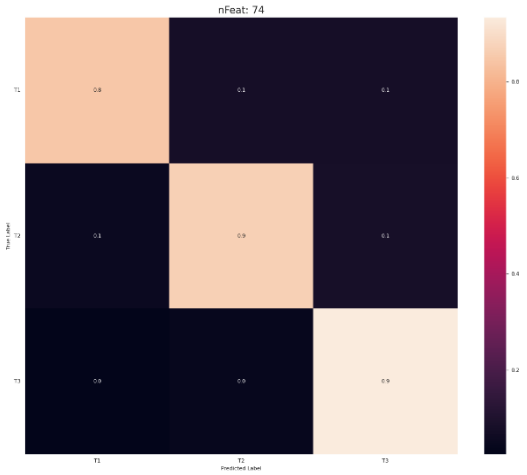
The normalized confusion matrices in Figure 33 reflect that mainly within class Q and class U misclassifications are present.

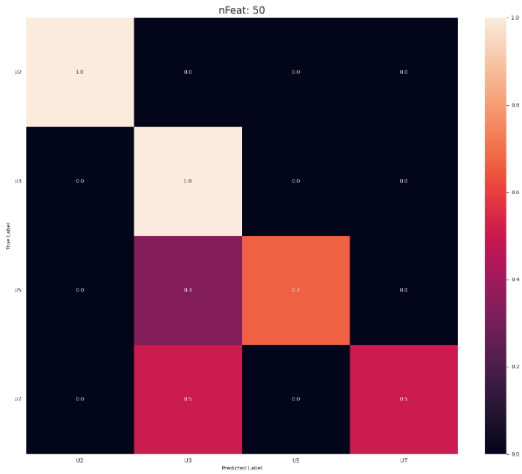

nFeat: 50
True Label
Predicted Label
N1
N3
a)

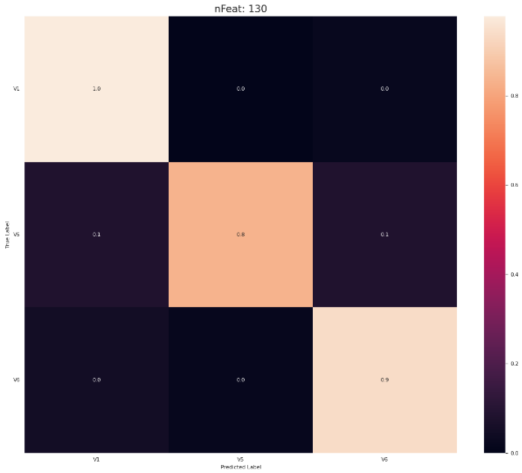

nFeat: 50
b)


nFeat: 61
c)


nFeat: 135
d)


nFeat: 74
e)


nFeat: 50
f)




g)

*Figure 33: Confusion matrices for modelled EUNIS2021 Level 2 habitat classes in: a) class N, b) class Q, c) class R, d) class S, e) class T, f) class U & g) class V.*

The habitat mapping up to EUNIS2021 Level 3 is shown in Figure 34.

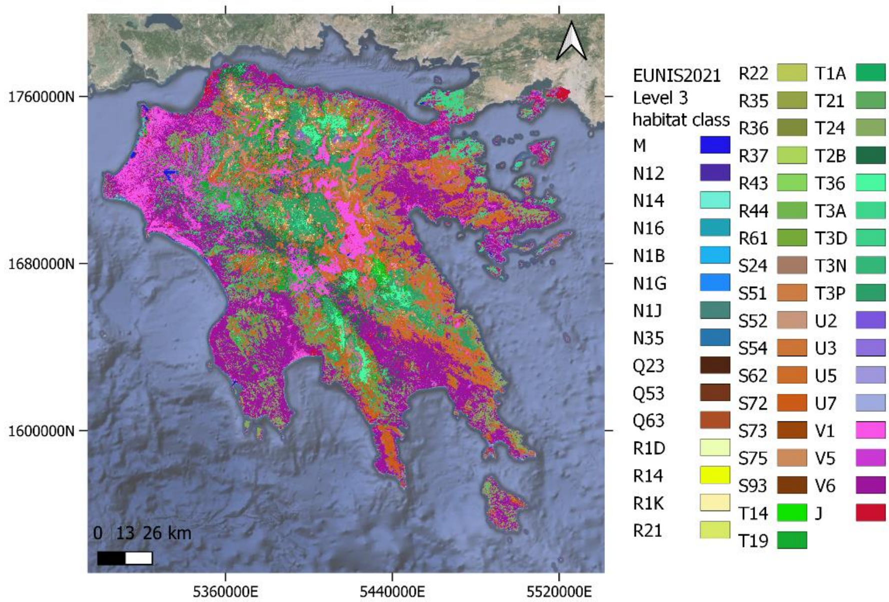



*Figure 34: VITO habitat map at EUNIS2021 Level 3 for Peloponnese.*

We provide some zoomed images on coastal areas for the Level 3 habitat map in Peloponnese (Figure 35). There is a general pattern of class M mapping just over the coastal zone, and class N following the border of the coastline (Figure 35).

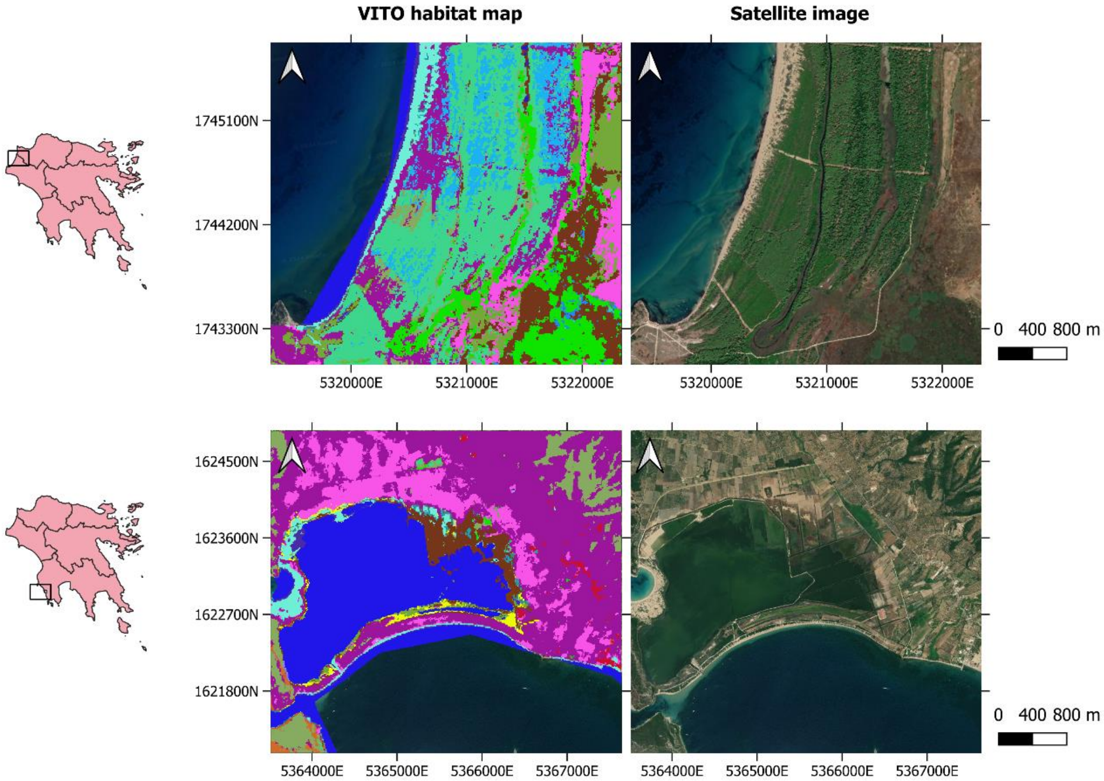
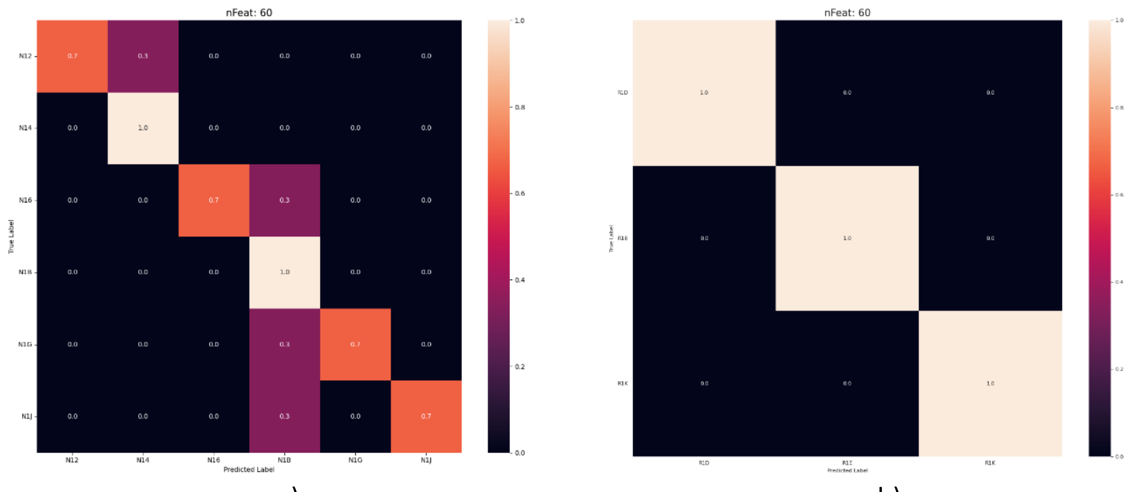
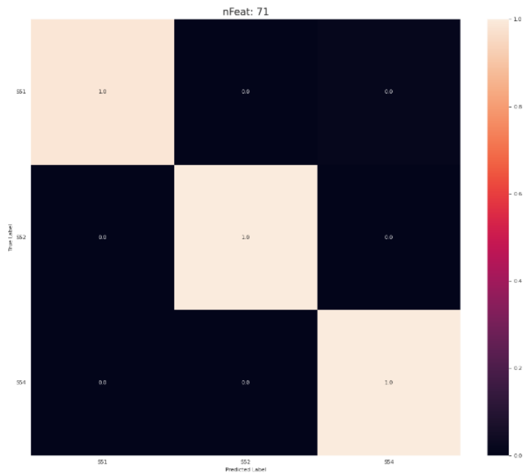


