TEXTE
157/2023

Final report

Creation of a harmonized land cover map as an example for the entire region of the Geneva Air Pollution Convention

by:
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publisher:
Earth Observation Solutions and Services GmbH (EOSS)

German Environment Agency

Umwelt Bundesamt

TEXTE 157/2023

Ressortforschungsplan of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Project No. (FKZ) 3721 19 201 0

Report No. (UBA-FB) FB001145/ENG

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On behalf of the German Environment Agency

Imprint

Publisher
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Report completed in:
September 2022

Edited by:
Section II 4.3 Environmental Health and Protection of Ecosystems, Air Pollution and Terrestrial Ecosystems
Dr. Christin Loran, Thomas Scheuschner

Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4804

Dessau-Roßlau, November 2023

Abstract: Creation of a harmonized land cover map as an example for the entire region of the Geneva Air Pollution Convention

For the calculation of the Critical Loads (CL) for terrestrial ecosystems throughout Europe, but also for the modelling of the air quality, the creation of an up-to-date harmonized land cover map is necessary. This is combined with a spatial extension to Eastern Europe, Caucasus, and Central Asia (EECCA). The updated harmonized European Land Cover Map must comply with the EUNIS Habitat Classification Scheme with as much Level 3 classes as possible. Based on an evaluation of the availability and suitability of different spatial data it was decided to 1) use CORINE Land Cover 2018 and Ecosystem Type Map v3.1 and apply transition rules towards EUNIS Level 1 and Level 2 for European countries covered by CORINE Land Cover Maps, 2) use Copernicus Global Land Cover Map and apply transition rules towards EUNIS Level 1 and Level 2 for European countries not-covered by CORINE Land Cover Maps, 3) use Global Potential Natural Vegetation (GPNV) maps and the Harmonized World Soil Database (HWSD) to further disaggregate Level 2 classes towards Level 3. More than 700,000 points from the European Vegetation Archive (EVA) classified at EUNIS Level 3 were provided by the expert system for automatic classification of European vegetation plots to EUNIS habitats. Features were extracted from the GPNV modelled data on BIOMEs and FAPAR. Random stratified sampling was performed to retrieve 60% training and 40% validation samples. Training samples were used to train Random Forest decision tree models. Accuracy assessment was done on the remaining 40% validation samples. Overall accuracies ranged from 60% to more than 90%. Likewise, class specific users' and producers' accuracies found moderate to very high percentages. The decision tree models were to produce the updated EUNIS Level 3 habitat for whole Europe and EECCA countries providing a total of 218 land cover classes from which 204 classes represent EUNIS Level 3 classes.

Kurzbeschreibung: Erstellung einer harmonisierten Landbedeckungskarte als Beispiel für die gesamte Region der Genfer Luftreinhaltekonvention

Für die Berechnung der Critical Loads (CL) für terrestrische Ökosysteme in ganz Europa, aber auch für die Modellierung der Luftqualität, ist die Erstellung einer aktuellen harmonisierten Landbedeckungskarte notwendig. Verbunden ist dies mit einer räumlichen Ausdehnung nach Osteuropa, Kaukasus und Zentralasien (EECCA). Die aktualisierte harmonisierte europäische Landbedeckungskarte muss dem EUNIS-Habitat-Klassifizierungssystem mit so vielen Level-3-Klassen wie möglich entsprechen. Basierend auf einer Bewertung der Verfügbarkeit und Eignung verschiedener Geodaten wurde entschieden, 1) CORINE Land Cover 2018 und Ecosystem Type Map v3.1 zu verwenden und Übergangsregeln zu EUNIS Level 1 und Level 2 für die von CORINE Land Cover Map abgedeckten europäischen Länder anzuwenden, 2) Copernicus Global Land Cover Map zu verwenden und Übergangsregeln zu EUNIS Level 1 und Level 2 für europäische Länder anzuwenden, die nicht von CORINE Land Cover Maps abgedeckt werden, 3) Global Potential Natural Vegetation (GPNV)-Karten und die Harmonized World Soil Database zu verwenden (HWSD) zur weiteren Aufschlüsselung der Level-2-Klassen in Richtung Level 3. Mehr als 700.000 Punkte aus dem European Vegetation Archive (EVA), die auf EUNIS-Level 3 klassifiziert wurden, wurden vom Expertensystem für die automatische Klassifizierung europäischer Vegetationsparzellen in EUNIS-Lebensräume bereitgestellt. Merkmale wurden aus den GPNV-modellierten Daten zu Biomen und FAPAR extrahiert. Auf diese wurde ein räumlich stratifiziertes zufälliges sampling durchgeführt, um 60 % der Trainings- und 40 % der Validierungsstichproben zu erhalten. Trainingsbeispiele wurden verwendet, um Random-Forest-Entscheidungsbaummodelle zu trainieren. Die Genauigkeitsbewertung wurde an den verbleibenden 40 % der Validierungsproben durchgeführt. Die Genauigkeit variiert zwischen 60 % und mehr als 90 %. Bei den klassenbezogenen Nutzer- und Produzentengenauigkeiten

wurden mäßige bis sehr hohe Prozentsätze ermittelt. Die Anwendung der Entscheidungsbaummodelle lieferte die aktualisierte EUNIS-Level-3-Lebensraum Karte für ganz Europa und die EECCA-Länder mit insgesamt 218 Landbedeckungsklassen, von denen 204 Klassen EUNIS-Level-3-Klassen darstellen.

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List of abbreviations

Abbreviation	Description
CCE	Coordination Centre for Effects
CCI	Climate Change Initiative
CCMEO	Canadian Centre for Mapping and Earth Observation
CEC	Commission for Environmental Cooperation
CGLS	Copernicus Global Land Service
CL	Critical Loads
CLC	CORINE Land Cover
CLRTAP	Geneva Air Pollution Control Convention
CONABIO	National Commission for the Knowledge and Use of Biodiversity, Mexico
CTM	Chemical Transport Model
DMEER	Digital Map of European Ecological Regions
EEA	European Environmental Agency
EECCA	Eastern Europe, Caucasus and Central Asia
ESA	European Space Agency
ESDAC	European Soil Data Centre
ESDB	European Soil Database
ETM	Ecosystem Type Map
EUNIS	European Nature Information System
EVA	European Vegetation Archive
FAO	Food and Agriculture Organization of the United Nations
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FFH	Fauna-Flora-Habitiat
GLC	Global Land Cover
GPNV	Global Potential Natural Vegetation
HRL	High Resolution Layers
HWSD	Harmonized World Soil Database
INEGI	Instituto Nacional de Estadística y Geografía, Mexico
JRC	Joint Research Centre
LCCS	Land Cover Classification System
LMCS	Land Monitoring Core Service
LoCo	Local Components
MRLC	Multi-Resolution Land Characteristics
N2K	Natura 2000
NALCMS	North American Land Change Monitoring System
NGCC	National Geomatics Centre of China
NLCD	National Land Cover Database

Abbreviation	Description
OSM	OpenStreetMap
PNV	Potential Natural Vegetation
RCG	REM-Calgrid
RZ	Riparean Zones
UA	Urban Atlas
UBA	Federal Environment Agency (Umweltbundesamt)
USGS	United States Geological Survey

Summary

Land cover represents important biophysical properties of the earth's surface. Changes in land cover can have a significant impact on the earth's ecological and biogeochemical processes (Tsendbazar, Herold, et al. 2021). Owing to continued interests in land cover monitoring, global land cover (GLC) mapping efforts have seen accelerated progress over the last three decades (Tsendbazar, Herold, et al. 2021; Arino et al. 2008; Ban, Gong, and Giri 2015; Bartholomé and Belward 2005; Buchhorn et al. 2019; Zanaga et al. 2021). While global efforts provide limited and generalized detail in spatial and thematic resolution, several campaigns were initiated to produce land cover maps on continental or regional scales e.g. for Europe and North America (Büttner 2014; Commission for Environmental Cooperation (CEC) 2015; European Environment Agency 2012).

For the calculation of the CL for terrestrial ecosystems throughout Europe, but also for the modeling of the air quality, the creation of an up-to-date harmonized land cover map is necessary. The land cover maps currently used to calculate the CL are based on original data from the 1990s and 2000s (Slootweg, Posch, and Warrink 2009; Cinderby et al. 2007). An update is urgently required combined with a spatial extension to the EECCA countries or to the participating countries of the Geneva Air Pollution Control Convention (CLRTAP).

Current map covers the following 49 countries/regions (Europe): *Åland, Albania, Andorra, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Gibraltar, Greece, Guernsey, Hungary, Ireland, Isle of Man, Italy, Jersey, Kosovo, Latvia, Liechtenstein, Lithuania, Luxembourg, Macedonia, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, Vatican City*

The updated map shall be expanded to include the following 7 countries (EECCA+): *Armenia, Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan*

The possibility of an extension to the *United States of America* and *Canada* (NA+) should also be analyzed.

In the future, the new land cover map will be used both for the calculation of CL and for chemical transport modeling with REM-Calgrid.

The map may have a maximum grid size of 100 x 100m^2 and must support three different classification schemes: 1) EUNIS classes up to level 3; 2) classification according to the Fauna-Flora-Habitat-Guideline (FFH) and 3) land-use classes of the RCG chemical transport modelling.

This first section of the report presents the evaluation of the availability and suitability of different spatial data for updating the land cover maps. It was researched and evaluated which geodata sets are suitable to create a land cover map for the entire region of the Geneva Air Pollution Control Convention that meets the above criteria. The respective sub sections provide an overview of most relevant land cover dataset with European, Global and North American coverage. Features and characteristics, summaries and citation to relevant publications are given. Subsequently an evaluation for each of the outlined maps on their suitability to update the requested European land cover map is provided.

Based on an evaluation of the availability and suitability of different spatial data it was decided to 1) use CORINE Land Cover 2018 and Ecosystem Type Map v3.1 and apply transition rules towards EUNIS Level 1 and Level 2 for European countries covered by CORINE Land Cover

Maps, 2) use Copernicus Global Land Cover Map and apply transition rules towards EUNIS Level 1 and Level 2 for European countries not-covered by CORINE Land Cover Maps, 3) use Global Potential Natural Vegetation (GPNV) maps and the Harmonized World Soil Database (HWSD) to further disaggregate Level 2 classes towards Level 3.

More than 700,000 points from the European Vegetation Archive (EVA) classified at EUNIS Level 3 were provided by Expert system for automatic classification of European vegetation plots to EUNIS habitats (Chytrỳ et al. 2021). These have been separated by Level 2 and Level 1 class. For each of these sample batches features were extracted from the GPNV modelled data on BIOMEs and FAPAR. Random stratified sampling was performed to retrieve 60% training and 40% validation samples. Training samples were used to train a Random Forest decision tree model for each EUNIS Level 2 and Level 1 strata. Accuracy assessment was done on the remaining 40% validation samples. Using the before translated updated EUNIS Level 2 map, the respective class decision tree model was applied to the different discrete classes in the map and with that the EUNIS Level 3 habitat map was processed for whole Europe and EECCA+ countries providing a total of 218 land cover classes from which 204 classes represent EUNIS Level 3 classes.

Zusammenfassung

Die Landbedeckung stellt wichtige biophysikalische Eigenschaften der Erdoberfläche dar. Veränderungen der Landbedeckung können erhebliche Auswirkungen auf die ökologischen und biogeochemischen Prozesse der Erde haben (Tsendbazar, Herold, et al. 2021). Aufgrund des anhaltenden Interesses an der Überwachung der Landbedeckung haben die Bemühungen zur Kartierung der globalen Landbedeckung (GLC) in den letzten drei Jahrzehnten bedeutende Fortschritte gemacht (Tsendbazar, Herold, et al. 2021; Arino et al. 2008; Ban, Gong und Giri 2015; Bartholomé und Belward 2005; Buchhorn et al. 2019; Zanaga et al. 2021). Während die globalen Bemühungen eine begrenzte und verallgemeinerte Detailgenauigkeit in räumlicher und thematischer Auflösung bieten, wurden mehrere Kampagnen zur Erstellung von Landbedeckungskarten auf kontinentaler oder regionaler Ebene initiiert, z. B. für Europa und Nordamerika (Büttner 2014; Commission for Environmental Cooperation (CEC) 2015; European Environment Agency 2012).

Für die Berechnung der Critical Load (CL) für terrestrische Ökosysteme in ganz Europa, aber auch für die Modellierung der Luftqualität, ist die Erstellung einer aktuellen harmonisierten Landbedeckungskarte notwendig. Die derzeit zur Berechnung der CL verwendeten Landbedeckungskarten beruhen auf Originaldaten aus den 1990er und 2000er Jahren (Slootweg, Posch und Warrink 2009; Cinderby et al. 2007). Eine Aktualisierung ist dringend erforderlich, verbunden mit einer räumlichen Ausweitung auf die EECCA-Länder oder auf die Teilnehmerländer des Genfer Luftreinhalteabkommens (CLRTAP).

Die aktuelle Karte umfasst die folgenden 49 Länder/Regionen (Europa): Åland, Albanien, Andorra, Belgien, Bosnien und Herzegowina, Bulgarien, Dänemark, Deutschland, Estland, Finnland, Frankreich, Georgien, Gibraltar, Griechenland, Guernsey, Irland, Isle of Man, Italien, Jersey, Kosovo, Kroatien, Lettland, Liechtenstein, Litauen, Luxemburg, Mazedonien, Moldawien, Montenegro, Niederlande, Norwegen, Österreich, Polen, Portugal, Rumänien, Russland, San Marino, Schweden, Schweiz, Serbien, Slowakei, Slowenien, Spanien, Tschechische Republik, Türkei, Ukraine, Ungarn, Vereinigtes Königreich, Vatikanstadt.

Die aktualisierte Karte wird um die folgenden 7 Länder (EECCA+) erweitert: Armenien, Aserbaidschan, Kasachstan, Kirgisistan, Tadschikistan, Turkmenistan, Usbekistan

Die Möglichkeit einer Ausweitung auf die Vereinigten Staaten von Amerika und Kanada (NA+) sollte ebenfalls geprüft werden.

In Zukunft wird die neue Landbedeckungskarte sowohl für die Berechnung der CL als auch für die Modellierung des Chemietransports mit REM-Calgrid verwendet werden.

Die Karte darf eine maximale Rastergröße von 100 x 100m² haben und muss drei verschiedene Klassifizierungsschemata unterstützen: 1) EUNIS-Klassen bis zur Stufe 3; 2) Klassifizierung nach der Fauna-Flora-Habitat-Richtlinie (FFH) und 3) Landnutzungsklassen der RCG-Chemietransportmodellierung.

In dem ersten Kapitel des Berichts wird die Verfügbarkeit und Eignung verschiedener Geodaten für die Aktualisierung der Landbedeckungskarten bewertet. Es wurde recherchiert und bewertet, welche Geodatensätze geeignet sind, um eine Landbedeckungskarte für die gesamte Region des Genfer Luftreinhalteabkommens zu erstellen, die die oben genannten Kriterien

erfüllt. Die jeweiligen Unterabschnitte geben einen Überblick über die relevantesten Landbedeckungsdatensätze mit europäischer, globaler und nordamerikanischer Abdeckung. Es werden Merkmale und Eigenschaften, Zusammenfassungen und Verweise auf einschlägige Veröffentlichungen gegeben. Anschließend wird für jede der skizzierten Karten eine Bewertung ihrer Eignung zur Aktualisierung der angeforderten europäischen Landbedeckungskarte vorgenommen.

Auf der Grundlage der Verfügbarkeit und Eignung der verschiedenen räumlichen Daten wurde die Verwendung folgender Daten beschlossen: 1) CORINE Land Cover 2018 und Ecosystem Type Map v3.1 und die Anwendung von Übergangsregeln zu EUNIS Level 1 und Level 2 für europäische Länder, die von CORINE Land Cover Maps abgedeckt werden, 2) Copernicus Global Land Cover Map und die Anwendung von Übergangsregeln zu EUNIS Level 1 und Level 2 für europäische Länder, die nicht von CORINE Land Cover Maps abgedeckt werden, 3) Global Potential Natural Vegetation (GPNV) Maps und der Harmonized World Soil Database (HWSD) zur weiteren Disaggregation von Level 2 Klassen zu Level 3.

Mehr als 700.000 Punkte aus dem Europäischen Vegetationsarchiv (EVA), die auf EUNIS Level 3 klassifiziert wurden, wurden von einem Expertensystem für die automatische Klassifizierung europäischer Vegetationsflächen in EUNIS Habitate bereitgestellt (Chytrý et al. 2021). Diese wurden nach Level 2 und Level 1 Klassen getrennt. Für jede dieser Stichprobenpartien wurden Merkmale aus den modellierten GPNV-Daten zu Biomen und FAPAR extrahiert. Es wurden zufällig geschichtete Stichproben gezogen, um 60 % Trainings- und 40 % Validierungsstichproben zu erhalten. Die Trainingsstichproben wurden verwendet, um ein Random-Forest-Entscheidungsbaummodell für jede EUNIS Level 2 und Level 1 Klasse zu trainieren. Die Genauigkeit wurde anhand der verbleibenden 40 % Validierungsstichproben bewertet. Unter Verwendung der zuvor übersetzten und aktualisierten EUNIS Level 2 Karte wurde das jeweilige Klassen-Entscheidungsbaummodell auf die verschiedenen diskreten Klassen in der Karte angewandt, und damit wurde die EUNIS Level 3 Lebensraumkarte für ganz Europa und die EECCA+-Länder bearbeitet, die insgesamt 218 Landbedeckungsklassen enthält, von denen 204 Klassen EUNIS Level 3 Klassen darstellen.

1 Evaluation of the availability and suitability of different spatial land cover data

1.1 Required land cover classification systems

The Coordination Centre for Effects (CCE), which is based at the German Federal Environment Agency (UBA), calculates the critical loads for terrestrial ecosystems throughout Europe and therefore requires an up-to-date European land cover map. Furthermore, the map is required to determine the air quality based on calculations with the chemical transport model (CTM) REM-Calgrid (RCG) for Europe. The aim of this project is to update the already existing European land cover map (Cinderby et al. 2007; Slootweg, Posch, and Warrink 2009) and to spatially expand it to include the EECCA+ countries. In addition, it should be checked which data bases are available in order to create a harmonized land coverage map for the entire region of the Geneva Air Pollution Control Convention.

In the future, the new land cover map will be used both for the calculation of critical loads and for chemical transport modelling with REM-Calgrid. Therefore, the updated land cover map must provide a maximum grid size of 100 x 100 m^2 and shall support the following 3 classification systems: i) EUNIS classes up to at least level 3, ii) the classification according to the Fauna-Flora-Habitat Directive (FFH), and iii) the 13 land use classes used by the RCG.

The current used land cover map already provides 54 classes at EUNIS levels 1 (4 classes), level 2 (27 classes), and level 3 (23 classes), whereby some classes represent aggrupation of EUNIS level 2 and/or level 3 classes. It is not only the aim, to update and maintain existing EUNIS classes but to extent those classes to new EUNIS level 2 and level 3 classes where source cartography allows to.

1.1.1 EUNIS Habitat Classification Scheme

The EUNIS (European Nature Information System) Habitat Classification, is the main comprehensive pan-European hierarchical classification of habitats covering both the marine and terrestrial realms (Rodwell, Evans, and Schaminée 2018).

Terrestrial habitats in EUNIS are often based on phytosociological vegetation types, species composition and vegetation structure; EUNIS also emphasizes the abiotic environment and geographic location as classification criteria and further it includes habitats in which plants are nearly or entirely absent (Chytrý et al. 2020). In consequence it appears to be difficult to translate and disaggregate existing land cover map classes (mainly derived by using satellite images) towards the EUNIS classification scheme at least in level 3 and subsequent levels.

Recently, the classification expert system EUNIS-ESy was published, which contains definitions of individual EUNIS habitats based on their species composition and geographic location, and with that provided an updated code set of the EUNIS classes at all 3 levels (Chytrý et al. 2020). Formal definitions were developed for 199 habitats at Level 3 of the EUNIS hierarchy, including 25 coastal, 18 wetland, 55 grassland, 43 shrubland, 46 forest and 12 man-made habitats. A total of 1,261,373 vegetation plots from the European Vegetation Archive (EVA) were classified into the different habitat classes and the data on each habitat were summarized in factsheets containing habitat description, distribution map, corresponding syntax and characteristic species combination (Chytrý et al. 2020).

With the new EUNIS scheme some classes were removed, *i.e.* the formerly class J (Constructed, industrial and other artificial habitats) and its subclasses and the formerly class G4 (Mixed

deciduous and coniferous woodland) and its subclasses. This appears to be critical when updating existing land cover maps towards the new EUNIS scheme and will be discussed later.

In general, the new EUNIS scheme describes 6 classes at level 1, 35 classes at level 2 and 246 classes at level 3. A comprehensive list of the EUNIS scheme is given in the Appendix (Table 20).

1.1.2 REM-CalGrid Classification Scheme

The REM-CALGRID model (RCG) is a three-dimensional chemical transport model, which allows the calculation of air quality values (Stern 2018). The RCG model requires land use data represented by 13 land cover classes (Table 21). Also, the proportions of each class in each grid cell are required. The target grid cell size of RCG land cover and land cover proportions is 2 x 2 km^2.

1.1.3 FFH Classification Scheme

Adopted in 1992, the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora aims to promote the maintenance of biodiversity, taking account of economic, social, cultural, and regional requirements (European Commission 2013). The Habitats Directive ensures the conservation of a wide range of rare, threatened, or endemic animal and plant species and about 200 rare and characteristic habitat types are targeted for conservation. The Habitats Directive requires Member States to report on the conservation status of habitats and species and an interpretation manual (European Environment Agency 2013) is provided for the interpretation the Annex 1 habitats with common definitions for all habitat types (European Commission 2003). Annex I lists 233 European natural habitat types. Annex I was initially based on the hierarchical classification of European habitats developed by the CORINE Biotopes project since that was the only existing classification at European level (Table 22).

1.2 A review on existing European Land Cover Datasets

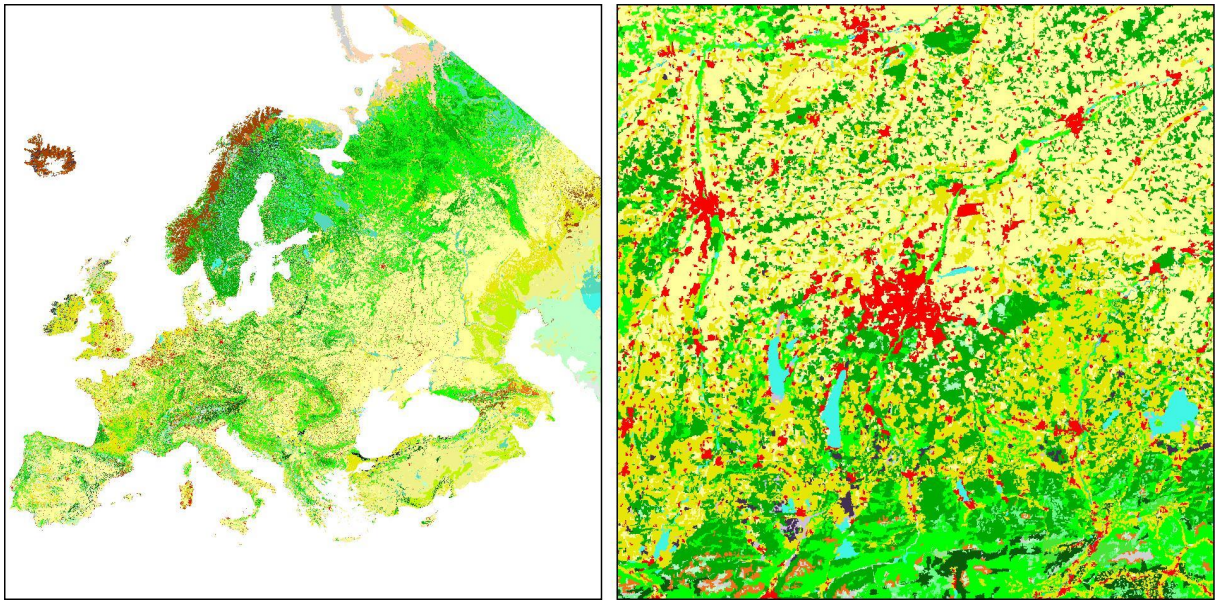
1.2.1 Harmonized European Land Cover Map

The harmonized European Land Cover Map is currently used by the CCE. It is based on the works described by (Slootweg, Posch, and Warrink 2009) and (Cinderby et al. 2007). The map is a combination of analogue and digital maps (e.g. Corine Land Cover 2000, SEI European Land Cover Map, FAO Soil Map of the World, EEA European Biogeographical regions). The dataset has especially been created for the use by modelers to assess the impact of air pollutants on European ecosystems and agriculture. The data have been modelled and combined to generate classes differentiating between various EUNIS codes. The dataset contains information down to EUNIS level 3 for specific habitat types (Cinderby et al. 2007). The map covers Europe including the European part of Russia, Turkey, Kazakhstan, Armenia and Azerbaijan. The map is available as raster dataset with a resolution of 100 x 100 m^2 with pixel values representing numeric EUNIS code down to level 3 of the EUNIS class scheme. A total of 57 distinct classes are represented in the land cover map (Table 23). From these numeric classes, however, three are missing an EUNIS class relation, namely classes 1020, 1030, and 25000 which all together sum up to 0.064% of the total map area. Strength and weaknesses of the Harmonized European Land Cover Map are provided in Table 1, a visual subset is provided in Figure 1.

Table 1: Strength and weaknesses of the Harmonized European Land Cover Map

Strength	Weaknesses
Full support of required CL EUNIS classes	Outdated
EECCA covered	No accuracy information available
Resolution fits target grid size	EECCA+ and NA+ not covered

Figure 1: Overview of Harmonized European Landcover Map at full extent and for the wider Munich area



Source: own illustration, EOSS GmbH; Slootweg, Posch, and Warrink 2009.

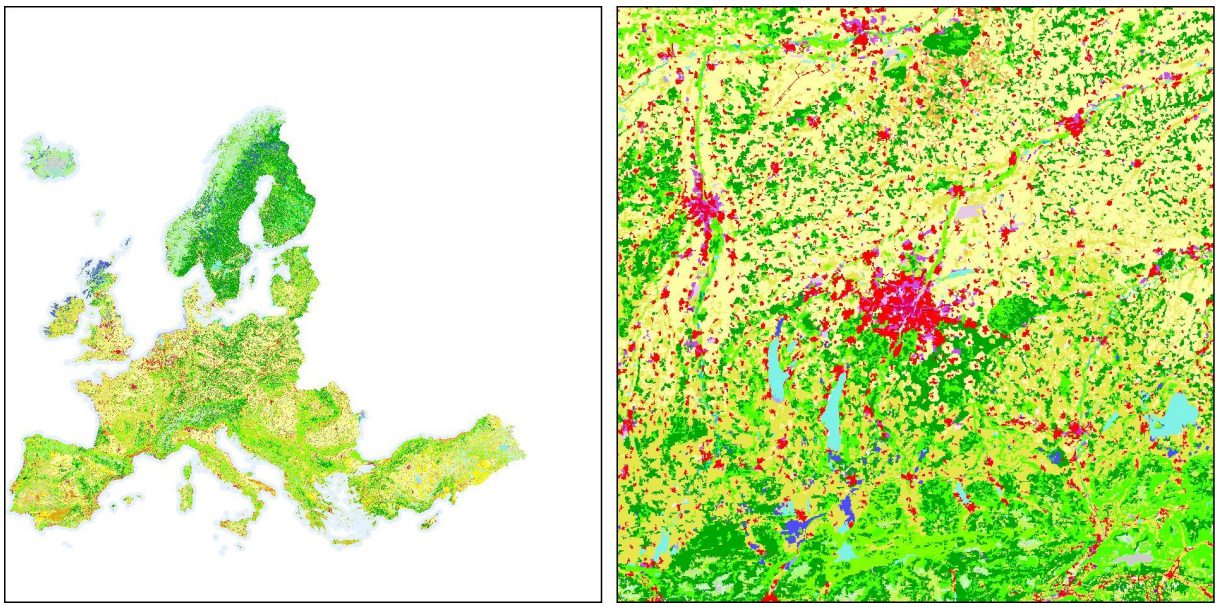
1.2.2 Copernicus CORINE Land Cover

The CORINE Land Cover (CLC) inventory is provided through the Copernicus Land Monitoring Service of the European Environmental Agency and was initiated in 1985 (reference year 1990) (Büttner 2014). Updates have been produced in 2000, 2006, 2012, and 2018. It consists of an inventory of land cover in 44 classes (Table 24). CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. The time series are complemented by change layers, which highlight changes in land cover with an MMU of 5 ha. The latest update of 2018 was sourced by Landsat-8 and Sentinel-2 satellite imagery. The thematic accuracy is reported with greater than 85%. 39 countries are currently involved and covered. From the 49 EECCA countries Andorra, Belarus and Russia are not covered. For Georgia, Moldova and Ukraine only pilot areas around the capitals of each country are produced. All 7 EECCA+ countries are not covered. For Armenia and Azerbaijan only pilot areas around the capitals of each country are produced. The map and change layers are available as vector dataset and raster datasets are derived with a resolution of 100 x 100 sqm with pixel values representing numeric CLC code down to level 3 of the CLC class scheme. Strength and weaknesses of the CORINE Land Cover Map are provided in Table 2, a visual subset is provided in Figure 2.

Table 2: Strength and weaknesses of the CORINE Land Cover Map

Strength	Weaknesses
Recent map for 2018 available	EECCA+ not completely covered
Resolution fits target grid size	EECCA+ and NA+ not covered
Accuracy information available	Thematic classes do not provide full required class scheme
Some thematic classes can be directly translated into required EUNIS class scheme	

Figure 2: Overview of CORINE Landcover Map 2018 at full extent and for the wider Munich area



Source: own illustration, EOSS GmbH; Corine Land Cover 2018.

1.2.3 EEA Ecosystem Type Map

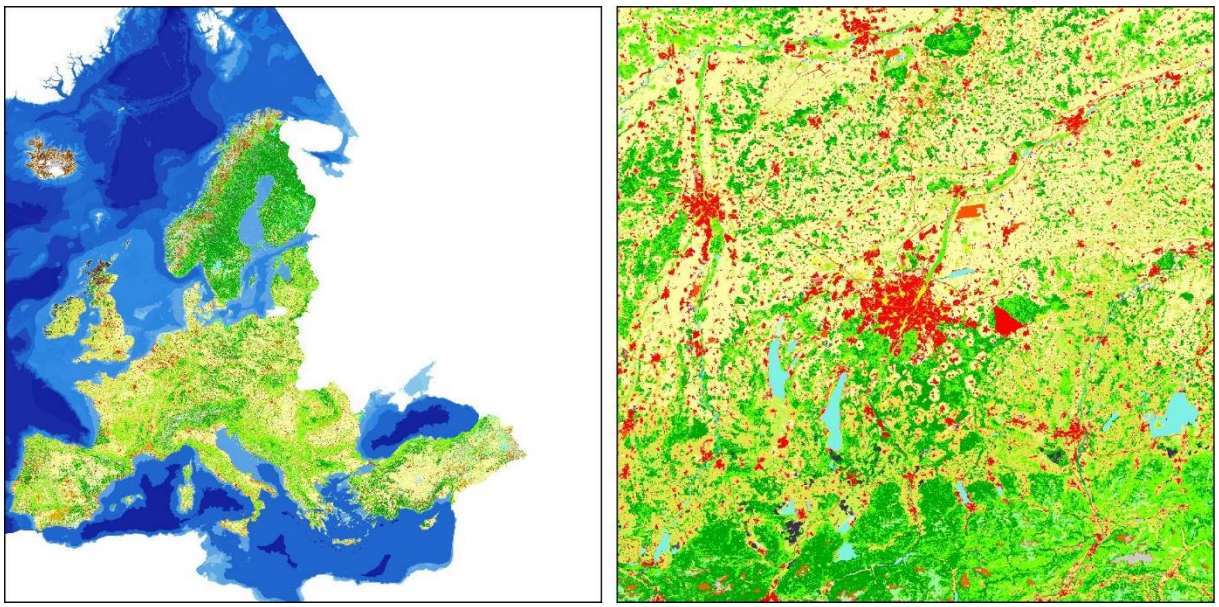
The aim of the Ecosystem Type Map was to combine spatially explicit land cover information with non-spatially referenced habitat information to improve our knowledge about ecosystems and their distribution across Europe. The first map (Ecosystem Type Map v2.1, ETM) was published in 2014 and based mainly on input datasets from reference year 2006 (e. g. CLC 2006). Primary output (ETM) is the actual map representing EUNIS classes on Level 2 with a resolution of 100 x 100m (European Environment Agency 2012). The derived class mapping rules were based on a set of stable core datasets that represents information not changing through time (e.g. the natural potential vegetation zone or distance to the coast or soil type) and the dynamic datasets. With updated input dynamic datasets of (Corine Land Cover 2012, HRL Forests 2012 (Forest Type, Tree Cover Density), HRL Imperviousness 2012, OpenStreetMap (OSM) data 2015 (main roads, land use information)) and the availability of the Local Components (LoCo) of the Copernicus Land Monitoring Service, consisting of Urban Atlas (UA), Riparian Zones (RZ) or Natura 2000 (N2k) and furthermore the High-Resolution Layers (HRL) Grasslands and HRL Permanent Water Bodies, a new version 3.1 was compiled. For integration of the new datasets crosswalks/mapping rules had been developed. The primary output (ETM)

is the actual map representing EUNIS classes on Level 2 with a resolution of 100 x 100 m2. The resulting map represents 47 classes describing EUNIS classes down to level 2 (Table 25). 84 additional classes describe marine habitats down to level 3 of the EUNIS scheme. With CORINE CLC 2012 being the primary input data source, the spatial coverage is equal to CLC. Strength and weaknesses of the Ecosystem Type Map v3.1 are provided in Table 3, a visual subset is provided in Figure 3.

