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Comparative analysis of EUNIS habitats modelling and extended ecosystem mapping: toward a shared and multifunctional map of European wetland and coastal ecosystems

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Introduction

Vegetation and habitat mapping have a long history in Europe (EEA, 2014). Earlier maps focused on vegetation mapping were usually produced for scientific purposes, with the objective of increasing our knowledge of the natural world and its biological diversity. Then, the identification, description, classification and mapping of natural and semi-natural habitats gained recognition in the sphere of environmental policy implementation, and although plant science remains at the core of the approach, habitat mapping increasingly finds applications in land planning and management and is often a necessary step in preparing nature and biodiversity conservation plans. Habitat maps have now been used and increasingly produced to address policy-related issues.

Indeed, a good knowledge of the condition and distribution of habitats is an important element to inform long-term and forward planning decision making. Key policy instruments, such as the Habitats Directive or the Bern Convention implicitly address the need for habitat mapping. In the same way, habitat maps are expected to play an important role in mapping and assessing ecosystems and ecosystem services, as ecosystems can be regarded as groupings of habitat types. That was the purpose of the Action 5 of the EU Biodiversity Strategy for 2020, better known as Mapping and Assessment of Ecosystems and their Services (MAES), followed-up by the new Strategy for 2030 and its aim to develop an EU-wide methodology to map, assess and achieve good condition of ecosystems, with the objective to set legally binding targets for the restoration of ecosystems.

The conservation and management of ecosystems has never been more central to the future of biodiversity and human well-being on Earth. The UN Sustainable Development Goals from 2015, and now the post-2020 agenda of the Convention on Biological Diversity (CBD), are mandating global action that depends on ecosystem assessments. Rapidly developing information infrastructure to support these global policy initiatives includes, among several other initiatives, the UN System of Environmental, Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA), listing criteria for the IUCN Red List of Ecosystems (RLE) or Key Biodiversity Areas (KBA). All of these require a standardised, globally consistent, spatially explicit typology and terminology for managing the world's ecosystems and their services.

Wetlands are one of the key ecosystems to be protected and restored, both for biodiversity itself and for human well-being. As defined by the Convention on Wetlands of International Importance in 1971 (Ramsar), wetlands include a wide variety of inland habitats such as marshes, wet grasslands and peatlands, floodplains, rivers and lakes, as well as coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, coral reefs and other marine areas no deeper than six meters at low tide. Human-made wetlands such as dams, reservoirs, rice paddies and wastewater treatment ponds and lagoons can also be categorized as wetlands. Still, from vegetation classification to ecosystem mapping, a wide diversity of wetland types and definitions exists, making the definition of a wetland ecosystem both challenging and controversial.

1 A recent history of describing nature in Europe

1.1 Vegetation types and habitat typologies

1.1.1 The CORINE biotopes initiative

The CORINE biotopes project was launched in the mid 1980's by the European Commission, with the objective of carrying out an inventory of biotopes of major importance in the European Community. Indeed, as only a few national classifications and phytosociological systems could allow to give a common framework for plant communities description in just some part of Europe, it became apparent that a European classification of habitats and biotopes (the two have become synonyms) was an essential prerequisite for such inventory. A first attempt for a European classification was published in 1991, mostly inspired by the Braun-Blanquet approach (Devillers, Devillers-Terschuren & Ledant, 1991). But it was not a phytosociological classification, and the level of detail varied considerably between the units (habitats or biotopes) described.

Still, this work was the basis for the selection of habitats listed in Annex I of the 1992 Habitats Directive. From 1996, the CORINE biotopes classification was further extended to the entire Palaearctic region, as the "Palaearctic habitat classification" (Devillers & Devillers-Terschuren, 1996). Neither CORINE biotopes nor the Palaearctic classifications gave criteria for distinguishing the classes, and they only included a summary treatment of marine habitats.

1.1.2 The Habitats Directive and related Annex I Habitat types

The "Habitats" Council Directive 92/43/EEC of 21 May 1992 is a Community legislative instrument in the field of nature conservation, that establishes a common framework for the conservation of wild animal, plant species and natural habitats of Community importance. It provides for the creation of the Natura 2000 network to *"maintain and restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest"*. Animal and plant species names are clearly presented in the Directive and, despite minor misspellings or use of synonyms, no major additional work needs to be done to allow a correct interpretation of Annex II. In contrast, the development of a common agreed definition appeared to be essential for the different habitat types.

The EU Habitats Directive aims to achieve a favourable conservation status for all habitat types listed in its Annex I, grouped along 9 groups (Coastal habitats, Dunes habitats, Freshwater habitats, Heath & scrub, Sclerophyllous scrubs, Grasslands, Bogs, mires & fens, Rocky habitats, Forests). This Annex I lists today 233 European natural habitat types, including 71 priority habitats (i.e. habitat types in danger of disappearance and whose natural range mainly falls within the territory of the European Union). This list was initially based on the hierarchical classification of European habitats developed by the CORINE Biotopes project 2, the only existing classification at European level at the time. A draft list of habitat types for Annex I was drawn up on the basis of this classification by Professor A. Noirfalise, and submitted to the national experts preparing the Directive as a working document in August 1989. Numerous discussions with the national experts took place between 1989 and 1991, culminating in the version of Annex I published in the Official Journal in May 1992.

In December 1991, while the Directive was being adopted, a thorough revision of the CORINE biotopes classification was published, introducing numerous changes within codes and habitat types, in particular involving the division of the latter into sub-types. Definitions had been prepared for the various categories. Consequently, the Annex I codes no longer corresponded fully to the codes and descriptive content of the various categories of CORINE biotopes. This resulted in considerable ambiguities in the interpretation of Annex I, on the basis of the CORINE classification, leading the Task Force/European Environment Agency to produce a paper establishing the correspondence between the habitat codes of Annex I and those of the 1991 version of the CORINE classification. This paper also included the description proposed in the 1991 CORINE version for the various habitat types of Annex I. Having in mind all these difficulties of classification, the Scientific Working Group set up by the Habitats Committee expressed in May 1992 the need to also prepare a manual for the interpretation of those Annex I.

A first manual for the interpretation of priority Annex I habitat types was compiled by the Commission and approved by the Habitats Committee in February 1994. Then, another interpretation manual was produced for an additional subset of 36 non-priority habitat types also causing interpretation problems. However, this first EUR 12 version did not consider the accession of Austria, Finland and Sweden within the EU, which has resulted in the inclusion of a new biogeographical region (the Boreal region) in the Directive. The EUR 15, EUR 25, EUR 27 and EUR 28 versions were therefore published over time as updates of the first EUR 12 version.