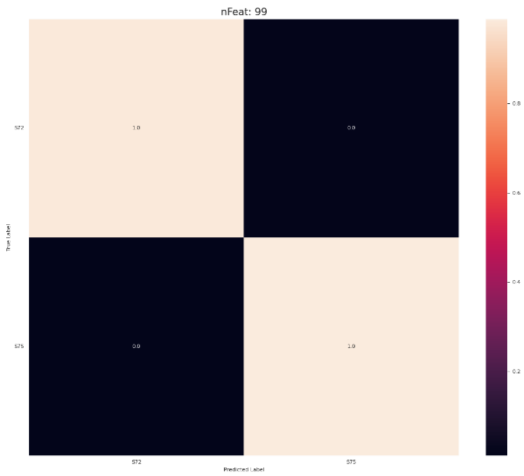

*Figure 35: Comparison between VITO habit map at EUNIS2021 Level 3 versus a satellite image (Bing) for two coastal areas of Peloponnese. Find the associated legend for EUNIS2021 Level 3 habitat class in Figure 34.*

The normalized confusion matrices of class N and class T indicate some misclassifications (Figure 36). For class N, this is probably related to a limited amount of training points. For class T, there is a large unbalance in amount of training points for all Level 3 classes.

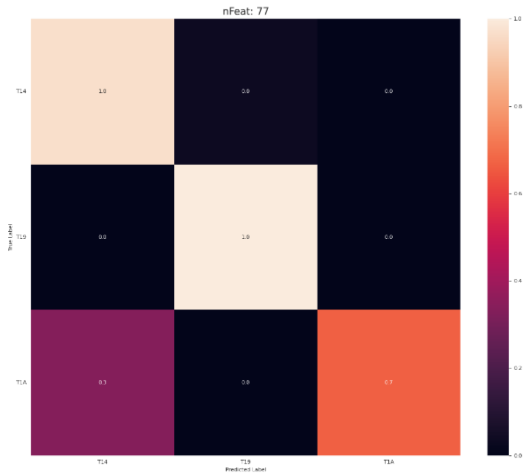




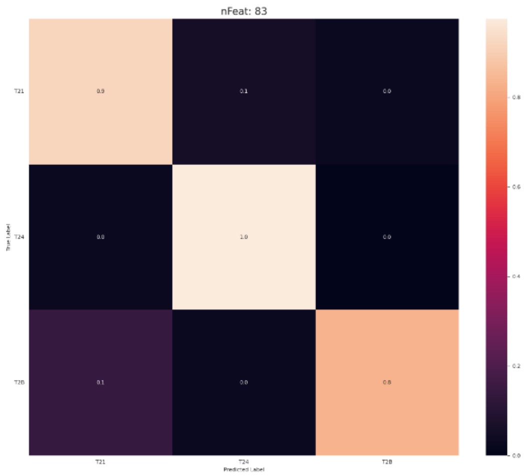

c)



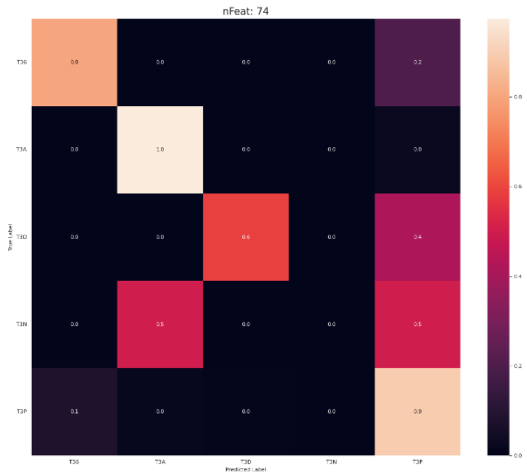

d)




e)




f)




g)

*Figure 36: Confusion matrices for modelled EUNIS2021 Level 3 habitat classes in: a) class N1, b) class R1, c) class S5, d) class S7, e) class T1, f) class T2 & g) class T3.*

Table 15 provides an overview of the modelling performance per hierarchical trained model.

*Table 15: Overview of modelling performances for EUNIS2021 hierarchical training in Peloponnese*

| EUNIS code | EUNIS type | Model performance (%) |
|---|---|---|

| | | |
|---|---|---|
| L1 | All level-1 types | 83 |
| L2 - N | Coastal types | 96 |
| L2 – Q | Inland wetland types | 90 |
| L2 – R | Grasslands types | 100 |
| L2 – S | Heathland, scrub and tundra types | 94 |
| L2 – T | Forest and other woodland types | 90 |
| L2 – U | Inland habitats with no or little soil or mostly with sparse vegetation types | 94 |
| L2 – V | Vegetated man-made habitat types | 95 |
| L3 – N1 | Coastal dunes and sandy shores types | 81 |
| L3 – R1 | Dry grassland types | 100 |
| L3 – S5 | Marquis, arborescent matorral and thermos-Mediterranean scrub types | 99 |
| L3 – T1 | Deciduous broadleaved forest types | 99 |
| L3 – T2 | Broadleaved evergreen forest types | 97 |
| L3 – T3 | Coniferous forest types | 91 |

## 2.3.3 Results ecosystem extent accounts

### 2.3.3.1 Slovakia SK03

First the ecosystem extent results for SK03 are compared with the reference map from the INCA tool (using the Corine Accounting layers) for Level-1. As shown in Figure 37, the general patterns are similar, however we see some clear differences in some ecosystem types as reported in Table 16.

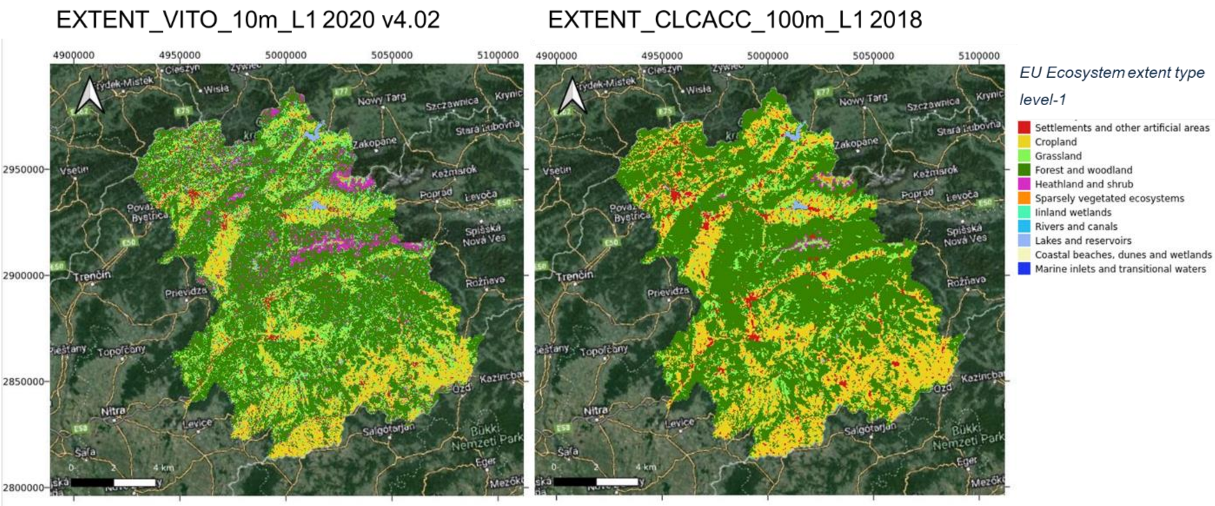



*Figure 37: Visual comparison ecosystem extent level-1 derived from PEOPLE-EA (left image) and from CORINE Accounting Layer (right image)*

*Table 16: Accounting table comparison ecosystem extent level-1 derived from PEOPLE-EA to CORINE Accounting Layer*

| value | Ecosystem Type | Opening area (ha) | Additions | Reductions | Net changes | Closing area CLCACC (ha) | Share of closing area | | Closing area VITO (ha) | Share of closing area |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | outside accounting area | | | | | 1321837 | | | | |
| 1 | Settlements and other artificial areas | | | | | 70,221 | 4.30% | | 36,237 | 2.22% |
| 2 | Cropland | | | | | 450,733 | 27.70% | | 244,098 | 14.96% |
| 3 | Grassland (pastures, semi-natural and natural grasslands) | | | | | 151,616 | 9.30% | | 311,536 | 19.09% |
| 4 | Forest and woodland | | | | | 934,403 | 57.40% | | 856,672 | 52.49% |
| 5 | Heathland and shrub | | | | | 9,164 | 0.60% | | 122,035 | 7.48% |
| 6 | Sparsely vegetated ecosystems | | | | | 2,171 | 0.10% | | 5,795 | 0.36% |
| 7 | Inland wetlands | | | | | 428 | 0.00% | | 25,939 | 0.00% |
| 8 | Rivers and Canals | | | | | 745 | 0.00% | | 20,648 | 0.00% |
| 9 | Lakes and reservoirs | | | | | 7,006 | 0.40% | | 9,162 | 0.56% |
| 10 | Marine inlets and transitional waters | | | | | - | 0.00% | | - | 0.00% |
| 11 | Coastal beaches, dunes, and wetlands | | | | | - | 0.00% | | - | 0.00% |
| 12 | Marine ecosystems | | | | | - | 0.00% | | - | 0.00% |
| | | | | | | | | | | |
| | Total Ecosystem Accounting Area | | | | | 1,626,487 | | | 1,632,123 | |

We should note that CLCACC represents the year 2018 and the statistics are derived from the 100m raster map, however the Minimum Mapping Unit (MMU) is 25 hectares. The VITO extent represents the year 2020 (although we do not expect a very large difference in years) and the statistics are derived from the 10m raster map with a Minimum Mapping Unit of 1 acre.