Table 3: Strength and weaknesses of the Ecosystem Type Map v3.1

Strength	Weaknesses
Resolution fits target grid size	Based on 2012 map data
Accuracy/Reliability information available	EECCA+ not completely covered
Some thematic classes can be directly translated into required EUNIS level 2 class scheme and extend the CLC relations	EECCA+ and NA+ not covered
Based on CLC	Thematic classes do not provide required class scheme for the EUNIS level 3 classes

Figure 3: Overview of Ecosystem Type Map v3.1 at full extent and for the wider Munich area



Source: own illustration, EOSS GmbH; EEA Ecosystem Type Map v2.1.

1.2.4 Copernicus High Resolution Layers

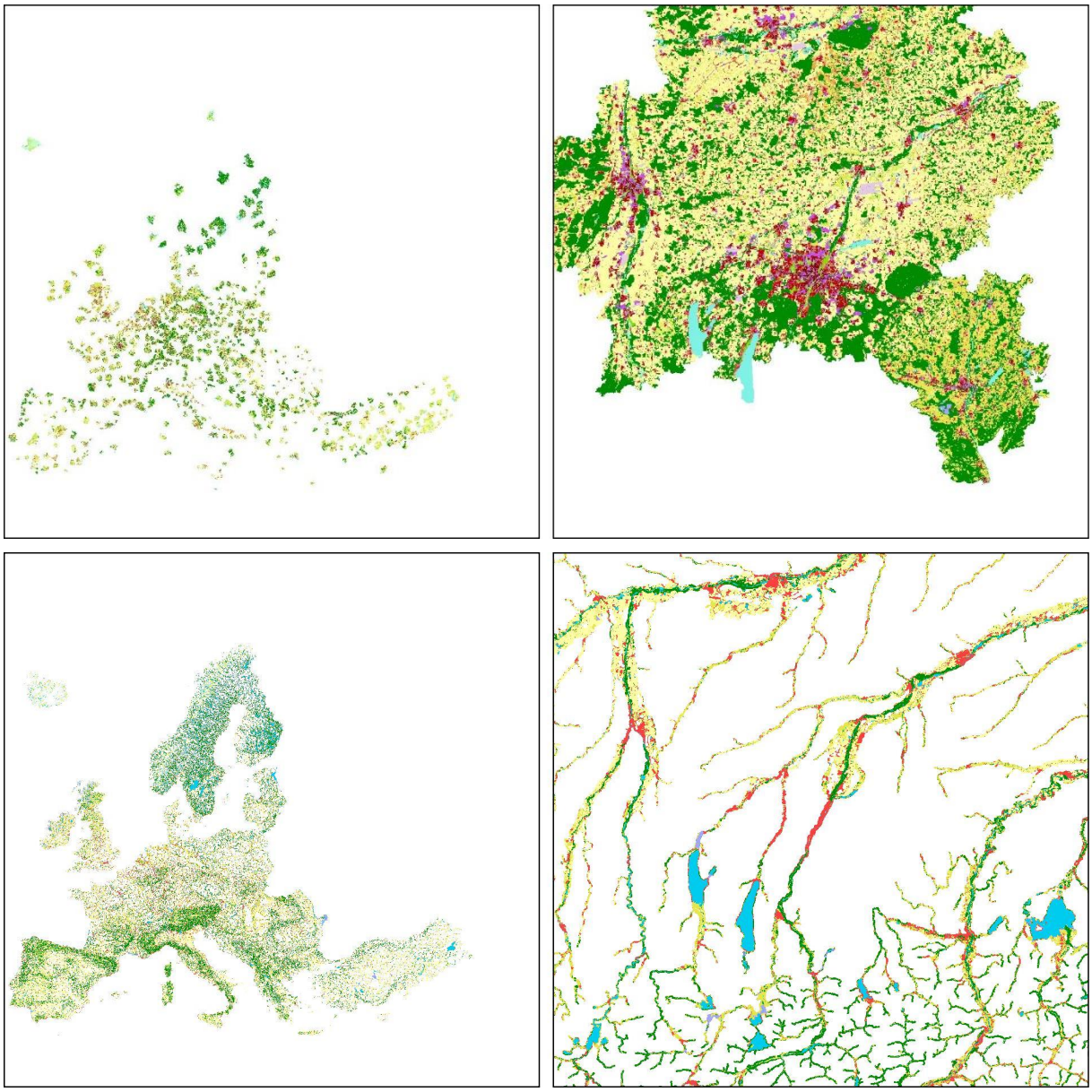
The Pan-European High Resolution Layers (HRL) are provided through the Copernicus Land Monitoring Service of the European Environmental Agency (Congedo et al. 2016). They provide information on specific land cover characteristics and are complementary to land cover / land use mapping such as in the CORINE land cover (CLC) datasets. Five theme layers corresponding with the main themes from CLC are provided, i.e. the level of sealed soil (imperviousness), tree cover density and forest type, grasslands, wetness and water, and small woody features. Since 2018 the products are based on Sentinel-2 and Sentinel-1, before they are based on time series of satellite images from several different sensors. All products are mapping the features under consideration for the whole of the EEA-39 area.

In addition, local component layers are produced namely the Urban Atlas, Riparian Zones, Natura2000 and Coastal Zone components to provide specific and more detailed information that is complementary to the information obtained through the Pan-European component. The local component focuses on different hotspots, i.e., areas that are prone to specific environmental challenges and problems. The Urban Atlas provides pan-European comparable land cover and land use data covering several Functional Urban Areas. The riparian zones address land cover and land use in areas along rivers. The aim of the Natura2000 layer is to map LC/LU in a selection of grassland rich sites and to assess whether those selected sites are being effectively preserved as well as, if a decline of certain grassland habitat types is being halted. The coastal zones LC/LU component provides maps from a 10 km landwards buffer of the European baseline. Strength and weaknesses of the Copernicus High Resolution Layers and a visual subset are provided in Table 4 and Figure 4.

Table 4: Strength and weaknesses of the Copernicus High Resolution Layers

Strength	Weaknesses
Resolution better than target grid size	Limited number of thematic classes
Have been used for ETM v3.1 map creation	Only in specific areas of interest
Complementary to CLC maps	
Updates for 2018 available	

Figure 4: Overview of Copernicus High Resolution Urban and Riparian Zone Layers at full extent and for the wider Munich area



Source: own illustration, EOSS GmbH; Copernicus Land Monitoring Service.

1.2.5 JRC Forest Distribution Maps

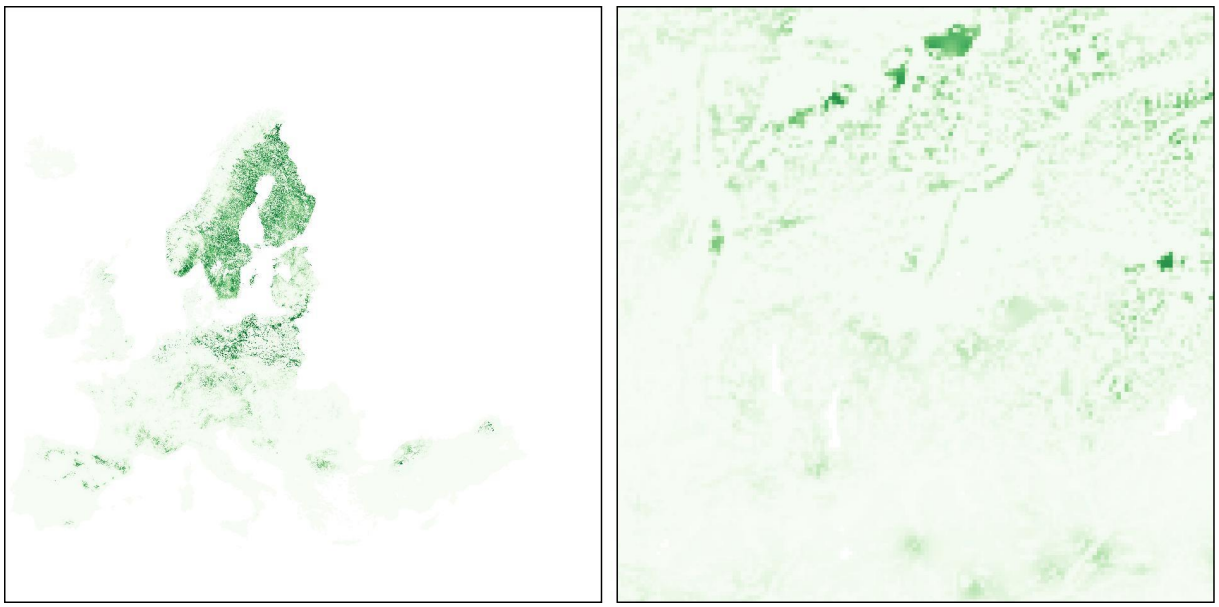
The Joint Research Centre of the European Union produces maps of forest tree species distribution in Europe. They are primarily based on National Forest Inventories, the ICP-Forest database of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forest (ICP-Forests), and the BioSoil database (Rigo et al. 2020). The JRC produces different types of tree species distribution maps, amongst others, Presence maps that show the locations where the geo-databases report the presence of the species; Presence-absence maps, not only where a species was recorded as present, but also where it was recorded as absent; Chorological maps that provide a synoptic overview of a species' distribution, as result of overlaps and comparisons of numerous and heterogeneous sources; and Model-derived maps like the Relative Probability of Presence (RPP) maps, that represent the probability (in 8 discrete probability interval classes) of tree species presence in a 1km^2 grid cell. Another

modelled map published is the Maximum Habitat Suitability (MHS) aiming to describe where bio-climatic conditions should allow a tree species to survive. Most distribution maps are dated 2016. Strength and weaknesses of the JRC Forest Distribution Maps are provided in Table 5, a visual subset is provided in Figure 5.

Table 5: Strength and weaknesses of the JRC Forest Distribution Maps

Strength	Weaknesses
Covers all Europe	Coarse resolution of 1km2
Many tree species represented	Distribution maps provide modelled presence and absence probabilities and not measured presence
Based on national tree inventories	

Figure 5: Overview of the Forest Distribution Map at full extent and for the wider Munich area



Source: own illustration, EOSS GmbH; JRC Forest Distribution Maps.

1.3 A review on existing Global Land Cover Datasets

1.3.1 Copernicus Global Land Cover

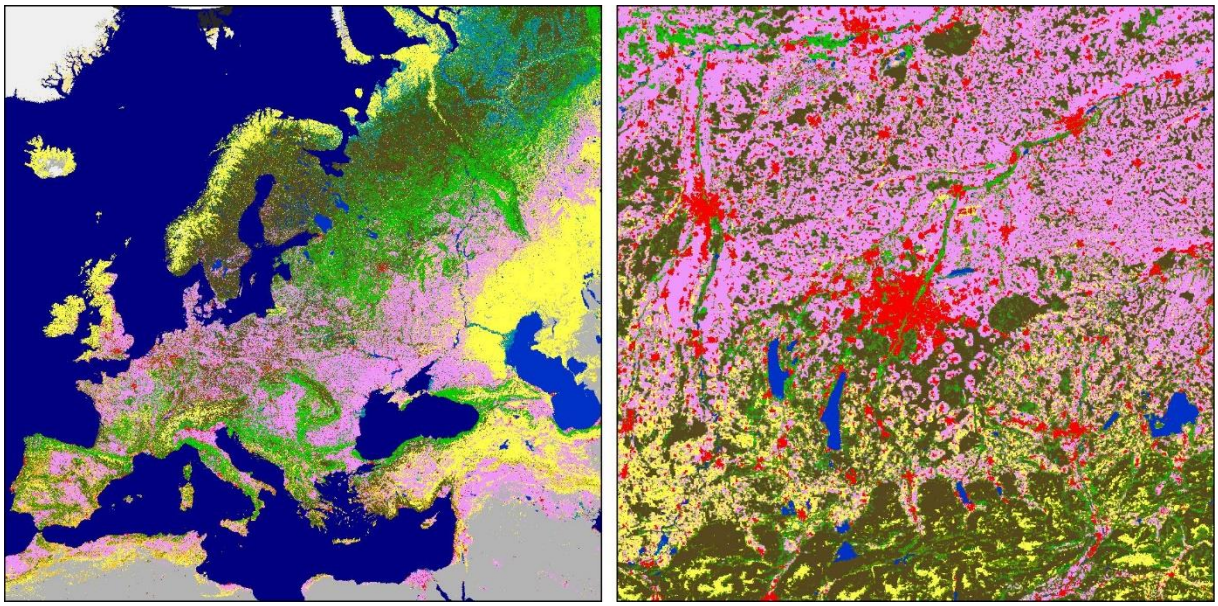
The Copernicus Global Land Service (CGLS) is a component of the Land Monitoring Core Service (LMCS) of Copernicus, the European flagship program on Earth Observation. The Global Land Service systematically produces a series of qualified bio-geophysical products on the status and evolution of the land surface, at global scale and at mid to low spatial resolution, complemented by the constitution of long-term time series. The products are used to monitor the vegetation, the water cycle, the energy budget and the terrestrial cryosphere. The yearly moderate-resolution land cover maps do primarily target land cover detection and their changes. The map is provided together with vegetation continuous field layers that provide proportional estimates of vegetation cover for several land cover types. Latest published map is provided for the reference year 2019 (Buchhorn et al. 2019). The map represents 22 discrete land cover classes at a resolution of 100 x 100m² (Table 26). The overall mapping accuracy is reported with 80.3%

(Tsendbazar, Herold, et al. 2021; Tsendbazar, Tarko, et al. 2021). Strength and weaknesses of the Copernicus Global Land Cover are provided in Table 6, a visual subset is provided in Figure 6.

Table 6: Strength and weaknesses of Copernicus Global Land Cover

Strength	Weaknesses
Resolution fits target grid size	Thematic classes do not provide full required class scheme for the EUNIS level 2 classes
Accuracy/Reliability information available	
Some thematic classes can be directly translated into required EUNIS class scheme	
Worldwide coverage	
Recent map for 2019 available	

Figure 6: Overview of Copernicus Global Landcover Map at European extent and for the wider Munich area



Source: own illustration, EOSS GmbH; Copernicus Global Land Service.

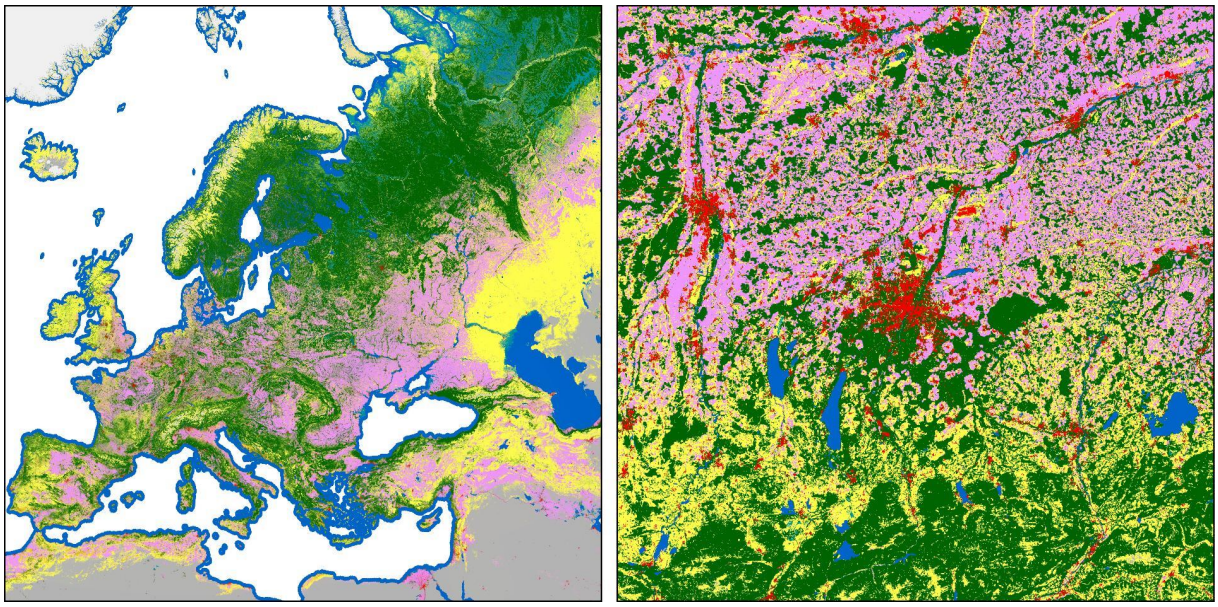
1.3.2 ESA World Cover

The ESA World Cover Dataset (Zanaga et al. 2021) provides to be one of the most recent global land cover maps and, based on Sentinel-2 and Sentinel-1 constellations, features a resolution of 10 x 10m. The overall accuracy is reported with 75% (Tsendbazar, Li, et al. 2021). The year of reference is 2020. The map provides 11 discrete land cover classes (Table 27). The map has been produced by a consortium of highly experienced major European service providers and research organizations. Strength and weaknesses of the ESA World Cover are provided in Table 7, a visual subset is provided in Figure 7.

Table 7: Strength and weaknesses of ESA World Cover

Strength	Weaknesses
Resolution of 10m overfits target grid size	Limited set of 11 land cover classes
Accuracy/Reliability information available	Thematic classes do not provide full required class scheme for the EUNIS level 2 classes
Worldwide coverage	
Recent map for 2020 available	

Figure 7: Overview of ESA World Cover Landcover Map at European extent and for the wider Munich area



Source: own illustration, EOSS GmbH; ESA World Cover.

1.3.3 NGCC GlobeLand 30

The Land Cover Map named GobalLand30 is provided by the National Geomatics Centre of China. It sourced Landsat imagery of sensors TM and ETM+ between 2000 and 2010 and is provided at a resolution of 30 x 30m2 (Chen and Chen 2018). The map was initially created with 10 classes (Table 28) for years 2000 and 2010. In September 2014, GlobeLand30 was donated by China to the United Nations for open access and international sharing. The map received an update by integrating a novel Pixel-Object-Knowledge-based (POK-based) approach by integrating pixel-based classification, object-based processing and knowledge-based interactive verification and yielded in an overall accuracy of 83% (Chen and Chen 2018; Chen et al. 2021; 2015). Strength and weaknesses of the NGCC GlobeLand30 are provided in Table 8.

Table 8: Strength and weaknesses of NGCC GlobeLand30

Strength	Weaknesses
Resolution of 30m overfits target grid size	Limited set of 10 land cover classes
Accuracy/Reliability information available	Thematic classes do not provide full required class scheme for the EUNIS level 2 classes
Worldwide coverage	Outdated 2015 map
	Data access limitations

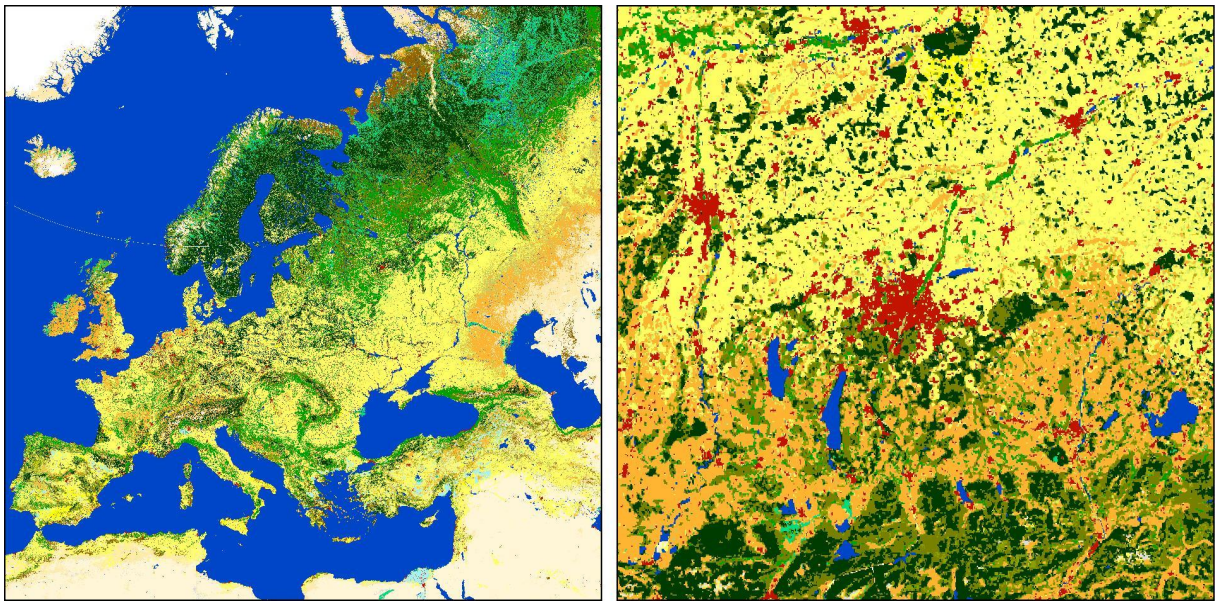
1.3.4 CCI Annual Global Land Cover Time Series 1992 to 2015

In the framework of the Climate Change Initiative (CCI) of the European Space Agency, the CCI Land Cover partnership releases the CCI 300 m annual global land cover time series from 1992 to 2015 (Cover 2017). This effort was supported by state-of-the-art reprocessing of the full archives of 5 different satellite missions providing daily observation of the Earth, including NOAA-AVHRR HRPT, SPOT-Vegetation, ENVISAT-MERIS FR and RR, ENVISAT-ASAR, and PROBA-V. The map products describe 22 land cover classes (Table 29) and are provided at 300m resolution (Defourny et al. 2012). The overall accuracy, weighted by the area proportions of the various land cover classes, is 73% (Defourny et al. 2009). Strength and weaknesses of the CCI Annual Global Landcover Map are provided in Table 9, a visual subset is provided in Figure 8.

Table 9: Strength and weaknesses of CCI Annual Global Land Cover Time Series

Strength	Weaknesses
Resolution fits target grid size	Thematic classes do not provide full required class scheme for the EUNIS level 2 classes
Accuracy/Reliability information available	Coarse resolution of 300m
Some of the 22 thematic classes can be directly translated into required EUNIS class scheme	Latest reference year is 2015
Worldwide coverage	

Figure 8: Overview of CCI Annual Global Landcover Map at European extent and for the wider Munich area



Source: own illustration, EOSS GmbH, CCI Annual Global Land Cover.

1.3.5 ESRI Land Cover

With the recently published ESRI Land Cover dataset (Karra et al. 2021), another 10m x 10m global land cover map is available. The map features 10 classes (Table 30) and was derived using Sentinel-2 images from 2020. This map was produced by a deep learning model trained using over 5 billion hand-labeled Sentinel-2 pixels, sampled from over 20,000 sites distributed across all major BIOMEs of the world. The model accuracy is reported to achieve 86% overall accuracy. Strength and weaknesses of the ESRI Land Cover are provided in Table 10.

Table 10: Strength and weaknesses of ESRI Land Cover

Strength	Weaknesses
Resolution of 10m	Only 10 land cover classes
Accuracy/Reliability information available	
Worldwide coverage	
Recent map for 2020 available	

1.4 A review on existing North American Land Cover Datasets

1.4.1 CEC North American Land Change Monitoring System

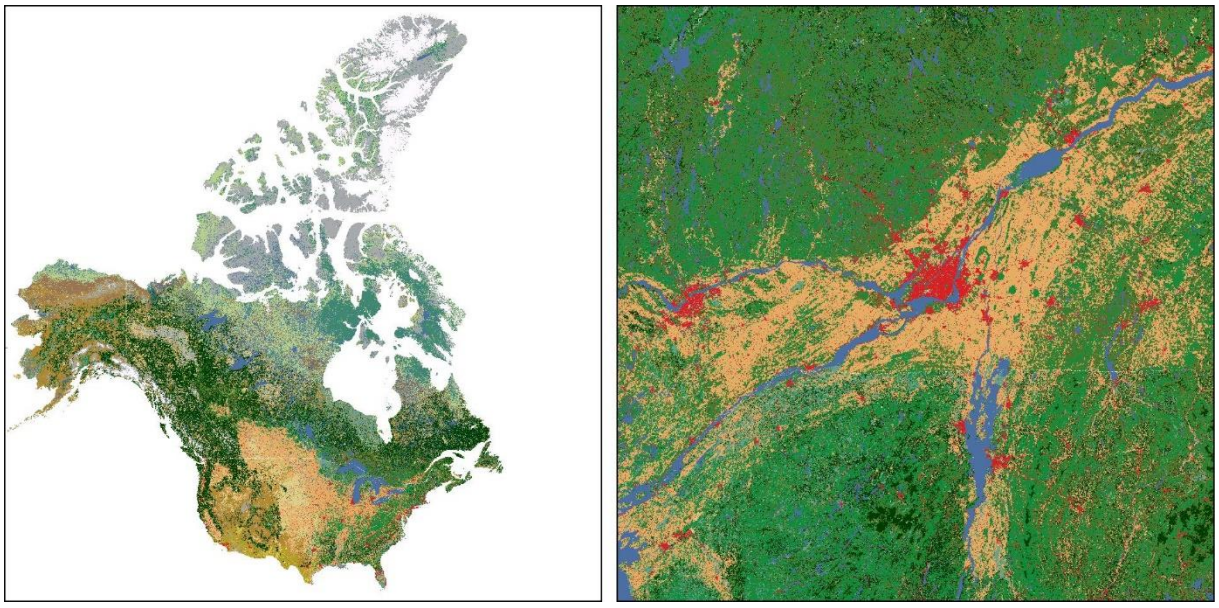
The North American Land Change Monitoring System (NALCMS) is a joint initiative between Natural Resources Canada (NRCan)'s Canada Centre for Mapping and Earth Observation (CCMEO), the United States Geological Survey (USGS), and three Mexican organizations: the National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía—INEGI), the National Commission for the Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad—Conabio), and the National Forestry Commission (Comisión Nacional Forestal—Conafor), and supported by the Commission for

Environmental Cooperation (CEC) (Commission for Environmental Cooperation (CEC) 2015; Latifovic et al. 2012). The 2015 map of North American land cover at a spatial resolution of 30 meters provides a harmonized view of the physical cover of Earth's surface across the continent based on 2015 Landsat satellite imagery for Canada and the United States, and RapidEye imagery for Mexico (Commission for Environmental Cooperation (CEC) 2015). Nineteen Level II land cover classes were defined using the Land Cover Classification System (LCCS) standard developed by the Food and Agriculture Organization (FAO) of the United Nations (Table 31). The overall accuracy is reported with 79%. Strength and weaknesses of the North American Land Change Monitoring System are provided in Table 11, a visual subset is provided in Figure 9.

Table 11: Strength and weaknesses of North American Land Change Monitoring System (NALCMS)

Strength	Weaknesses
Resolution of 30m overfits fits target grid size	Thematic classes do not provide full required class scheme for the EUNIS level 2 classes
Accuracy/Reliability information available	Latest map of 2015
Some thematic classes can be directly translated into required EUNIS class scheme	
Dedicated land cover class scheme for North America	
Covering Canada and USA	

Figure 9: Overview of North American NALCMS Landcover Map



Source: own illustration, EOSS GmbH; NALCMS, Commission for Environmental Cooperation (CEC).

1.4.2 MRLC National Land Cover Database

The Multi-Resolution Land Characteristics (MRLC) consortium is a group of United States federal agencies who coordinate and generate consistent and relevant land cover information at the national scale for a wide variety of environmental, land management, and modelling applications. The U.S. Geological Survey (USGS) has released the National Land Cover Database (NLCD) 2019 with 34 different land cover products across 8 epochs from 2001-2019. The 2019 land cover map features nationwide data on land cover and land cover change at a 30m resolution with a 20-class legend (Table 32). Previous version NLCD 2016 had a reported overall accuracy of 83% (Homer et al. 2020). Strength and weaknesses of the MRLC National Land Cover Map are provided in Table 12, a visual subset is provided in.

Table 12: Strength and weaknesses of MRLC National Land Cover Database

Strength	Weaknesses
Resolution of 30m overfits fits target grid size	Thematic classes do not provide full required class scheme for the EUNIS level 2 classes
Accuracy/Reliability information available	Covering USA only
Some thematic classes can be directly translated into required EUNIS class scheme	
Dedicated land cover class scheme for USA with 34 classes	
Latest map for 2019 available	

1.5 A review on existing other reference datasets

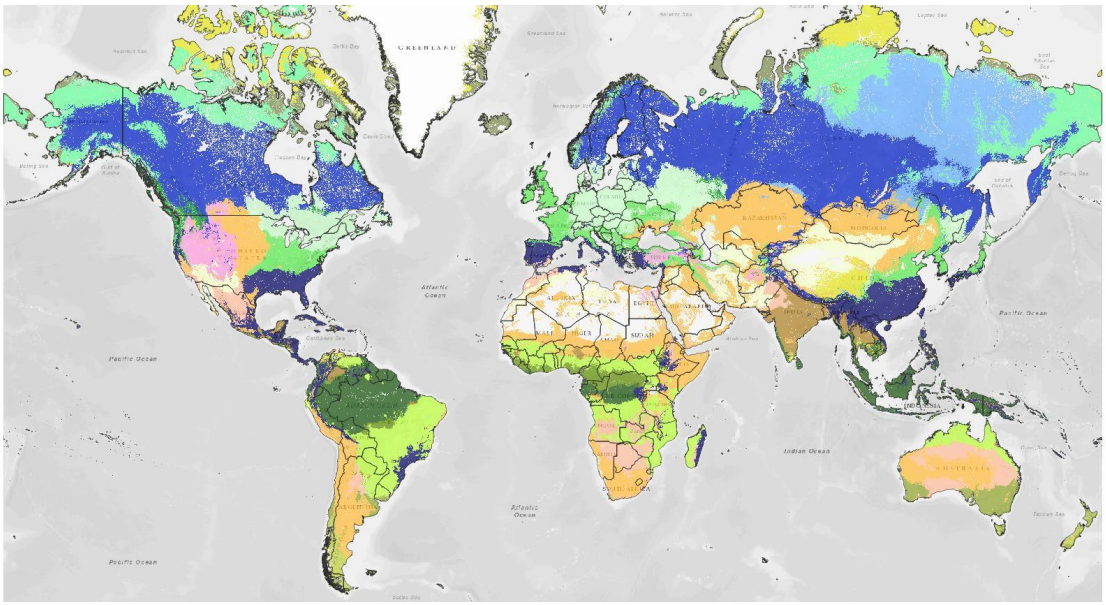
1.5.1 Global maps of potential vegetation

The Potential Natural Vegetation (PNV) is the vegetation cover in equilibrium with climate, that would exist at a given location non-impacted by human activities (Hengl et al. 2018). Predictions for 1) global distribution of BIOMEs based on the BIOME 6000 data, (2) distribution of forest tree species in Europe and (3) global monthly Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) values are available in in 1km raster dataset (Hengl 2018). The derivation of the distribution maps is driven by model-based predictions using more than 100 variables derived from ground observations (BIOME 6000 vegetation reconstruction samples, European Forest Plots for 73 forest species) and ESA's global land cover maps at 300m resolution. A total of 19 global BIOME classes are provided (Table 33) and 73 tree species distribution maps are published. Strength and weaknesses of the Global Potential Vegetation Maps are provided in Table 13, a visual subset is provided in Figure 10 and Figure 11.

Table 13: Strength and weaknesses of Global Potential Vegetation Maps

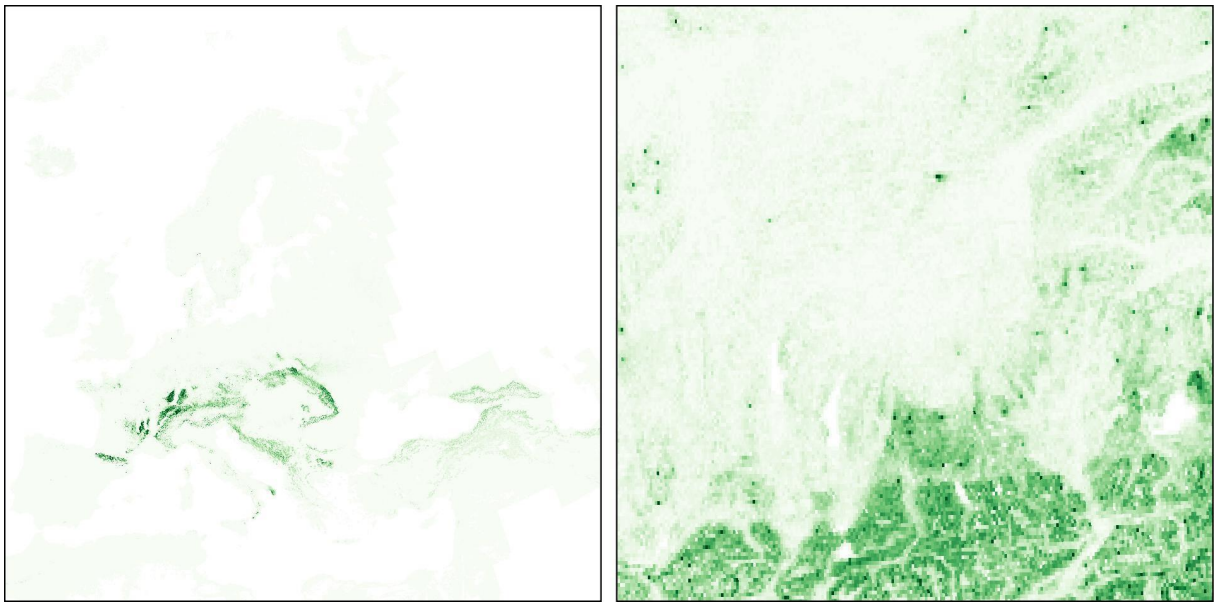
Strength	Weaknesses
Worldwide coverage for BIOMEs (29 classes)	Coarse resolution of 1km2
19 BIOME classes, 73 forest tree species (Europe)	Distribution maps provide modelled presence probabilities and not measured presence

Figure 10: Overview of global BIOMEs map at 1km resolution



Source: Potential Natural Vegetation (PNV) , Hengll et al. 2018.