1.1.3 The EUNIS Habitat classification

The EUNIS Habitat classification (European Nature Information System) has been designed to give a common pan-European reference set of natural and semi-natural habitat, with a shared description of all those units through a common hierarchical classification. It was meant to provide a common language for the description of all marine, freshwater and terrestrial habitats throughout Europe, to be objective and scientifically based with clear definitions and principles, and most importantly to seek to achieve a consensus amongst those concerned with habitat classification, as developers or users.

EUNIS was developed up to a level 3, for terrestrial habitats, and to a level 4 for marine habitats. Those final level 3 & 4 units are still very broad and were not intended to supplant existing national or sectoral classification systems, only to give an overall harmonization at the pan-European level. Still, as to give a more detailed classification, additional sub-levels were included in the classification system by adding the appropriate classes from other classifications, such as Biomar or the Palaearctic classification. Therefore, units from levels 1-3 for terrestrial habitats and 1-4 for marine habitats are the only verified and homogeneous for the whole pan-European domain, while all units from lower levels are only listed for information, and should be used in complement to national or sub-regional classifications. Terrestrial habitats in EUNIS are often based on phytosociological vegetation types such as those defined in EuroVegChecklist, based on species composition and vegetation structure, but they also emphasize the abiotic environment and geographic location as classification criteria. EUNIS also includes habitats in which plants are nearly or entirely absent. Still, most of the terrestrial habitats of EUNIS can be successfully defined using methods of vegetation science (Chytry et al., 2020).

To improve the uses of this 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. This revision established more consistency, removed ambiguity and overlaps in definitions of types, and extended the typology to the entire European continent and adjacent seas, although still with some gaps especially in eastern Europe (Russia and some adjacent countries). The proposals for revision of grassland, shrubland and forest habitat classification were summarized in a series of reports (Schaminée et al., 2012, 2013, 2014, 2016a), allowing the European Red List of Habitats to use a preliminary version of the revised EUNIS Habitat Classification.

The revisions included additions of new units, splitting or merging existing units and changes in habitat names and definitions. The review of the revised EUNIS classification has undergone public consultations with international experts and country representatives of Eionet, a partnership network of the European Environment Agency (https://www.eionet.europa.eu/). The public consultations resulted in further changes in the delimitation of individual habitats and their names. Based on the consultation proposals, a refinement of the classification for grassland, shrubland and forest habitats was made by Schaminée et al. (2018), for coastal and wetland habitats by Schaminée et al. (2019) and for vegetated man-made habitats by Schaminée et al. (2020). The work on the remaining sections is still under way.

EUNIS is now the main comprehensive pan-European hierarchical classification of habitats covering both the marine and terrestrial realms, and allows the reporting of habitat data in a comparable manner for use in nature conservation (inventories, monitoring and assessments) (Evans, 2012; Rodwell et al., 2018). EUNIS is extensively used in research and for various applications, including the implementation of European Community directives related to environmental protection. It has become one of the key elements for the European Directive 2007/2/EC on Infrastructure for Spatial Information in the European Union (INSPIRE, 2013), as well as for the updated version of Resolution 4 of the Bern Convention on the Conservation of European Wildlife and Natural Habitats, which is the legislative basis for the EMERALD network — a complement of the Natura 2000 network in the European countries that are not members of the European Union (Council of Europe, 2018). EUNIS was also used as a reference for the European Red List of Habitats (Janssen et al., 2016), the first attempt for an EU-wide comprehensive and systematic overview of the degree of endangerment of 490 natural and semi-natural habitat types occurring within the European territory of the EU.

"Habitat" definition

A "habitat" is defined as: "a place where plants or animals normally live, characterized primarily by its physical features (topography, plant or animal physiognomy, soil characteristics, climate, water quality etc.) and secondarily by the species of plants and animals that live there" (Davis et al., 2004).

Most, but not all EUNIS habitats, are in fact "biotopes", that is to say "areas with particular environmental conditions that are sufficiently uniform to support a characteristic assemblage of organisms".

Some EUNIS habitats, such as moss and lichen tundra, or deep-sea mud, may be of vast extent. Others, such as cave entrances or springs, spring brooks and geysers, are much smaller. A few other EUNIS habitats, such as glaciers and highly artificial non-saline standing waters, may be devoid of living organisms other than microbes. These features, although not strictly habitats, are included for completeness.

1.2 Ecosystem mapping and assessment

The EUNIS classification and the Habitats Directive do not define ecosystems but natural habitats, meaning terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural. In contrast, ecosystem mapping is the spatial delineation of ecological units, following an agreed ecosystem typology of ecosystem types which strongly depends on mapping purpose and scale. Global approaches to ecosystem classification and mapping (or reporting) apply two basic principles: typological and regional, or their combination. The typological approach divides nature into ecosystem types – classes that can occur at more geographical locations (i.e., temperate broadleaf and mixed forests). The regional approach describes ecosystems from a regional (spatially unique) perspective (e.g., Dinaric mixed forests). Ecosystem mapping also has to satisfy a management perspective and is largely determined by data availability.

In the absence of an agreed and regularly updated European ecosystem map, the task of mapping European ecosystems could be interpreted as aggregation of proxy spatial information that describes, as good as possible, the biophysical complex on the ground surface and adequate representation in freshwater bodies and the seas. Such mapping should aim at providing quantitative aspects of the 'state of ecosystems', such as their distribution and extent (Maes *et al*., 2013). But just as policies, natural ecosystems are also difficult to classify into a unique category and overlaps occur frequently. Technically, overlaps may lead to double counting of ecosystem processes, condition indicators, or ecosystem services. In practice these overlaps are sometimes unavoidable. The MAES initiative, has been confronted with the difficulties that emerge when trying to categorise and delineate ecosystem types (Maes *et al*., 2020).

1.2.1 The MAES Ecosystem classification

The ecosystem types of the MAES classification have been identified because of their distinct natural properties which are reflected by their abiotic characteristics, biodiversity, vegetation structure, and their ecosystem functions. But the different ecosystems also are subject to different policies and management forms, each with their specific objectives, targets, governance, or level of competence, which makes it useful to assess them separately and formulate bespoke policy and management options (Maes et al., 2020).

A practical approach to the spatial delimitation of an ecosystem is to build up a series of overlays of significant factors, mapping the location of discontinuities, such as in the distribution of organisms, the biophysical environment (soil types, drainage basins, depth in a water body), and spatial interactions (home ranges, migration patterns, fluxes of matter). A useful ecosystem boundary is the place where a number of these relative discontinuities coincide. Ecosystems within each category share a suite of biological, climatic, and social factors that tend to differ across categories.