The following main differences are seen:

- Settlements are half size, mainly related to MMU difference. The CLCACC is assumed to over-estimate.
- Croplands are half size, and mainly identified as grassland and heathland. This is further investigated, see below.
- Forest and woodland are roughly same, as the MMU is less important here.
- Rivers and canals are much higher, mainly related to the imprint of the OSM layer. The rasterization at 10m probably overestimates this ecosystem type.
- Inland wetlands are much higher, to be further investigated.

First two areas were selected, as shown in Figure 38 to investigate the large difference at Level-1 between cropland and (1) heathland and (2) grasslands.

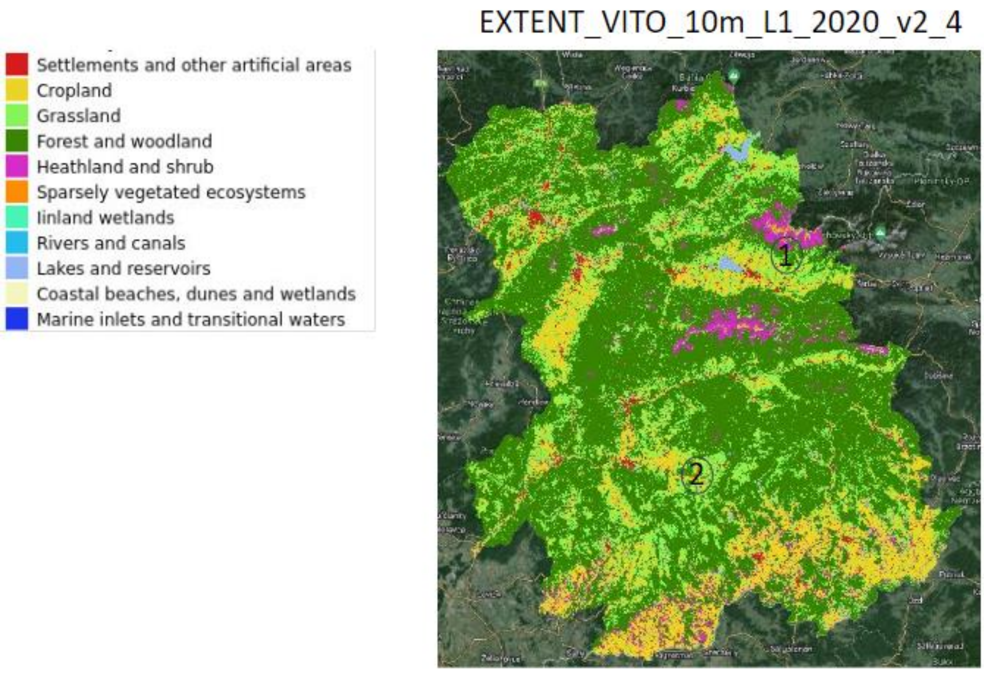


*Figure 38: Areas for further analysis SK03.*

The first zoom in North-East (1), as depicted in Figure 39, is known as an area (upper part of zoom) with small pine trees and hence is correctly identified as a heathland. Historically this was a pasture size but became a national parc being a non-intervention zone many years ago. The area is located in mountains; hence the vegetation is slowly growing, explaining the scrubs.

The zoom also shows that more grasslands are detected in between the forest (as we can also see in the google earth image) as well as cropland (in CLCACC) which is classified as grassland (in PEOPLE-EA). This PEOPLE-EA extent map also seems more correct, as these is an area with small patches of fields which are abandoned due to subsidiary policy to not plant the agriculture fields and thereby converting them to grass fields.

Further we can also see in the zoom that the Urban area is more finely classified (in PEOPLE-EA extent) and some misclassifications in CLCACC (right bottom) is not appearing in PEOPLE-EA extent maps.
So, in general the PEOPLE-EA map is seen as more realistic, however a more in-depth validation is required, especially in the definition between grassland and scrubs.

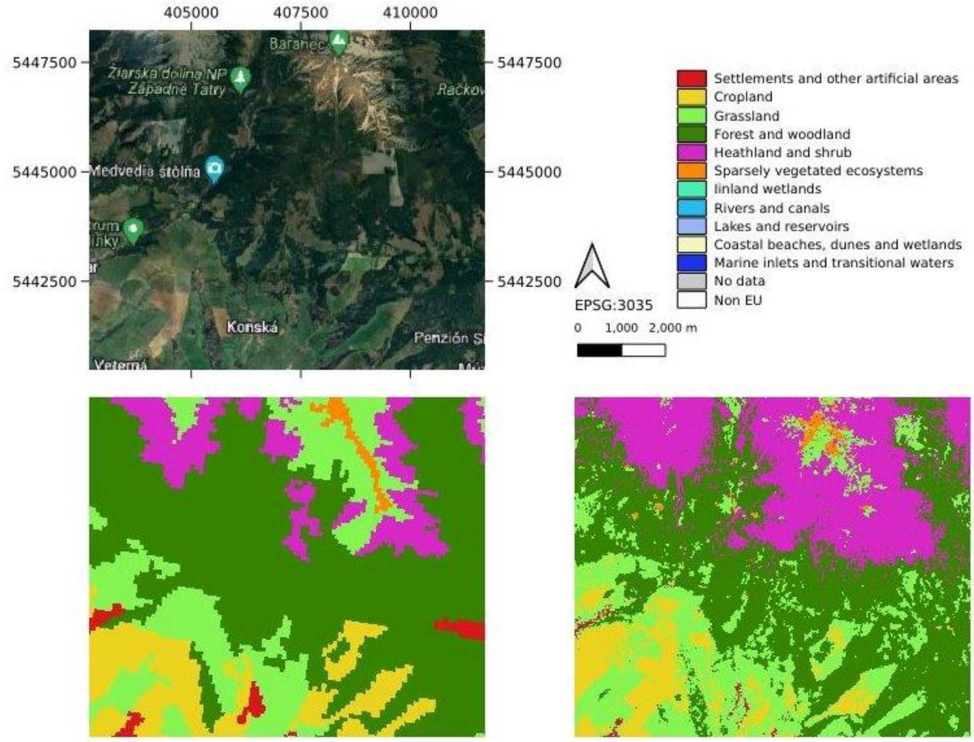



*Figure 39: Zoom in North-East zone, top image is Google Earth imagery, bottom left is extent L1 derived from CLCACC, bottom right is extent L1 from PEOPLE-EA.*

The second zoom in South-Wet (2), as depicted in Figure 40, is a zone rich on biodiversity and proposed as a UNESCO site due to its unique landscape. The CLCACC extent seems to be hindered by the MMU here, as the area consists of a lot of small cropland patches with lots of grass and some forest in between. So, at first sights it seems that the PEOPLE-EA extent reflects better the reality.

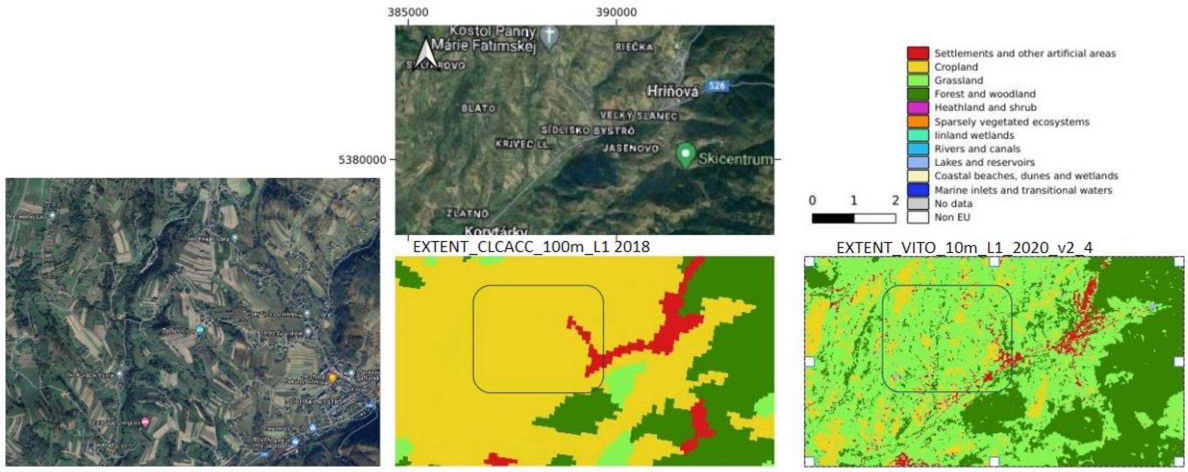



*Figure 40: Zoom in South-West zone, left image is context from google earth imagery. Mid-top figure is a zoom of google earth imagery in context, Mid-bottom is CLCACC extent and right is PEOPLE-EA extent L1.*

The larger accounting area for wetlands could be potentially linked to old agriculture fields (during soviet time) cultivated for rice. This production is now stopped and turned into wetlands. This hypothesis requires further investigations.