Figure 11: Overview of PNV Abies alba distribution map at European extent and for the wider Munich area

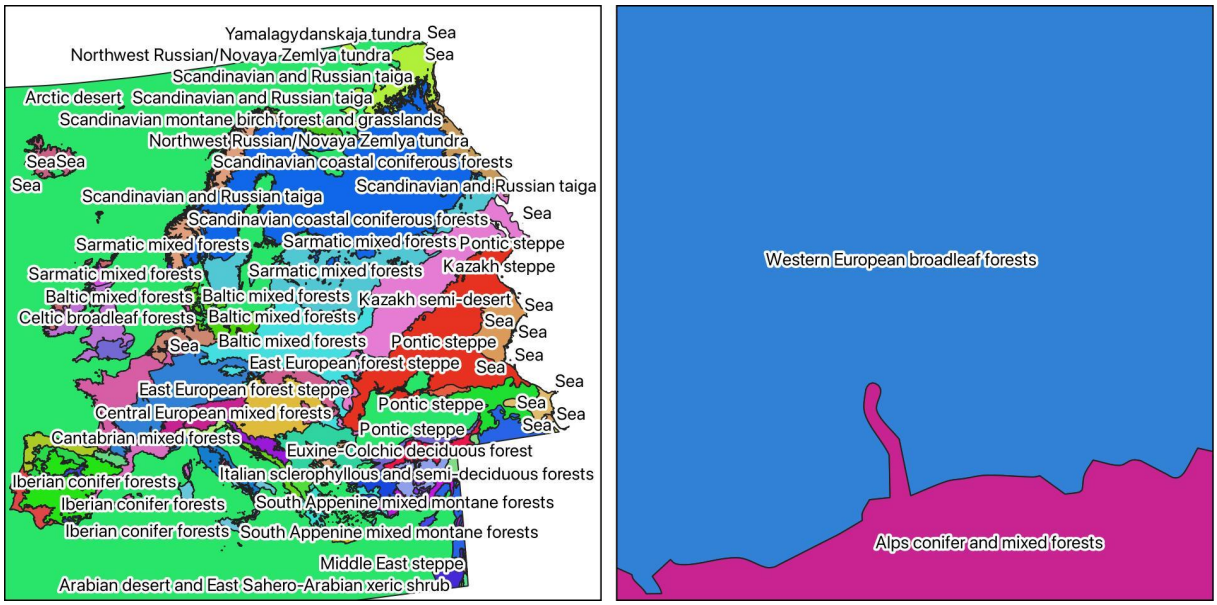


Source: own illustration, EOSS GmbH; Potential Natural Vegetation (PNV) , Hengll et al. 2018.

1.5.2 EEA Digital Map of European Ecological Regions

The objective of the map of ecological regions in Europe is to show the extent of areas with relatively homogeneous ecological conditions, within which, comparisons and assessments of different expressions of biodiversity are meaningful. The Digital Map of European Ecological Regions DMEER (Figure 12) - delineates and describes ecological distinct areas in Europe, based on climatic, topographic and geobotanical European data. The map is provided by the European Environmental Agency (European Environment Agency 2003) and received a last update in 2017. The nominal map scale is 1:2500000.

Figure 12: Overview of EEA Digital Map of European Ecological Regions at European extent and for the wider Munich area

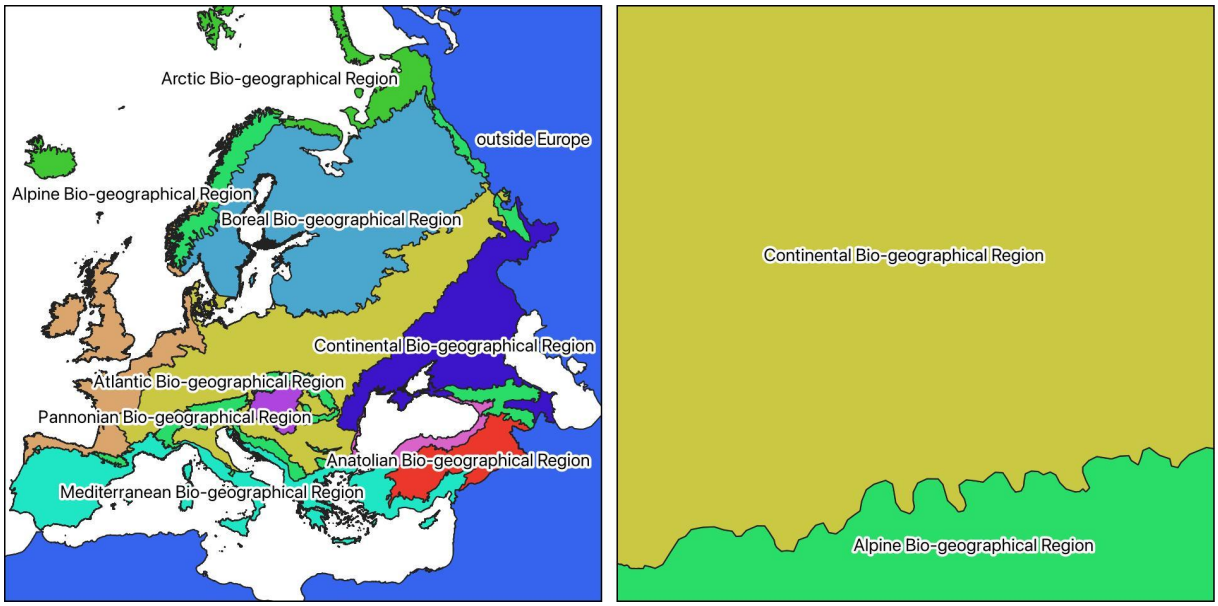


Source: own illustration, EOSS GmbH; EEA Digital Map of European Ecological.

1.5.3 EEA Biogeographical regions

The digital map on biogeographical regions of Europe (Figure 13) is provided by the EEA (European Environment Agency 2016). Biogeographical boundaries were obtained from the EU Member States and from the Emerald Network countries. These were merged to produce a European wide map of the biogeographical regions independent of political boundaries. In total a set of 11 biogeographical regions are assigned at a map scale of roughly 1:1000000.

Figure 13: Overview of EEA Biogeographical Regions at European extent and for the wider Munich area

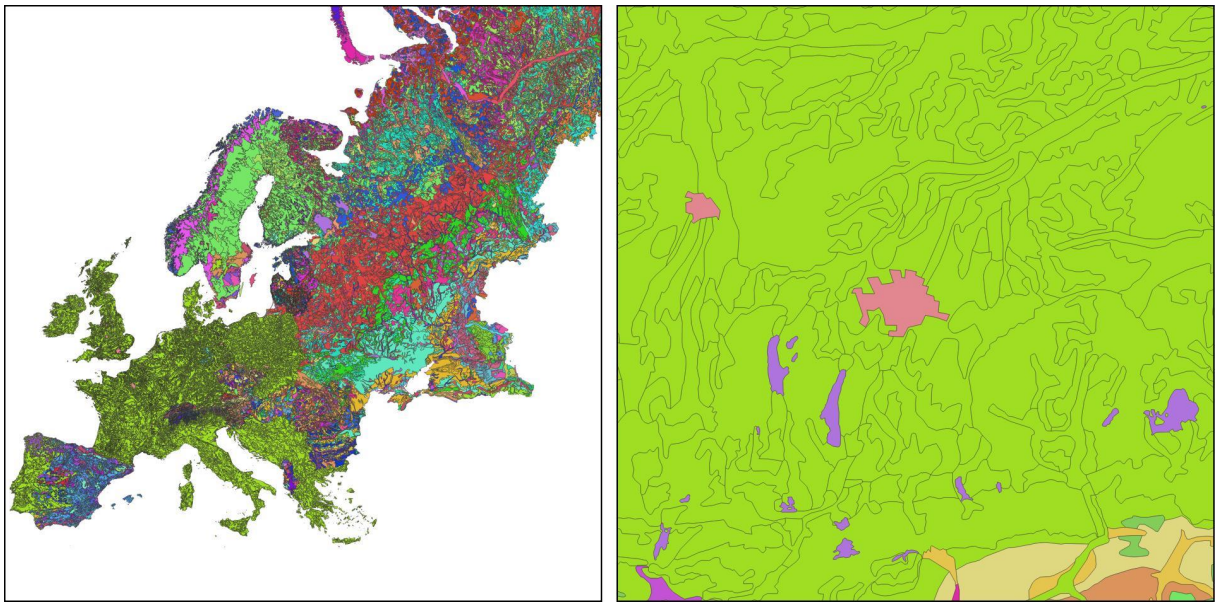


Source: own illustration, EOSS GmbH; EEA biogeographical regions of Europe.

1.5.4 European soil database version 2

The European Soil Database (ESDB, Figure 14) provides Pan-European data for 73 primary or derived soil attributes including information with a spatial coverage on (i) soil classification (ii) texture (iii) parent material (iv) impermeable layer within the soil profile (v) soil water regime (vi) most important limitation to agricultural use (Tóth et al. 2013). ESBD is provided by the European Soil Data Centre (ESDAC) at the Joint Research Centre (Panagos et al. 2012). The spatial information of soil attributes presented on a nominal scale of 1:1000000 The digital map on is available through ESDAC both in vector and raster formats with full coverage of Europe.

Figure 14: Overview of ESDAC Map of European Soil Database at European extent and for the wider Munich area

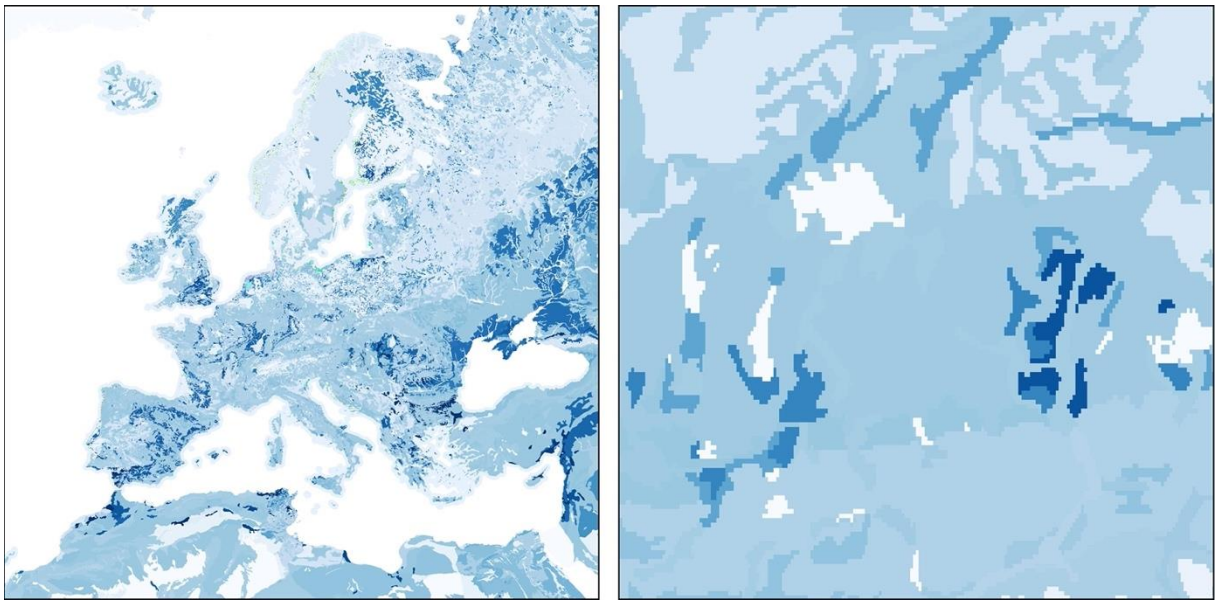


Source: own illustration, EOSS GmbH; European Soil Database.

1.5.5 Harmonized World Soil Database

Over 16000 different soil mapping units are recognized in the Harmonized World Soil Database Version 1.1 (HWSD) (Figure 15) (Nachtergaele et al. 2008) which are linked to harmonized attribute data. Use of a standardized structure allows linkage of the attribute data with GIS to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). The resulting raster database consists of 21600 rows and 43200 columns, of which 221 million grid cells cover the globe's land territory having a spatial resolution of about 1 km (30 arc seconds by 30 arc seconds).

Figure 15: Topsoil Clay Fraction layer from the Harmonized World Soil Database at European extent and for the wider Munich area



Source: own illustration, EOSS GmbH; Harmonized World Soil Database Version 1.1.

1.6 Evaluation of the Suitability of Existing Land Cover Datasets

To evaluate the suitability of any of the above-described land cover datasets to update the required land cover maps one needs to define a set of hard criteria. These criteria should reflect the most prominent map characteristics in terms of spatial coverage and resolution, thematic resolution and compatibility with required classification schemes, reference year and actuality (Table 14).

Table 14: Summary and evaluation of existing land cover maps and their usage for updating the land cover maps

The table provides categories and assigns how good a dataset fits those criteria. A label X represents full fit, while O represents partial fit.

Dataset	Thematic						Regional				Resolution/Scale				Temporal	Format		License	Accuracy
	# Classes	EUNIS 1	EUNIS 2	EUNIS 3	FFH	RCG	Europe	EECCA+	NA+		< 100 m	100 m	> 100 m	Reference Year	Vector	Raster	Free	
Harmonized European Land Cover Map	57	X	X	O		X	X			100		X		2000		X	X	N/A
CORINE Land Cover 2018	44	X	O			X	O			100		X		2018	X	X	X	85 %
EEA Ecosystem Type Map v3.1	47	X	X	O		X	O			100		X		2012		X	X	N/A
Copernicus High Resolution Layers	44	X	O				O			10	X			2018	X	X	X	N/A
JRC Forest Distribution Maps	1	O	O				O			1000			x	2016		X	X	N/A
Copernicus Global Land Cover	22	X	O			X	X	X	X	100		X		2019		X	X	80 %
ESA World Cover	11	X	O			O	X	X	X	10	X			2020		X	X	75 %
NGCC GlobeLand30	10	X	O			O	X	X	X	30	X			2010		X	O	83 %
CCI Annual Global Land Cover	22	X	O			X	X	X	X	300			X	2015		X	X	73 %
ESRI Land Cover	10	X	O			O	X	X	X	10	X			2020		X	X	86 %
CEC NALCMS	19	X	O			X			X	30	X			2015		X	X	79 %

Above table shows that high thematic agreement towards the RCG scheme is provided by most land cover datasets. Also, the EUNIS classes at level 1 can be mapped by these land cover maps. EUNIS Level 2, however, is only provided through the outdated Harmonized European Land Cover Map (whereby not all Level 2 classes area assigned). The best fit with EUNIS Level 2 is achieved with the Ecosystem Type Map v3.1, where almost all terrestrial and maritime classes are represented, this map, however, is outdated too with reference data from 2012. The most recent and thematic detailed dataset is the CORINE Land Cover 2018 map. CLC2018 does provide 44 land cover classes that can further be disaggregated into EUNIS Level 2 by making use of the ETM v3.1 map and its inherent transition rules from CLC to EUNIS (Weiss and Banko 2018). Both maps, however, do not represent all the 49 countries available in the original harmonized European Land Cover Map. The countries Andorra, Belarus, Russia, Georgia, Moldova, and Ukraine are not covered. In addition, none of the 7 EECCA+ countries are covered and, of course, the North American countries are not covered either.

To improve these uses of the EUNIS Habitat Classification, the EEA initiated a process of its revision at Level 3 (for the terrestrial realm) and 4 (for the marine realm) of the classification hierarchy. Recent works of Chytrỳ et al. therefore aimed to: (a) develop a classification expert system for automatic assignment of vegetation-plot records to coastal, wetland, grassland, shrubland, forest and man-made habitats of the revised EUNIS Habitat Classification at Level 3 of the classification hierarchy; (b) base this system on algebraic and set-theoretic concepts combined using formal logic; (c) assign all available European vegetation plots to EUNIS habitats; (d) define the characteristic species combination for each habitat based on a statistical analysis of the plots assigned to this habitat by the expert system; and (e) provide distribution maps of individual habitats based on the location of vegetation plots assigned to these habitats (Chytrỳ et al. 2020). However, the application of this classification scheme targets the classification of vegetation plots mainly based on species and floristic combination and is impossible to be derived using satellite-based land cover maps. The distribution maps might therefore be of help in disaggregating towards EUNIS Level 3, however, the authors mention that their modelling exercise yielded unstable and often incorrect results, especially in extrapolations to data-poor areas in eastern Europe and therefore they refrained from complementing the maps with their publication (Chytrỳ et al. 2020). Also, no information on the characteristics and accessibility of these distribution maps is given.

To overcome this constraint additional reference datasets might be of use, even though these are mainly model derived maps and are represented at coarse nominal map scales. For Europe, the JRC Forest Distribution Maps (namely the Relative Probability of Presence (RPP) maps and/or the Chorological maps) can be useful to further disaggregate so far derived EUNIS Level 2 forest classes towards Level 3. Further, the Global Potential Vegetation maps shall be applied, especially the 73 European forest species distribution maps.

Also, the global BIOMEs of the Potential Natural Vegetation dataset, the European Maps on Ecoregions and Biogeographical regions might support delineation of at least some EUNIS Level 3 classes. This is because most vegetation classes in EUNIS Level 3 are discriminated mainly based on their biogeographical distribution.

For the countries not covered by CLC and ETM v3.1, global datasets must be applied. From those reviewed, the Copernicus Global Land Cover map provides to be the best candidate with 22 land cover classes, a compatible spatial resolution of 100m and very recent reference data of 2019.

However, EUNIS classes will in most cases be represented only in Level 1, only few classes can be translated towards Level 2.

The North American NALCMS land cover dataset provides to be the best source for mapping USA and Canada land cover towards EUNIS. The map provides 19 land cover classes which allow the derivation of EUNIS Level 1 and partly Level 2 classes.

1.7 Recommendations for updating the Harmonized European Land Cover Map and its extension to EECCA+ and NA+

From the above evaluated input datasets, we draw the following recommendations for updating the Harmonized European Land Cover Map and its extension to EECCA+ and NA+.

Recommendations for European countries covered by CORINE Land Cover Maps

- Use CORINE Land Cover 2018 and apply transition rules towards EUNIS Level 1 and Level 2
- Use Ecosystem Type Map v3.1 to further disaggregate towards EUNIS Level 2 classes
- Use Global Potential Natural Vegetation and Harmonized World Soil Database to further disaggregate Level 2 vegetation classes towards Level 3

Recommendations for European countries not covered by CORINE Land Cover Maps

- Use Copernicus Global Land Cover Map and apply transition rules towards EUNIS Level 1 and Level 2
- Use Global Potential Natural Vegetation and Harmonized World Soil Database to further disaggregate Level 2 vegetation classes towards Level 3

Recommendations for USA and Canada

- Use NALCMS Map and apply transition rules towards EUNIS Level 1 and Level 2

Recommendations for Providing Updated Land Cover Maps at REM-CalGrid classification scheme

- Use updated Land Cover Maps at EUNIS Level 2 for aggregating towards REM-CalGrid 13 land cover classes to provide class consistency between maps

Recommendations for Providing Updated Land Cover Maps at FFH classification scheme

- Use updated Land Cover Maps at EUNIS Level 2 and 3 for translating land cover classes towards FFH habitat types classification schemes at level 2 and potentially level 3

2 Updated European Land Cover Map for the calculation of Critical Loads

2.1 Materials

The Corine Landcover Map of 2018 (CLC2018) forms the principal input land cover map. The CORINE Land Cover inventory is provided through the Copernicus Land Monitoring Service of the European Environmental Agency and was initiated in 1985 (reference year 1990) (Büttner 2014). It consists of an inventory of land cover in 44 classes. CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. The time series are complemented by change layers, which highlight changes in land cover with an MMU of 5 ha. The latest update of 2018 was sourced by Landsat-8 and Sentinel-2 satellite imagery. The thematic accuracy is reported with greater than 85%. 39 countries are currently involved and covered. From the 49 countries Andorra, Belarus and Russia are not covered. For Georgia, Moldova and Ukraine only pilot areas around the capitals of each country are produced. All 7 EECCA+ countries are not covered. For Armenia and Azerbaijan only pilot areas around the capitals of each country are produced. The map is available as raster datasets with a resolution of 100 x 100 m^2 with pixel values representing numeric CLC code down to level 3 of the CLC class scheme.

CLC2018 is accomplished by the Ecosystem Type Map from 2012 (ETM v3.1). The Ecosystem Type Map combines spatially explicit land cover information with non-spatially referenced habitat information to improve our knowledge about ecosystems and their distribution across Europe (European Environment Agency 2012). The derived class mapping rules were based on a set of stable core datasets that represent information not changing through time (e.g., the natural potential vegetation zone or distance to the coast or soil type) and the dynamic datasets. With updated input dynamic datasets (Corine Land Cover 2012, HRL Forests 2012 (Forest Type, Tree Cover Density), HRL Imperviousness 2012, OpenStreetMap (OSM) data 2015 (main roads, land use information)) and the availability of the Local Components (LoCo) of the Copernicus Land Monitoring Service, consisting of Urban Atlas (UA), Riparian Zones (RZ) or Natura 2000 (N2k) and furthermore the High-Resolution Layers (HRL) Grasslands and HRL Permanent Water Bodies, a new version 3.1 was compiled. For integration of the new datasets crosswalks/mapping rules had been developed. The primary output (ETM) is the actual map representing EUNIS classes on Level 2 with a resolution of 100 x 100 m2. The resulting map represents 47 classes describing EUNIS classes down to level 2. 84 additional classes describe marine habitats down to level 3 of the EUNIS scheme. With CORINE CLC 2012 being the primary input data source, the spatial coverage is equal to CLC.

ESA's Global Land Cover Map from 2019 serves as principal input land cover map for regions not covered by CLC2018 and ETM v3.1. The Copernicus Global Land Service (CGLS) is a component of the Land Monitoring Core Service (LMCS) of Copernicus, the European flagship program on Earth Observation. The Global Land Service systematically produces a series of qualified bio-geophysical products on the status and evolution of the land surface, at global scale and at mid to low spatial resolution, complemented by the constitution of long-term time series. The products are used to monitor the vegetation, the water cycle, the energy budget and the terrestrial cryosphere. The yearly moderate-resolution land cover maps do primarily target land cover detection and their changes. The map is provided together with vegetation continuous field

layers that provide proportional estimates of vegetation cover for several land cover types. The latest published map is provided for the reference year 2019 (Buchhorn et al. 2019). The map represents 22 discrete land cover classes at a resolution of 100 x 100m^2. The overall mapping accuracy is reported with 80.3% (Tsendbazar, Herold, et al. 2021; Tsendbazar, Tarko, et al. 2021).

The data layers provided by the Global Map of Potential Natural Vegetation (Hengl et al. 2018) are used as describing feature dataset for predicting EUNIS Level 3 habitat classes. The Potential Natural Vegetation (PNV) is the vegetation cover in equilibrium with climate, that would exist at a given location non-impacted by human activities (Hengl et al. 2018). Predictions for 1) global distribution of BIOMEs based on the BIOME 6000 data, (2) distribution of forest tree species in Europe and (3) global monthly Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) values are available in in 1km raster dataset (Hengl 2018). The derivation of the distribution maps is driven by model-based predictions using more than 100 variables derived from ground observations (BIOME 6000 vegetation reconstruction samples, European Forest Plots for 73 forest species) and ESA's global land cover maps at 300m resolution. A total of 19 global BIOME classes is provided and 73 tree species distribution maps are published.

The Harmonized World Soil Database Version 1.1 (Nachtergaele et al. 2008) is used as additional feature stack for EUNIS Level 3 class prediction. Over 16000 different soil mapping units are recognized in the Harmonized World Soil Database (HWSD) which are linked to harmonized attribute data. Use of a standardized structure allows linkage of the attribute data with GIS to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). The resulting raster database consists of 21600 rows and 43200 columns, of which 221 million grid cells cover the globe's land territory having a spatial resolution of about 1 km (30 arc seconds by 30 arc seconds).

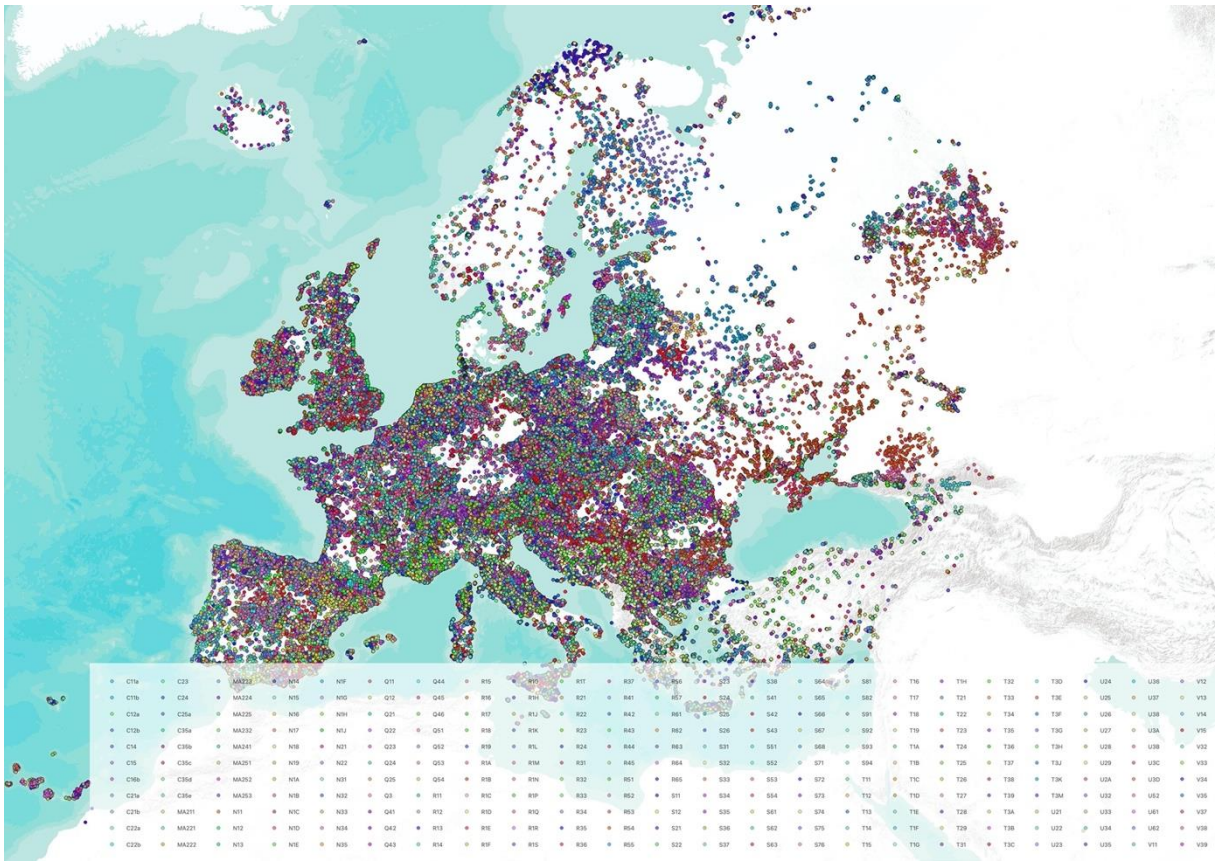
With the EUNIS-ESy expert classification system, EUNIS habitats were characterized for the first time in terms of their species composition and distribution, based on a classification of a European database of vegetation plots (Chytrỳ et al. 2020; 2021). Chytrỳ and co-workers applied their expert system and classified more than 1 million vegetation plots of the European Vegetation Archive, EVA (Chytrý et al. 2016) to EUNIS habitat groups at level 3 including 25 coastal, 18 wetland, 55 grassland, 43 shrubland, 46 forest and 12 man-made habitats. A total of 768,200 classified vegetation plots have been made available to us (Figure 16).

In order to obtain the EVA data, we requested access from the EVA coordinating board and were approved and listed as project number 146[1]. The database of classified EVA plots was provided by the coordination board and presented to be a compilation from individual 85 EVA databases, approved and provided by the responsible database custodians.

Those have been used as reference and evaluation dataset for prediction model training and for the evaluation of classification results.

[1] http://euroveg.org/requests/EVA-data-request-form-2022-03-28-Loran.pdf

Figure 16: Distribution of the EVA point samples classified at EUNIS Level 3



Source: own illustration, EOSS GmbH; European Vegetation Archive.

2.2 General workflow description

Updating and extending the European Land Cover Map towards EUNIS Level 2 and Level 3 followed the data and workflow visualized in Figure 17.

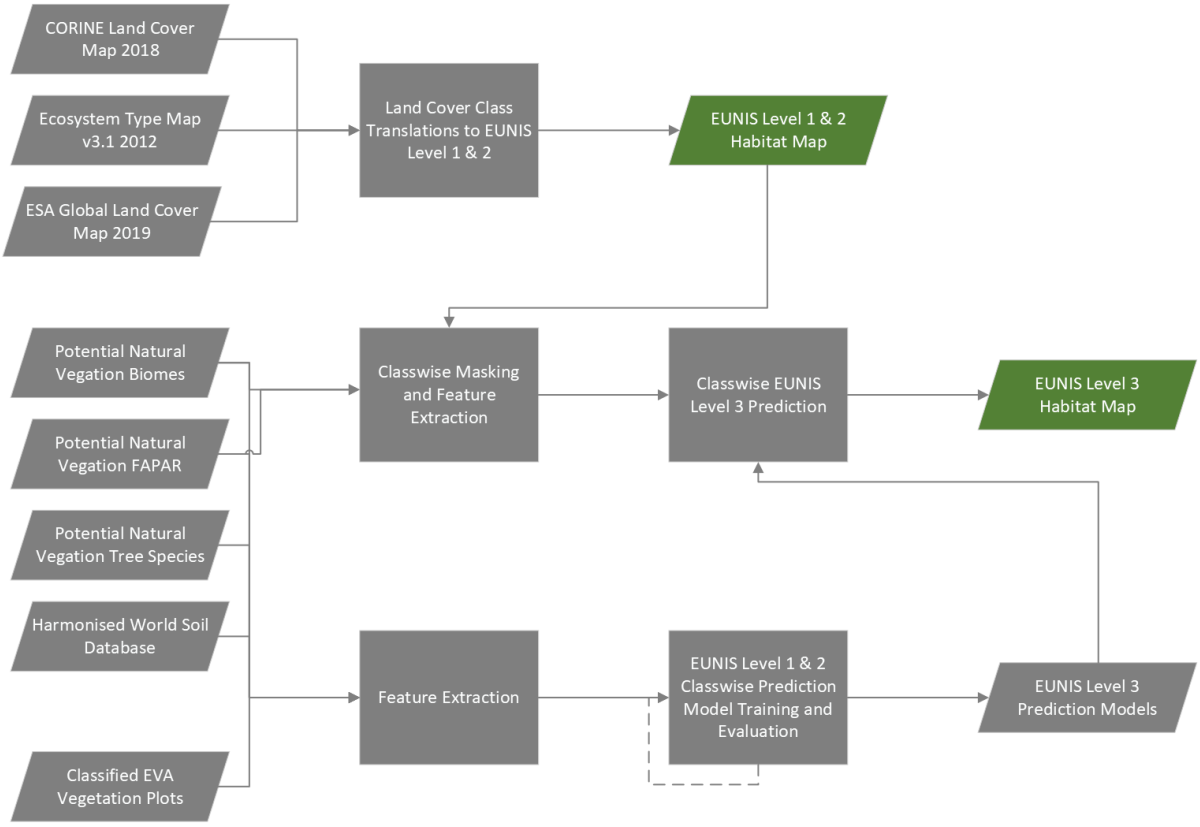
In a first step, based on the evaluation of the availability and suitability of different spatial data, we used CORINE Land Cover 2018 and Ecosystem Type Map v3.1 and applied transition rules towards EUNIS Level 1 and Level 2 for European countries covered by CORINE Land Cover Maps. We furthermore used Copernicus Global Land Cover Map and applied transition rules towards EUNIS Level 1 and Level 2 for European countries not covered by CORINE Land Cover Maps. The process of updating towards EUNIS Level 1 and 2 is described in chapter 2.3 and resulted in a land cover map representing 46 EUNIS Level 1 and 2 classes.

To further disaggregate the updated Level 1 and 2 habitat maps towards Level 3 classes, we made use of the European Vegetation Archive (EVA), the Global Potential Natural Vegetation (GPNV) maps and the Harmonized World Soil Database (HWSD). Therefore, for each distinct EUNIS habitat class at Level 1 and 2 in the beforehand updated map, decision tree models were trained using EVA samples for training and evaluation and the GPNV and HWSD data as sample features. That means for each distinct Level 1 or 2 EUNIS class, EVA samples for this class were subset. Pixel values from the GPNV and HWSD raster images were extracted at the spatial position of each of these class samples and served as descriptive features for each sample. With all samples for the distinct class, a Random Forest model was trained using 60% of labelled samples for training and 40% for model evaluation. The derived models were then applied to

the full map extent and Level 3 EUNIS habitat map was processed. Thereby, all feature raster images were masked to conserve the positions of the current Level 1 and Level 2 class and the respective class prediction model was applied to all unmasked pixels. Classification results for each applied class model were stored as raster images and combined into the final map in a final merging step. In total, 46 prediction models were trained, and using the before translated updated EUNIS Level 2 map, the respective class decision tree model was applied to the different discrete classes in the map and with that the EUNIS Level 3 habitat map was processed for whole Europe providing 233 distinct classes. This process is described in detail in chapter 2.4.