More specifically, there generally is greater similarity within than between each ecosystem type in:

- Climatic conditions;
- Geophysical conditions;
- Dominant use by humans;
- Surface cover (based on type of vegetative cover in terrestrial ecosystems or on fresh water, brackish
- water, or salt water in aquatic ecosystems);
- Species composition;
- Resource management systems and institutions

For practical purposes, mainly triggered by data availability, and because of the strong links to the emerging Copernicus land monitoring services, the proposed method of ecosystem mapping for the EU Ecosystem assessment implies that CORINE Land Cover (CLC) classes monitored in Copernicus are aggregated into ecosystem types, in the most meaningful way possible to represent broad-scale ecosystems, and combined with ecosystem-relevant information. This aggregation is based on detailed expert analysis of the relationships between land cover classes and habitat classification systems (i.e. EUNIS) to ensure consistency between these approaches.

The proposal for level 1 and 2 corresponds directly with the EUNIS habitat classification and SEBI 004 indicator on ecosystem coverage. It is relevant for EU policies and it is compatible with global ecosystem classifications. It is typological (enabling comparison between different parts of the Europe's territory), keeps a pan-European scale and takes into consideration regular mapping aspects (applying CLC data for spatial delineation). The present typology separates at level 1 three major ecosystems: terrestrial systems, fresh water and the marine environment. It also anticipates the different reporting schemes of the environmental directives (HD, WFD, MSFD) and the implemented typologies.

The following paragraphs provide a brief description of proposed ecosystem types.

- The terrestrial ecosystems as delineated from Corine Land Cover classification and map are subdivided into urban systems, cropland, grassland, woodland and forest, heathland and shrub, sparsely vegetated land and wetlands.
- Freshwater ecosystems include at level 2 one single class: rivers and lakes

- The typology of marine ecosystems reduces the 3-dimensional structure of the ocean to the 2 dimensions of the seabed (benthic) habitats, attributing the 3rd dimension, the water column (pelagic habitats), to depth zones. Brackish water and marine ecosystems in the land-sea interface are grouped together in a single type.

1.2.2 The IUCN Global Ecosystem Typology

The IUCN Global Ecosystem Typology is a very recently developed hierarchical classification system that, in its upper levels, defines ecosystems by their convergent ecological functions and, in its lower levels, distinguishes ecosystems with contrasting assemblages of species engaged in those functions (Figure 1) (Keith et al, 2020).

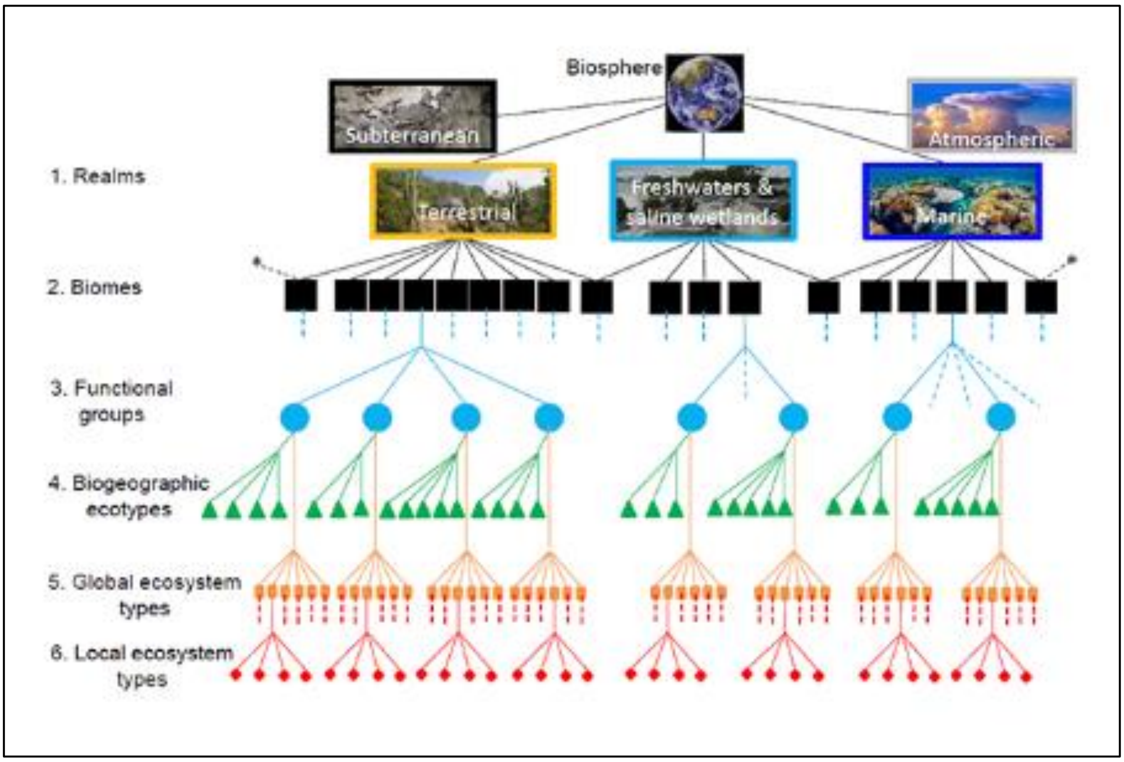


Figure 1: Overview of the 6th levels of the IUCN Global Ecosystem Typology

The three upper levels of the hierarchy provide a framework for understanding and comparing the key ecological traits of functionally different ecosystems and their drivers. They divide the biosphere into five global realms: i) terrestrial; ii) subterranean; iii) freshwater (including saline water bodies on land); iv) marine; and v) the atmosphere. The interfaces between these core realms are recognised as transitional realms, accommodating ecosystems, such as mangroves, that depend on unique conditions and fluxes between contrasting environments.

At Level 2, the typology defines 25 biomes – components of a core or transitional realm united by one or a few common major ecological drivers that regulate major ecological functions. These include familiar terrestrial biomes, such as tropical/subtropical forests and deserts, as well functionally distinctive groupings that fall outside the traditional scope of the biome concept, including lentic and lotic freshwater biomes, pelagic and deep sea benthic marine biomes, subterranean freshwater biomes, and several anthropogenic biomes. Ecosystems in this latter group are created by human activity, which continues to drive and maintain their assembly. Level 3 of the typology includes 108 Ecosystem Functional Groups that encompass related ecosystems within a biome that share common ecological drivers and dependencies, and thus exhibit convergent biotic traits. Examples include temperate deciduous forests, annual croplands, seasonal upland streams, intertidal forests, epipelagic ocean waters, and deep-sea trenches and troughs.

"Ecosystem" definition

An ecosystem is usually defined as "a complex of living organisms with their (abiotic) environment and their mutual relations". Although this definition applies to all hierarchical levels, from a single water drop with its microorganisms to Earth's biomes, for the practical purposes of the EU Mapping and assessment of ecosystems and their Services initiative, an ecosystem is considered at the scale of habitat/biotope or landscape.