Thereafter at Level-2 and Level-3 extent accounts were further visually checked and discussed. Note it is not possible here to compare with CLCACC extent as the latter cannot reach Level-3.

First at Level-2, most grasslands close to the settlements are modified and intensive grasslands which are quite often mowed. Natural and semi-natural areas are more located in the highlands and only mowed once or twice. The level of detail that can be seen in the maps is shown in Figure 41.

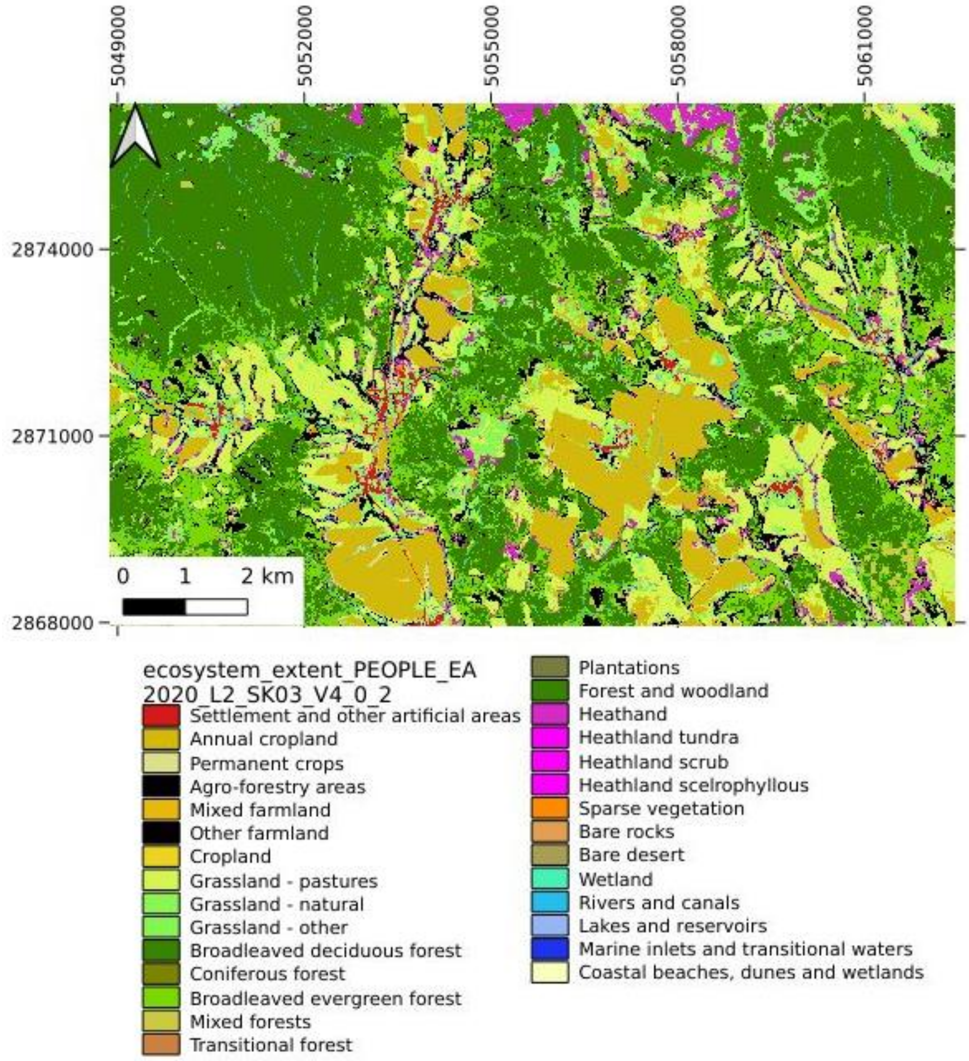



*Figure 41: Ecosystem extent Level-2 PEOPLE-EA SK03, 2020*

Figure 42 depicts a Level-3 map, focusing on forest and woodland ecosystem type. Plantations have a very limited accounting area and mostly now coniferous while in the past they were deciduous. Evergreen forest is almost not appearing, and its confusion is mainly due to misclassification in the EUNIS training data, so these G2 pixels should be either reclassified as G3 or removed from the EUNIS training dataset. Agro-forestry is land converted from cropland to solitary trees (mostly oaks) with some grassland in-between for cattle grazing. Orchards are also important. The LPIS dataset could be used to make this distinction. Riparian forests are mostly ‘almas’ species (typical leaves).

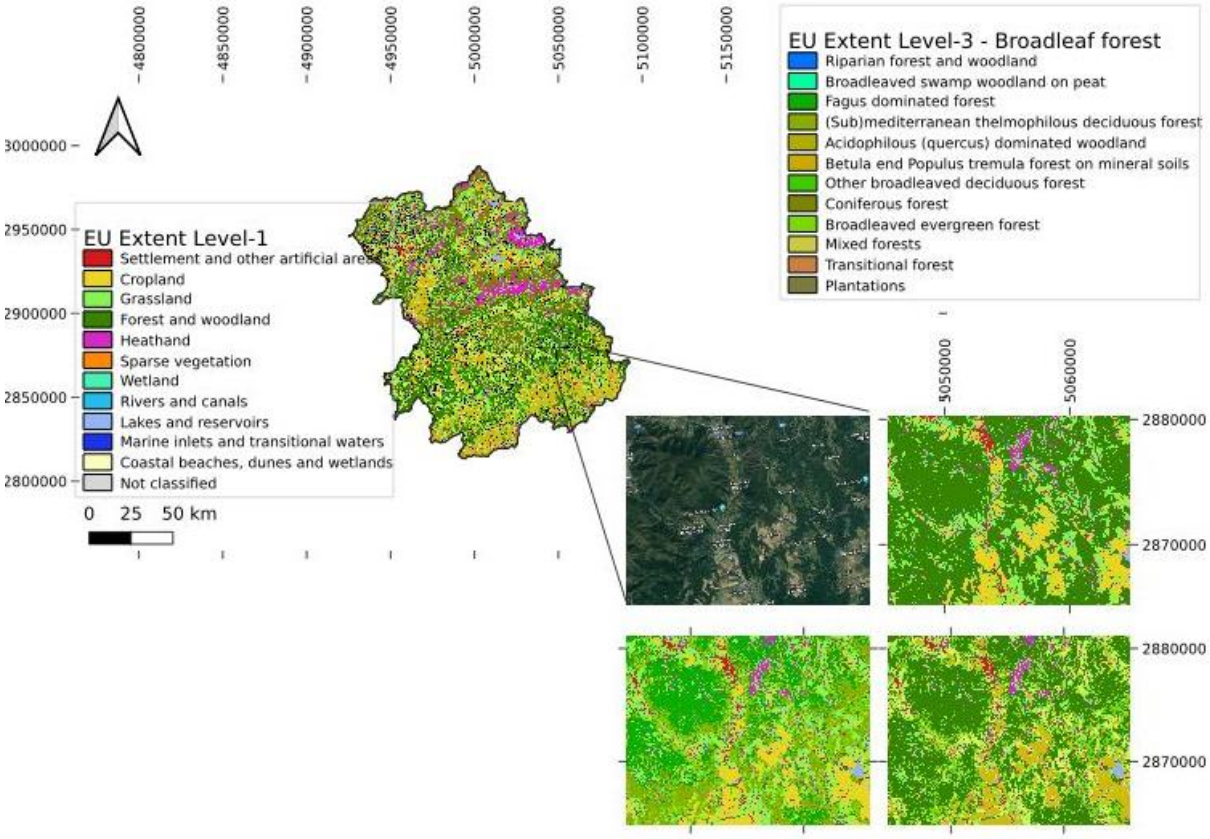



*Figure 42: PEOLE-EA extent Forest level-3*

Table 17 shows the accounting table at EU L3 for the forest and woodland ecosystem type. As explained earlier transitional forest and plantations could not be detected (and hence a value of zero) and require further work and/or complementary data. Further we can see that coniferous and broadleaved evergreen cannot be further split from L2 to L3. This is mainly due to the EUNIS maps which are limited to the L2 EUNIS classes for these types, as additional training data is required to include L3 EUNIS classes. As explained earlier the evergreen forest (4% of area) is misclassified and should be broadleaved deciduous, again a limitation of the EUNIS training dataset. Further we can see a detailed distribution of the broadleaved deciduous forest class, mainly dominated by Fagus and Quercus woodlands. The mixed forest class is dominated by broadleaved species.