Finally, the EUNIS Level 3 land cover map was separated into distinct country datasets for each country totally covered by the map.

Figure 17: General workflow of updating the European Land Cover Map towards EUNIS Level 3 classes



Source: own illustration, EOSS GmbH.

2.3 Updating European Land Cover Map at EUNIS Level 2

2.3.1 Translating CORINE Land Cover classes to EUNIS class scheme

Based on the CORINE Land Cover class scheme at level 3 a mapping ruleset towards the EUNIS classification scheme has been derived and is presented in the following figure (Figure 18). Many of the CLC classes can be mapped towards EUNIS directly. This allows for a mapping towards 31 EUNIS classes, whereby some target classes remain in EUNIS level 1.

Figure 18: Mapping ruleset from CORINE Land Cover classes to EUNIS Level 1 and Level 2 classes

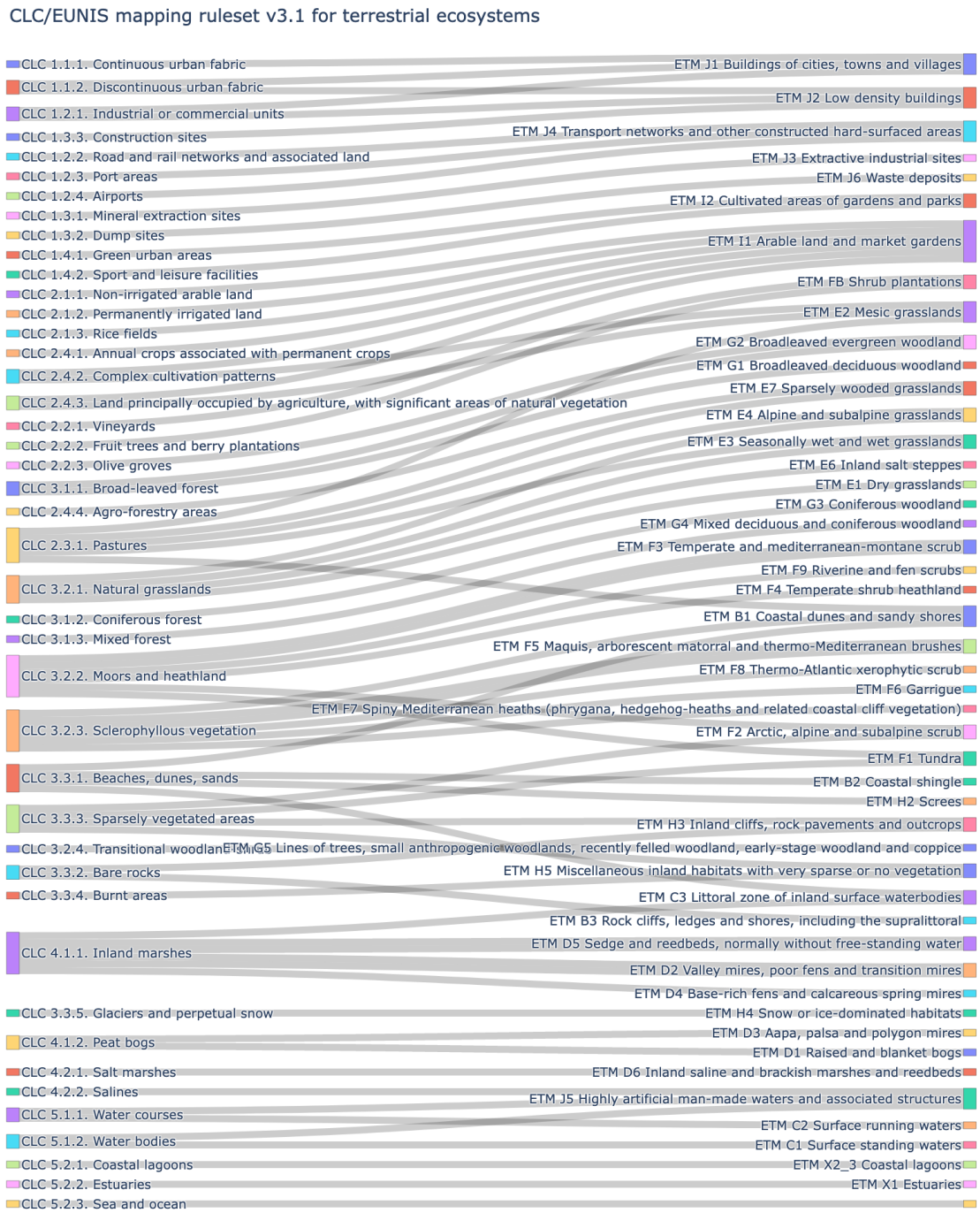
Source: own illustration, EOSS GmbH.

2.3.2 Disaggregating CORINE Land Cover classes to EUNIS Level 2 classes using EEA Ecosystem Type Map 3.1

The Ecosystem Type Map ETM v3.1 allowed for further disaggregation into 47 terrestrial land cover classes at EUNIS level 2. Thereby the developed datasets crosswalks/mapping rules were inherently applied. A comprehensive representation of these rules is given in Table “CLC/EUNIS mapping ruleset v3.1” in the Appendix (Table 34).

Even though, the reference year of ETM of 2012 is outdated, its transition rules can directly be applied to disaggregate CLC2018 into 47 terrestrial land cover classes at EUNIS level 2 (Figure 19, Table 34). Pixels that represent a change between CLC 2012 and CLC 2018 cannot be represented by this conditional transition and will remain in the base assignment from the previous described CLC transition rules.

Figure 19: Mapping ruleset from CORINE Land Cover classes to ETM v3.1 EUNIS Level 2 classes

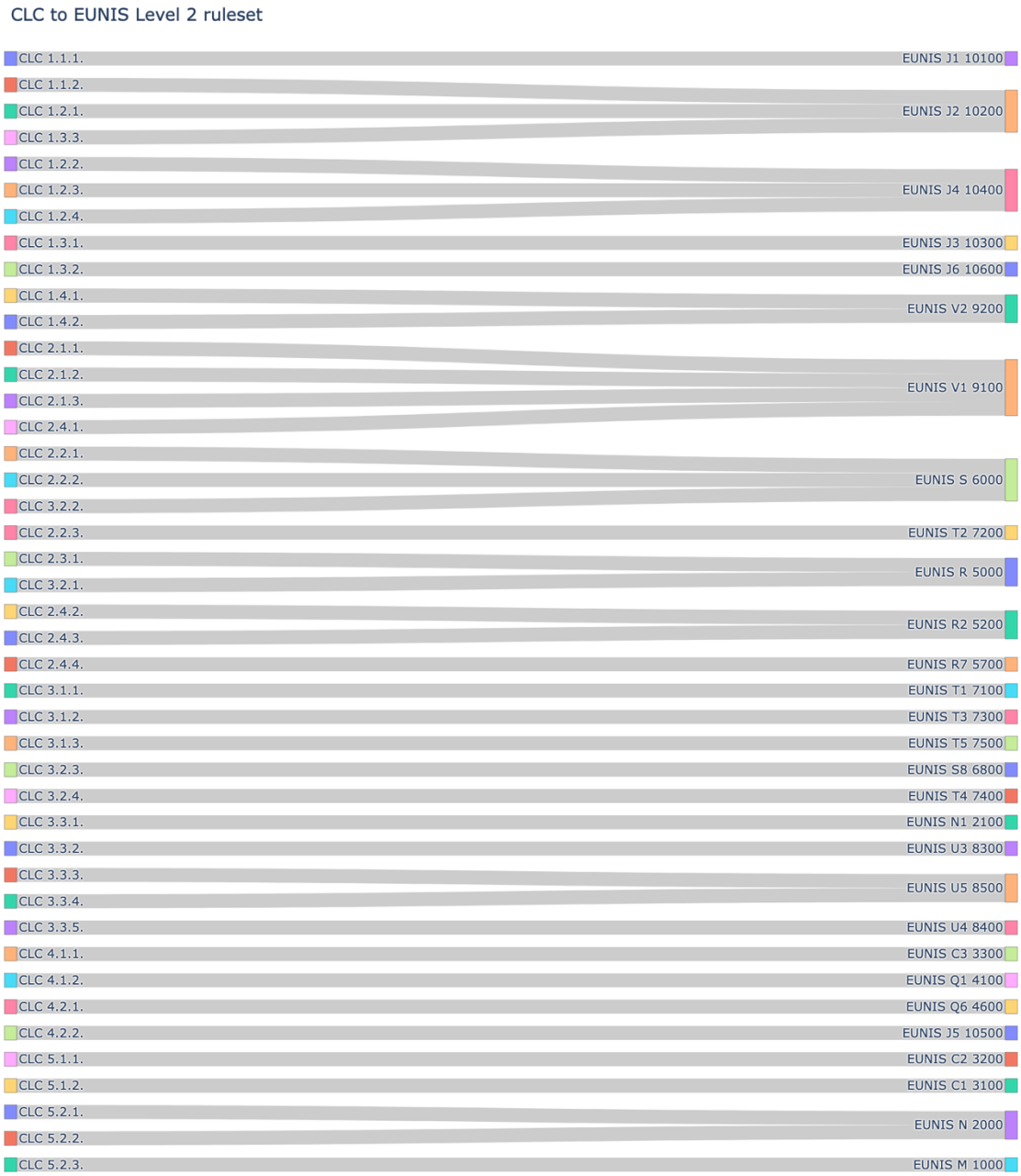


Source: own illustration, EOSS GmbH.

2.3.3 Application of map translations towards EUNIS Level 2

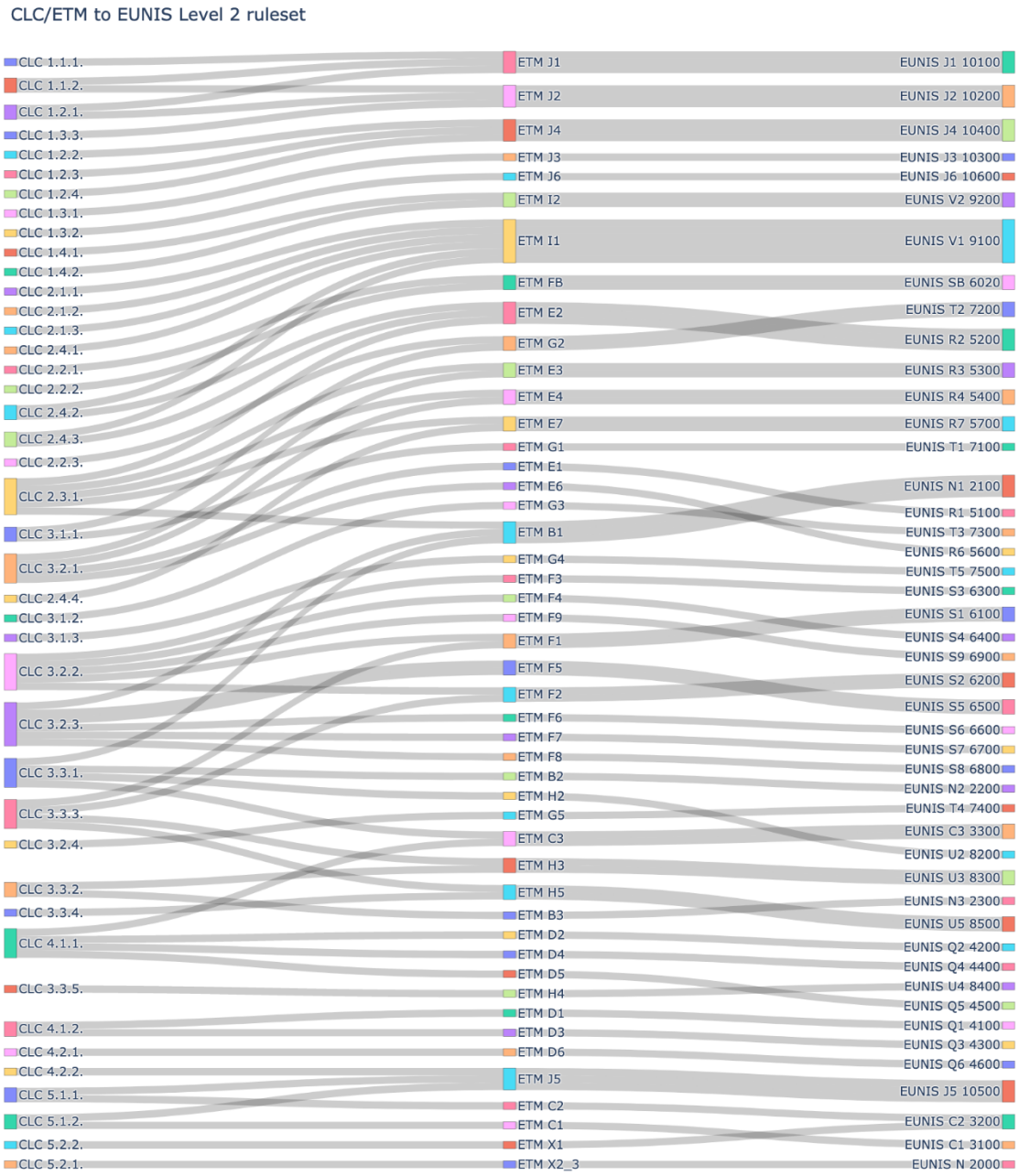
With the above derived translation rules and the new EUNIS classification scheme a twofold land cover class mapping / translation using CORINE Land Cover 2018 and the Ecosystem Type Map v3.1 was applied. Therefore, transition rules were adopted to actual land cover class codes from the two source maps and the target codes were adopted to the new EUNIS classification scheme at level 2. In a first step, the current CLC2018 map was translated to EUNIS level 2 classes (Figure 20), which allowed the derivation of 29 EUNIS Level 1 and 2 classes, from which four classes remain at EUNIS Level 1. In a second step, CLC classes were further disaggregated using transition rules derived from the ETM v3.1 map (Figure 21), based on which a total of 46 target EUNIS Level 2 classes were derived.

Figure 20: Applied mapping ruleset from CORINE Land Cover classes to EUNIS Level 2 classes and defined EUNIS habitat numeric class codes



Source: own illustration, EOSS GmbH.

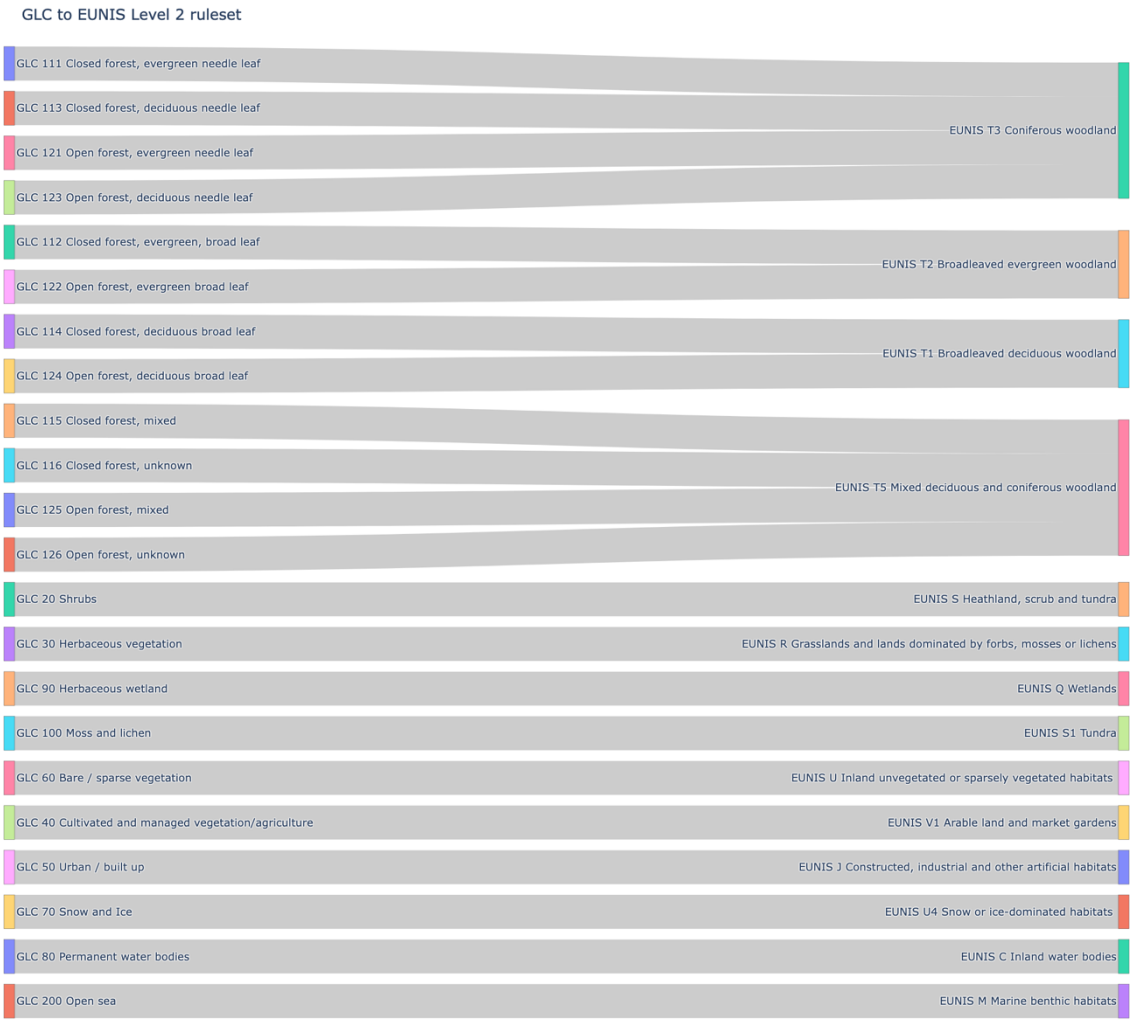
Figure 21: Applied mapping ruleset from CORINE Land Cover and EEA Ecosystem Type Map classes to EUNIS Level 2 classes and defined EUNIS habitat numeric class codes



Source: own illustration, EOSS GmbH.

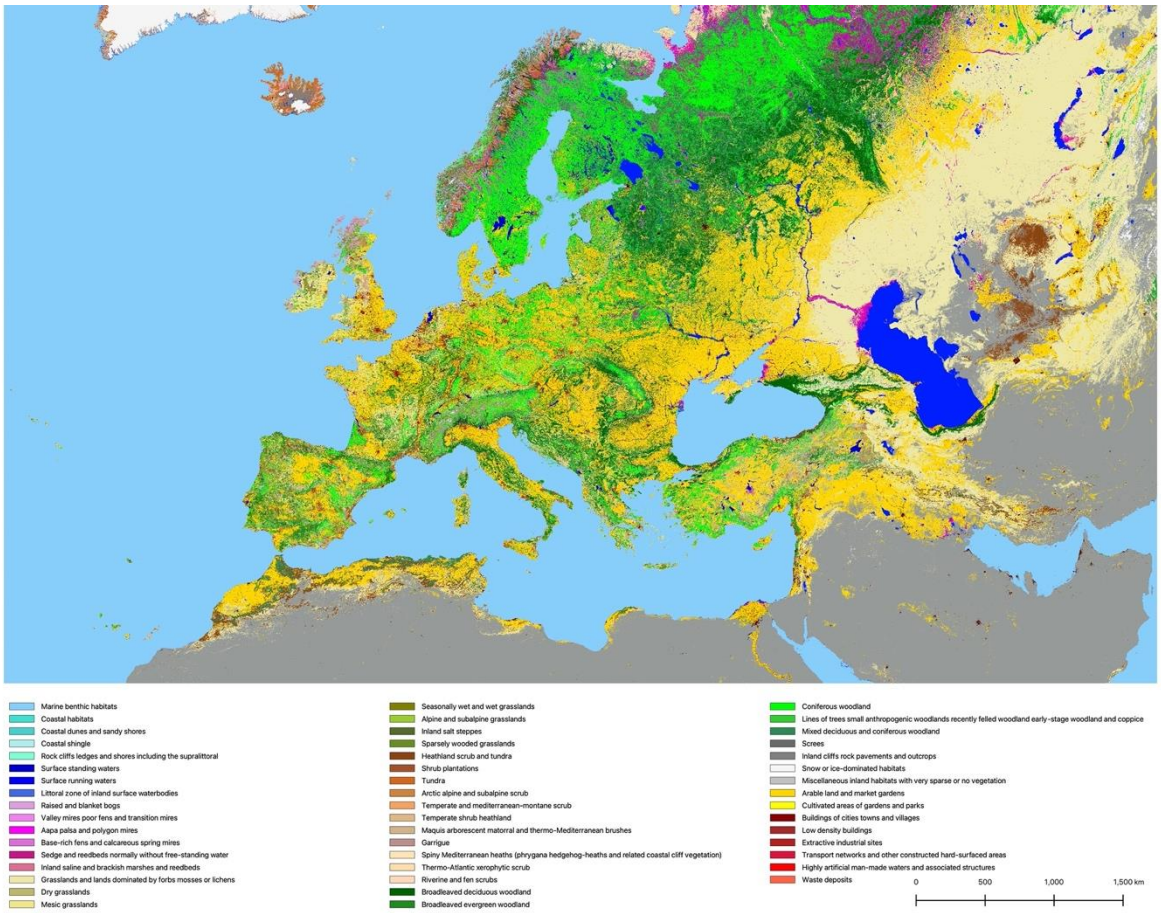
For regions not covered by CLC2018 and ETM v3.1 maps the ESA's Global Land Cover Map from 2019 was used and transition rules were derived for mapping towards EUNIS Level 1 and Level 2 (Figure 22). These rules were then applied to pixels outside CLC and ETM coverage. As result, a discrete updated land cover map for whole Europe and parts of Asia featuring EUNIS Level 1 and 2 habitat classes was derived (Figure 23).

Figure 22: Applied mapping ruleset from Copernicus Global Land Cover classes to EUNIS Level 1 and 2 classes



Source: own illustration, EOSS GmbH.

Figure 23: Updated European EUNIS Level 2 habitat map



Source: own illustration, EOSS GmbH.

2.4 Updating European Land Cover Map at EUNIS Level 3

Final updating to EUNIS Level 3 habitat classes is sourced by the before derived Level 1 and 2 discrete land cover maps. For each of the distinct Level 1 and 2 land cover classes a prediction model was trained using samples derived from the classified vegetation plots of the EVA database that have the same level 1 or 2 EUNIS class. From those samples 60 percent of random selected points were used for model training while the remaining points were used for accuracy assessment. Different features combinations of potential natural vegetation type data and the global soil database were used and evaluated for their predictive contribution. Class based prediction models were then applied to produce the final EUNIS Level 2 land cover map. The map was finally relabelled to all 3 EUNIS base levels and country specific maps were derived.

2.4.1 Reference data from EVA database

More than 780,000 points from the European Vegetation Archive (EVA) classified at EUNIS Level 3 were provided by the Expert system for automatic classification of European vegetation plots to EUNIS habitats (EUNIS-ESy). In a first step the classified vegetation plots of the EVA database were analysed and aggregated into Level 2 and Level 1 classes.

Following Table 15 provides a summary of EVA point aggregation at level 2 and the respective number of points in each level 2 habitat class and the number of level 3 subclasses described by these points. Following that, the EVA points were split into separate archives for each distinct level 1 and level 2 habitat class. As a result, a total of 45 sample datasets were produced, 9 sample datasets were produced for EUNIS Level 1 classes C, M, N, Q, R, S, T, U and V. 36 sample datasets for EUNIS Level 2 classes were produced.

Table 15: Summary of EVA samples grouped by EUNIS Codes at Levels 1 and 2 (EUNIS_C1, EUNIS_C2), respective raster grid codes (EUNIS_G1, EUNIS_G2), the number of EVA samples per EUNIS Level 2 group (N_SAMPLES) and the number of EUNIS Level 3 classes per group (N_CLASSES)

EUNIS_C1	EUNIS_C2	EUNIS_G1	EUNIS_G2	N_SAMPLES	N_CLASSES
C	C1	3000	3100	15381	7
C	C2	3000	3200	10578	7
C	C3	3000	3300	8383	5
M	M2	1000	1200	20677	11
N	N1	2000	2100	28115	18
N	N2	2000	2200	613	2
N	N3	2000	2300	3499	5
Q	Q1	4000	4100	4814	2
Q	Q2	4000	4200	17683	5
Q	Q3	4000	4300	285	1
Q	Q4	4000	4400	8419	6
Q	Q5	4000	4500	41317	4
R	R1	5000	5100	79229	27
R	R2	5000	5200	76483	4
R	R3	5000	5300	45676	7
R	R4	5000	5400	21962	5
R	R5	5000	5500	21591	7
R	R6	5000	5600	4300	5
S	S1	6000	6100	1146	2
S	S2	6000	6200	12996	6

EUNIS_C1	EUNIS_C2	EUNIS_G1	EUNIS_G2	N_SAMPLES	N_CLASSES
S	S3	6000	6300	10981	8
S	S4	6000	6400	6813	3
S	S5	6000	6500	4832	4
S	S6	6000	6600	2536	8
S	S7	6000	6700	1843	6
S	S8	6000	6800	410	2
S	S9	6000	6900	6554	4
T	T1	7000	7100	129221	17
T	T2	7000	7200	11551	9
T	T3	7000	7300	58478	20
U	U2	8000	8200	3132	9
U	U3	8000	8300	3142	11
U	U5	8000	8500	5	1
U	U6	8000	8600	73	2
V	V1	9000	9100	33691	5
V	V3	9000	9300	42691	7

2.4.2 Feature extraction

For each of the 45 EVA sample batches (9 EUNIS Level 1 and the 36 Level 2 EVA sample batches) features were extracted from the GPNV modelled data on BIOMEs, monthly FAPAR, and Tree Species and selected properties of the HWSD data. For doing so, pixel values from the feature raster stacks were extracted for the respective geographic location of the EVA sample.

The main feature here is the monthly FAPAR. This is based on monthly FAPAR images for 2014–2017 from the Copernicus land monitoring service and reflects plant phenology during the year. From the four years of derived FAPAR images the authors build a regression model and predicted the MEAN FAPAR over all years (Hengl 2018). It is therefore a suitable dataset reflecting vegetation dynamics in natural landscapes and suits an essential feature data space for EUNIS Level 3 vegetation class prediction. Also, the GPNV authors provide a dataset on global BIOMEs whereby each pixel provides the probabilities of belonging to each of the mapped BIOMEs, namely: Cold deciduous forest, Cold evergreen needleleaf forest, Cool evergreen needleleaf forest, Cool mixed forest, Cool temperate rain forest, Desert, Erect dwarf shrub tundra, Graminoid and forb tundra, Low and high shrub tundra, Prostrate dwarf shrub tundra, Steppe, Temperate deciduous broadleaf forest, Temperate evergreen needleleaf open woodland,

Temperate sclerophyll woodland and shrubland, Tropical deciduous broadleaf forest and woodland, Tropical evergreen broadleaf forest, Tropical savanna, Tropical semi evergreen broadleaf forest, Warm temperate evergreen and mixed forest, Xerophytic woods scrub.

The GPNV data layers have been stored as three individual virtual raster datasets for i) modelled BIOMEs probability containing 20 raster layers; ii) modelled monthly average FAPAR containing 12 individual raster bands; and iii) the probability of tree species presence for 71 tree species in 71 data layers.

A total of 30 soil properties from the HWSD database have been extracted and transformed to raster representation from which a virtual raster was created covering the project area. The 30 properties used are provided in the following table (Table 16).

With that 4 feature vectors for a single plot were created for BIOMEs, FAPAR, tree species and soil properties. In addition, each plot is labelled with the respective EUNIS Level 3 class.

Table 16: Physio-chemical properties of the Harmonized World Soil Database

Acronym	Soil property	Acronym	Soil property
T_GRAVEL	Topsoil Gravel Content	S_GRAVEL	Subsoil Gravel Content
T_SAND	Topsoil Sand Fraction	S_SAND	Subsoil Sand Fraction
T_SILT	Topsoil Silt Fraction	S_SILT	Subsoil Silt Fraction
T_CLAY	Topsoil Clay Fraction	S_CLAY	Subsoil Clay Fraction
T_REF_BULK_DENSITY	Topsoil Reference Bulk Density	S_REF_BULK_DENSITY	Subsoil Reference Bulk Density
T_OC	Topsoil Organic Carbon	S_OC	Subsoil Organic Carbon
T_PH_H2O	Topsoil pH (H2O)	S_PH_H2O	Subsoil pH (H2O)
T_CEC_CLAY	Topsoil CEC (clay)	S_CEC_CLAY	Subsoil CEC (clay)
T_CEC_SOIL	Topsoil CEC (soil)	S_CEC_SOIL	Subsoil CEC (soil)
T_BS	Topsoil Base Saturation	S_BS	Subsoil Base Saturation
T_TEB	Topsoil TEB	S_TEB	Subsoil TEB
T_CACO3	Topsoil Calcium Carbonate	S_CACO3	Subsoil Calcium Carbonate
T_CASO4	Topsoil Gypsum	S_CASO4	Subsoil Gypsum
T_ESP	Topsoil Sodicity (ESP)	S_ESP	Subsoil Sodicity (ESP)
T_ECE	Topsoil Salinity (Elco)	S_ECE	Subsoil Salinity (Elco)

2.4.3 Prediction models and feature evaluation

Supporting a class wise prediction of EUNIS Level 3 habitat types 45 prediction models were trained using beforehand derived samples and features. Random stratified sampling was performed to retrieve 60% training and 40% validation samples for each of the 45 sample batches datasets. Training samples were used to train a Random Forest decision tree model and a C4.5 decision tree model (Salzberg 1994; Quinlan 1992) for each EUNIS Level 2 and Level 1 strata represented by its respective training sample batch. Accuracy assessment was done on the remaining 40% validation samples.

Firstly, using only FAPAR features, the different classification algorithms were tested. Likewise, different feature combinations were tested. For doing so, Random Forest Classification models were created for BIOMEs features only, BIOME and FAPAR features combined, and BIOME, FAPAR and tree species features combined, and finally BIOME, FAPAR and soil features combined. Again, 60% of the input samples were randomly selected for model training and the remaining 40% were used for model accuracy evaluation.

Classification was implemented in Python using sklearn machine learning library and DecisionTreeClassifier[2], RandomForestClassifier[3]. While a decision tree is a single tree derived from all training samples, a random forest is an ensemble of decision trees derived from randomly selected training samples. Derived prediction model objects were stored as Python Pickles allowing later deserialization for final raster map classifications.

2.4.4 Accuracy assessment and prediction model selection

Accuracy assessment was done using the respective 40% validation samples whereby the given EUNIS Level 3 class was compared to the predicted class. For each analysed model and feature combination the accuracy assessment reports were stored. From the calculated confusion matrix for each prediction model, overall accuracy and class-based producer's and user's accuracies were derived. The accuracy for the EUNIS Level 3 classes varies between 60% to more than 90% (Figure 24 to 26). Median producers' and users' accuracies were 65.3 % and 75.5 %, however confusions with other classes can only occur in the specific level 2 class domain, i.e. a Level 2 deciduous forest pixel can only be classified into one of the Level 3 deciduous forest subclasses and confusions can only occur between those classes. The exact producer's and user's accuracy for each EUNIS level 3 class is listed in Table 35 (Annex 2).

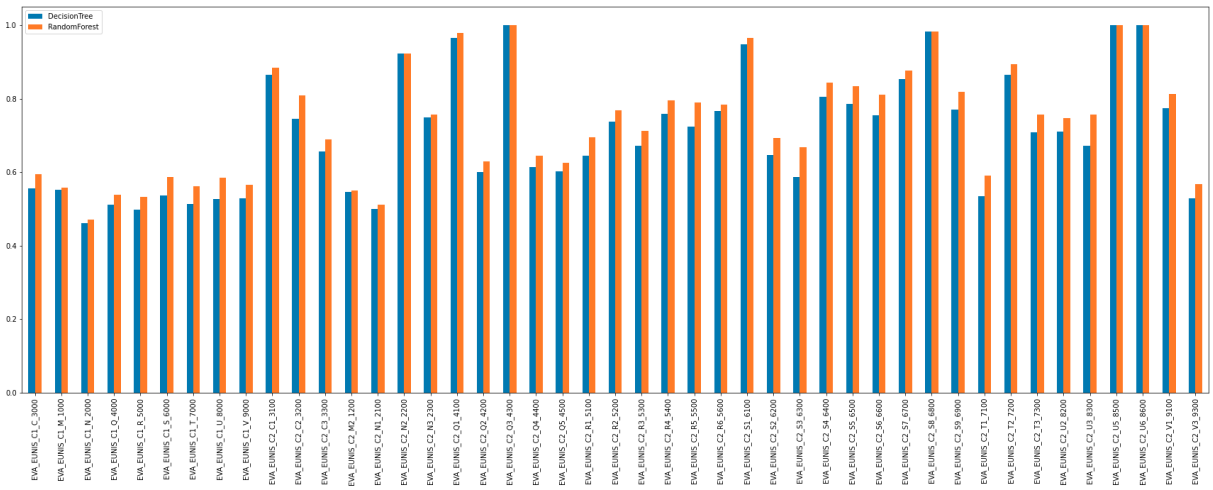
The confusion matrix (Figure 28) is a cross-tabulation of the class labels allocated by predicted map and reference data. The elements show the number of samples which represent a map class and reference class. Here, the predicted map classes are represented in rows and the actual reference classes in rows. The diagonal of the matrix contains the correctly classified data points, whereas the cells off the diagonal show commission and omission errors. Commission error, calculated for each of the map classes, is the probability that the spatial unit classified into a given category on the map represents that category in the reference data. Omission error, calculated for each of the map classes, is the probability that the spatial unit classified into a given category in the reference data represents that category in the map data. Commission error is the complimentary measure to user's accuracy (UA), calculated by subtracting 100% from the user's accuracy for each class. Omission error is the complimentary measure to producer's

[2] https://scikit-learn.org/stable/modules/tree.html
[3] https://scikit-learn.org/stable/modules/ensemble.html#forests-of-randomized-trees

accuracy, calculated by subtracting 100% from the producer's accuracy (PA) for each class (FAO [Food and agriculture organization of the United Nations] 2016).