1.3 Ecosystem extent and condition accounting

1.3.1 The SEEA Standards

The principles of economic accounting are defined in the System of National Accounts (SNA), an internationally agreed standard on how to measure and record economic activity. Still, conventional economic accounts lack sufficient consideration of the importance and state of the environment, and neither the mostly negative effects of economic activities on natural environment, nor the vital contributions of nature to human economy and wellbeing, are reflected well in economic accounts. One of the issues about including stocks and flows of natural capital into economic and decision-making is the inconsistency of standardised methods to report and quantify the value of the ecosystems across different scales (Eppink et al., 2012; Maes et al., 2013; Crossman et al., 2013).

To address this, the international community is working to develop an ecosystem accounting framework as the main tool to quantify the contributions of natural capital to human well-being in economic terms (Mäler et al., 2008; Obst et al., 2016; La Notte et al., 2019). An international framework to link economic and environmental data was established, the System of Environmental-Economic Accounting (SEEA), covering accounts for a range of topics for which the interaction between the economy and the environment are known to be important, such as agriculture, forestry and fisheries, air emissions or environmental taxes. One of the topics of the SEEA are ecosystem accounts.

1.3.2 The SEEA-EA framework

The *System of Environmental-Economic Accounting — Ecosystem Accounting* (SEEA-EA) is a spatially-based, integrated statistical framework for organizing biophysical information about ecosystems, measuring ecosystem services, tracking changes in ecosystem extent and condition, valuing ecosystem services and assets and linking this information to measures of economic and human activity. It was developed to respond to a range of policy demands and challenges, with a focus on making visible the contributions of nature to the economy and people. The SEEA-EA framework has two differential parts: first, it measures the value of the ecosystem in bio-physical terms (extent, condition, and ecosystem services); second, it translates this bio-physical value into monetary terms through valuation techniques of ecosystem services (EEA, 2018).

In the same way, the international community developed a global system of accounting national statistics (SNA) to make a common accounting framework in the mid-XX century (Allin and Hand, 2017). In addition, United Nations are developing their initiative of System of Environmental-Economic Accounting (SEEA), an ecosystem accounting framework to report the value of the ecosystem and natural capital in economic terms (Hein et al, 2020; United Nations et al, 2021).

The SEEA-EA complements the measurement of the relationship between the environment and the economy described in the *System of Environmental-Economic Accounting 2012—Central Framework*

(SEEA Central Framework) (United Nations et al., 2014a). The SEEA, encompassing the SEEA Central Framework and the SEEA-EA, provides on its side a system that complements the System of National Accounts (SNA) using accounting principles to integrate physical and monetary measures concerning the environment, in a way that allows for comparison to the data from the national accounts.

Figure 2 shows the flowchart to a coherent and integrated framework for assessing the ecosystem assets into economic and other human activities (United Nations et al, 2021).

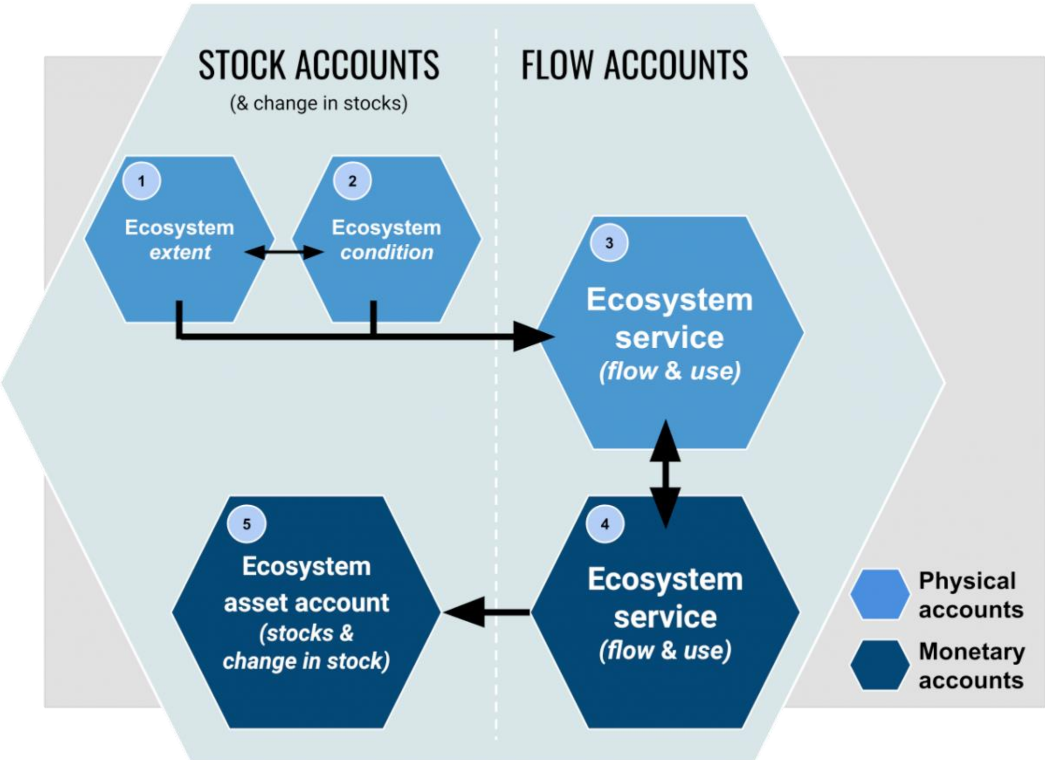


Figure 2: Structure of the SEEA EA ecosystem accounts

Briefly, the five accounts in which this framework is divided to obtain the monetary value of ecosystems from biophysical information are:

1. Extent: The size of the different ecosystem types and their changes in extension;
2. Condition: Measure the state and functioning of ecosystems, represented by indicators and reference levels;
3. Ecosystem services, physical terms: Flow of ecosystem services, expressed in physical units;
4. Ecosystem services, monetary terms: Flow of ecosystem services, expressed in monetary units;
5. Assets: Translated the ecosystem services monetary valuation into economic sectors, using economic methods such as production functions.

The framework described in the SEEA-EA refines the original conceptual framework for ecosystem accounting described in the SEEA Central Framework from 2012. In many areas, the revisions provide additional explanations and clarifications. However, there were some areas where reinterpretation or re-expression of the original framework reflecting the outcomes of ongoing discussions and conversations with a wider range of experts. This is particularly evident in the application of concepts concerning ecology and biodiversity and in the discussion on the monetary valuation of ecosystem services and assets.

1.3.3 The EU INCA project

EU bodies have helped develop ecosystem accounting concepts and methods for many years, but their practical application only gained real momentum with the start of the INCA project in 2015. The INCA project aimed to pilot an integrated set of ecosystem accounts at EU level by 2020. This project was closely linked with the initiative Mapping and Assessment of Ecosystems and their Services (MAES), that brought together policy makers and scientists from Member States and EU institutions and developed methods to classify and map ecosystems, and assess their condition using a set of agreed indicators in a consistent way for the whole of EU.