*Table 17: Ecosystem extent accounting table for L2 and L3 Slovakia SK03*

| value | Ecosystem Type | Opening area (ha) | Additions | Reductions | Net changes | Closing area (ha) | Share of closing area |
|---|---|---|---|---|---|---|---|
| 0 | outside accounting area | | | | | 1321837 | |
| *4* | *Forest and woodland - Totals* | | | | | *856,672* | *52.49%* |
| *4.0* | *Unallocated L2* | | | | | *100,585* | *6.16%* |
| *4.1* | *Broadleaved deciduous forest - Subtotals* | | | | | *380,126* | *23.29%* |
| *4.1.0* | *Unallocated L3* | | | | | - | *0.00%* |
| 4.1.1 | Riparian forest and woodland | | | | | *10* | *0.00%* |
| 4.1.2 | Broadleaved swamp woodland on non-acid and acid peat | | | | | *86* | *0.01%* |
| 4.1.3 | Fagus dominated forest | | | | | *270,999* | *16.60%* |
| 4.1.4 | Submediterranean and Mediterranean thermophilous deciduous forest | | | | | *109,031* | *6.68%* |
| 4.1.5 | Acidophilous [Quercus]- dominated woodland | | | | | - | *0.00%* |
| 4.1.6 | Temperate and boreal and Southern European Betula and *Populus tremula* forest on mineral soils | | | | | - | *0.00%* |
| 4.1.7 | Other broadleaved deciduous forest, excluding highly-modified plantations | | | | | - | *0.00%* |
| 4.1.8 | Highly modified broadleaved deciduous forests including stands of non-native trees species that have long been established in European ecosystems stands | | | | | - | *0.00%* |
| *4.2* | *Coniferous forests - Subtotals* | | | | | *197,949* | *12.13%* |
| *4.2.0* | *Unallocated L3* | | | | | *197,949* | *12.13%* |
| *4.3* | *Broadleaved evergreen forest - Subtotals* | | | | | *69,876* | *4.28%* |
| *4.3.0* | *Unallocated L3* | | | | | *69,876* | *4.28%* |
| *4.4* | *Mixed forests - Subtotals* | | | | | *108,135* | *6.63%* |
| *4.4.0* | *Unallocated L3* | | | | | - | *0.00%* |
| 4.4.1 | Mixed forests dominated by coniferous species | | | | | *23,230* | *1.42%* |
| 4.4.2 | Mixed forests dominated by broadleaved species | | | | | *82,103* | *5.03%* |
| 4.4.3 | Other mixed forests including stands of non-native trees species that have long been established in European ecosystems stands | | | | | *2,802* | *0.17%* |
| *4.5* | *Transitional forest - Subtotals* | | | | | - | |
| *4.6* | *Plantations - Subtotals* | | | | | - | |

## 2.3.3.2 Greece Peloponnesus

A second round-robin exercise was performed with focus on the coastal ecosystem type for Peloponnese, as shown in Figure 43. At EU L1 the ecosystem type patterns were first analysed and found representative. Some zooms at the coastal area show again the level of spatial detail that can be reached. The accounting table for EU L1 can be found at Table 18.

The coastal ecosystem was further decomposed in L2 and thereafter L3 through integrating the EUNIS habitat maps as well as the 'coastal buffer' mask. The resulting accounting table can be found in Table 19. The coastal rocky shores could not be further decomposed as there was no EUNIS information available, also for coastal saltmarshes and salines. So again, it is important to carefully investigate that all (potential) present classes are represented by the EUNIS maps – or to find and integrate complementary data sources – and hence collect a fully representative EUNIS training data.

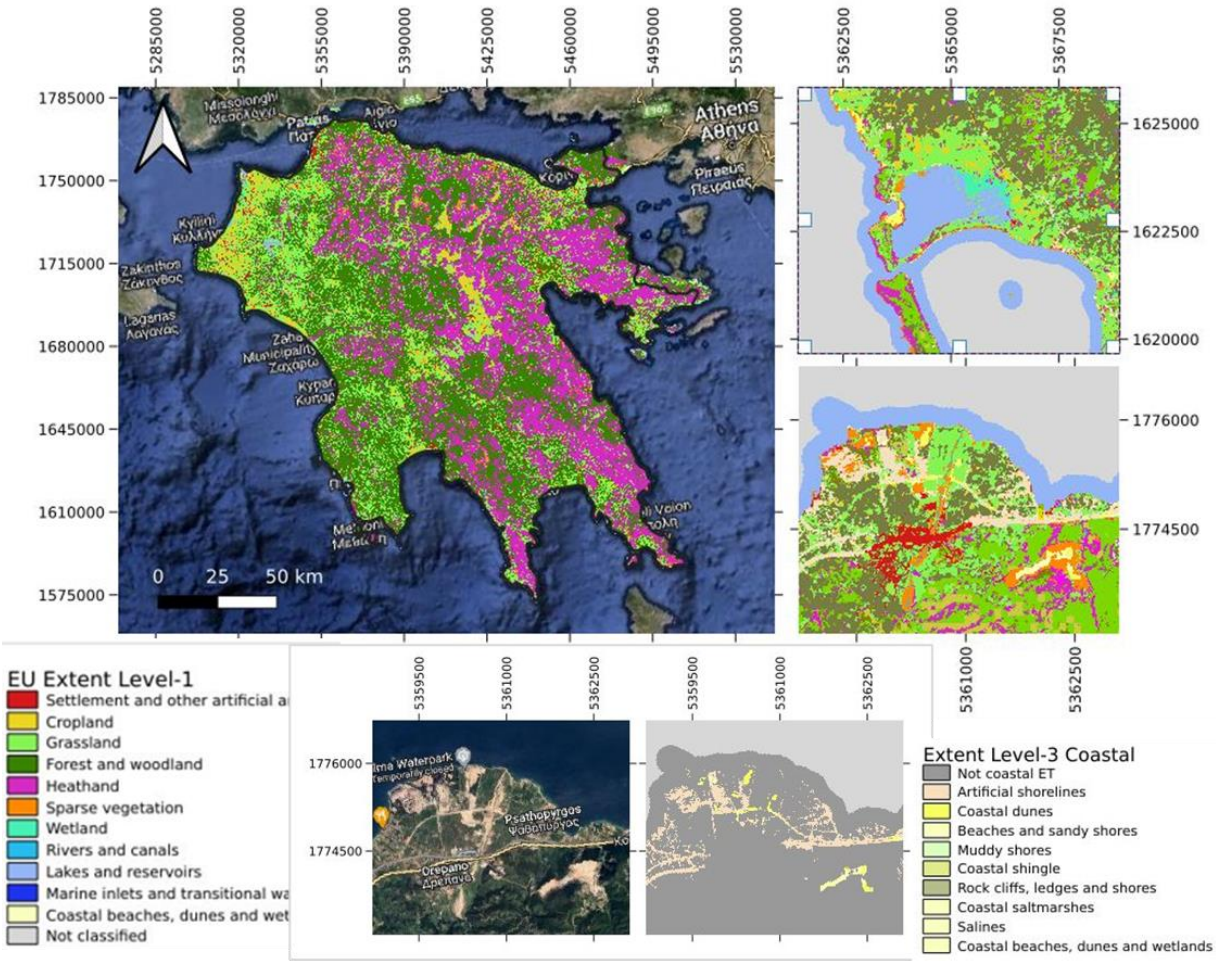



*Figure 43: Ecosystem Account map Level-1 (top left) for Peloponnese with some zooms (right) at coast and Level-3 coastal ecosystem type (bottom).*

*Table 18: Ecosystem Account table Level-1, Peloponnese*

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

*Table 19: Ecosystem Account table Level-3, Peloponnese Coastal beaches, dunes and wetlands ecosystem type*

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

### 2.3.3.3 Uncertainties

The EUNIS habitat classifier outputs a probability for every class at the given hierarchical level. The classifier assigns the pixel with the highest probability to the winning class. However, a post-processing module, as part of the habitat mapping component, verifies if the winning class from the classifier is actually corresponding to the classification on a reference map (we used the CLC+ backbone layer) (Table 20).

*Table 20: EUNIS Level 1 classification with corresponding CLC+ class.*

| **Level 1 EUNIS2021 class** | **CLC+ class** |
|---|---|
| R: Grasslands and lands dominated by forbs, mosses or lichens | 6: Permanent herbaceous<br>7: Periodically herbaceous<br>8: Lichens and mosses |
| S: Heathland, scrub and tundra | 5: Low-growing woody plants (bushes, shrubs) |
| T: Forest and other wooded land | 2: Woody - needle leaved trees<br>3: Woody - broadleaved deciduous trees<br>4: Woody - broadleaved evergreen trees |
| V: Vegetated man-made habitats | 5: Low-growing woody plants (bushes, shrubs)<br>6: Permanent herbaceous<br>7: Periodically herbaceous<br>9: Non-, and sparsely-vegetated |
| C: Inland surface waters | 10: Water |
| J: Constructed, industrial and other artificial habitats | 1: Sealed |

In case there is a match, the habitat classification is evaluated as ‘High confidence’ in habitat mapping. If there is no match, the second winning class (i.e., the habitat class that has the second highest probability) is cross-checked. Note that this step is only taken into account if the second winner has a probability of minimum 40%, and a difference in probability of maximum 10% with the first winner (to assure the likelihood of identifying the second winner as a good candidate for classification). If a match is found here, the second winner is recognized as the correct level 1 habitat and the class is converted from the first to the second winner. Then, a ‘Medium confidence’ is assigned. In case neither the first nor second winner correspond, the original habitat classification winner remains but is evaluated as ‘Low confidence’. Class J makes an exception to this rule; if the winning class does not, the second winning class will be assigned the level 1 habitat regardless of its probability, difference in probability to the first winning class or its correspondence to the CLC+ classification. The areas for which the habitat is then assigned to class C, despite a mismatch with CLC+, are masked as ‘no data’ due to low confidence in classification.

So eventually the EUNIS habitat maps provide a quality layer that provides a confidence level per pixel in the highest nibble of the byte:

- Low confidence
- Medium confidence
- High confidence

The lowest nibble of the byte corresponds to the actual probability of the selected class.