From the classification models applied (Random Forest, Decision Tree, Supported Vector Machines and Maximum Likelihood), using only FAPAR features, the Decision Tree and Random Forest classifiers performed best when comparing overall accuracies derived from the individual prediction model accuracy reports. Comparing those two reveals that the Random Forest classification models slightly perform better. For the Level 1 classifiers (predicting all Level 3 sub classes) only moderate accuracies around 50% to 60% were achieved, while for the Level 2 class-based classifiers moderate to very high overall accuracies were achieved with about 60% to more than 90% (Figure 24). The lower accuracies for level 1 prediction models in comparison to those from the Level 2 prediction models can simply be explained by the number of Level 3 classes each model predicts. While a Level 2 model, e.g., the 7300 coniferous forest model, is trained only to predict its Level 3 sub-classes (in this example 13 coniferous forest classes), the Level 1 model is trained to predict all 39 forest classes at EUNIS Level 3. With broadening the number of prediction classes the rate of confusion and with that of prediction errors increase. However, the Level 1 based models have only been applied to those pixels, where a change in Land Cover class in CLC appeared between 2012 and 2018 and transition rules combining CLC2018 and ETM v3.1 2012 could not be applied towards EUNIS Levels 2 (those pixels, however, count 7331232 out of 734942178 and do only represent 0.9975% of the total area) and to those regions outside CLC coverage sourced by Global Land Cover were transition rules for land cover classes only allowed the assignation of EUNIS Level 1 classes (namely EUNIS S heathland, scrubs; EUNIS R grasslands, EUNIS Q wetlands, EUNIS U sparsely vegetated, EUNIS J constructed, EUNIS C inland water bodies and EUNIS M marine habitats).

Figure 24: Class-based overall accuracies for EUNIS Level 3 prediction models derived from Decision Tree and Random Forest Classifiers

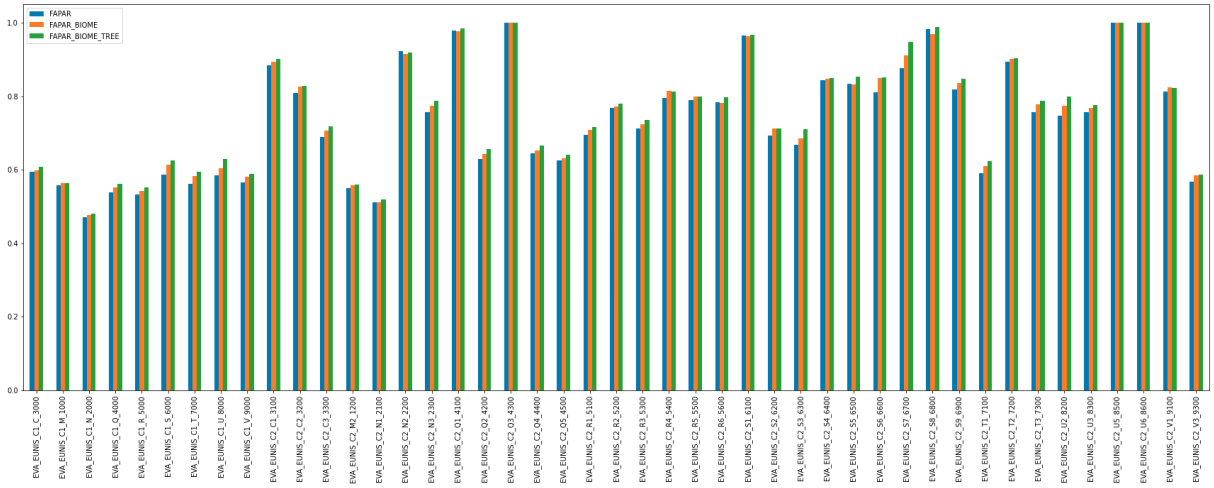


Source: own illustration, EOSS GmbH.

Further feature analysis was supported by Random Forest classification models. The first feature combinations that were compared were sourced by the Potential Natural Vegetation layers. Three feature combinations (1. monthly FAPAR only, 2. FAPAR and BIOME layers, and 3. FAPAR, BIOME, and tree species layers) were used. While the sole usage of FAPAR features already provided moderate to high overall accuracies the additional utilisation of the BIOME layers provided a small increase in overall accuracies. Overall accuracies did not benefit from the

additional usage of the tree species layers (Figure 25). Also, the spatial coverage of the tree species layers does not cover the complete project region and with that it was decided to us monthly FAPAR and the BIOMEs layers of the GPNV maps as final features.

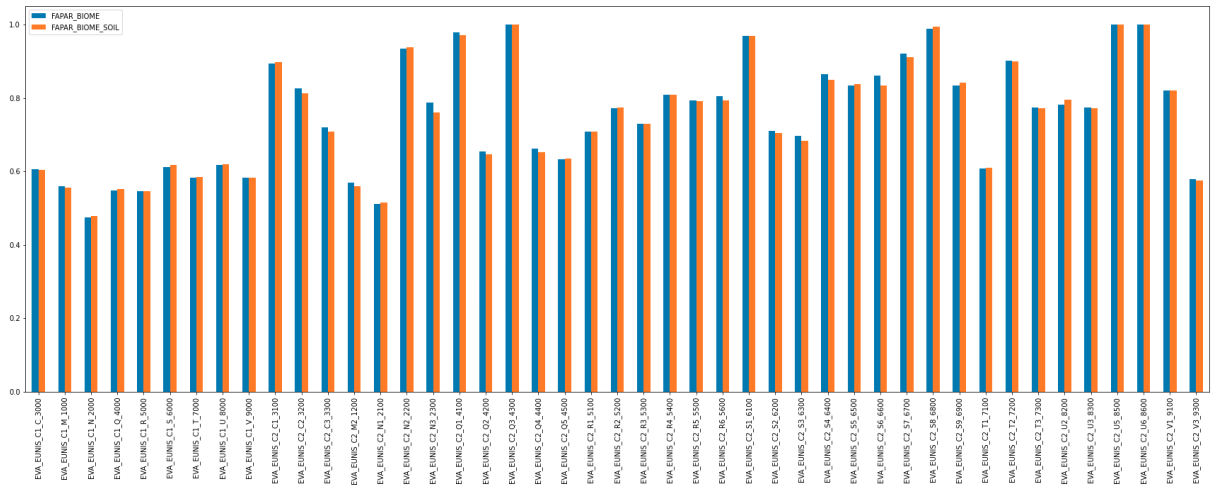
Figure 25: Class-based overall accuracies for EUNIS Level 3 prediction models using Random Forest Classifier and different combinations of the Potential Natural Vegetation features



Source: own illustration, EOSS GmbH.

Finally, the contribution of the 30 soil property layers from the Harmonized World Soil Database was analysed by adding those features to the selected GPNV data layers. There was no significant increase in overall accuracies for the models trained with additional soil features as compared to those sourced by selected FAPAR and BIOME GPNV data layers (Figure 26). This can be explained, because the models applied for producing the GPNV data layers also incorporate global soil property maps and with that BIOME layers already are described by those as well leading to feature redundancy and correlation.

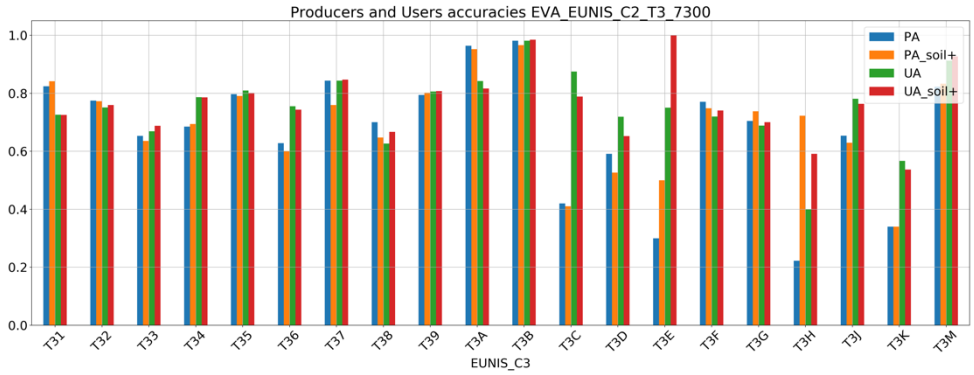
Figure 26: Class-based overall accuracies for EUNIS Level 3 prediction models using Random Forest Classifier and different combinations of the Potential Natural Vegetation and Harmonized World Soil Database features



Source: own illustration, EOSS GmbH.

These findings are supported by analysing not only overall accuracies but also producers and users' accuracies for the individual EUNIS Level 3 classes. Following figure provides an example of producers and users accuracies for the EUNIS T3 (Coniferous Forest) classes (Figure 27). For all Level 3 classes there was no significant increase in overall accuracies for the models trained with additional soil features as compared to those sourced by selected FAPAR and BIOME GPNV data layers.

Figure 27: Producers (PA) and Users accuracies (UA) for EUNIS Level 3 prediction models using Random Forest Classifier and different combinations of the Potential Natural Vegetation and Harmonized World Soil Database features (soil+) for the EUNIS T3 Coniferous Forest class

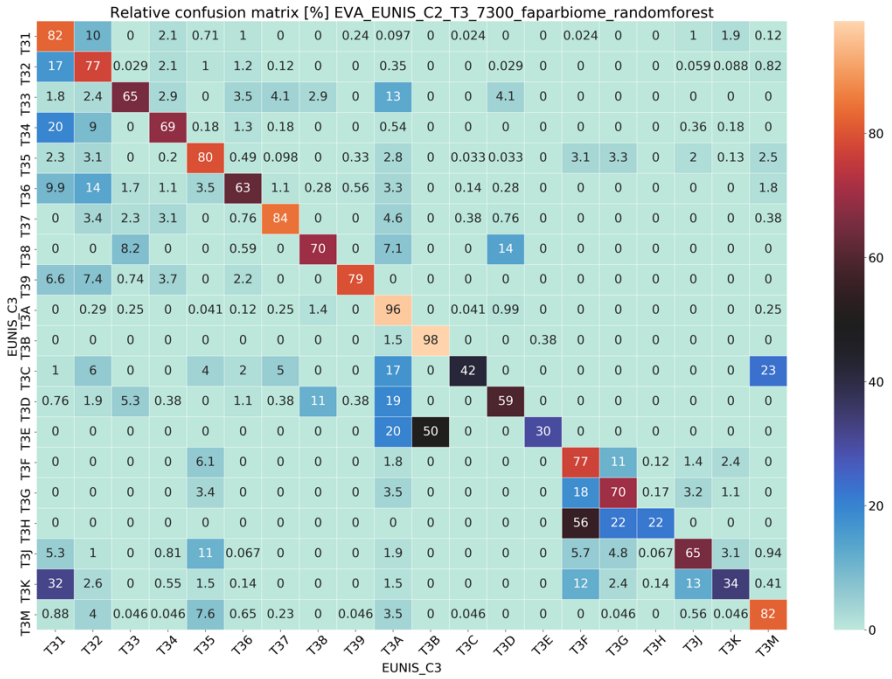


Source: own illustration, EOSS GmbH.

Based on these findings the Random Forest classification models sourced by GPNV, monthly FAPAR and BIOME layers were chosen for final land cover classification. A total of 45 models were trained (based on 45 EVA sample batches (see chapter 2.4.3). Nine models were trained for the EUNIS Level 1 classes and another 36 models for EUNIS Level 2 classes. For each model training, only EVA samples from the respective Level 1 or Level 2 class were used. Again, 60% of samples were used for training and the remaining 40% for accuracy assessment.

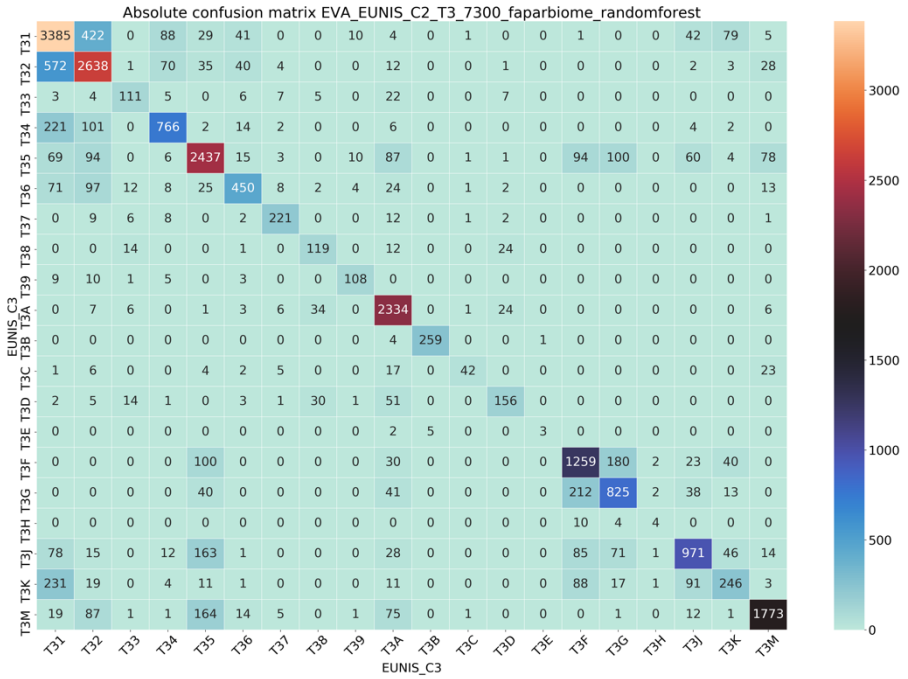
Accuracy assessment was done using the Python multi-class confusion matrix library PyCM (Haghighi et al. 2018). Confusion matrices and derived statistics of users' and producers' accuracies were calculated and stored for every classifier. A complete listing of all EUNIS Level 3 class based derived Producers and Users accuracies is provided in the Annex of this report. As an example, the relative confusion matrix and the absolute confusion matrix for the EUNIS Level 2 class prediction model T3 (Coniferous Forest) are provided in Figure 28 and Figure 29. The model allowed to classify and disaggregate the coniferous tree class into a total of 20 Level 3 subclasses. The producers' accuracy in percent for each of these subclasses can directly be identified in the diagonal values, omission and commission errors towards other classes can be identified in the rows and columns of each class respectively. While the relative confusion matrix provides percentages of accuracies and errors, the absolute confusion matrix shows the actual number of samples correctly classified and misclassified for each class.

Figure 28: Relative confusion matrix derived from accuracy assessment for the EUNIS T3 Coniferous Forest class



Source: own illustration, EOSS GmbH.

Figure 29: Absolute confusion matrix derived from accuracy assessment for the EUNIS T3 Coniferous Forest class



Source: own illustration, EOSS GmbH.

2.4.5 EUNIS Level 3 habitat classification

Base layer for the final EUNIS Level 3 habitat classification is the discrete before calculated EUNIS Level 2 map. To speed up processing and allow for scaling towards parallel processing, the complete map was split into smaller subsets. For each subset, feature stacks used for feature extraction from the Potential Natural Vegetation FAPAR and BIOMEs layer were clipped and resampled to the current processing subset on-the-fly. For each distinct landcover class from the 45 available classes of the Level 2 map, the before derived and assigned classification model was applied. While looping through the distinct Levels 2 classes of the current subset, all pixels not represented by the current land cover class were masked out and features were extracted for non-masked pixels only. The respective classification model was then executed on the conserved feature pixels to predict the final EUNIS Level 3 class. Each pixel is then labelled with the predicted EUNIS Level 3 land cover class. Final classification results from all discrete class predictions where then combined to a classified subset image. Finally, all classified subsets (EUNIS level 1, 2 and 3) were combined by mosaicking them to a final EUNIS Level 3 land cover map for the whole region.

2.4.6 Final EUNIS habitat map composition

In correspondence with the client discussions a final remapping for selected classes was applied. All pixels classified into one of the maritime habitat classes was translated back to the level 1 Maritime habitats class (EUNIS Code M, Pixel Code 1000). This was necessary because the samples provided with the classified EVA dataset only represented small portions of the entire

maritime class and described only coastal maritime habitats and in consequence resulted in misclassification of most open sea pixels towards a coastal maritime Level 3 habitat class.

Also, the EUNIS Level 3 class J5 (Highly artificial man-made waters and associated structures) was translated to the Level 1 Inland surface waters class (EUNIS Code C, Pixel Code 3000).

For some EUNIS Level 2 classes, available samples from the classified EVA database provided only one or two Level 3 classes and with that do not provide to be a representative training dataset for the whole region of interest. It was therefore decided, to translate those back to the respective EUNIS Level 2 class. These were the classes with raster code 4301 (EUNIS Code Q31, Palsa mires) which was translated to class 4300 (EUNIS Code Q3, Palsa and polygon mires), the class 8501 (U52, Polar Desert) which was translated to class 8500 (EUNIS Code U5, Miscellaneous inland habitats usually with very sparse or no vegetation). Finally, the classes 8601 (Subarctic volcanic field) and 8602 (Mediterranean, Macaronesian and temperate volcanic field) which were translated to class 8600 (U6, Recent volcanic features).

The final EUNIS Level 3 land cover map provides a total of 217 land cover classes. From those, 203 classes represent EUNIS Level 3 classes. 11 EUNIS Level 2 classes could not be further disaggregated to Level 3 because of insufficient or unavailable Level 3 EVA samples. Three Level 1 classes were not disaggregated towards Level 2 and level 3, namely the before translated maritime habitats (EUNIS code M, Pixel code 1000), and the inland surface waters (EUNIS code C, Pixel code 3000) for regions where only COPERNICUS Global land Cover could be applied providing only one single water class, and the Constructed, industrial and other artificial habitats (EUNIS code J, Pixel Code 10000) for regions where only COPERNICUS Global land Cover could be applied providing only one single urban class.

The following table (Table 17) presents the final classification scheme for the updated European Land Cover Map at EUNIS Level 3.

Table 17: Final classification scheme for the updated European Land Cover Map at EUNIS Level 3 with EUNIS class codes (C) and grid codes (G)

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
M			1000			Marine habitats
N	N1	N11	2000	2100	2101	Atlantic, Baltic and Arctic sand beach
N	N1	N12	2000	2100	2102	Mediterranean and Black Sea sand beach
N	N1	N13	2000	2100	2103	Atlantic and Baltic shifting coastal dune
N	N1	N14	2000	2100	2104	Mediterranean, Macaronesian and Black Sea shifting coastal dune
N	N1	N15	2000	2100	2105	Atlantic and Baltic coastal dune grassland (grey dune)
N	N1	N16	2000	2100	2106	Mediterranean and Macaronesian coastal dune grassland (grey dune)
N	N1	N17	2000	2100	2107	Black Sea coastal dune grassland (grey dune)

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
N	N1	N1A	2000	2100	2110	Atlantic and Baltic coastal dune scrub
N	N1	N1B	2000	2100	2111	Mediterranean and Black Sea coastal dune scrub
N	N1	N1C	2000	2100	2112	Macaronesian coastal dune scrub
N	N1	N1D	2000	2100	2113	Atlantic and Baltic broad-leaved coastal dune forest
N	N1	N1G	2000	2100	2116	Mediterranean coniferous coastal dune forest
N	N1	N1H	2000	2100	2117	Atlantic and Baltic moist and wet dune slack
N	N1	N1J	2000	2100	2118	Mediterranean and Black Sea moist and wet dune slack
N	N2	N21	2000	2200	2201	Atlantic, Baltic and Arctic coastal shingle beach
N	N2	N22	2000	2200	2202	Mediterranean and Black Sea coastal shingle beach
N	N3	N32	2000	2300	2302	Mediterranean and Black Sea rocky sea cliff and shore
N	N3	N33	2000	2300	2303	Macaronesian rocky sea cliff and shore
N	N3	N35	2000	2300	2305	Mediterranean and Black Sea soft sea cliff
C			3000			Inland surface waters
C	C1	C11b	3000	3100	3102	Permanent oligotrophic lakes, ponds and pools
C	C1	C12b	3000	3100	3104	Permanent mesotrophic lakes, ponds and pools
C	C1	C15	3000	3100	3106	Permanent inland saline and brackish lakes, ponds and pools
C	C1	C16b	3000	3100	3107	Temporary lakes, ponds and pools
C	C2	C21a	3000	3200	3201	Springs, spring brooks and geysers a
C	C2	C21b	3000	3200	3202	Springs, spring brooks and geysers b
C	C2	C22a	3000	3200	3203	Permanent non-tidal, fast, turbulent watercourses a
C	C2	C22b	3000	3200	3204	Permanent non-tidal, fast, turbulent watercourses b
C	C2	C23	3000	3200	3205	Permanent non-tidal, smooth-flowing watercourses
C	C2	C24	3000	3200	3206	Tidal rivers, upstream from the estuary
C	C2	C25a	3000	3200	3207	Temporary running waters
C	C3	C35a	3000	3300	3301	Periodically inundated shores with pioneer and ephemeral vegetation a

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
C	C3	C35c	3000	3300	3303	Periodically inundated shores with pioneer and ephemeral vegetation c
C	C3	C35d	3000	3300	3304	Periodically inundated shores with pioneer and ephemeral vegetation d
C	C3	C35e	3000	3300	3305	Periodically inundated shores with pioneer and ephemeral vegetation e
Q	Q1	Q11	4000	4100	4101	Raised bogs
Q	Q1	Q12	4000	4100	4102	Blanket bogs
Q	Q2	Q22	4000	4200	4202	Poor fens and soft-water spring mires
Q	Q2	Q23	4000	4200	4203	Apennine acidic fens
Q	Q2	Q24	4000	4200	4204	Intermediate fen and soft-water spring mire
Q	Q2	Q25	4000	4200	4205	Non-calcareous quaking mire
Q	Q3	Q3	4000	4300		Palsa and polygon mires
Q	Q4	Q41	4000	4400	4401	Alkaline, calcareous, carbonate-rich small-sedge spring fen
Q	Q4	Q42	4000	4400	4402	Extremely rich moss-sedge fen
Q	Q4	Q44	4000	4400	4404	Calcareous quaking mire
Q	Q4	Q45	4000	4400	4405	Arctic-alpine rich fen
Q	Q5	Q51	4000	4500	4501	Tall-helophyte bed
Q	Q5	Q52	4000	4500	4502	Small-helophyte bed
Q	Q5	Q53	4000	4500	4503	Tall-sedge bed
Q	Q5	Q54	4000	4500	4504	Inland saline or brackish helophyte bed
Q	Q6		4000	4600		Inland saline and brackish marshes and reedbeds
R	R1	R11	5000	5100	5101	Pannonian and Pontic sandy steppe
R	R1	R12	5000	5100	5102	Cryptogam- and annual-dominated vegetation on siliceous rock outcrops
R	R1	R13	5000	5100	5103	Cryptogam- and annual-dominated vegetation on calcareous and ultramafic rock outcrops
R	R1	R15	5000	5100	5105	Continental dry rocky steppic grassland and dwarf scrub on chalk outcrops
R	R1	R16	5000	5100	5106	Perennial rocky grassland of Central and South-Eastern Europe

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
R	R1	R18	5000	5100	5108	Perennial rocky calcareous grassland of subatlantic-submediterranean Europe
R	R1	R19	5000	5100	5109	Dry steppic submediterranean pasture of the Amphi-Adriatic region
R	R1	R1A	5000	5100	5110	Semi-dry perennial calcareous grassland (meadow steppe)
R	R1	R1B	5000	5100	5111	Continental dry grassland (true steppe)
R	R1	R1C	5000	5100	5112	Desert steppe
R	R1	R1D	5000	5100	5113	Mediterranean closely grazed dry grassland
R	R1	R1E	5000	5100	5114	Mediterranean tall perennial dry grassland
R	R1	R1F	5000	5100	5115	Mediterranean annual-rich dry grassland
R	R1	R1G	5000	5100	5116	Iberian oromediterranean siliceous dry grassland
R	R1	R1H	5000	5100	5117	Iberian oromediterranean basiphilous dry grassland
R	R1	R1J	5000	5100	5118	Cyrno-Sardean oromediterranean siliceous dry grassland
R	R1	R1K	5000	5100	5119	Balkan and Anatolian oromediterranean dry grassland
R	R1	R1M	5000	5100	5121	Lowland to montane, dry to mesic grassland usually dominated by *Nardus stricta*
R	R1	R1N	5000	5100	5122	Open Iberian supramediterranean dry acid and neutral grassland
R	R1	R1P	5000	5100	5123	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils
R	R1	R1Q	5000	5100	5124	Inland sanddrift and dune with siliceous grassland
R	R1	R1R	5000	5100	5125	Mediterranean to Atlantic open, dry, acid and neutral grassland
R	R1	R1T	5000	5100	5127	Azorean open, dry, acid to neutral grassland
R	R2	R21	5000	5200	5201	Mesic permanent pasture of lowlands and mountains
R	R2	R22	5000	5200	5202	Low and medium altitude hay meadow
R	R2	R23	5000	5200	5203	Mountain hay meadow
R	R2	R24	5000	5200	5204	Iberian summer pasture (vallicar)
R	R3	R31	5000	5300	5301	Mediterranean tall humid inland grassland

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
R	R3	R32	5000	5300	5302	Mediterranean short moist grassland of lowlands
R	R3	R33	5000	5300	5303	Mediterranean short moist grassland of mountains
R	R3	R34	5000	5300	5304	Submediterranean moist meadow
R	R3	R35	5000	5300	5305	Moist or wet mesotrophic to eutrophic hay meadow
R	R3	R36	5000	5300	5306	Moist or wet mesotrophic to eutrophic pasture
R	R3	R37	5000	5300	5307	Temperate and boreal moist or wet oligotrophic grassland
R	R4	R41	5000	5400	5401	Snow-bed vegetation
R	R4	R42	5000	5400	5402	Boreal and arctic acidophilous alpine grassland
R	R4	R43	5000	5400	5403	Temperate acidophilous alpine grassland
R	R4	R44	5000	5400	5404	Arctic-alpine calcareous grassland
R	R4	R45	5000	5400	5405	Alpine and subalpine calcareous grassland of the Balkans and Apennines
R	R5	R51	5000	5500	5501	Thermophilous forest fringe of base-rich soils
R	R5	R53	5000	5500	5503	Macaronesian thermophilous forest fringe
R	R5	R54	5000	5500	5504	Pteridium aquilinum vegetation
R	R5	R55	5000	5500	5505	Lowland moist or wet tall-herb and fern fringe
R	R5	R56	5000	5500	5506	Montane to subalpine moist or wet tall-herb and fern fringe
R	R5	R57	5000	5500	5507	Herbaceous forest clearing vegetation
R	R6	R61	5000	5600	5601	Mediterranean inland salt steppe
R	R6	R62	5000	5600	5602	Continental inland salt steppe
R	R6	R63	5000	5600	5603	Temperate inland salt marsh
R	R6	R64	5000	5600	5604	Semi-desert salt pan
R	R6	R65	5000	5600	5605	Continental subsaline alluvial pasture and meadow
R	R7		5000	5700		Sparsely wooded grasslands
S			6020	6020	6020	Heathland, scrub and tundra
S	S1	S11	6000	6100	6101	Shrub tundra

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
S	S1	S12	6000	6100	6102	Moss and lichen tundra
S	S2	S21	6000	6200	6201	Subarctic and alpine dwarf *Salix* scrub
S	S2	S22	6000	6200	6202	Alpine and subalpine ericoid heath
S	S2	S23	6000	6200	6203	Alpine and subalpine *Juniperus* scrub
S	S2	S25	6000	6200	6205	Subalpine and subarctic deciduous scrub
S	S2	S26	6000	6200	6206	Subalpine *Pinus mugo* scrub
S	S3	S31	6000	6300	6301	Lowland to montane temperate and submediterranean *Juniperus* scrub
S	S3	S32	6000	6300	6302	Temperate *Rubus* scrub
S	S3	S33	6000	6300	6303	Lowland to montane temperate and submediterranean genistoid scrub
S	S3	S34	6000	6300	6304	Balkan-Anatolian submontane genistoid scrub
S	S3	S35	6000	6300	6305	Temperate and submediterranean thorn scrub
S	S3	S36	6000	6300	6306	Low steppic scrub
S	S3	S37	6000	6300	6307	*Corylus avellana* scrub
S	S3	S38	6000	6300	6308	Temperate forest clearing scrub
S	S4	S41	6000	6400	6401	Wet heath
S	S4	S42	6000	6400	6402	Dry heath
S	S5	S51	6000	6500	6501	Mediterranean maquis and arborescent matorral
S	S5	S52	6000	6500	6502	Submediterranean pseudomaquis
S	S5	S53	6000	6500	6503	*Spartium junceum* scrub
S	S5	S54	6000	6500	6504	Thermomediterranean arid scrub
S	S6	S61	6000	6600	6601	Western basiphilous garrigue
S	S6	S62	6000	6600	6602	Western acidophilous garrigue
S	S6	S63	6000	6600	6603	Eastern garrigue
S	S6	S64	6000	6600	6604	Macaronesian garrigue
S	S6	S65	6000	6600	6605	Mediterranean gypsum scrub
S	S6	S66	6000	6600	6606	Mediterranean halo-nitrophilous scrub

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
S	S6	S67	6000	6600	6607	Aralo-Caspian semi-desert
S	S6	S68	6000	6600	6608	Semi-desert sand dune with sparse scrub
S	S7	S71	6000	6700	6701	Western Mediterranean spiny heath
S	S7	S72	6000	6700	6702	Eastern Mediterranean spiny heath (phrygana)
S	S7	S73	6000	6700	6703	Western Mediterranean mountain hedgehog-heath
S	S7	S74	6000	6700	6704	Central Mediterranean mountain hedgehog-heath
S	S7	S75	6000	6700	6705	Eastern Mediterranean mountain hedgehog-heath
S	S7	S76	6000	6700	6706	Canarian mountain hedgehog-heath
S	S8	S81	6000	6800	6801	Canarian xerophytic scrub
S	S9	S91	6000	6900	6901	Temperate riparian scrub
S	S9	S92	6000	6900	6902	*Salix* fen scrub
S	S9	S93	6000	6900	6903	Mediterranean riparian scrub
S	S9	S94	6000	6900	6904	Semi-desert riparian scrub
T	T1	T11	7000	7100	7101	Temperate *Salix* and *Populus* riparian forest
T	T1	T12	7000	7100	7102	*Alnus glutinosa-Alnus incana* forest on riparian and mineral soils
T	T1	T13	7000	7100	7103	Temperate hardwood riparian forest
T	T1	T14	7000	7100	7104	Mediterranean and Macaronesian riparian forest
T	T1	T16	7000	7100	7106	Broadleaved mire forest on acid peat
T	T1	T17	7000	7100	7107	*Fagus* forest on non-acid soils
T	T1	T18	7000	7100	7108	*Fagus* forest on acid soils
T	T1	T19	7000	7100	7109	Temperate and submediterranean thermophilous deciduous forest
T	T1	T1A	7000	7100	7110	Mediterranean thermophilous deciduous forest
T	T1	T1B	7000	7100	7111	Acidophilous *Quercus* forest
T	T1	T1C	7000	7100	7112	Temperate and boreal mountain *Betula* and *Populus tremula* forest on mineral soils
T	T1	T1D	7000	7100	7113	Southern European mountain *Betula* and *Populus tremula* forest on mineral soils

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
T	T1	T1E	7000	7100	7114	*Carpinus* and *Quercus* mesic deciduous forest
T	T1	T1F	7000	7100	7115	Ravine forest
T	T1	T1H	7000	7100	7117	Broadleaved deciduous plantation of non site-native trees
T	T2	T21	7000	7200	7201	Mediterranean evergreen *Quercus* forest
T	T2	T22	7000	7200	7202	Mainland laurophyllous forest
T	T2	T23	7000	7200	7203	Macaronesian laurophyllous forest
T	T2	T24	7000	7200	7204	*Olea europaea-Ceratonia siliqua* forest
T	T2	T25	7000	7200	7205	*Phoenix theophrasti* vegetation
T	T2	T28	7000	7200	7208	Macaronesian heathy forest
T	T2	T29	7000	7200	7209	Broadleaved evergreen plantation of non site-native trees
T	T3	T31	7000	7300	7301	Temperate mountain *Picea* forest
T	T3	T32	7000	7300	7302	Temperate mountain *Abies* forest
T	T3	T33	7000	7300	7303	Mediterranean mountain *Abies* forest
T	T3	T34	7000	7300	7304	Temperate subalpine *Larix, Pinus cembra* and *Pinus uncinata* forest
T	T3	T35	7000	7300	7305	Temperate continental *Pinus sylvestris* forest
T	T3	T36	7000	7300	7306	Temperate and submediterranean montane *Pinus sylvestris-Pinus nigra* forest
T	T3	T37	7000	7300	7307	Mediterranean montane *Pinus sylvestris-Pinus nigra* forest
T	T3	T38	7000	7300	7308	Mediterranean montane *Cedrus* forest
T	T3	T39	7000	7300	7309	Mediterranean and Balkan subalpine *Pinus heldreichii-Pinus peuce* forest
T	T3	T3A	7000	7300	7310	Mediterranean lowland to submontane *Pinus* forest
T	T3	T3B	7000	7300	7311	*Pinus canariensis* forest
T	T3	T3D	7000	7300	7313	Mediterranean Cupressaceae forest
T	T3	T3E	7000	7300	7314	Macaronesian *Juniperus* forest
T	T3	T3F	7000	7300	7315	Dark taiga
T	T3	T3G	7000	7300	7316	*Pinus sylvestris* light taiga