The INCA project used the classification of EU ecosystem types developed by MAES to build ecosystem extent accounts, and the results of the assessment of ecosystem condition of MAES to provide examples how readily available data may be used to build initial ecosystem condition accounts. MAES, on the other hand, used part of the outputs of the INCA ecosystem services accounts for the EU Ecosystem Assessment. In comparison with the MAES assessment, the INCA used a more rigorous and structured approach of accounting to describe ecosystems, their services and how they change over time.

2 Mapping European wetland areas, what has been done?

2.1 Mapping EUNIS wetland & coastal habitats

The methodological processing line from individual recorded vegetation plots into a final EUNIS habitat probability map, roughly comprises three steps (Figure 3):

1. Assigning *in-situ* vegetation plot data stored in the European Vegetation Database (EVA) to EUNIS habitat classes, to create the **distribution map** of the EUNIS class. Expert rules are used to define the floristic composition of each EUNIS units (which species should be present and which species should be absent), as for each vegetation relevé to be classified into the EUNIS habitat classes

2. Using the Maxent software to produce the **suitability map**, a combination of the distribution map of vegetation relevés with data on climate, topographic, soil, remotely sensed Essential Biodiversity Variables (EBV's) and other environmental data stored in 1km resolution grid maps at a European scale. The software calculates which environmental layers have the largest contribution to the model, meaning which layers explains the best the distribution of the recorded vegetation plot data. The suitability map indicates how suitable an area is, in terms of climate and soil conditions, for the specific EUNIS habitat class, expressed on a scale of 0 to 1.

3. Implementing a top-down approach using spaceborne observations such as satellite derived land cover data, to refine the potential habitat suitability map into an actual **probability map**.

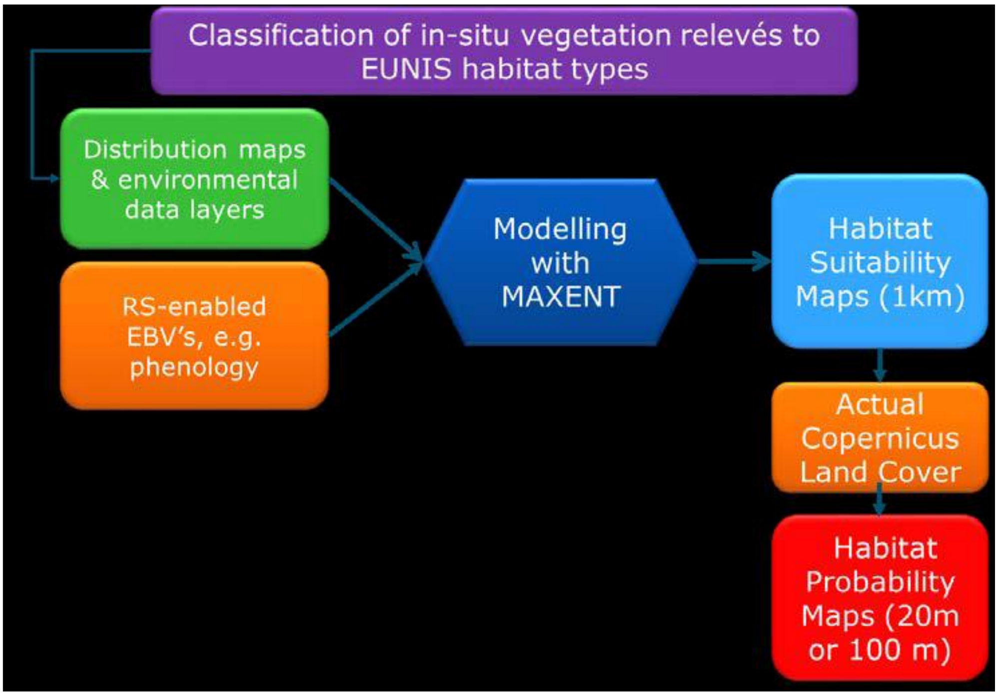


Figure 3: The 3-step process of producing EUNIS habitat probability maps

2.1.1 Distribution maps based on vegetation plots

In 2019, all EUNIS habitat types belonging to wetlands (Q) and coastal habitats (N) have been revised under the EEA Framework Contract Specific Contract No. 3417/B2019/EEA.57640 and Framework Service Contract No. EEA/NSS/17/002/Lot 1 (Schaminée et al. 2019). Within that specific framework contract, almost all habitat types of the new categories N and Q could be crosswalked. For updating the crosswalks of the revised EUNIS Habitat Classification for coastal habitats and wetlands with EuroVegChecklist 2016, the latest version of the EUNIS list of habitat types at level 3 for coastal habitats (Group B) and wetlands (Group E) was provided by EEA as a 'working list'. During the process of crosswalking, this list proved to be stable and it was only slightly modified (Schaminée et al. 2019). For the coastal habitat types (N), the only exception was habitat type N1k (Machair grasslands). Concerning the wetlands (Q), the exceptions were the habitat types Q13 (Ombrotrophic percolation mire) and Q32 (Aapa mire).

The revision resulted in an improved classification that was used to assign a large part of the European Vegetation Archive (EVA) to EUNIS habitat types, and to enable their description. This work was the starting point for the ETC/BD study under the Task 1.7.5.1 (Action Plan 2020) to deliver distribution, suitability and probability maps for the EUNIS habitat types belonging to group N and Q. This resulted in newly defined EUNIS habitat suitability maps which were also based on much more in-situ vegetation plot data (Hennekens, 2019).

2.1.2 Automatic habitat suitability modelling

The Maxent modelling procedure considers presence data (known observations of a given entity) and background data, a set of points used to describe the environmental variation of the study area according to the available environmental layers. It is assumed that these layers represent well the most important ecological gradients on a European scale. The layers were selected from meaningful environmental predictors commonly used for modelling non-tropical plant and vegetation diversity, and are not mutually strongly correlated.

In addition to what was selected as predictors in 2016 and 2017, additional data also called RS-EBV's (Remote Sensed Essential Biodiversity Variables; predictors based on remote sensing data) were used, such as Land Use Land Cover, Phenology, Inundation or Vegetation height (Hennekens 2016, 2017). It is assumed that by using additional meaningful predictors such as those RS-EBV's, the modelling will result in more realistic suitability maps with less outliers (prediction in areas where the habitat is not expected to be present).

Maxent is expected to perform well for estimating the geographic distribution of EUNIS habitats in Europe. However, as with any other modelling techniques, this method is sensitive to sampling bias, i.e. when the spatial distribution of presence data is reflecting an unequal sampling effort in different geographic regions. It has been proposed that the best way to account for sampling bias (when bias is known or expected to occur) is to generate background data reflecting the same bias of the presence data, to a maximum of 5,000 locations. Those locations can be randomly selected by Maxent from the study area, and it appears that all maps using randomly selected background data were far better than maps produced using background data randomly derived from the EVA database (Figure 4).