At this moment the EUNIS quality layer is used and exported to the Ecosystem Extent map at each level since the extent workflow is prioritizing EUNIS as a data source. However, some improvements should be further envisioned on what to do with imprints of complementary data sources, in our case the Open Street Map. Currently, the imprinted pixels still have the EUNIS quality but in case there is no match then this quality measure can’t be used as an uncertainty measure in the ecosystem accounting.

# 3. Conclusions and next steps

We have developed a workflow that generate ecosystem extent accounts (maps, as we use QGIS unique value for reporting) at Level-2 for non-anthropogenic classes and explored Level-3 for the forest & woodland and coastal ecosystems. The workflow is based on EUNIS habitat maps which provides the necessary detail to reach extent accounts at Level-3. We have demonstrated the added-value of this workflow for Slovakia (better delineation and more realistic accounting areas) with focus on forest ecosystems and for Greece (better thematic detail) with focus on coastal ecosystems. The final accounts are under evaluation and their results will be reported in the validation reports.

We have also shown that the thematic detail and quality of the EUNIS habitat maps derived from Sentinel-1 and Sentinel-2 temporal aggregated data are very much relying on the quality of the training datasets, so special attention was given to the gathering (or selection) of training points from different existing sources. Once the EUNIS habitat maps achieve the right quality, they can be easily integrated in crosswalks to EU extent accounts. The habitat maps at level-3 provide even more thematic detail than is requested by the EU typology at level-3 and hence the habitat maps (at level-3) can be considered as complementary data to the extent maps; and support member states to further split some level-3 classes which are of interest for e.g., land management decisions.

We have also seen that any error in the EUNIS training dataset (e.g., evergreen forest in Slovakia) or missing class (e.g., coastal rocks in Peloponnese) lead to an error in the extent accounts. Furthermore, we have seen that some classes (e.g., rivers from canals) are hard to impossible to distinguish from remote sensing and additional complementary data (e.g., Open Street Map) is required.

Finally accounting for changes in ecosystems is probably the most important aspects of the accounting tables. Here some work was explored to develop a separate workflow to detect changes directly derived from the EO data (Sentinel-2) instead of applying a traditional approach of classifying each timestep and perform a posteriori operation to remove the uncertainties (noise) between the classified maps. Despite this approach of an independent change detection workflow provides a promising perspective, further work is to be conducted to select the best deep learning network and training dataset to capture the expected transitions in ecosystems. Therefore, it is proposed to follow a dual approach, combining the deep learning and traditional approach and investigate its overlap and complementary.

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# Annex I. EU Ecosystem Extent Typology

Table 21 below details the classes at Level-2 to be mapped, as well as the selected Level-3 classes for the demonstrator.

*Table 21: EU ecosystem typology[6] at Level-2 and selected (non-greyed) Level-3 classes*

| EU ecosystem typology: level 1 | EU ecosystem typology | EU Ecosystem typology: level 3 (EUNIS) |
|---|---|---|
| 1. Settlements and other artificial areas | 1.1 Continuous settlement area | 1.1.1 Continuous residential area<br>1.1.2 Continuous commercial and industrial area |
| | 1.2 Discontinuous settlement area | 1.2.1 Discontinuous residential area<br>1.2.2 Discontinuous commercial and industrial area |
| | 1.3 Infrastructure | 1.3.1 Road and rail networks and associated land<br>1.3.2 Port areas<br>1.3.3 Airports<br>1.3.4 Other infrastructure (e.g., water purification plants, energy plants, transforming stations).<br>1.3.5 Mineral extraction sites (excluding peat extraction sites)<br>1.3.6 Dump areas<br>1.3.7 Construction sites |
| | 1.4 Urban greenspace | 1.4.1 Parks, including Zoos and botanical gardens<br>1.4.2 Sports and recreation sites<br>1.4.3 Other urban green including urban tree alleys |
| | 1.5 Other artificial areas | 1.5.1. Permanent greenhouses<br>1.5.2 Cemeteries<br>1.5.3 Archaeological sites<br>1.5.4 Urban blue |
| 2. Cropland[7] | 2.1 Annual cropland | 2.1.1 Cereals excluding rice (C1000) excluding maize (C1500)<br>2.1.2 Maize (C1500 + G3000)<br>2.1.3 Dry pulses and protein crops (P0000)<br>2.1.4 Root crops (R0000)<br>2.1.5 Vegetables (including melons) and strawberries (V0000_S0000)<br>2.1.6 Industrial crops including annual bioenergy crops (I0000)<br>2.1.7 Flowers and ornamental plants (N0000)<br>2.1.8 Fallow land (Q0000)<br>2.1.9 Temporary grasses and grazing areas (G1000)<br>2.1.10 Other crops (further categories may be added by Member States, depending upon nationally important crop types). |
| | 2.2 Rice fields | 2.2.1 Rice fields (C2000) |
| | 2.3 Permanent crops | 2.3.1 Olives (O1000)<br>2.3.2 Grapes (W1000)<br>2.3.3 Pome fruits (F1100)<br>2.3.4 Stone fruits (F1200)<br>2.3.5 Berries excluding strawberries (F3000)<br>2.3.6 Citrus fruits (T1000)<br>2.3.7 Nuts (F4000)<br>2.3.8 Other perennial crops and orchards |
| | 2.4 Agro-forestry areas | 2.4.1 Holm and cork oak forests<br>2.4.2 Other agro-forestry areas |

[6] Based on the Guidance note 'final draft version' of 03 February 2023. Will need to be updated in May 2023.
[7] The breakdown of cropland uses the terms and breakdown of crop statistics at level 3 of the EU ecosystem typology for classes 2.1 – 2.3 (i.e. for annual cropland, rice fields and permanent crops). The codes in brackets at level 3 refer to crop statistics codes.

| EU ecosystem typology: level 1 | EU ecosystem typology | EU Ecosystem typology: level 3 (EUNIS) |
|---|---|---|
| | 2.5 Mixed farmland | 2.5.1 Mosaic farmland (comprising cropland, grassland and (semi-)natural components) |
| | 2.6 Other farmland | 2.6.1 Nurseries<br>2.6.2 Christmas tree plantations<br>2.6.3 Perennial bioenergy crops<br>2.6.4 Field margins and other agriculture landscape elements |
| | 2.7 Hedgerows and tree rows in cropland | 2.7.1 Hedgerows in cropland<br>2.8.2 Tree rows in cropland |
| 3. Grassland (pastures, semi-natural and natural grasslands) | 3.1 Sown pastures and fields (modified grasslands) | 3.1.1 Sown pastures used for grazing<br>3.1.2 Sown grassland mown frequently for fodder or silage |
| | 3.2 Natural and semi-natural grasslands | 3.2.1 Dry grasslands<br>3.2.2 Seasonally wet and wet grasslands<br>3.2.3 Alpine and subalpine grasslands<br>3.2.4 Woodland fringes and clearings and tall forb stands<br>3.2.5 Inland salt steppes<br>3.2.6 Sparsely wooded grasslands<br>3.2.7 Mesophilous extensive grassland |
| | 3.3 Hedgerows and tree rows in grassland | 3.3.1 Hedgerows in grassland<br>3.3.2 Tree rows in grassland |
| 4. Forest and woodlands | 4.1 Broadleaved deciduous forest | 4.1.1 Riparian forest and woodland<br>4.1.2 Broadleaved swamp woodland on non-acid and acid peat<br>4.1.3 Fagus dominated forest<br>4.1.4 Sub-Mediterranean and Mediterranean thermophilous deciduous forest<br>4.1.5 Acidophilous [Quercus]- dominated woodland<br>4.1.6 Temperate and boreal and Southern European Betula and *Populus tremula* forest on mineral soils<br>4.1.7 Other broadleaved deciduous forest, excluding highly-modified plantations<br>4.1.8 Highly modified broadleaved deciduous forests including stands of non-native trees species that have long been established in European ecosystems stands |
| | 4.2 Coniferous forests | 4.2.1 Boreal and temperate fir and spruce forest<br>4.2.2 Mediterranean mountain fir and spruce forest<br>4.2.3 Temperate subalpine Larix, *Pinus cembra* and *Pinus uncinata* forest<br>4.2.4 Pine forest, excluding mires, non-thermophilous<br>4.2.5 Mediterranean thermophilous lowland pine forest<br>4.2.6 Spruce, pine and larch mire forest<br>4.2.7 Taiga forests<br>4.2.8 Other coniferous forests, excluding plantations<br>4.2.9 Highly modified coniferous forests including stands of non-native trees species that have long been established in European ecosystems stands |
| | 4.3 Broadleaved evergreen forest | 4.3.1 Mediterranean evergreen Quercus forest<br>4.3.2 Mainland laurophyllous forest<br>4.3.3 Macaronesian laurophyllous forest<br>4.3.4 Olea europaea-Ceratonia siliqua forest<br>4.3.5 Palm groves (G25)<br>4.3.6 Other broadleaved evergreen forests<br>4.3.7 Highly modified broadleaved evergreen forests including stands of non-native trees species that have long been established in European ecosystems stands |
| | 4.4 Mixed forests | 4.4.1 Mixed forests dominated by coniferous species<br>4.4.2 Mixed forests dominated by broadleaved species |