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
T	T3	T3J	7000	7300	7318	*Pinus* and *Larix* mire forest
T	T3	T3K	7000	7300	7319	*Picea* mire forest
T	T3	T3M	7000	7300	7320	Coniferous plantation of non site-native trees
T	*T5*		*7000*	*7500*		*Mixed deciduous and coniferous woodland*
U	U2	U21	8000	8200	8201	Boreal and arctic siliceous scree and block field
U	U2	U22	8000	8200	8202	Temperate high-mountain siliceous scree
U	U2	U24	8000	8200	8204	Mediterranean siliceous scree
U	U2	U25	8000	8200	8205	Boreal and arctic base-rich scree and block field
U	U2	U26	8000	8200	8206	Temperate high-mountain base-rich scree and moraine
U	U2	U27	8000	8200	8207	Temperate, lowland to montane base-rich scree
U	U2	U28	8000	8200	8208	Western Mediterranean base-rich scree
U	U2	U29	8000	8200	8209	Eastern Mediterranean base-rich scree
U	U2	U2A	8000	8200	8210	Crimean base-rich screes
U	U3	U32	8000	8300	8301	Temperate high-mountain siliceous inland cliff
U	U3	U33	8000	8300	8302	Temperate, lowland to montane siliceous inland cliff
U	U3	U34	8000	8300	8303	Mediterranean siliceous inland cliff
U	U3	U35	8000	8300	8304	Boreal and arctic base-rich inland cliff
U	U3	U36	8000	8300	8305	Temperate high-mountain base-rich inland cliff
U	U3	U37	8000	8300	8306	Temperate, lowland to montane base-rich inland cliff
U	U3	U38	8000	8300	8307	Mediterranean base-rich inland cliff
U	U3	U3A	8000	8300	8308	Temperate ultramafic inland cliff
U	U3	U3C	8000	8300	8310	Macaronesian inland cliff
U	U3	U3D	8000	8300	8311	Wet inland cliff
U	U4		8000	8400		Snow or ice-dominated habitats
U	U5	U52	8000	8500	8500	Miscellaneous inland habitats usually with very sparse or no vegetation

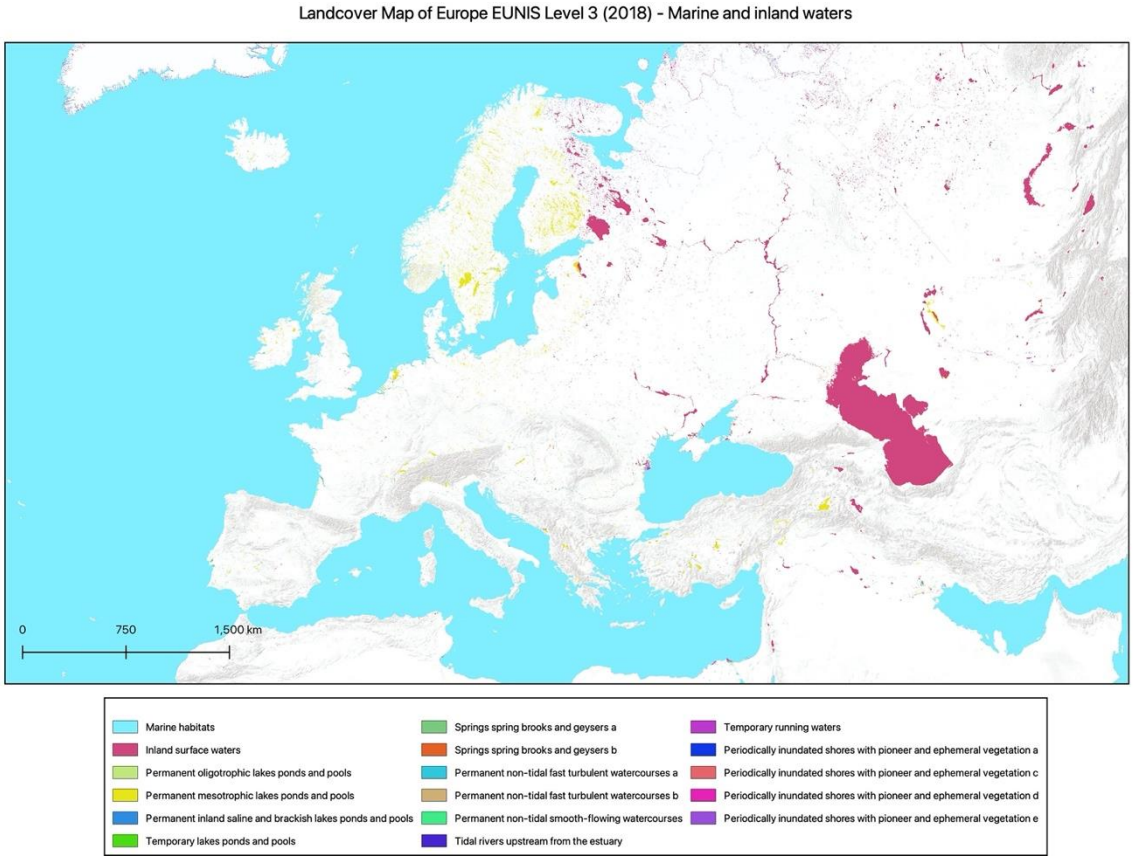
EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
U	U6		8000	8600		Recent volcanic features
V	V1	V11	9000	9100	9101	Intensive unmixed crops
V	V1	V12	9000	9100	9102	Mixed crops of market gardens and horticulture
V	V1	V13	9000	9100	9103	Arable land with unmixed crops grown by low-intensity agricultural methods
V	V1	V14	9000	9100	9104	Inundated or inundatable croplands, including rice fields
V	V1	V15	9000	9100	9105	Bare tilled, fallow or recently abandoned arable land
V	V2		9000	9200		Cultivated areas of gardens and parks
J			10000			Constructed, industrial and other artificial habitats
J	J1		10000	10100		Buildings of cities, towns and villages
J	J2		10000	10200		Low density buildings
J	J3		10000	10300		Extractive industrial sites
J	J4		10000	10400		Transport networks and other constructed hard-surfaced areas
J	J6		10000	10600		Waste deposits

The following figures (Figure 30 to Figure 37) provide illustrations of the final updated land cover map as thematic subsets for all level 2 EUNIS classes.

Figure 30: Updated land cover map of Europe - Coastal and wetland habitats

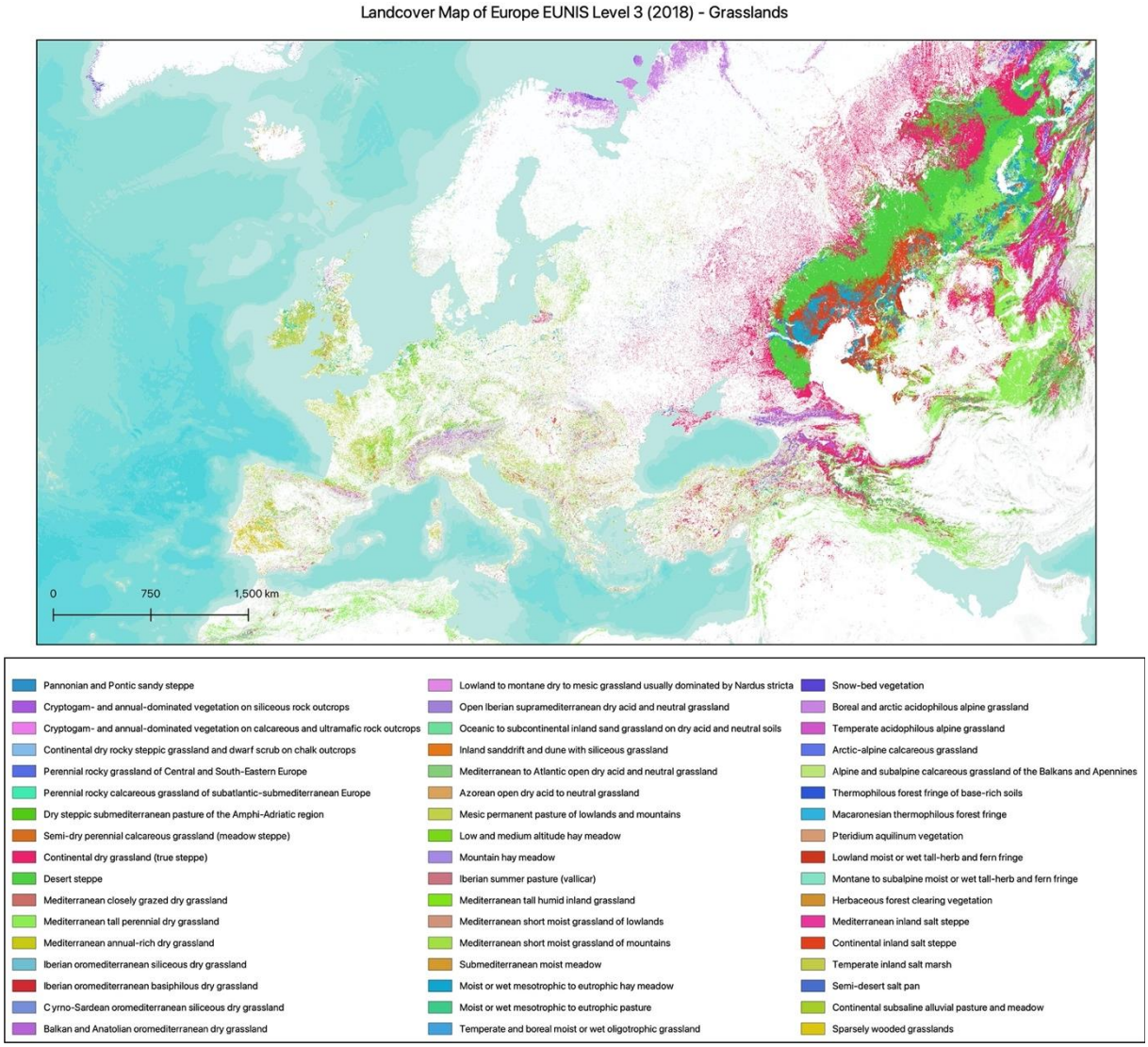
Source: own illustration, EOSS GmbH.

Figure 31: Updated land cover map of Europe - Marine and inland waters



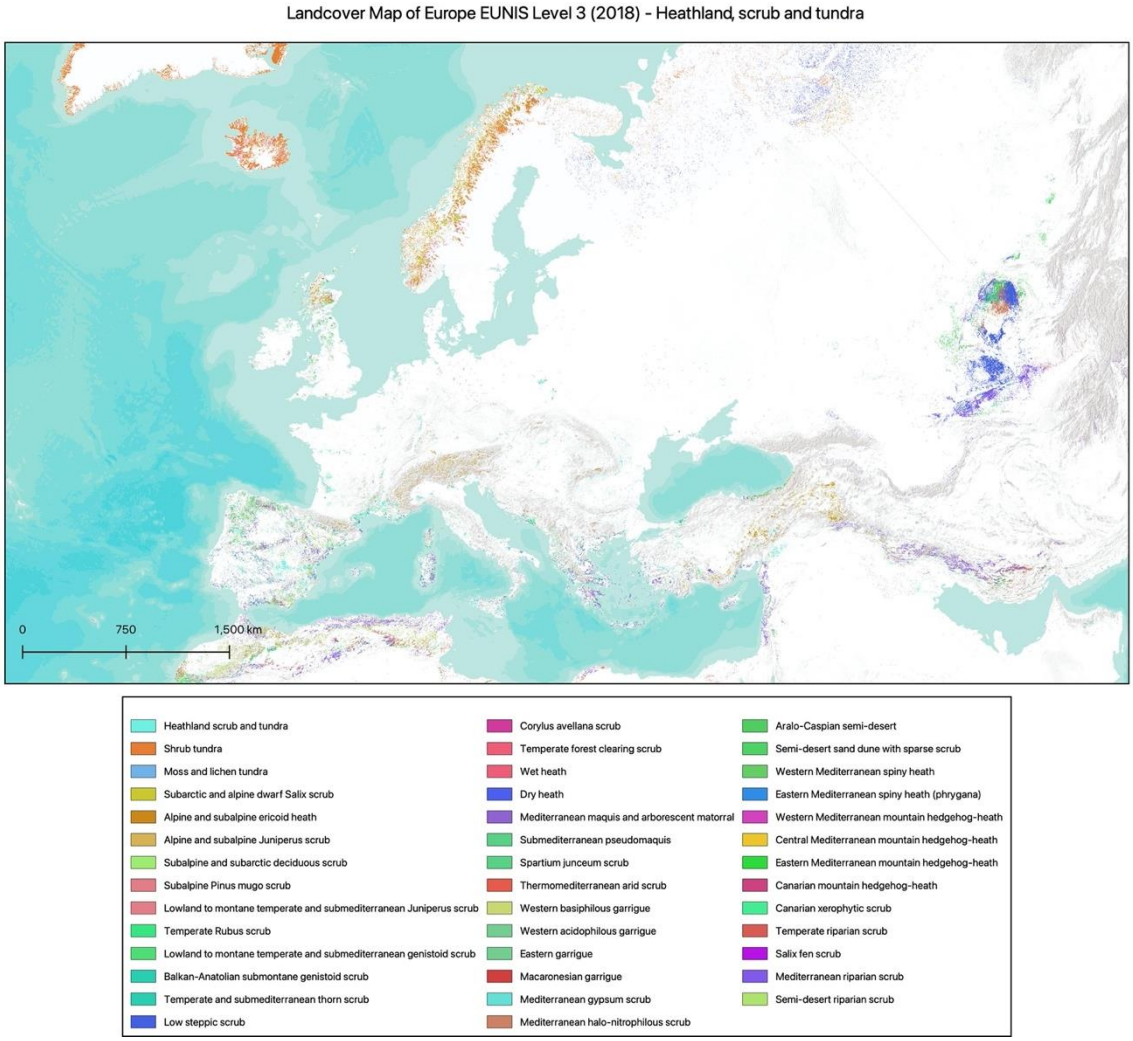
Source: own illustration, EOSS GmbH.

Figure 32: Updated land cover map of Europe - Grasslands



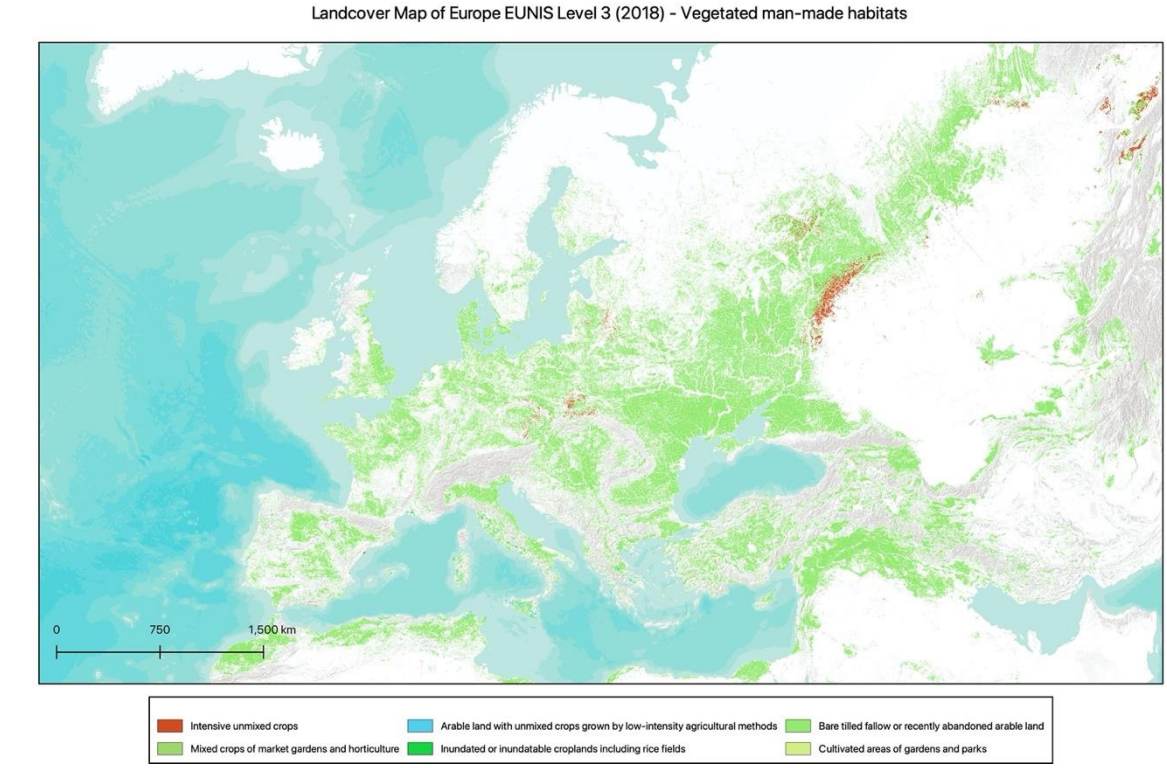
Source: own illustration, EOSS GmbH.

Figure 33: Updated land cover map of Europe - Heathland, scrub and tundra



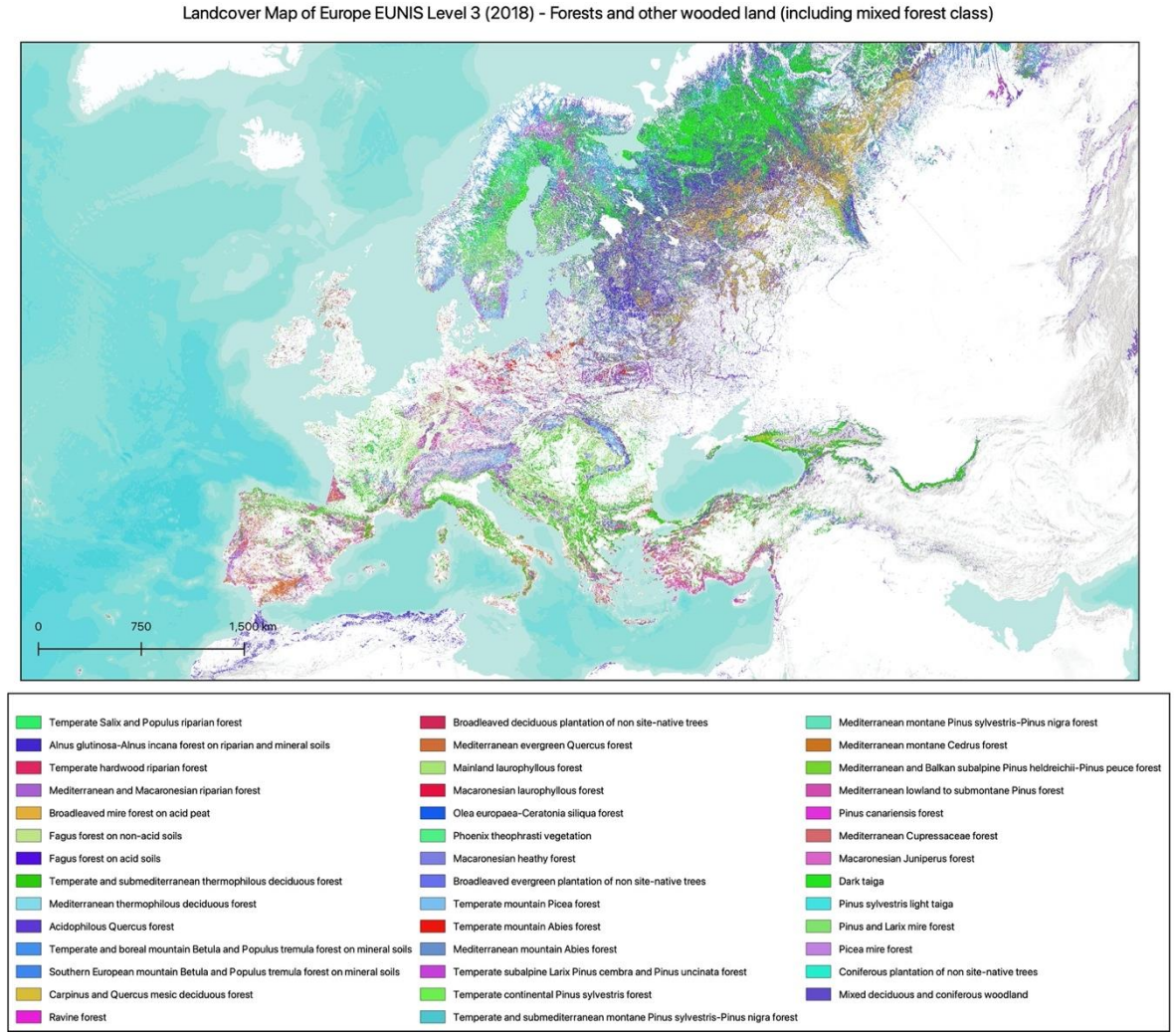
Source: own illustration, EOSS GmbH.

Figure 34: Updated land cover map of Europe - Vegetated man-made habitats



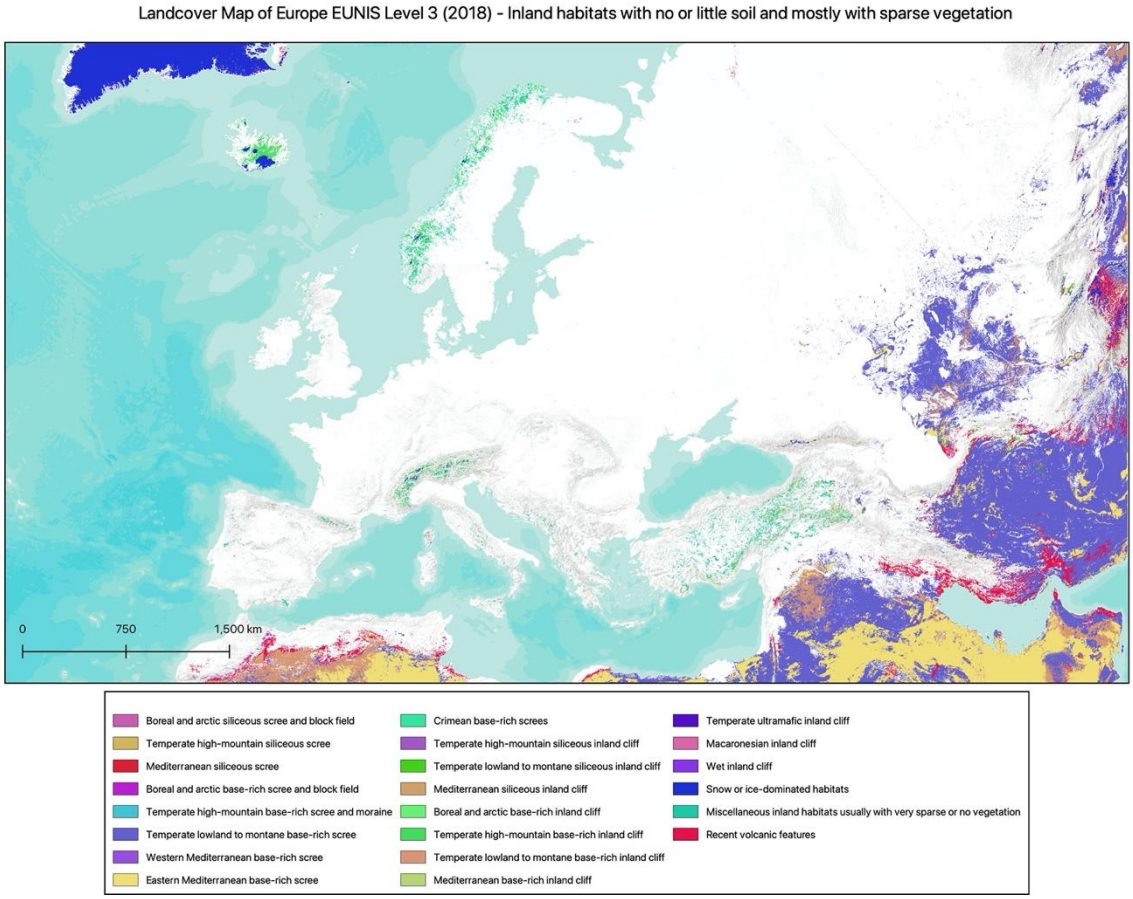
Source: own illustration, EOSS GmbH.

Figure 35: Updated land cover map of Europe - Forest and wooded land



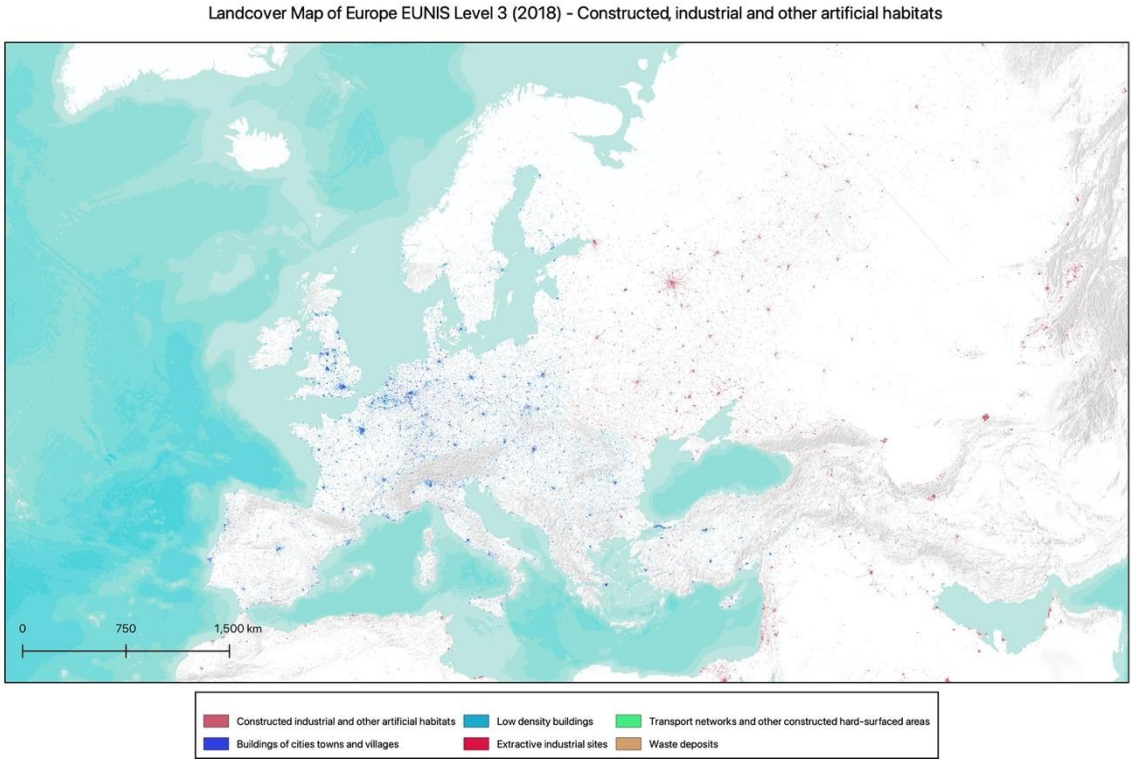
Source: own illustration, EOSS GmbH.

Figure 36: Updated land cover map of Europe - Unvegetated habitats



Source: own illustration, EOSS GmbH.

Figure 37: Updated land cover map of Europe - Artificial



Source: own illustration, EOSS GmbH.

2.5 Updated European REM-CALGRID Land Cover Map

The REM-CALGRID model (RCG) is a three-dimensional chemical transport model, which allows the calculation of air quality values (Stern 2018). The RCG model requires land use data represented by 13 land cover classes.

Based on the updated EUNIS Level 2 Land Cover map a mapping ruleset towards the RCG classification scheme has been derived and is presented in the Table 18. These rules were applied to the Level 2 EUNIS Land Cover map and provided the updated RCG land cover map featuring 13 land cover classes (Figure 38).

In addition to the land cover map, the proportions of each class in each grid cell are required. The target grid cell size of RCG land cover and land cover proportions is 2 x 2 km² for the European map and 1 x 1 km² for the map covering Germany only.

For doing so regular grids featuring the required cell size and spatial extent were created and for each cell the relative proportion for each of the 13 underlying land cover classes was calculated. Proportions range from 0 to 100 representing the respective percentage. With the 2 grids applied (European 2km grid and the 1km German grid) and the 13 distinct land cover classes a total of 26 land cover proportion layers were processed. Each of these layers was reprojected to the desired geographic projection (EPSG:4326) with target pixel sizes of 0.00833333333333 degrees for the German layers and 0.016667 for the European layers.

Figure 39 provides an example of the updated European REM- CALGRID Grassland land cover proportions from the European layer (2km grid).

Figure 40 provides an example of the updated German REM- CALGRID Coniferous forest land cover proportions from the German layer (1km grid).