The distribution maps of vegetation plots also helped to analyse the distance to the coastline of all coastal habitats (N formation), which were all encountered within 5 kilometers from the coast. Finally, all EUNIS habitat suitability maps have been refined by using a 10-percentile threshold, that were a result of the MAXENT models. It is assumed that suitability percentages lower that the 10-percentile threshold are not valid.

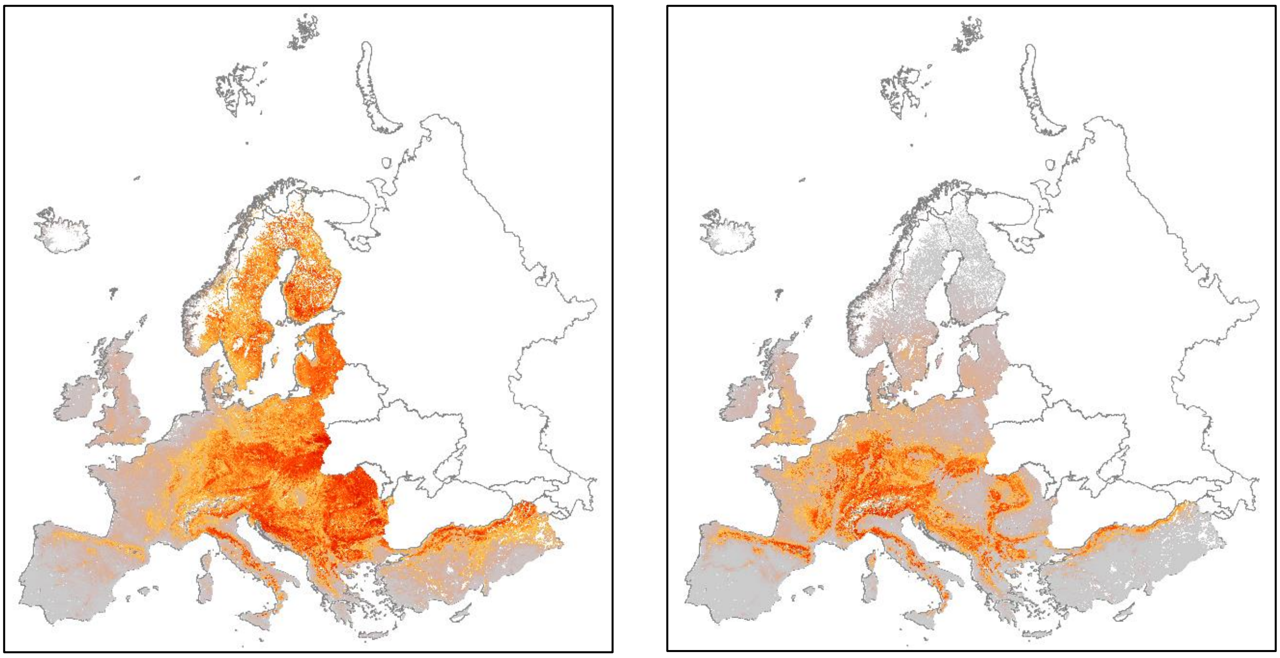


Figure 4: EUNIS habitat F1.6a suitability map using a) Background data based on locations from randomly selected plots in the EVA database, and b) background data randomly selected from the study area by Maxent.

2.1.3 From potential suitability maps to probability maps

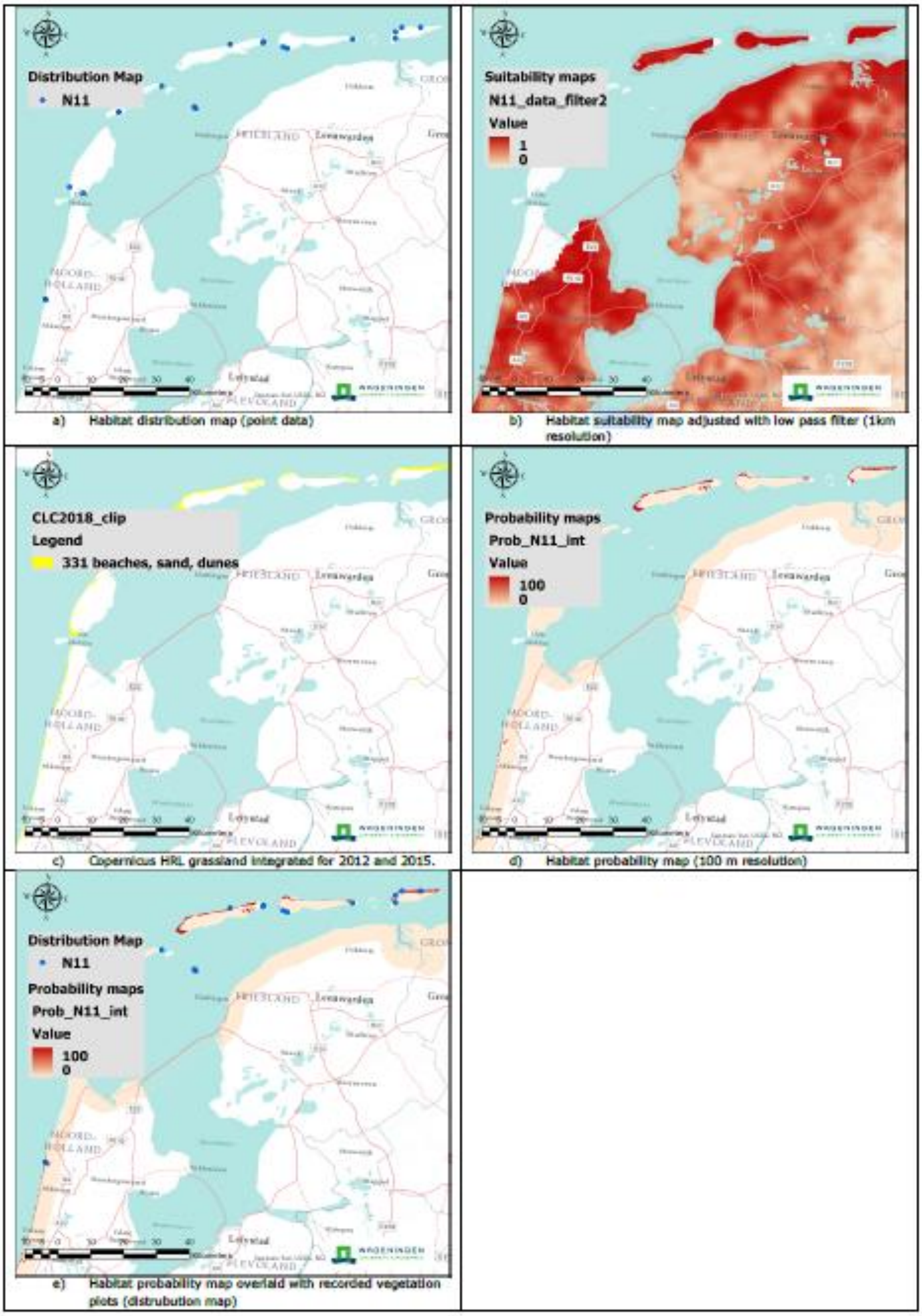
The EUNIS habitat probability maps are created by downscaling the habitat suitability maps with a 1km resolution, by the actual land cover. Indeed, actual land cover information plays a key role to fine-tune the habitat suitability maps into habitat probability maps. All the 35 habitat probability maps for wetland and coastal habitats have been produced at a 100 meters resolution.