| EU ecosystem typology: level 1 | EU ecosystem typology | EU Ecosystem typology: level 3 (EUNIS) |
|---|---|---|
| | | 4.4.3 Other mixed forests including stands of non-native trees species that have long been established in European ecosystems stands |
| | 4.5 Transitional forest and woodland shrub | 4.5.1 Transitional woodland/forest land including recently felled or clear-cut, burnt, replanted or newly afforested |
| | 4.6 Plantations | 4.6.1 Monoculture plantations of non-native tree species (note: forest stands of single or mixed species consisting of native and/or non-native trees species that have long been established in European ecosystems and have diverse undergrowth typical for forest ecosystems should be classified as part of types 4.1 to 4.4) |
| | | 4.6.2. Mixed plantations of a few species of non-European coniferous and broadleaved trees with underdeveloped undergrowth. Forest stands of single or mixed species consisting of native and/or non-native trees species that have long been established in European ecosystems and have diverse undergrowth typical for forest ecosystems should be classified as part of types 4.1 to 4.4) |
| 5. Heathland and shrub | 5.1 Tundra (F1) | 5.1.1 Tundra (F1x) |
| | 5.2 Heathland and (sub-) alpine shrubs | 5.2.1 Arctic alpine, subalpine and lowland shrub and heathland<br>5.2.2 Temperate and Mediterranean montane and hilly shrub and heathland<br>5.2.3 Temperate and Mediterranean lowland shrub and heathland |
| | 5.3 Sclerophyllous vegetation | 5.3.1 Maquis, arborescent matorral and thermo-Mediterranean shrub<br>5.3.2 Garrigue<br>5.3.3 Spiny Mediterranean heaths (phrygana, hedgehog-heaths & coastal cliff vegetation)<br>5.3.4 Thermo-Atlantic xerophytic shrub (Madeira and Canary Islands) |
| 6. Sparsely vegetated ecosystems | 6.1 Bare rocks | 6.1.1 Rocky pavements, outcrops, and screes<br>6.1.2 Lava flows |
| | 6.2 Semi-desert, desert and other sparsely vegetated areas | 6.2.1 Semi-desert steppes<br>6.2.2 Cool deserts and semi-desert steppes<br>6.2.3 Other sparsely vegetated areas |
| | 6.3 Ice sheets, glaciers and perennial snowfields | 6.3.1 Ice sheets, glaciers and perennial snowfields |
| 7. Inland wetlands | 7.1 Inland marshes on mineral soil | 7.1.1 Reedbeds<br><br>7.1.2 Inland salt marshes<br>7.1.3 Other marshland and water-fringing ecosystems |
| | 7.2 Mires, bogs and fens | 7.2.1 Raised bogs<br>7.2.2 Blanket bogs<br>7.2.3 Valley mires, poor fens and transition mires<br>7.2.4 Aapa, palsa and polygon mires<br>7.2.5 Base-rich fens and calcareous spring mires<br>7.2.6 Peat extraction sites |
| 8. Rivers and canals | 8.1 Rivers | 8.1.1 Rivers |
| | 8.2 Canals, ditches and drains | 8.2.1 Canals, ditches and drains |
| 9. Lakes and reservoirs | 9.1 Lakes | 9.1.1 Lakes |
| | 9.2 Artificial reservoirs | 9.2.1 Artificial reservoirs |
| | 9.3 Geothermal pools and wetlands (Iceland) | 9.3.1 Geothermal pools and wetlands (Iceland) |

| EU ecosystem typology: level 1 | EU ecosystem typology | EU Ecosystem typology: level 3 (EUNIS) |
|---|---|---|
| 10. Marine inlets and transitional waters | 10.1 Coastal lagoons | 10.1.1 Coastal lagoons |
| | 10.2 Estuaries and bays | 10.2.1 Estuaries and bays |
| | 10.3 Intertidal flats | 10.3.1 Intertidal flats (e.g., Wadden Sea) |
| | 10.4 Deepwater coastal inlets (fjords) | 10.4.1 Deepwater coastal inlets (fjords) |
| 11. Coastal beaches, dunes and wetlands | 11.1 Artificial shorelines | 11.1.1 Artificial shorelines |
| | 11.2 Coastal dunes, beaches and sandy and muddy shores | 11.2.1 Coastal dunes<br>11.2.2 Beaches and sandy shores<br>11.2.3 Muddy shores |
| | 11.3 Rocky shores | 11.3.1 Coastal shingle<br>11.3.2 Rock cliffs, ledges and shores |
| | 11.4 Coastal saltmarshes and salines | 11.4.1 Coastal saltmarshes<br>11.4.2 Salines |
| 12. Marine ecosystems | | |

| EU ecosystem typology: level 1 | EU ecosystem typology | EU Ecosystem typology: level 3 (EUNIS) |
|---|---|---|
| 1. Settlements and other artificial areas | 1.6 Continuous settlement area | |
| | 1.7 Discontinuous settlement area | |
| | 1.8 Infrastructure | |
| | 1.9 Urban greenspace | 1.4.1 Parks, including Zoos and botanical gardens<br>1.4.2 Sports and recreation sites<br>1.4.3 Other urban green including urban tree alleys |
| | 1.10 Other artificial areas | |
| 2. Cropland[8] | 2.1 Annual cropland | |
| | 2.2 Rice fields | |
| | 2.3 Permanent crops | |
| | 2.4 Agro-forestry areas | |
| | 2.5 Mixed farmland | |
| | 2.6 Other farmland | |
| | 2.7 Hedgerows and tree rows in cropland | 2.7.1 Hedgerows in cropland<br>2.8.2 Tree rows in cropland |
| 3. Grassland (pastures, semi-natural and natural grasslands) | 3.1 Sown pastures and fields (modified grasslands) | 3.1.1 Sown pastures used for grazing<br>3.1.2 Sown grassland mown frequently for fodder or silage |
| | 3.2 Natural and semi-natural grasslands | 3.2.1 Dry grasslands<br>3.2.2 Seasonally wet and wet grasslands<br>3.2.3 Alpine and subalpine grasslands<br>3.2.4 Woodland fringes and clearings and tall forb stands<br>3.2.5 Inland salt steppes<br>3.2.6 Sparsely wooded grasslands<br>3.2.7 Mesophilous extensive grassland |
| | 3.3 Hedgerows and tree rows in grassland | 3.3.1 Hedgerows in grassland<br>3.3.2 Tree rows in grassland |
| 4. Forest and woodlands | 4.1 Broadleaved deciduous forest | 4.1.1 Riparian forest and woodland<br>4.1.2 Broadleaved swamp woodland on non-acid and acid peat<br>4.1.3 Fagus dominated forest<br>4.1.4 Sub-Mediterranean and Mediterranean thermophilous deciduous forest<br>4.1.5 Acidophilous [Quercus]- dominated woodland<br>4.1.6 Temperate and boreal and Southern European Betula and *Populus tremula* forest on mineral soils<br>4.1.7 Other broadleaved deciduous forest, excluding highly-modified plantations<br>4.1.8 Highly modified broadleaved deciduous forests including stands of non-native trees species that have long been established in European ecosystems stands |
| | 4.2 Coniferous forests | 4.2.1 Boreal and temperate fir and spruce forest<br>4.2.2 Mediterranean mountain fir and spruce forest<br>4.2.3 Temperate subalpine Larix, *Pinus cembra* and *Pinus uncinata* forest<br>4.2.4 Pine forest, excluding mires, non-thermophilous<br>4.2.5 Mediterranean thermophilous lowland pine forest<br>4.2.6 Spruce, pine and larch mire forest<br>4.2.7 Taiga forests<br>4.2.8 Other coniferous forests, excluding plantations<br>4.2.9 Highly modified coniferous forests including stands of non-native trees species that have long been established in European ecosystems stands |

[8] The breakdown of cropland uses the terms and breakdown of crop statistics at level 3 of the EU ecosystem typology for classes 2.1 – 2.3 (i.e. for annual cropland, rice fields and permanent crops). The codes in brackets at level 3 refer to crop statistics codes.

| EU ecosystem typology: level 1 | EU ecosystem typology | EU Ecosystem typology: level 3 (EUNIS) |
|---|---|---|
| | 4.3 Broadleaved evergreen forest | 4.3.1 Mediterranean evergreen Quercus forest<br>4.3.2 Mainland laurophyllous forest<br>4.3.3 Macaronesian laurophyllous forest<br>4.3.4 Olea europaea-Ceratonia siliqua forest<br>4.3.5 Palm groves (G25)<br>4.3.6 Other broadleaved evergreen forests<br>4.3.7 Highly modified broadleaved evergreen forests including stands of non-native trees species that have long been established in European ecosystems stands |
| | 4.4 Mixed forests | 4.4.1 Mixed forests dominated by coniferous species<br>4.4.2 Mixed forests dominated by broadleaved species<br>4.4.3 Other mixed forests including stands of non-native trees species that have long been established in European ecosystems stands |
| | 4.5 Transitional forest and woodland shrub | 4.5.1 Transitional woodland/forest land including recently felled or clear-cut, burnt, replanted or newly afforested |
| | 4.6 Plantations | 4.6.1 Monoculture plantations of non-native tree species |
| | | 4.6.2. Mixed plantations of a few species of non-European coniferous and broadleaved trees with underdeveloped undergrowth. |
| 5. Heathland and shrub | 5.1 Tundra (F1) | |
| | 5.2 Heathland and (sub-) alpine shrubs | |
| | 5.3 Sclerophyllous vegetation | |
| 6. Sparsely vegetated ecosystems | 6.1 Bare rocks | |
| | 6.2 Semi-desert, desert and other sparsely vegetated areas | |
| | 6.3 Ice sheets, glaciers and perennial snowfields | |
| 7. Inland wetlands | 7.1 Inland marshes on mineral soil | |
| | 7.2 Mires, bogs and fens | |
| 8. Rivers and canals | 8.1 Rivers | |
| | 8.2 Canals, ditches and drains | |
| 9. Lakes and reservoirs | 9.1 Lakes | |
| | 9.2 Artificial reservoirs | |
| | 9.3 Geothermal pools and wetlands (Iceland) | |
| 10. Marine inlets and transitional waters | | |
| 11. Coastal beaches, dunes and wetlands | 11.1 Artificial shorelines | 11.1.1 Artificial shorelines |
| | 11.2 Coastal dunes, beaches and sandy and muddy shores | 11.2.1 Coastal dunes<br>11.2.2 Beaches and sandy shores<br>11.2.3 Muddy shores |
| | 11.3 Rocky shores | 11.3.1 Coastal shingle<br>11.3.2 Rock cliffs, ledges and shores |
| | 11.4 Coastal saltmarshes and salines | 11.4.1 Coastal saltmarshes<br>11.4.2 Salines |
| 12. Marine ecosystems | | |