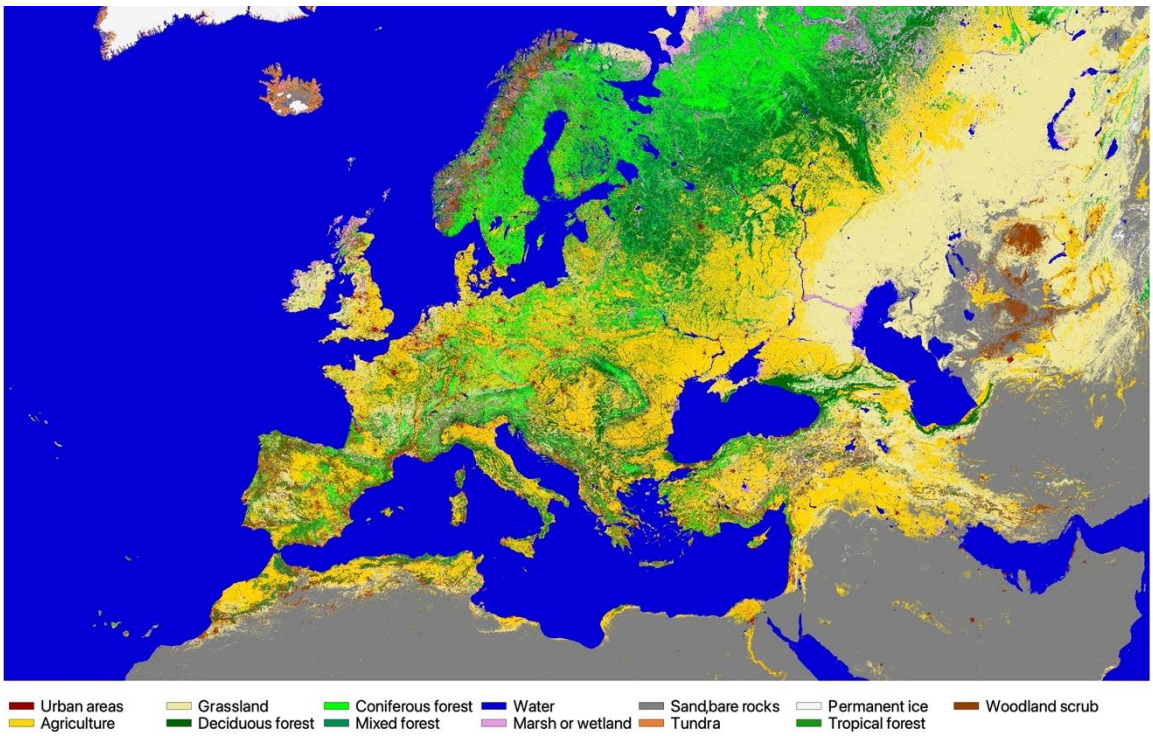
Table 18: Transition rules for converting EUNIS Level 2 map towards RCG land cover classes

EUNIS GRID CODE	EUNIS CODE	EUNIS LABEL	RCG GRID CODE	RCG LABEL
1000	M	Marine benthic habitats	7	Water
2000	N	Coastal habitats	8	Marsh or wetland
2100	N1	Coastal dunes and sandy shores	9	Sand, bare rocks
2200	N2	Coastal shingle	9	Sand, bare rocks
2300	N3	Rock cliffs, ledges and shores, including the supralittoral	9	Sand, bare rocks
3100	C1	Surface standing waters	7	Water
3200	C2	Surface running waters	7	Water
3300	C3	Littoral zone of inland surface waterbodies	9	Sand, bare rocks
4100	Q1	Raised and blanket bogs	8	Marsh or wetland
4200	Q2	Valley mires, poor fens and transition mires	8	Marsh or wetland

EUNIS GRID CODE	EUNIS CODE	EUNIS LABEL	RCG GRID CODE	RCG LABEL
4300	Q3	Aapa, palsa and polygon mires	8	Marsh or wetland
4400	Q4	Base-rich fens and calcareous spring mires	8	Marsh or wetland
4500	Q5	Sedge and reedbeds, normally without free-standing water	8	Marsh or wetland
4600	Q6	Inland saline and brackish marshes and reedbeds	8	Marsh or wetland
5000	R	Grasslands and lands dominated by forbs, mosses or lichens	3	Grassland
5100	R1	Dry grasslands	3	Grassland
5200	R2	Mesic grasslands	3	Grassland
5300	R3	Seasonally wet and wet grasslands	3	Grassland
5400	R4	Alpine and subalpine grasslands	3	Grassland
5600	R6	Inland salt steppes	3	Grassland
5700	R7	Sparsely wooded grasslands	3	Grassland
6000	S	Heathland, scrub and tundra	13	Woodland scrub
6020	SB	Shrub plantations	13	Woodland scrub
6100	S1	Tundra	10	Tundra
6200	S2	Arctic, alpine and subalpine scrub	13	Woodland scrub
6300	S3	Temperate and mediterranean-montane scrub	13	Woodland scrub
6400	S4	Temperate shrub heathland	13	Woodland scrub
6500	S5	Maquis, arborescent matorral and thermo-Mediterranean brushes	13	Woodland scrub
6600	S6	Garrigue	13	Woodland scrub
6700	S7	Spiny Mediterranean heaths (phrygana, hedgehog-heaths and related coastal cliff vegetation)	13	Woodland scrub
6800	S8	Thermo-Atlantic xerophytic scrub	13	Woodland scrub
6900	S9	Riverine and fen scrubs	13	Woodland scrub
7100	T1	Broadleaved deciduous woodland	4	Deciduous forest
7200	T2	Broadleaved evergreen woodland	12	Tropical forest
7300	T3	Coniferous woodland	5	Coniferous forest
7400	T4	Lines of trees, small anthropogenic woodlands, recently felled woodland, early-stage woodland and coppice	13	Woodland scrub

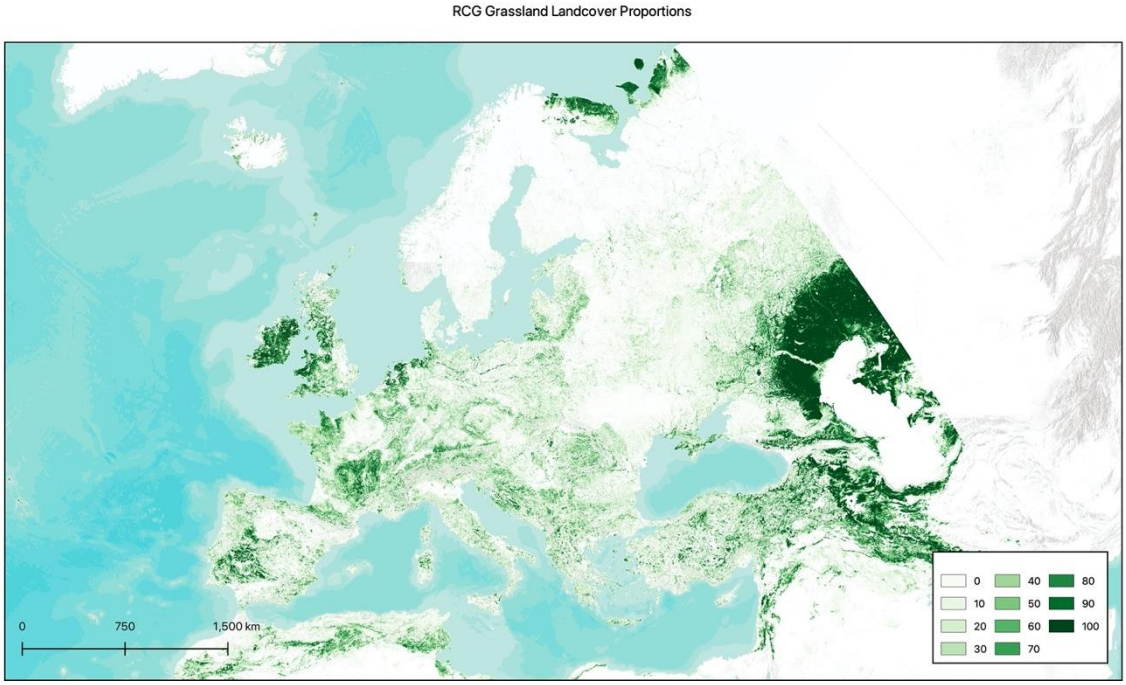
EUNIS GRID CODE	EUNIS CODE	EUNIS LABEL	RCG GRID CODE	RCG LABEL
7500	T5	Mixed deciduous and coniferous woodland	6	Mixed forest
8200	U2	Screes	9	Sand, bare rocks
8300	U3	Inland cliffs, rock pavements and outcrops	9	Sand, bare rocks
8400	U4	Snow or ice-dominated habitats	11	Permanent ice
8500	U5	Miscellaneous inland habitats with very sparse or no vegetation	9	Sand, bare rocks
9100	V1	Arable land and market gardens	2	Agriculture
9200	V2	Cultivated areas of gardens and parks	2	Agriculture
10100	J1	Buildings of cities, towns and villages	1	Urban areas
10200	J2	Low density buildings	1	Urban areas
10300	J3	Extractive industrial sites	1	Urban areas
10400	J4	Transport networks and other constructed hard-surfaced areas	1	Urban areas
10500	J5	Highly artificial man-made waters and associated structures	1	Urban areas
10600	J6	Waste deposits	1	Urban areas

Figure 38: Updated European REM- CALGRID Land Cover Map



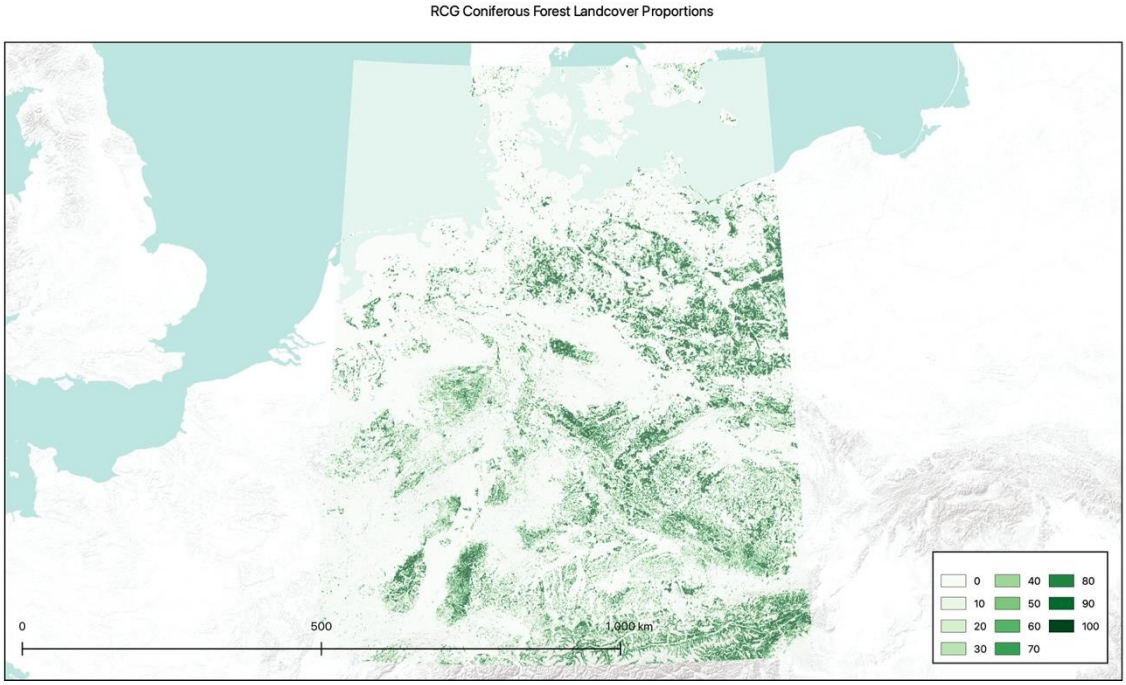
Source: own illustration, EOSS GmbH.

Figure 39: Updated European REM- CALGRID Land Cover Map. Grassland land cover proportions, European layer.



Source: own illustration, EOSS GmbH.

Figure 40: Updated European REM- CALGRID Land Cover Map. Coniferous forest land cover proportions, German layer.



Source: own illustration, EOSS GmbH.

2.6 Discussion on the derivation of an European FFH classification map based on the updated EUNIS Level 3 habitat map

Adopted in 1992, the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora aims to promote the maintenance of biodiversity, taking account of economic, social, cultural, and regional requirements (European Commission 2013). The Habitats Directive ensures the conservation of a wide range of rare, threatened, or endemic animal and plant species and about 200 rare and characteristic habitat types are targeted for conservation. The Habitats Directive requires Member States to report on the conservation status of habitats and species. An interpretation manual (European Environment Agency 2013) is provided for the interpretation of the Annex 1 habitats with common definitions for all habitat types (European Commission 2003). Annex I lists 233 European natural habitat types. Annex I was initially based on the hierarchical classification of European habitats developed by the CORINE Biotopes project since that was the only existing classification at European level.

The latest EUNIS terrestrial habitat classification system from 2021 provides crosswalks to the Annex 1 habitat types through the following relations (European Environment Agency 2021). Those relations are only assigned at EUNIS Level 3 habitat classes, no links are given to levels 1 and 2 as these are too numerous. There are 4 principal relations given summarized in the following table (Table 19).

Table 19: Relationship assignments of EUNIS Level 3 classes to Annex 1 FFH classes

Relationship	Description
=	The revised EUNIS habitat is equal to the Annex I habitat type
#	The revised EUNIS habitat overlaps with the Annex I habitat type
<	The revised EUNIS habitat is narrower than the Annex I habitat type
>	The revised EUNIS habitat is wider than the Annex I habitat type
Blank	The revised EUNIS habitat is not linked to an Annex I type or is outside EU

In order to successfully translate EUNIS Level 3 classes towards FFH Habitat types of Annex 1 the relation type must either be '=' (EUNIS habitat is equal to the Annex I habitat type) or '>' (EUNIS habitat is wider than the Annex I habitat type). Also, a direct 1:1 relation is required, meaning there is exactly one source and one target class defined in the crosswalk.

Analyzing the derived EUNIS Level 3 classes in the updated land cover map with the Annex 1 crosswalks (European Environment Agency 2021) reveals, that from the 203 distinct EUNIS Level 3 classes in the map, only 109 classes have a crosswalk definition towards Annex 1 habitats. However, for these 109 habitats, a total of 218 crosswalk relations to Annex 1 habitat classes are defined. Only 61 habitats provide a direct 1:1 relation to one of the Annex 1 habitats, while 48 do have at least 2 related Annex 1 classes. The highest number of related Annex 1 habitats for one single EUNIS Level 3 habitat class was found to be 12.

With respect of the required '=' and '>' relation types it was found that from the 218 defined crosswalks only 17 are describing the '=' relation and 83 describe '>' relations.

Summarizing up the before derived statistics one must argue that only 50% of the mapped EUNIS Level 3 classes do have a defined Annex 1 FFH habitat type relation. From those not even 50% of classes do provide a '=' or '>' relation which would allow for a direct habitat class transformation. From this one must conclude that a translation of the derived updated EUNIS Level 3 land cover (habitat) map is unlikely or even impossible to be successful.

2.7 Outlook

The updated EUNIS Land Cover Map is provided in line with the defined requirements in data format, resolution and projection. Country-wise map subsets were created to support direct usage in the Critical Loads modelling software framework.

We see, however, some obstacles that will hinder the application of the modelling software especially for the broader geographical coverage (EECCA+) of the updated Land Cover Map.

The data entry interface of the Critical Loads software requires the definition of different input data, amongst others the land cover maps for each country. The following list provides a description of the suitability and availability of each of these input datasets.

1. Soils input file

- This currently points to the current European Soil Database (ESDB) in ESRI Shapefile format but must be extended with the Harmonized World Soil Database (WSDB) to support coverage to the full geographic extent

2. SMU-STU relationship file

- This text file defines the SMU-STU relationships used in the ESDB soil map, however, this relationship is only available for ESDB and not for HWSD. Also a documentation is missing on which attributes from the ESDB are actually used.

3. GADM 3.6 countries file

- This is the Global vector database of country boundaries. It has also been used to create the country representations of the updated land cover map. A recent 4.0 version is, however, available.

4. Landuse ascii files

- Folder with land use country files as ASCII raster files of the country land cover maps. Those have been provided in this project.

5. ZDEUNIS file

- This excel file provides the mapping of EUNIS class codes to raster class codes in the land cover maps. However, this is not even covering all classes from the 'old' land cover map. There is no documentation available. On request we received an information from the authors of the modelling software but it remains unclear if and how this file is used ("Somehow I think ZDEUNIS is not needed (anymore)").

6. EFISCEN file

- This file represents a modelled forest growth vector dataset and is not covering full area. Unfortunately, there is no documentation on how this file has been produced or how it can be reproduced to include the new geographic areas.

7. N2000 file

- This is a vector dataset with borders of Natura 2000 sites. An updated version is available. The dataset only covers European countries. There is no documentation available on how this file is used during modelling.

8. Distance to Coast file

- World wide distance to coast raster dataset which is still valid.

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A Appendix 1

A.1 Target land cover map legends

Table 20: EUNIS classification scheme

The EUNIS classification scheme for levels 1 and 2

Level	Code 2018	Name 2018
1	N	Coastal habitats
2	N1	Coastal dunes and sandy shores
2	N2	Coastal shingle
2	N3	Rock cliffs, ledges and shores, including the supralittoral
1	R	Grasslands and lands dominated by forbs, mosses or lichens
2	R1	Dry grasslands
2	R2	Mesic grasslands
2	R3	Seasonally wet and wet grasslands
2	R4	Alpine and subalpine grasslands
2	R5	Forest fringes and clearings and tall forb stands
2	R6	Inland salt steppes and salt marshes
2	R7	Sparsely wooded grasslands
1	T	Forest and other wooded land
2	T1	Deciduous broadleaved forest
2	T2	Broadleaved evergreen forest
2	T3	Coniferous forest
2	T4	Lines of trees, small anthropogenic forests, recently felled forest, early-stage forest and coppice

Level	Code 2018	Name 2018
1	S	Heathland, scrub and tundra
2	S1	Tundra
2	S2	Arctic, alpine and subalpine scrub
2	S3	Temperate and mediterranean-montane scrub
2	S4	Temperate shrub heathland
2	S5	Maquis, arborescent matorral and thermo-Mediterranean scrub
2	S6	Garrigue
2	S7	Spiny Mediterranean heaths (phrygana, hedgehog-heaths and related coastal cliff vegetation)
2	S8	Thermo-Atlantic xerophytic scrub
2	S9	Riverine and fen scrubs
1	U	Inland habitats with no or little soil and mostly with sparse vegetation
2	U1	Terrestrial underground caves, cave systems, passages and waterbodies
2	U2	Screes
2	U3	Inland cliffs, rock pavements and outcrops
2	U4	Snow or ice-dominated habitats
2	U5	Miscellaneous inland habitats usually with very sparse or no vegetation
2	U6	Recent volcanic features
1	V	Vegetated man-made habitats
2	V1	Arable land and market gardens
2	V2	Cultivated areas of gardens and parks
2	V3	Artificial grasslands and herb dominated habitats

Level	Code 2018	Name 2018
2	V4	Hedgerows
2	V5	Shrub plantations
2	V6	Tree dominated man-made habitats

Table 21: REM-CalGrid classification scheme

Code	Class
1	Urban areas
2	Agriculture
3	Grassland
4	Deciduous forest
5	Coniferous forest
6	Mixed forest
7	Water
8	Marsh or wetland
9	Sand, bare rocks
10	Tundra
11	Permanent ice
12	Tropical forest
13	Woodland scrub

Table 22: FFH classification system according to Annex 1 of Directive 92/43/EEC

The FFH classification scheme for levels 1 and 2

Level	Code	Name
1	1	COASTAL AND HALOPHYTIC HABITATS
2	11	Open sea and tidal areas
2	12	Sea cliffs and shingle or stony beaches
2	13	Atlantic and continental salt marshes and salt meadows
2	14	Mediterranean and thermo-Atlantic salt marshes and salt meadows
2	15	Salt and gypsum inland steppes
2	16	Boreal Baltic archipelago, coastal and landupheaval areas
1	2	COASTAL SAND DUNES AND INLAND DUNES
2	21	Sea dunes of the Atlantic, North Sea and Baltic coasts
2	22	Sea dunes of the Mediterranean coast
2	23	Inland dunes, old and decalcified
1	3	FRESHWATER HABITATS
2	31	Standing water
2	32	Running water – sections of water courses with natural or semi-natural dynamics (minor, average and major beds) where the water quality shows no significant deterioration
1	4	TEMPERATE HEATH AND SCRUB
1	5	SCLEROPHYLLOUS SCRUB (MATORRAL)
2	51	Sub-Mediterranean and temperate scrub
2	52	Mediterranean arborescent matorral
2	53	Thermo-Mediterranean and pre-steppe brush
2	54	Phrygana
1	6	NATURAL AND SEMI-NATURAL GRASSLAND FORMATIONS
2	61	Natural grasslands
2	62	Semi-natural dry grasslands and scrubland facies
2	63	Sclerophillous grazed forests (dehesas)
2	64	Semi-natural tall-herb humid meadows

Level	Code	Name
2	65	Mesophile grasslands
1	7	RAISED BOGS AND MIRES AND FENS
2	71	Sphagnum acid bogs
2	72	Calcareous fens
2	73	Boreal mires
1	8	ROCKY HABITATS AND CAVES
2	81	Scree
2	82	Rocky slopes with chasmophytic vegetation
2	83	Other rocky habitats
1	9	FORESTS
2	90	Forests of Boreal Europe
2	91	Forests of Temperate Europe
2	91	* Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
2	92	Mediterranean deciduous forests
2	93	Mediterranean sclerophyllous forests
2	94	Temperate mountainous coniferous forests
2	95	Mediterranean and Macaronesian mountainous coniferous forests

A.2 Land cover map legends

Table 23: Harmonised European Land Cover Map Legend

Critical Loads legend including EUNIS transitions

Map Code	EUNIS Code	Label
1000	A	Marine habitats
1102	A1 or A2 without A2.5	Littoral rock and other hard substrata or Littoral sediment without Coastal saltmarshes and saline reedbeds
1250	A2.5	Coastal saltmarshes and saline reedbeds
1304	A3 or A4	Infralittoral rock and other hard substrata or Circalittoral rock and other hard substrata
1349	A3 or A4 or A5	Infralittoral rock and other hard substrata or Circalittoral rock and other hard substrata or Sublittoral rock
1500	A5	Sublittoral sediment
2000	B	Coastal habitats
3100	C1	Surface standing waters
3102	C1 or C2	Surface standing waters and surface running waters
3200	C2	Surface running waters
3300	C3	Littoral zone of inland surface waterbodies
4100	D1	Raised and blanket bogs
4204	D2 or D4	Valley mires, poor fens and transition mires or Base-rich fens and calcareous spring mires
5109	E1 without E1.2, E1.7, E1.8, E1.9, E1.A	Dry grasslands without Perrenial grasslands and basic steppes or Non-Mediterranean dry acid and neutral closed grassland or Non-Mediterranean dry acid and neutral closed grassland or Mediterranean dry acid and neutral closed grassland or Mediterranean dry acid and neutral open grassland
5120	E1.2	Perrenial grasslands and basic steppes
5179	E1.7 or E1.9	Non-Mediterranean dry acid and neutral closed grassland or Non-Mediterranean dry acid and neutral closed grassland
5189	E1.8 or E1.A	Mediterranean dry acid and neutral closed grassland or Mediterranean dry acid and neutral open grassland
5209	E2 without 2.3	Mesic grasslands without Mountain hay meadows
5230	E2.3	Mountain hay meadows
5300	E3	Seasonally wet and wet grasslands
5400	E4	Alpine and subalpine grasslands
5500	E5	Woodland fringes and clearings and tall forb stands
6100	F1	Tundra

Map Code	EUNIS Code	Label
6200	F2	Arctic, alpine and subalpine scrub
6400	F4	Temperate shrub heathland
6506	F5 or F6	Maquis, arborescent matorral and thermo-Mediterranean brushes or Garrigue
6900	F9	Riverine and fen scrubs
7100	G1	Broadleaved deciduous woodland
7101	G1.1	Riparian Salix, Alnus and Betula woodland
7106	G1.6	Fagus woodland
7200	G2	Broadleaved evergreen woodland
7201	G2.1	Mediterranean evergeeen [Quercus] woodland
7300	G3	Coniferous woodland
7301	G3.1	Abies and Picea woodland
7302	G3.2	Alpine Larix -Pinus cembra woodland
7304	G3.4	Pinus sylvestriswoodland south of the taiga
7306	G3.6	Subalpine mediterranean Pinus woodland
7400	G4	Mixed deciduous and coniferous woodland
7401	G4.1	Mixed swamp woodland
7402	G4.2	Mixed taiga woodland with Betula
7403	G4.3	Mixed subtaiga-taiga woodland with acidiphilous Quercus
7404	G4.4	Mixed Pinus sylvestris -Betula woodland
7406	G4.6	Mixed Abies -Picea -Fagus woodland
7407	G4.7	Mixed Pinus sylvestris -acidiphilous Quercus woodland
7411	G4.B	Mixed mediterranean Pinus -thermophilous Quercus woodland
7412	G4.C	Mixed Pinus sylvestris -thermophilous Quercus woodland
7414	G4.E	Mixed mediterranean pine -evergreen oak woodland
8000	H	Inland vegetated or sparsely vegetated habitats
8300	H3	Inland cliffs, rock pavements and outcrops
8400	H4	Snow or ice-dominated habitats

Map Code	EUNIS Code	Label
8500	H5	Miscellaneous inland habitats with very sparse or no vegetation
9100	II	Irrigated arable land
9200	IN	Non-irrigated arable land
10000	J	Constructed, industrial and other artificial habitats

Table 24: CORINE Land Cover Legend

CLC legend at three levels including raster representation grid code

Map Code	CLC_CODE1	LABEL1	CLC_CODE2	LABEL2	CLC_CODE3	LABEL3
1	1.	Artificial surfaces	1.1.	Urban fabric	1.1.1.	Continuous urban fabric
2	1.	Artificial surfaces	1.1.	Urban fabric	1.1.2.	Discontinuous urban fabric
3	1.	Artificial surfaces	1.2.	Industrial, commercial and transport units	1.2.1.	Industrial or commercial units
4	1.	Artificial surfaces	1.2.	Industrial, commercial and transport units	1.2.2.	Road and rail networks and associated land
5	1.	Artificial surfaces	1.2.	Industrial, commercial and transport units	1.2.3.	Port areas
6	1.	Artificial surfaces	1.2.	Industrial, commercial and transport units	1.2.4.	Airports
7	1.	Artificial surfaces	1.3.	Mine, dump and construction sites	1.3.1.	Mineral extraction sites
8	1.	Artificial surfaces	1.3.	Mine, dump and construction sites	1.3.2.	Dump sites
9	1.	Artificial surfaces	1.3.	Mine, dump and construction sites	1.3.3.	Construction sites
10	1.	Artificial surfaces	1.4.	Artificial, non-agricultural vegetated areas	1.4.1.	Green urban areas
11	1.	Artificial surfaces	1.4.	Artificial, non-agricultural vegetated areas	1.4.2.	Sport and leisure facilities
12	2.	Agricultural areas	2.1.	Arable land	2.1.1.	Non-irrigated arable land
13	2.	Agricultural areas	2.1.	Arable land	2.1.2.	Permanently irrigated land
14	2.	Agricultural areas	2.1.	Arable land	2.1.3.	Rice fields
15	2.	Agricultural areas	2.2.	Permanent crops	2.2.1.	Vineyards
16	2.	Agricultural areas	2.2.	Permanent crops	2.2.2.	Fruit trees and berry plantations
17	2.	Agricultural areas	2.2.	Permanent crops	2.2.3.	Olive groves
18	2.	Agricultural areas	2.3.	Pastures	2.3.1.	Pastures
19	2.	Agricultural areas	2.4.	Heterogeneous agricultural areas	2.4.1.	Annual crops associated with permanent crops

Map Code	CLC_CODE1	LABEL1	CLC_CODE2	LABEL2	CLC_CODE3	LABEL3
20	2.	Agricultural areas	2.4.	Heterogeneous agricultural areas	2.4.2.	Complex cultivation patterns
21	2.	Agricultural areas	2.4.	Heterogeneous agricultural areas	2.4.3.	Land principally occupied by agriculture, with significant areas of natural vegetation
22	2.	Agricultural areas	2.4.	Heterogeneous agricultural areas	2.4.4.	Agro-forestry areas
23	3.	Forest and semi natural areas	3.1.	Forests	3.1.1.	Broad-leaved forest
24	3.	Forest and semi natural areas	3.1.	Forests	3.1.2.	Coniferous forest
25	3.	Forest and semi natural areas	3.1.	Forests	3.1.3.	Mixed forest
26	3.	Forest and semi natural areas	3.2.	Scrub and/or herbaceous vegetation associations	3.2.1.	Natural grasslands
27	3.	Forest and semi natural areas	3.2.	Scrub and/or herbaceous vegetation associations	3.2.2.	Moors and heathland
28	3.	Forest and semi natural areas	3.2.	Scrub and/or herbaceous vegetation associations	3.2.3.	Sclerophyllous vegetation
29	3.	Forest and semi natural areas	3.2.	Scrub and/or herbaceous vegetation associations	3.2.4.	Transitional woodland-shrub
30	3.	Forest and semi natural areas	3.3.	Open spaces with little or no vegetation	3.3.1.	Beaches, dunes, sands
31	3.	Forest and semi natural areas	3.3.	Open spaces with little or no vegetation	3.3.2.	Bare rocks
32	3.	Forest and semi natural areas	3.3.	Open spaces with little or no vegetation	3.3.3.	Sparsely vegetated areas
33	3.	Forest and semi natural areas	3.3.	Open spaces with little or no vegetation	3.3.4.	Burnt areas
34	3.	Forest and semi natural areas	3.3.	Open spaces with little or no vegetation	3.3.5.	Glaciers and perpetual snow
35	4.	Wetlands	4.1.	Inland wetlands	4.1.1.	Inland marshes
36	4.	Wetlands	4.1.	Inland wetlands	4.1.2.	Peat bogs
37	4.	Wetlands	4.2.	Maritime wetlands	4.2.1.	Salt marshes
38	4.	Wetlands	4.2.	Maritime wetlands	4.2.2.	Salines
39	4.	Wetlands	4.2.	Maritime wetlands	4.2.3.	Intertidal flats
40	5.	Water bodies	5.1.	Inland waters	5.1.1.	Water courses
41	5.	Water bodies	5.1.	Inland waters	5.1.2.	Water bodies
42	5.	Water bodies	5.2.	Marine waters	5.2.1.	Coastal lagoons
43	5.	Water bodies	5.2.	Marine waters	5.2.2.	Estuaries
44	5.	Water bodies	5.2.	Marine waters	5.2.3.	Sea and ocean

Table 25: EEA Ecosystem Type Map Legend for terrestrial classes

Value	EUNIS	EUNIS_L2	EUNIS_L1
9	X1	Estuaries	A - Marine habitats
10	X2_3	Coastal lagoons	A - Marine habitats
11	B1	Coastal dunes and sandy shores	B - Coastal habitats
12	B2	Coastal shingle	B - Coastal habitats
13	B3	Rock cliffs, ledges and shores, including the supralittoral	B - Coastal habitats
14	C1	Surface standing waters	C - Inland surface waters
15	C2	Surface running waters	C - Inland surface waters
16	C3	Littoral zone of inland surface waterbodies	C - Inland surface waters
17	D1	Raised and blanket bogs	D - Mires, bogs and fens
18	D2	Valley mires, poor fens and transition mires	D - Mires, bogs and fens
19	D3	Aapa, palsa and polygon mires	D - Mires, bogs and fens
20	D4	Base-rich fens and calcareous spring mires	D - Mires, bogs and fens
21	D5	Sedge and reedbeds, normally without free-standing water	D - Mires, bogs and fens
22	D6	Inland saline and brackish marshes and reedbeds	D - Mires, bogs and fens
23	E1	Dry grasslands	E - Grasslands and land dominated by forbs, mosses or lichens
24	E2	Mesic grasslands	E - Grasslands and land dominated by forbs, mosses or lichens
25	E3	Seasonally wet and wet grasslands	E - Grasslands and land dominated by forbs, mosses or lichens
26	E4	Alpine and subalpine grasslands	E - Grasslands and land dominated by forbs, mosses or lichens
28	E6	Inland salt steppes	E - Grasslands and land dominated by forbs, mosses or lichens
29	E7	Sparsely wooded grasslands	E - Grasslands and land dominated by forbs, mosses or lichens
30	F1	Tundra	F - Heathland, scrub and tundra
31	F2	Arctic, alpine and subalpine scrub	F - Heathland, scrub and tundra
32	F3	Temperate and mediterranean-montane scrub	F - Heathland, scrub and tundra
33	F4	Temperate shrub heathland	F - Heathland, scrub and tundra
34	F5	Maquis, arborescent matorral and thermo-Mediterranean brushes	F - Heathland, scrub and tundra

Value	EUNIS	EUNIS_L2	EUNIS_L1
35	F6	Garrigue	F - Heathland, scrub and tundra
36	F7	Spiny Mediterranean heaths (phrygana, hedgehog-heaths and related coastal cliff vegetation)	F - Heathland, scrub and tundra
37	F8	Thermo-Atlantic xerophytic scrub	F - Heathland, scrub and tundra
38	F9	Riverine and fen scrubs	F - Heathland, scrub and tundra
40	FB	Shrub plantations	F - Heathland, scrub and tundra
41	G1	Broadleaved deciduous woodland	G - Woodland, forest and other wooded land
42	G2	Broadleaved evergreen woodland	G - Woodland, forest and other wooded land
43	G3	Coniferous woodland	G - Woodland, forest and other wooded land
44	G4	Mixed deciduous and coniferous woodland	G - Woodland, forest and other wooded land
45	G5	Lines of trees, small anthropogenic woodlands, recently felled woodland, early-stage woodland and coppice	G - Woodland, forest and other wooded land
47	H2	Screes	H - Inland unvegetated or sparsely vegetated habitats
48	H3	Inland cliffs, rock pavements and outcrops	H - Inland unvegetated or sparsely vegetated habitats
49	H4	Snow or ice-dominated habitats	H - Inland unvegetated or sparsely vegetated habitats
50	H5	Miscellaneous inland habitats with very sparse or no vegetation	H - Inland unvegetated or sparsely vegetated habitats
52	I1	Arable land and market gardens	I - Arable land and market gardens
53	I2	Cultivated areas of gardens and parks	I - Arable land and market gardens
54	J1	Buildings of cities, towns and villages	J - constructed, industrial and other artificial habitats
55	J2	Low density buildings	J - constructed, industrial and other artificial habitats
56	J3	Extractive industrial sites	J - constructed, industrial and other artificial habitats
57	J4	Transport networks and other constructed hard-surfaced areas	J - constructed, industrial and other artificial habitats
58	J5	Highly artificial man-made waters and associated structures	J - constructed, industrial and other artificial habitats
59	J6	Waste deposits	J - constructed, industrial and other artificial habitats

Table 26: Copernicus Global Land Cover Legend

Map code	Land Cover Class
0	No input data available
111	Closed forest, evergreen needle leaf
113	Closed forest, deciduous needle leaf
112	Closed forest, evergreen, broad leaf
114	Closed forest, deciduous broad leaf
115	Closed forest, mixed
116	Closed forest, unknown
121	Open forest, evergreen needle leaf
123	Open forest, deciduous needle leaf
122	Open forest, evergreen broad leaf
124	Open forest, deciduous broad leaf
125	Open forest, mixed
126	Open forest, unknown
20	Shrubs
30	Herbaceous vegetation
90	Herbaceous wetland
100	Moss and lichen
60	Bare / sparse vegetation
40	Cultivated and managed vegetation/agriculture
50	Urban / built up

Map code	Land Cover Class
70	Snow and Ice
80	Permanent water bodies
200	Open sea

Table 27: ESA World Cover Legend

Map code	Land Cover Class
10	Tree cover
20	Shrubland
30	Grassland
40	Cropland
50	Built-up
60	Bare / sparse vegetation
70	Snow and Ice
80	Permanent water bodies
90	Herbaceous wetland
95	Mangroves
100	Moss and lichen

Table 28: NGCC GlobeLand 30 Legend

Map Code	Landcover Class
10	Cultivated land
20	Forest

Map Code	Landcover Class
30	Grassland
40	Shrubland
50	Wetland
60	Water bodies
70	Tundra
80	Artificial Surfaces
90	Bare Land
100	Permanent snow and ice

Table 29: CCI Annual Global Land Cover Time Series 1992 to 2015 Legend

Map Code	Landcover Class
0	No Data
10	Cropland, rainfed
20	Cropland, irrigated or post-flooding
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)
50	Tree cover, broadleaved, evergreen, closed to open (>15%)
60	Tree cover, broadleaved, deciduous, closed to open (>15%)
70	Tree cover, needleleaved, evergreen, closed to open (>15%)
80	Tree cover, needleleaved, deciduous, closed to open (>15%)
90	Tree cover, mixed leaf type (broadleaved and needleleaved)

Map Code	Landcover Class
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)
120	Shrubland
130	Grassland
140	Lichens and mosses
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)
160	Tree cover, flooded, fresh or brakish water
170	Tree cover, flooded, saline water
180	Shrub or herbaceous cover, flooded, fresh/saline/brakish water
190	Urban areas
200	Bare areas
210	Water bodies
220	Permanent snow and ice

Table 30: ESRI Land Cover Legend

Map Code	Landcover Class
1	Water
2	Trees
3	Grass
4	Flooded vegetation
5	Crops

Map Code	Landcover Class
6	Scrub/shrub
7	Built Area
8	Bare ground
9	Snow/Ice
10	Clouds

Table 31: CEC North American Land Change Monitoring System Legend

Map Code	Land Cover Class
1	Temperate or sub-polar needleleaf forest
2	Sub-polar taiga needleleaf forest
3	Tropical or sub-tropical broadleaf evergreen forest
4	Tropical or sub-tropical broadleaf deciduous forest
5	Temperate or sub-polar broadleaf deciduous forest
6	Mixed forest
7	Tropical or sub-tropical shrubland
8	Temperate or sub-polar shrubland
9	Tropical or sub-tropical grassland
10	Temperate or sub-polar grassland
11	Sub-polar or polar shrubland-lichen-moss
12	Sub-polar or polar grassland-lichen-moss
13	Sub-polar or polar barren-lichen-moss
14	Wetland