In principle, four models in ARCGIS PRO were used for each EUNIS habitat, namely:

1. Thresholding the habitat suitability maps with the 10 percentile thresholds
2. Crosswalk analysis (Sample tool) between the distribution maps and the actual land cover information (CLC2018 & WAW2015) to support the decision rules.
3. Process the probability maps at 100 meters spatial resolution by integrating the actual land cover with the habitat suitability maps on basis of decision rules
4. Export the probability maps to geotiffs.

The processing of coastal habitat probability maps showed that the habitat suitability maps did not cover the exact coastline, leading to empty probability maps. The main reason was that most coastal habitats only occur in a small fringe along the coastline, for example affiliated with the CLC class 331 'beaches, sand and dunes'. Therefore, it was proposed that the original suitability maps could be extended towards to coastline by applying a low pass filter (an averaging (smoothing) filter https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/filter.htm). This low pass filter was used twice, with the option 'Ignore NoData in calculation', resulting in more smoothed suitability map that cover the whole coastline (Figure 5).

The double low pass filter was applied on the original suitability maps, meaning without applying the 10-percentile thresholds. However, the suitability maps with a 10-percentile threshold were still applied for the wetland habitats.



a) Habitat distribution map (point data)

b) Habitat suitability map adjusted with low pass filter (1km resolution)

c) Copernicus HRL grassland integrated for 2012 and 2015.

d) Habitat probability map (100 m resolution)

e) Habitat probability map overlaid with recorded vegetation plots (distrubution map)

Figure 5: Overview of the methodological steps for a small area on the Northern part of the Netherlands, for EUNIS habitat type N11 “Atlantic, Baltic and Arctic sand beach”

Going from habitat suitability maps to habitat probability maps through actual land cover information makes a big difference. But despite this fact, many of the EUNIS wetland and coastal habitat probability maps show local misfits between the probability maps and the recorded vegetation plots (distribution maps). This can be due to several reasons:

1. The geographic location of the in-situ vegetation plot is sometimes not accurate enough;
2. The Copernicus land cover layer misses sometimes smaller patches related to wetlands and coastal habitats. Notice that the smallest mapping unit of Corine land cover is 25 ha. So the HRL's are preferred, but as mentioned before the relationship between Water and Wetness product (WAW2015) and the wetlands and coastal habitats is quite disappointing, and therefore could not play a major role;
3. Some of the recorded vegetation plot might have disappeared over the last twenty years.

Therefore, ETC/BD recommender to always do an independent assessment of the habitat probability maps based on Article 17 database.

2.1.4 Data used

The Copernicus land cover databases that was exploited for this purpose were the HRL product Water and Wetness from 2015 (WAW 2015), and the Corine Land Cover database from 2018 (CLC2018), with spatial resolutions of respectively 20 and 100 meters. The WAW product is a thematic product showing the occurrence of water and wet surfaces over the period 2009 to 2015 (Langanke, 2018). The 2015 reference year for the WAW is a new baseline product, which fully replaces the previous 2012 separate "permanent water" and "wetland" products (https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness).

In principle, the EUNIS habitat suitability maps were refined on basis of the actual Copernicus land cover (CLC 2018), the WAW2015 for some classes, and the distance to the coast for the coastal habitats (<= 5km). But since only the distribution data for 6 habitats showed a clear relationship with WAW2015, the suitability maps for EUNIS wetland and coastal habitats depended much more on CLC2018 than it was expected in the first instance.

There is an existing crosswalk with the EUNIS habitats and the CORINE Land Cover that was made by Moss (2012). However, such crosswalk does not exist with the Water and Wetness (WAW) HRL product. An additional analysis was made by overlaying the individual EUNIS habitat distribution maps (point data) with the land cover layers (CLC2018 and WAW2015), by using the Sample tool in Spatial Analyst of ArcGIS Pro. The spatial model leads to a crosswalk (available in an Excel sheet) for each of the 37 wetlands and coastal EUNIS habitats.

There is a strong relationship between the recorded vegetation plots and the actual land cover (CLC 2018) for wetlands and coastal habitats, although the relationship is many to many. Surprisingly, there is in most cases no strong relationship between the recorded vegetation plots and the HRL Water and Wetness: the distribution data of only 6 EUNIS habitats showed a clear relationship with WAW2015.

In the end, the final probability maps of EUNIS wetland and coastal Level 3 habitats depend more on CLC 2018 than on WAW 2015. Therefore all 35 EUNIS habitat probability maps have been produced at a 100 meters resolution. When taking a close look at the Marine saltmarsh models, which are supposed to be located along the coast at close distance to the sea, the best performing predictor is the Digital Elevation Model. This seems obvious, as coastal related habitats are all located more or less at sea level. Nevertheless, the suitability and binary maps show that coastal habitats may also occur inland.

This artefact may be caused by:

- Too much location uncertain for some of the observation data. Unfortunately, the location uncertainty is unknow for a large number of plots.

- A mismatch with the Land Use Land Cover, showing that only 25 % of all MA2-classified plots are linked to the class 'Saltmarshes' (Figure 6).

Some of the plots are, although to a lesser extent, linked to the class 'pastures' and 'non-irrigated arable land' and these categories are occurring everywhere in Europe. A matching of 11 % with intertidal flats makes sense as this land use type occurs in the vicinity of salt marshes.

Distribution map – map of known occurrences based on recording of local in-situ vegetation plots which have been assigned to a EUNIS habitat class. They show localities where the habitat is known to occur and has been observed (at least at the time of survey), but give an incomplete record of the actual distribution across Europe.

Suitability maps – modelling of areas where the environment is suitable for the habitat. So in fact it shows more the potential suitable areas for that specific habitat.

Probability maps – the modelled suitability maps is refined by using actual land cover information, and in some cases by other actual environmental information.