# Annex 2. National datasets

| Country | Validation of | Dataset | Source |
|---|---|---|---|
| Slovakia | Extent | Ecosystem map (EUNIS) | Datasets which identify individual ecosystems and their spatial distribution, status, and selected properties. The impetus to produce this map is the need of various stakeholders, especially nature protection bodies, forestry management, agricultural management and public administration, for better data on the distribution of ecosystems. The methodology mostly involves using GIS analytical tools to combine datasets on nature protection, forestry, and agriculture which list attributes related to habitat identification. |
| Greece | Extent | Ecosystem map (MAES level-3) | LIFE-IP 4 NATURA dataset |
| Greece | Extent | Natura 2000 habitat type map 1:5000 | Ministry of Environment and Energy |
| Norway | Extent | SAT-SKOG dataset; Landsat-5 and Landsat-7 | https://kart8.nibio.no/nedlasting/dashboard<br>or<br>https://www.nibio.no/tjenester/wms-tjenester/wms-tjeneste-sat-skog |
| Norway | Extent - Urban | Land use 2021 Geonorge – KartKatalog<br><br>Urban settlements | https://kartkatalog.geonorge.no/metadata/land-use/a965a979-c12a-4b26-90a0-f09de47dbecd<br>LiDAR-data https://hoydedata.no/LaserInnsyn2/<br><br>https://kartkatalog.geonorge.no/metadata/tettsteder/173f4a15-dead-4f82-b92e-f37396b72cea |

# Annex 3. Crosswalk between levels 1 and 2 of the EU ecosystem typology and the IUCN Global Ecosystem Typology

| EU ecosystem typology: level 1 | EU ecosystem typology: level 2 | IUCN GET Ecosystem Functional Group |
|---|---|---|
| 1. Settlements and other artificial areas | 1.1 Continuous settlement area | T7.4 Urban and industrial ecosystems |
| | 1.2 Discontinuous settlement area | T7.4 Urban and industrial ecosystems |
| | 1.3 Infrastructure | T7.4 Urban and industrial ecosystems |
| | 1.4 Urban greenspace | T7.4 Urban and industrial ecosystems |
| | 1.5 Other artificial areas | T7.4 Urban and industrial ecosystems |
| 2. Cropland | 2.1 Annual cropland | T7.1 Annual croplands |
| | 2.2 Rice fields | F3.3 Rice paddies |
| | 2.3 Permanent crops | T7.3 Plantations |
| | 2.4 Agro-forestry areas | T7.3 Plantations |
| | 2.5 Mixed farmland | T7.1 Annual croplands |
| | 2.6 Other farmland | T7.3 Plantations |
| | 2.7 Hedgerows and tree rows in cropland | TBD |
| 3. Grassland (pastures, semi-natural and natural grasslands) | 3.1 Sown pastures and fields (modified grassland) | T7.2 Sown pastures and fields |
| | 3.2 Natural and semi-natural grassland | T7.5 Derived semi-natural pastures and Oldfields; OR T4.5 Temperate subhumid grassland |
| | 3.3 Hedgerows and tree rows in grassland | TBD |
| 4. Forest and woodlands | 4.1 Broadleaved deciduous forest | T2.1 Boreal and temperate high montane forests and woodlands; OR T2.2 Deciduous temperate forests |
| | 4.2 Coniferous forests | T2.1 Boreal and temperate high montane forests and woodlands |
| | 4.3 Broadleaved evergreen forest | T2.4 Warm temperate laurophyll forests; OR T2.6 Temperate pyric sclerophyll forests and woodlands |
| | 4.4 Mixed forests | T2.2 Deciduous temperate forests |
| | 4.5 Transitional forest and woodland shrub | T2.1 Boreal and temperate high montane forests and woodlands OR T2.2 Deciduous temperate forests |
| | 4.6 Plantations | T7.3 Plantations |

| EU ecosystem typology: level 1 | EU ecosystem typology: level 2 | IUCN GET Ecosystem Functional Group |
|---|---|---|
| 5. Heathland and shrub | 5.1 Tundra | T6.3 Polar tundra and deserts |
| | 5.2 Heathland and (sub-) alpine shrub | T3.3 Cool temperate heathlands |
| | 5.3 Sclerophyllous vegetation | T3.2 Seasonally dry temperate heaths and shrublands |
| 6. Sparsely vegetated ecosystems | 6.1 Bare rocks | T3.4 Rocky pavements, screes and lava flows |
| | 6.2 Semi-desert, desert and other sparsely vegetated areas | T5.1 Semi-desert steppes |
| | 6.3 Ice sheets, glaciers and perennial snowfields | T6.1 Ice sheets, glaciers and perennial snowfields |
| 7. Inland wetlands | 7.1 Inland marshes on mineral soil | TF1.3 Permanent marshes; OR<br>TF1.4 Seasonal floodplain marshes |
| | 7.2 Mires, bogs and fens | TF1.6 Boreal, temperate and montane peat bog; OR<br>TF1.7 Boreal and temperate fens |
| 8. Rivers and canals | 8.1 Rivers | F1 Rivers and streams (Note that F1 is a 'Biome' in IUCN GET; the current EU typology does not permit subdividing this into the ecosystem functional groups. |
| | 8.2 Canals, ditches and drains | F3 Artificial fresh waters (as cell above) |
| 9. Lakes and reservoirs | 9.1 Lakes | F2 Lakes (as cell above) |
| | 9.2 Artificial reservoirs | F3 Artificial fresh waters (as above) |
| | 9.3 Geothermal pools and wetlands (Iceland) | F2.9 Geothermal pools and wetlands |
| 10. Marine inlets and transitional waters | 10.1 Coastal lagoons | FM1.3 Intermittently closed and open lakes and lagoons |
| | 10.2 Estuaries and bays | FM1.2 Permanently open riverine estuaries and bays |
| | 10.3 Intertidal flats | MT1.2 Muddy shores; OR<br>MT1.3 Sandy shores |
| | 10.4 Deepwater coastal inlets (fjords) | FM1.1 Deepwater coastal inlets |
| 11. Coastal beaches, dunes and wetlands | 11.1 Artificial shorelines | MT3.1 Artificial shores |
| | 11.2 Coastal dunes, beaches and sandy and muddy shores | MT2.1 Coastal shrublands and grasslands |
| | 11.3 Rocky shores | MT1.1 Rocky shores |
| | 11.4 Coastal saltmarshes and salines | MFT1.3 Coastal saltmarshes and reedbeds |
| 12. Marine ecosystems | 12.1 Marine macrophytes | M1.2 Kelp forests |

| EU ecosystem typology: level 1 | EU ecosystem typology: level 2 | IUCN GET Ecosystem Functional Group |
|---|---|---|
| | | M1.1 Seagrass meadows |
| | 12.2 Coral reefs | M1.3 Photic coral reef |
| | 12.3 Shellfish beds and reefs | M1.4 Shellfish beds and reefs |
| | 12.4 Subtidal sand beds and mud plains | M1.7 Subtidal sand beds; OR<br>M1.8 Subtidal mud plains |
| | 12.5 Subtidal rocky substrates | M1.6 Subtidal rocky reefs |
| | 12.6 Continental and island slopes | M3.1 Continental and island slopes |
| | 12.7 Deepwater benthic and pelagic ecosystems | M2 Pelagic ocean waters; OR<br>M3 Deep sea floors |
| | 12.8 Sea ice | M2.5 Sea ice |

# Annex 4. EUNIS typology

To easily distinguish the revised classification 2021 from the earlier version of 2012, the codes at level 1 have been changed. Habitat group names are different in some revised EUNIS 2021 habitat groups compared to the previous version 2012. More information can be found at https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification-1/eunis-terrestrial-habitat-classification-review-2021/eunis-terrestrial-habitat-classification-2021.

| Code 2021 | Name 2021 | Code 2012 | Name 2012 |
|---|---|---|---|
| N | Coastal habitats | B | Coastal habitats |
| R | Grasslands and lands dominated by forbs, mosses or lichens | E | Grasslands and lands dominated by forbs, mosses or lichens |
| S | Heathland, scrub and tundra | F | Heathland, scrub and tundra |
| T | Forest and other wooded land | G | Woodland, forest and other wooded land |
| U | Inland habitats with no or little soil and mostly with sparse vegetation | H | Inland unvegetated or sparsely vegetated habitats |
| V | Vegetated man-made habitats | I | Regularly or recently cultivated agricultural, horticultural and domestic habitats |