Map Code	Land Cover Class
15	Cropland
16	Barren lands
17	Urban
18	Water
19	Snow and Ice

Table 32: MRLC National Land Cover Database Legend

Map Code	Land Cover Class
11	Open Water
12	Perennial Ice/Snow
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed High Intensity
31	Barren Land (Rock/Sand/Clay)
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
51	Dwarf Scrub
52	Shrub/Scrub
71	Grassland/Herbaceous

Map Code	Land Cover Class
72	Sedge/Herbaceous
73	Lichens
74	Moss
81	Pasture/Hay
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

Table 33: Potential natural vegetation global BIOMEs

Adopted from (Hengl et al. 2018)

Number	New.global.consolidated.BIOME.scheme	Mega_BIOME_classification
1	tropical evergreen broadleaf forest	tropical forest
2	tropical semi-evergreen broadleaf forest	tropical forest
3	tropical deciduous broadleaf forest and woodland	tropical forest
4	warm-temperate evergreen and mixed forest	warm-temperate forest
7	cool-temperate rainforest	warm-temperate forest
8	cool evergreen needleleaf forest	temperate forest
9	cool mixed forest	temperate forest
13	temperate deciduous broadleaf forest	temperate forest
14	cold deciduous forest	boreal forest
15	cold evergreen needleleaf forest	boreal forest
16	temperate sclerophyll woodland and shrubland	savanna and dry woodland

Number	New.global.consolidated.BIOME.scheme	Mega_BIOME_classification
17	temperate evergreen needleleaf open woodland	savanna and dry woodland
18	tropical savanna	savanna and dry woodland
20	xerophytic woods/scrub	grassland and dry shrubland
22	steppe	grassland and dry shrubland
27	desert	desert
28	graminoid and forb tundra	dry tundra
30	erect dwarf shrub tundra	tundra
31	low and high shrub tundra	tundra
32	prostrate dwarf shrub tundra	tundra

A.3 Classification Scheme Translations

Table 34: CLC/EUNIS mapping ruleset applied to ETM v3.1 map

Adopted from (Weiss and Banko 2018)

CLC Code	CLC-Class name	Comment on mapping rules/Priority	Exclude	Final EUNIS code
111	Continuous urban fabric	J1		J1
112	Discontinuous urban fabric	1. J2 if soil sealing <= 30		J2
112	Discontinuous urban fabric	2. J1 = rest		J1
121	Industrial or commercial units	1. J2 if soil sealing <= 50		J2
121	Industrial or commercial units	2. J1 = rest		J1
122	Road and rail networks and associated land	J4		J4
123	Port areas	J4		J4

CLC Code	CLC-Class name	Comment on mapping rules/Priority	Exclude	Final EUNIS code
124	Airports	J4		J4
131	Mineral extraction sites	J3	J2, H3	J3
132	Dump sites	J6		J6
133	Construction sites	J2		J2
141	Green urban areas	I2	E2	I2
142	Sport and leisure facilities	I2	E2	I2
211	Non-irrigated arable land	I1		I1
212	Permanently irrigated land	I1		I1
213	Rice fields	I1		I1
221	Vineyards	FB		FB
222	Fruit trees and berry plantations	FB	G1, G2	FB
223	Olive groves	G2		G2
231	Pastures	1. E4 in subalpine	E1	E4
231	Pastures	2. B1 in potNatVeg = coastal AND dist_coast < 500	E1	B1
231	Pastures	3. E7 in potNatVeg = 9+10 AND forest>10%	E1	E7
231	Pastures	4. E3 on wet soils	E1	E3
231	Pastures	5. E2 = rest	E1	E2
241	Annual crops associated with permanent crops	I1		I1
242	Complex cultivation patterns	1. I1 if HANTS mixed agriculture = arable	E2, I2	I1
242	Complex cultivation patterns	2. E2 = rest	E2, I2	E2

CLC Code	CLC-Class name	Comment on mapping rules/Priority	Exclude	Final EUNIS code
243	Land principally occ. by agr., with sign. areas of nat. veg.	1. E2 if HANTS mixed agriculture = grassland		E2
243	Land principally occ. by agr., with sign. areas of nat. veg.	2. I1 = rest		I1
244	Agro-forestry areas	E7		E7
311	Broad-leaved forest	1. G2 in potNatVeg = 10 AND HANTS = evergreen	B1	G2
311	Broad-leaved forest	2. G1 = rest	B1	G1
312	Coniferous forest	G3	B1	G3
313	Mixed forest	G4		G4
321	Natural grassland	1. E4 in subalpine	E2	E4
321	Natural grassland	2. E3 on wet soils	E2	E3
321	Natural grassland	3. E6 in Art.17	E2	E6
321	Natural grassland	4. E1=rest	E2	E1
322	Moors and heathland	1. F2 in subalpine		F2
322	Moors and heathland	2. F9 in JRC riparian > 10%		F9
322	Moors and heathland	3. F3 in Art. 17		F3
322	Moors and heathland	4. F4 in Art. 17 AND potNatVeg=14 AND Soil_acid = 1		F4
322	Moors and heathland	5. F1 in potNatVeg1213		F1
322	Moors and heathland	6. F1 in ecoreg = 1		F1
322	Moors and heathland	7. F3b = rest		F3
323	Sclerophyllous vegetation	1. F8 in Macaronesia		F8

CLC Code	CLC-Class name	Comment on mapping rules/Priority	Exclude	Final EUNIS code
323	Sclerophyllous vegetation	2. F6 in Art. 17 in MED		F6
323	Sclerophyllous vegetation	3. F7 in Art. 17 in MED		F7
323	Sclerophyllous vegetation	4. F5 in Art. 17 in MED		F5
323	Sclerophyllous vegetation	5. B1 in coast < 500		B1
323	Sclerophyllous vegetation	6. F5b = rest		F5
324	Transitional woodland shrub	G5	E1, E5	G5
331	Beaches, dunes, and sand plains	1. B1 in Art17_b1b2 AND potNatVeg = 1	E1, F3, F4	B1
331	Beaches, dunes, and sand plains	2. B2 in Art17_b1b2 AND dist_coast <500m	E1, F3, F4	B2
331	Beaches, dunes, and sand plains	3. B1 in Art17_b1 AND dist_coast <500m	E1, F3, F4	B1
331	Beaches, dunes, and sand plains	4. B2 in Art17_b2 AND dist_coast <500m	E1, F3, F4	B2
331	Beaches, dunes, and sand plains	5. C3 in JRC_riparian	E1, F3, F4	C3
331	Beaches, dunes, and sand plains	6. H2 = rest	E1, F3, F4	H2
332	Bare rock	1. B3 in Art.17 AND dist_coast <500m		B3
332	Bare rock	2. B3b adjacent to coast_rocks AND dist_coast <500m		B3
332	Bare rock	3. rest = H3		H3
333	Sparsely vegetated areas	1. F2 in potNatVeg = 13 (arctic)	H6	F2
333	Sparsely vegetated areas	2. F2b in subalpine	H6	F2

CLC Code	CLC-Class name	Comment on mapping rules/Priority	Exclude	Final EUNIS code
333	Sparsely vegetated areas	3. F1 in potNatVeg = 12 (polar mountains)	H6	F1
333	Sparsely vegetated areas	4. H3 in slope_degree >= 15	H6	H3
333	Sparsely vegetated areas	5. rest = H5	H6	H5
334	Burnt areas	H5		H5
335	Glaciers and perpetual snow	H4		H4
411	Inland marshes	1. D5 in Art. 17	C2, C3, D6	D5
411	Inland marshes	2. D2 in Art 17, but not D4	C2, C3, D6	D2
411	Inland marshes	3. D4 in Art. 17 but not D2	C2, C3, D6	D4
411	Inland marshes	4. D4b, if Art17 = D4 AND soil=calcareous	C2, C3, D6	D4
411	Inland marshes	5. D2b, if Art17 D2	C2, C3, D6	D2
411	Inland marshes	6. C3 around lakes	C2, C3, D6	C3
411	Inland marshes	7. D5b = rest	C2, C3, D6	D5
412	Peatbogs	1. D3 in Art.17		D3
412	Peatbogs	2. D1 in Art. 17		D1
412	Peatbogs	3. D3b in ecoregNorth		D3
412	Peatbogs	4. D1b = rest		D1
421	Salt marshes	only D6 when inland!	E6	D6
422	Salines	J5		J5
423	Intertidal flats	not selected for terrestrial part of ETM (covered by marine part)	A2	A1
511	Water courses	1. J5 in WFD = artificial		J5

CLC Code	CLC-Class name	Comment on mapping rules/Priority	Exclude	Final EUNIS code
511	Water courses	2. C2 = rest		C2
512	Water bodies	1. J5 in WFD = artificial		J5
512	Water bodies	2. C1 = rest		C1
521	Coastal lagoons	X2_3		X2_3
522	Estuaries	X1		X1
523	Sea and ocean	not selected for terrestrial part of ETM (covered by marine part)		

B Appendix 2

B.1 Accuracy Assessment of EUNIS Level 3 Land Cover Classes

Table 35: Calculated Producers and Users accuracies for the EUNIS Level 3 classes derived from random stratified sampling of 40% of EVA samples not used for model training

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
C11b	3102	Permanent oligotrophic lakes, ponds and pools	C1_3100_faparBIOME	63.7%	81.7%
C12b	3104	Permanent mesotrophic lakes, ponds and pools	C1_3100_faparBIOME	98.0%	90.6%
C15	3106	Permanent inland saline and brackish lakes, ponds and pools	C1_3100_faparBIOME	33.1%	79.1%
C16b	3107	Temporary lakes, ponds and pools	C1_3100_faparBIOME	73.4%	86.8%
C21a	3201	Springs, spring brooks and geysers a	C2_3200_faparBIOME	84.4%	80.8%
C21b	3202	Springs, spring brooks and geysers b	C2_3200_faparBIOME	27.3%	100.0%
C22a	3203	Permanent non-tidal, fast, turbulent watercourses a	C2_3200_faparBIOME	57.2%	71.5%
C22b	3204	Permanent non-tidal, fast, turbulent watercourses b	C2_3200_faparBIOME	51.0%	67.8%
C23	3205	Permanent non-tidal, smooth-flowing watercourses	C2_3200_faparBIOME	94.2%	86.4%
C24	3206	Tidal rivers, upstream from the estuary	C2_3200_faparBIOME	31.9%	69.2%
C25a	3207	Temporary running waters	C2_3200_faparBIOME	14.3%	50.0%
C35a	3301	Periodically inundated shores with pioneer and ephemeral vegetation a	C3_3300_faparBIOME	72.3%	74.1%
C35c	3303	Periodically inundated shores with pioneer and ephemeral vegetation c	C3_3300_faparBIOME	65.5%	77.8%
C35d	3304	Periodically inundated shores with pioneer and ephemeral vegetation d	C3_3300_faparBIOME	85.0%	93.3%
C35e	3305	Periodically inundated shores with pioneer and ephemeral vegetation e	C3_3300_faparBIOME	57.3%	78.0%
N11	2101	Atlantic, Baltic and Arctic sand beach	N1_2100_faparBIOME	15.8%	50.0%
N12	2102	Mediterranean and Black Sea sand beach	N1_2100_faparBIOME	13.3%	44.1%
N13	2103	Atlantic and Baltic shifting coastal dune	N1_2100_faparBIOME	46.6%	65.7%
N14	2104	Mediterranean, Macaronesian and Black Sea shifting coastal dune	N1_2100_faparBIOME	86.6%	36.1%
N15	2105	Atlantic and Baltic coastal dune grassland (grey dune)	N1_2100_faparBIOME	27.9%	54.1%
N16	2106	Mediterranean and Macaronesian coastal dune grassland (grey dune)	N1_2100_faparBIOME	30.2%	66.1%
N17	2107	Black Sea coastal dune grassland (grey dune)	N1_2100_faparBIOME	56.8%	82.4%
N1A	2110	Atlantic and Baltic coastal dune scrub	N1_2100_faparBIOME	53.4%	56.3%

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
N1B	2111	Mediterranean and Black Sea coastal dune scrub	N1_2100_faparBIOME	27.8%	53.7%
N1C	2112	Macaronesian coastal dune scrub	N1_2100_faparBIOME	32.1%	90.0%
N1D	2113	Atlantic and Baltic broad-leaved coastal dune forest	N1_2100_faparBIOME	46.5%	57.8%
N1G	2116	Mediterranean coniferous coastal dune forest	N1_2100_faparBIOME	48.7%	72.5%
N1H	2117	Atlantic and Baltic moist and wet dune slack	N1_2100_faparBIOME	70.8%	72.9%
N1J	2118	Mediterranean and Black Sea moist and wet dune slack	N1_2100_faparBIOME	60.2%	59.1%
N21	2201	Atlantic, Baltic and Arctic coastal shingle beach	N2_2200_faparBIOME	100.0%	93.0%
N22	2202	Mediterranean and Black Sea coastal shingle beach	N2_2200_faparBIOME	48.4%	100.0%
N32	2302	Mediterranean and Black Sea rocky sea cliff and shore	N3_2300_faparBIOME	99.4%	74.1%
N33	2303	Macaronesian rocky sea cliff and shore	N3_2300_faparBIOME	73.9%	100.0%
N35	2305	Mediterranean and Black Sea soft sea cliff	N3_2300_faparBIOME	37.5%	85.7%
Q11	4101	Raised bogs	Q1_4100_faparBIOME	98.5%	98.8%
Q12	4102	Blanket bogs	Q1_4100_faparBIOME	95.9%	95.0%
Q22	4202	Poor fens and soft-water spring mires	Q2_4200_faparBIOME	55.7%	59.9%
Q23	4203	Apennine acidic fens	Q2_4200_faparBIOME	63.8%	71.4%
Q24	4204	Intermediate fen and soft-water spring mire	Q2_4200_faparBIOME	70.9%	67.3%
Q25	4205	Non-calcareous quaking mire	Q2_4200_faparBIOME	68.1%	68.8%
Q41	4401	Alkaline, calcareous, carbonate-rich small-sedge spring fen	Q4_4400_faparBIOME	78.0%	63.9%
Q42	4402	Extremely rich moss-sedge fen	Q4_4400_faparBIOME	64.3%	68.2%
Q44	4404	Calcareous quaking mire	Q4_4400_faparBIOME	52.2%	63.1%
Q45	4405	Arctic-alpine rich fen	Q4_4400_faparBIOME	69.2%	72.5%
Q51	4501	Tall-helophyte bed	Q5_4500_faparBIOME	80.2%	65.5%
Q52	4502	Small-helophyte bed	Q5_4500_faparBIOME	50.6%	62.9%
Q53	4503	Tall-sedge bed	Q5_4500_faparBIOME	34.0%	50.6%
Q54	4504	Inland saline or brackish helophyte bed	Q5_4500_faparBIOME	47.4%	79.3%
R11	5101	Pannonian and Pontic sandy steppe	R1_5100_faparBIOME	62.5%	80.3%
R12	5102	Cryptogam- and annual-dominated vegetation on siliceous rock outcrops	R1_5100_faparBIOME	23.5%	53.8%
R13	5103	Cryptogam- and annual-dominated vegetation on calcareous and ultramafic rock outcrops	R1_5100_faparBIOME	33.0%	54.1%

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
R15	5105	Continental dry rocky steppic grassland and dwarf scrub on chalk outcrops	R1_5100_faparBIOME	60.9%	62.0%
R16	5106	Perennial rocky grassland of Central and South-Eastern Europe	R1_5100_faparBIOME	58.3%	67.4%
R18	5108	Perennial rocky calcareous grassland of subatlantic-submediterranean Europe	R1_5100_faparBIOME	48.0%	59.7%
R19	5109	Dry steppic submediterranean pasture of the Amphi-Adriatic region	R1_5100_faparBIOME	42.3%	74.4%
R1A	5110	Semi-dry perennial calcareous grassland (meadow steppe)	R1_5100_faparBIOME	86.5%	71.6%
R1B	5111	Continental dry grassland (true steppe)	R1_5100_faparBIOME	71.0%	75.8%
R1C	5112	Desert steppe	R1_5100_faparBIOME	64.0%	70.9%
R1D	5113	Mediterranean closely grazed dry grassland	R1_5100_faparBIOME	36.0%	52.8%
R1E	5114	Mediterranean tall perennial dry grassland	R1_5100_faparBIOME	71.6%	72.9%
R1F	5115	Mediterranean annual-rich dry grassland	R1_5100_faparBIOME	47.8%	64.6%
R1G	5116	Iberian oromediterranean siliceous dry grassland	R1_5100_faparBIOME	88.5%	81.8%
R1H	5117	Iberian oromediterranean basiphilous dry grassland	R1_5100_faparBIOME	67.6%	63.7%
R1J	5118	Cyrno-Sardean oromediterranean siliceous dry grassland	R1_5100_faparBIOME	94.3%	86.8%
R1K	5119	Balkan and Anatolian oromediterranean dry grassland	R1_5100_faparBIOME	55.4%	93.9%
R1M	5121	Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta	R1_5100_faparBIOME	44.4%	83.3%
R1N	5122	Open Iberian supramediterranean dry acid and neutral grassland	R1_5100_faparBIOME	37.7%	43.4%
R1P	5123	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils	R1_5100_faparBIOME	52.9%	64.4%
R1Q	5124	Inland sanddrift and dune with siliceous grassland	R1_5100_faparBIOME	42.2%	64.7%
R1R	5125	Mediterranean to Atlantic open, dry, acid and neutral grassland	R1_5100_faparBIOME	64.3%	69.1%
R21	5201	Mesic permanent pasture of lowlands and mountains	R2_5200_faparBIOME	49.0%	68.5%
R22	5202	Low and medium altitude hay meadow	R2_5200_faparBIOME	90.0%	79.4%
R23	5203	Mountain hay meadow	R2_5200_faparBIOME	65.9%	77.6%
R24	5204	Iberian summer pasture (vallicar)	R2_5200_faparBIOME	60.9%	71.2%
R31	5301	Mediterranean tall humid inland grassland	R3_5300_faparBIOME	72.0%	74.1%
R32	5302	Mediterranean short moist grassland of lowlands	R3_5300_faparBIOME	43.4%	62.2%
R33	5303	Mediterranean short moist grassland of mountains	R3_5300_faparBIOME	80.0%	83.7%
R34	5304	Submediterranean moist meadow	R3_5300_faparBIOME	82.9%	88.4%

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
R35	5305	Moist or wet mesotrophic to eutrophic hay meadow	R3_5300_faparBIOME	81.4%	75.6%
R36	5306	Moist or wet mesotrophic to eutrophic pasture	R3_5300_faparBIOME	67.4%	69.1%
R37	5307	Temperate and boreal moist or wet oligotrophic grassland	R3_5300_faparBIOME	58.6%	68.3%
R41	5401	Snow-bed vegetation	R4_5400_faparBIOME	27.3%	52.9%
R42	5402	Boreal and arctic acidophilous alpine grassland	R4_5400_faparBIOME	89.9%	84.5%
R43	5403	Temperate acidophilous alpine grassland	R4_5400_faparBIOME	91.4%	83.0%
R44	5404	Arctic-alpine calcareous grassland	R4_5400_faparBIOME	73.6%	79.8%
R45	5405	Alpine and subalpine calcareous grassland of the Balkans and Apennines	R4_5400_faparBIOME	71.2%	78.9%
R51	5501	Thermophilous forest fringe of base-rich soils	R5_5500_faparBIOME	33.8%	76.4%
R53	5503	Macaronesian thermophilous forest fringe	R5_5500_faparBIOME	77.8%	87.5%
R54	5504	Pteridium aquilinum vegetation	R5_5500_faparBIOME	48.5%	75.8%
R55	5505	Lowland moist or wet tall-herb and fern fringe	R5_5500_faparBIOME	95.1%	80.2%
R56	5506	Montane to subalpine moist or wet tall-herb and fern fringe	R5_5500_faparBIOME	79.3%	81.9%
R57	5507	Herbaceous forest clearing vegetation	R5_5500_faparBIOME	23.2%	60.3%
R61	5601	Mediterranean inland salt steppe	R6_5600_faparBIOME	96.5%	94.8%
R62	5602	Continental inland salt steppe	R6_5600_faparBIOME	84.7%	78.1%
R63	5603	Temperate inland salt marsh	R6_5600_faparBIOME	74.3%	82.4%
R64	5604	Semi-desert salt pan	R6_5600_faparBIOME	71.9%	68.3%
R65	5605	Continental subsaline alluvial pasture and meadow	R6_5600_faparBIOME	39.4%	76.5%
S11	6101	Shrub tundra	S1_6100_faparBIOME	100.0%	96.9%
S12	6102	Moss and lichen tundra	S1_6100_faparBIOME	6.7%	100.0%
S21	6201	Subarctic and alpine dwarf Salix scrub	S2_6200_faparBIOME	60.6%	73.3%
S22	6202	Alpine and subalpine ericoid heath	S2_6200_faparBIOME	85.9%	71.1%
S23	6203	Alpine and subalpine Juniperus scrub	S2_6200_faparBIOME	54.2%	67.4%
S25	6205	Subalpine and subarctic deciduous scrub	S2_6200_faparBIOME	47.0%	67.7%
S26	6206	Subalpine Pinus mugo scrub	S2_6200_faparBIOME	57.9%	73.5%
S31	6301	Lowland to montane temperate and submediterranean Juniperus scrub	S3_6300_faparBIOME	63.8%	78.2%
S32	6302	Temperate Rubus scrub	S3_6300_faparBIOME	57.4%	67.8%

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
S33	6303	Lowland to montane temperate and submediterranean genistoid scrub	S3_6300_faparBIOME	72.4%	77.1%
S34	6304	Balkan-Anatolian submontane genistoid scrub	S3_6300_faparBIOME	85.9%	91.7%
S35	6305	Temperate and submediterranean thorn scrub	S3_6300_faparBIOME	83.7%	64.6%
S36	6306	Low steppic scrub	S3_6300_faparBIOME	73.1%	81.1%
S37	6307	Corylus avellana scrub	S3_6300_faparBIOME	49.6%	70.1%
S38	6308	Temperate forest clearing scrub	S3_6300_faparBIOME	41.4%	75.9%
S41	6401	Wet heath	S4_6400_faparBIOME	60.5%	82.4%
S42	6402	Dry heath	S4_6400_faparBIOME	95.5%	87.3%
S51	6501	Mediterranean maquis and arborescent matorral	S5_6500_faparBIOME	95.2%	85.0%
S52	6502	Submediterranean pseudomaquis	S5_6500_faparBIOME	72.3%	76.7%
S53	6503	Spartium junceum scrub	S5_6500_faparBIOME	36.3%	77.1%
S54	6504	Thermomediterranean arid scrub	S5_6500_faparBIOME	29.7%	74.2%
S61	6601	Western basiphilous garrigue	S6_6600_faparBIOME	95.2%	89.1%
S62	6602	Western acidophilous garrigue	S6_6600_faparBIOME	56.9%	97.1%
S63	6603	Eastern garrigue	S6_6600_faparBIOME	94.7%	76.1%
S64	6604	Macaronesian garrigue	S6_6600_faparBIOME	80.0%	87.5%
S65	6605	Mediterranean gypsum scrub	S6_6600_faparBIOME	51.4%	86.4%
S66	6606	Mediterranean halo-nitrophilous scrub	S6_6600_faparBIOME	48.8%	79.6%
S67	6607	Aralo-Caspian semi-desert	S6_6600_faparBIOME	87.2%	95.3%
S68	6608	Semi-desert sand dune with sparse scrub	S6_6600_faparBIOME	81.8%	94.7%
S71	6701	Western Mediterranean spiny heath	S7_6700_faparBIOME	90.4%	79.7%
S72	6702	Eastern Mediterranean spiny heath (phrygana)	S7_6700_faparBIOME	84.0%	89.0%
S73	6703	Western Mediterranean mountain hedgehog-heath	S7_6700_faparBIOME	80.8%	97.7%
S74	6704	Central Mediterranean mountain hedgehog-heath	S7_6700_faparBIOME	96.9%	92.7%
S75	6705	Eastern Mediterranean mountain hedgehog-heath	S7_6700_faparBIOME	92.3%	92.7%
S76	6706	Canarian mountain hedgehog-heath	S7_6700_faparBIOME	100.0%	100.0%
S81	6801	Canarian xerophytic scrub	S8_6800_faparBIOME	100.0%	98.7%
S91	6901	Temperate riparian scrub	S9_6900_faparBIOME	67.6%	83.7%

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
S92	6902	Salix fen scrub	S9_6900_faparBIOME	92.4%	81.4%
S93	6903	Mediterranean riparian scrub	S9_6900_faparBIOME	84.8%	95.0%
S94	6904	Semi-desert riparian scrub	S9_6900_faparBIOME	68.4%	86.7%
T11	7101	Temperate Salix and Populus riparian forest	T1_7100_faparBIOME	41.1%	67.1%
T12	7102	Alnus glutinosa-Alnus incana forest on riparian and mineral soils	T1_7100_faparBIOME	39.0%	52.4%
T13	7103	Temperate hardwood riparian forest	T1_7100_faparBIOME	42.9%	51.4%
T14	7104	Mediterranean and Macaronesian riparian forest	T1_7100_faparBIOME	76.8%	82.7%
T16	7106	Broadleaved mire forest on acid peat	T1_7100_faparBIOME	47.5%	59.5%
T17	7107	Fagus forest on non-acid soils	T1_7100_faparBIOME	79.4%	66.1%
T18	7108	Fagus forest on acid soils	T1_7100_faparBIOME	35.3%	56.5%
T19	7109	Temperate and submediterranean thermophilous deciduous forest	T1_7100_faparBIOME	76.5%	71.7%
T1A	7110	Mediterranean thermophilous deciduous forest	T1_7100_faparBIOME	33.8%	63.6%
T1B	7111	Acidophilous Quercus forest	T1_7100_faparBIOME	50.0%	53.1%
T1C	7112	Temperate and boreal mountain Betula and Populus tremula forest on mineral soils	T1_7100_faparBIOME	70.2%	89.8%
T1D	7113	Southern European mountain Betula and Populus tremula forest on mineral soils	T1_7100_faparBIOME	55.6%	81.6%
T1E	7114	Carpinus and Quercus mesic deciduous forest	T1_7100_faparBIOME	64.7%	53.3%
T1F	7115	Ravine forest	T1_7100_faparBIOME	36.9%	59.7%
T1H	7117	Broadleaved deciduous plantation of non site-native trees	T1_7100_faparBIOME	45.9%	59.4%
T21	7201	Mediterranean evergreen Quercus forest	T2_7200_faparBIOME	94.7%	94.5%
T22	7202	Mainland laurophyllous forest	T2_7200_faparBIOME	48.4%	91.8%
T23	7203	Macaronesian laurophyllous forest	T2_7200_faparBIOME	65.8%	69.4%
T24	7204	Olea europaea-Ceratonia siliqua forest	T2_7200_faparBIOME	76.4%	65.8%
T25	7205	Phoenix theophrasti vegetation	T2_7200_faparBIOME	18.2%	66.7%
T28	7208	Macaronesian heathy forest	T2_7200_faparBIOME	43.5%	55.6%
T29	7209	Broadleaved evergreen plantation of non site-native trees	T2_7200_faparBIOME	16.7%	100.0%
T31	7301	Temperate mountain Picea forest	T3_7300_faparBIOME	82.4%	72.6%
T32	7302	Temperate mountain Abies forest	T3_7300_faparBIOME	77.5%	75.1%

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
T33	7303	Mediterranean mountain Abies forest	T3_7300_faparBIOME	65.3%	66.9%
T34	7304	Temperate subalpine Larix, Pinus cembra and Pinus uncinata forest	T3_7300_faparBIOME	68.5%	78.6%
T35	7305	Temperate continental Pinus sylvestris forest	T3_7300_faparBIOME	79.7%	80.9%
T36	7306	Temperate and submediterranean montane Pinus sylvestris-Pinus nigra forest	T3_7300_faparBIOME	62.8%	75.5%
T37	7307	Mediterranean montane Pinus sylvestris-Pinus nigra forest	T3_7300_faparBIOME	84.4%	84.4%
T38	7308	Mediterranean montane Cedrus forest	T3_7300_faparBIOME	70.0%	62.6%
T39	7309	Mediterranean and Balkan subalpine Pinus heldreichii-Pinus peuce forest	T3_7300_faparBIOME	79.4%	80.6%
T3A	7310	Mediterranean lowland to submontane Pinus forest	T3_7300_faparBIOME	96.4%	84.2%
T3B	7311	Pinus canariensis forest	T3_7300_faparBIOME	98.1%	98.1%
T3D	7313	Mediterranean Cupressaceae forest	T3_7300_faparBIOME	59.1%	71.9%
T3E	7314	Macaronesian Juniperus forest	T3_7300_faparBIOME	30.0%	75.0%
T3F	7315	Dark taiga	T3_7300_faparBIOME	77.1%	72.0%
T3G	7316	Pinus sylvestris light taiga	T3_7300_faparBIOME	70.5%	68.9%
T3J	7318	Pinus and Larix mire forest	T3_7300_faparBIOME	65.4%	78.1%
T3K	7319	Picea mire forest	T3_7300_faparBIOME	34.0%	56.7%
T3M	7320	Coniferous plantation of non site-native trees	T3_7300_faparBIOME	82.3%	91.2%
U21	8201	Boreal and arctic siliceous scree and block field	U2_8200_faparBIOME	63.6%	63.6%
U22	8202	Temperate high-mountain siliceous scree	U2_8200_faparBIOME	66.3%	74.9%
U24	8204	Mediterranean siliceous scree	U2_8200_faparBIOME	71.9%	67.2%
U25	8205	Boreal and arctic base-rich scree and block field	U2_8200_faparBIOME	63.6%	63.6%
U26	8206	Temperate high-mountain base-rich scree and moraine	U2_8200_faparBIOME	79.8%	76.8%
U27	8207	Temperate, lowland to montane base-rich scree	U2_8200_faparBIOME	90.1%	81.6%
U28	8208	Western Mediterranean base-rich scree	U2_8200_faparBIOME	64.6%	72.1%
U29	8209	Eastern Mediterranean base-rich scree	U2_8200_faparBIOME	90.5%	97.4%
U32	8301	Temperate high-mountain siliceous inland cliff	U3_8300_faparBIOME	44.4%	77.8%
U33	8302	Temperate, lowland to montane siliceous inland cliff	U3_8300_faparBIOME	48.1%	88.1%
U34	8303	Mediterranean siliceous inland cliff	U3_8300_faparBIOME	36.8%	72.4%
U35	8304	Boreal and arctic base-rich inland cliff	U3_8300_faparBIOME	100.0%	100.0%

EUNIS C3	EUNIS G3	EUNIS LABEL	Model	PA	UA
U36	8305	Temperate high-mountain base-rich inland cliff	U3_8300_faparBIOME	82.8%	75.8%
U37	8306	Temperate, lowland to montane base-rich inland cliff	U3_8300_faparBIOME	89.8%	78.9%
U38	8307	Mediterranean base-rich inland cliff	U3_8300_faparBIOME	86.7%	72.3%
U3A	8308	Temperate ultramafic inland cliff	U3_8300_faparBIOME	47.1%	100.0%
U3C	8310	Macaronesian inland cliff	U3_8300_faparBIOME	90.0%	90.0%
U3D	8311	Wet inland cliff	U3_8300_faparBIOME	27.3%	52.9%
V11	9101	Intensive unmixed crops	V1_9100_faparBIOME	63.5%	69.4%
V12	9102	Mixed crops of market gardens and horticulture	V1_9100_faparBIOME	6.3%	25.6%
V13	9103	Arable land with unmixed crops grown by low-intensity agricultural methods	V1_9100_faparBIOME	40.4%	57.1%
V14	9104	Inundated or inundatable croplands, including rice fields	V1_9100_faparBIOME	73.9%	91.9%
V15	9105	Bare tilled, fallow or recently abandoned arable land	V1_9100_faparBIOME	95.9%	88.1%

C Appendix 3

C.1 Deliverables

All resulting archives were delivered to the client maintaining following folder structure.

Folders	Folder content description
├── EUNIS	All files and maps related to the updated EUNIS land cover map
│ ├── accuracies	Tabular (csv) and graphical (png) results of the accuracy assessment for the applied 45 random forest decision tree models
│ ├── maps	Updated land cover maps in raster (geotiff) and ascii (ascii grid) image formats
│ │ └── countries	Updated land cover maps for individual countries
│ │ ├── 3035	Updated land cover maps (geotiff) in European Lambert Azimuthal Equal Area (LAEA) projection
│ │ ├── 4326	Updated land cover maps (geotiff) in Geographic projection
│ │ └── 4326_ascii	Updated land cover maps (ascii grid) in Geographic projection
│ ├── models	Stored random forest models (python pickles) for the 45 classification models
│ ├── reference_data	Data used as reference data as derived from the data provider
│ │ ├── CLC	Raster data of Corine Land Cover 2018
│ │ ├── ETM	Raster data of Ecosystem Type Map 3.1
│ │ ├── EVA	Tabular and spatial point data from the EVA database
│ │ ├── GLC	Raster data from the Global Land Cover map
│ │ ├── HWSD	Geodatabase and derived raster images and global vector dataset and value tables of the Harmonized World Soil Database
│ │ └── PNV	Raster images from all layers of the Potential Natural Vegetation dataset

│ └── tables	Tables of final classification scheme, EUNIS terrestrial habitats scheme, and final class accuracies derived from accuracy assessment. Transition rules for Level 1 and 2 classifications.
├── RCG	Raster datasets of land cover map and land cover grid proportions for the European and the German grid
└── REPORTS	Final project report and literature database (bibtex)