While the suitability map can be considered as a potential distribution map, the probability map presents more the actual distribution of the habitat type. Although the probably map still represents a modelled distribution and the probably overestimates the actual distribution

2.2 Mapping wetland ecosystems under the MAES initiative

2.2.1 The need for an ecosystem-based and inclusive map of wetlands

The development of an extended EU wetland ecosystem layer was an explicit policy request in Europe, built on an ecosystem-based justification of an inclusive definition and mapping of wetlands. Indeed, at the European level, the spatial distribution of wetlands was mainly taken from the time-series of CORINE Land Cover (CLC) Copernicus datasets, but where some areas considered in the Ramsar Convention on Wetlands are not classified as wetlands (i.e. category 4.X.X.).

Therefore, an extended wetland ecosystem layer covering the EEA-39 Member States for the year of 2012 was produced in the context of ETC/ULS Task 1.7.5.1 "Support to MAES activities for 2019 ecosystem assessment". The final target of this work was to build a time-series of the extended wetland layers, from 2000 to 2018, using an optimized number of ancillary layers in order to reduce the noise and uncertainties coming from the use of many independent sources.

The definition of wetland area using an ecosystem-based definition and the harmonization of the MAES nomenclature fully cover the wide range of wetland ecosystems, allowing this map to be overlaid with the boundaries resulting from different policy and management instruments (EU HD, WFD, MSFD, Climate decision, among others), as to support more integrated assessment and management built on ecosystem-basis. This Extended layer was based on the results of the Horizon 2020 project SWOS "Satellite-based Wetland Observation Service", that produced a satellite-based service to delimit, and spatially and temporally monitor at the global scale (Abdul Malak et al., 2016; Fitoka et al., 2017).

2.2.2 Recomposing the extended Wetland ecosystem class

The "Satellite-based Wetland Observation Service" project proposed the reclassification of the wetland ecosystems within the MAES nomenclature, following the modifications introduced with the Copernicus Riparian Zones local product and following a) the Ramsar Classification of Wetland Types and b) the EUNIS habitat classification. This extended wetland ecosystems layers should now include transitional habitats that correspond to wetlands, such as riparian forests, wet grasslands, estuaries and rice fields. Those new wetland ecosystem classes proposed to be integrated in the MAES nomenclature moved from other MAES ecosystems to the newly defined wetland one, implying class shifts for rice fields (moved from croplands), wet grasslands (moved from grasslands), wet heathlands (moved from heathland and scrub) and Riparian forests (moved from forests).

Results of the 2012 layer developed show a wetland coverage of about 370,000 km² at EU-28 level, of which 26 % corresponds to the share of wetlands covered by previous MAES wetland assessment (inland marshes and peatbogs), 7 % to the share of coastal wetlands and 67 % are newly added classes matching the hydro-ecological wetlands dimension.

2.2.3 Data used

Whenever possible, it was preferred to use the Corine Land Cover (CLC) layers instead of the Ecosystem Type Maps (ETM) ones, to make the approach replicable for all the requested years (2012 and 2018). The EUNIS nomenclature and the ETM methodologies have been revised in the ETM v3.1 2012 version, and it could be challenging to compare the classes derived from the 2 ETM layers (v2.1, 2006 and v3.1, 2012). For the same reason, the use of the Riparian Zone Land cover/ Land use product (RZL), which is only available for the period 2011-2013, could be substituted by the Water & Wetness Copernicus HRL product (WaW), in combination with the CLC layers (Figure 6).

Name	Acronym	Temporal converage		Resolution	Notes
Ecosystem Type Map	ETM	v2.1	2006	100m	EUNIS nomenclature
		v3.1	2012		
Riparian Zone Land Cover/Land Use Product	RZL	2011-2013		0.5 Ha, 10m	MAES nomenclature
Natura 2000 Copernicus Local Product	N2K	2004-2008, 2010-2014		0.5 Ha, 10m	Grassland rich sites; MAES nomenclature
Water & Wetness Copernicus High Resolution Layer product	WaW	2009-2015		20m, 100m	Available classes: 1) permanent water 2) temporary water 3) permanent wetness 4) temporary wetness
Global Surface Water Explorer	GSWE	1984-2015		25m	Available products: 1) Water Occurrence 2) Occurrence Change Intensity 3) Seasonality 4) Recurrence 5) Transitions 6) Maximum water extent

Figure 6: Overview of the available dataset to be potentially used for the classification of the extended wetland layer

Despite this, the production of the extended wetland layers was limited to the baseline year 2012. Indeed, the class “5.1.1.4 Riverine and fen scrubs” could only be derived from the ETM layer (EUNIS F9), because the possibility to use the WaW to identify fluvial, riparian and swamp forest habitats and the wet grasslands first needed to be properly assessed.

The main CLC classes contributing to the new layer for the EEA39 region are “Lakes, ponds and reservoirs” and “Marine waters”, while the mapping of the “Wet heaths” class contributed to increase the extent of wetland ecosystems in many northern countries (in particular in Iceland, Norway and Sweden).

2.3 Available mapping materials

2.3.1 Probability maps of EUNIS wetland and coastal habitat types

The work dedicated to mapping EUNIS wetland and coastal habitat types only produced specific maps for each EUNIS units, without any global overview of all EUNIS wetland habitats distribution.

Out of the 37 EUNIS habitat suitability maps for wetlands and coastal habitats, 35 new habitat probability maps have been processed by exploiting Copernicus land cover data. Indeed, no habitat probability maps have been produced for two habitats, namely N31 ‘Atlantic and Baltic Rocky sea cliff and shore’ and N32 ‘Mediterranean and Black Sea rocky sea cliff shore’, due to a lack of appropriate environmental data sets (lack of geomorphological maps related to sea cliffs).

- **Example of Q51 ‘Tall-helophyte bed’**

“Tall-helophyte bed” characteristically occupies a zone from shallow to moderately deep mesotrophic to eutrophic fresh or slightly brackish water along the banks of rivers and lakes, in artificial water bodies and at nutrient-rich terrestrial sites on waterlogged ground. It is a very widespread, but naturally fragmented habitat, throughout the European lowlands. The occurrence of different dominant species depends on water depth, duration of flooding, substratum, trophic level, disturbance by waves or current, herbivory and human influence, some of the plants being cut for fodder or thatching. Because of the competitive ability and clonal growth of tall helophytes, the stands are usually species-poor and often dominated by one or a few co-dominants. The habitat is vulnerable to drainage and pollution, land reclamation for agricultural and urban development, and the decline of marshland exploitation for renewable crops.

An EU-wide Distribution & Probability map is given for each habitat (Figure 7), accompanied with a dedicated “zoom-in” for a specific area, showing the detailed relation between the initial vegetation plots and the final modelized and land-use proofed probability distribution (Figure 8).

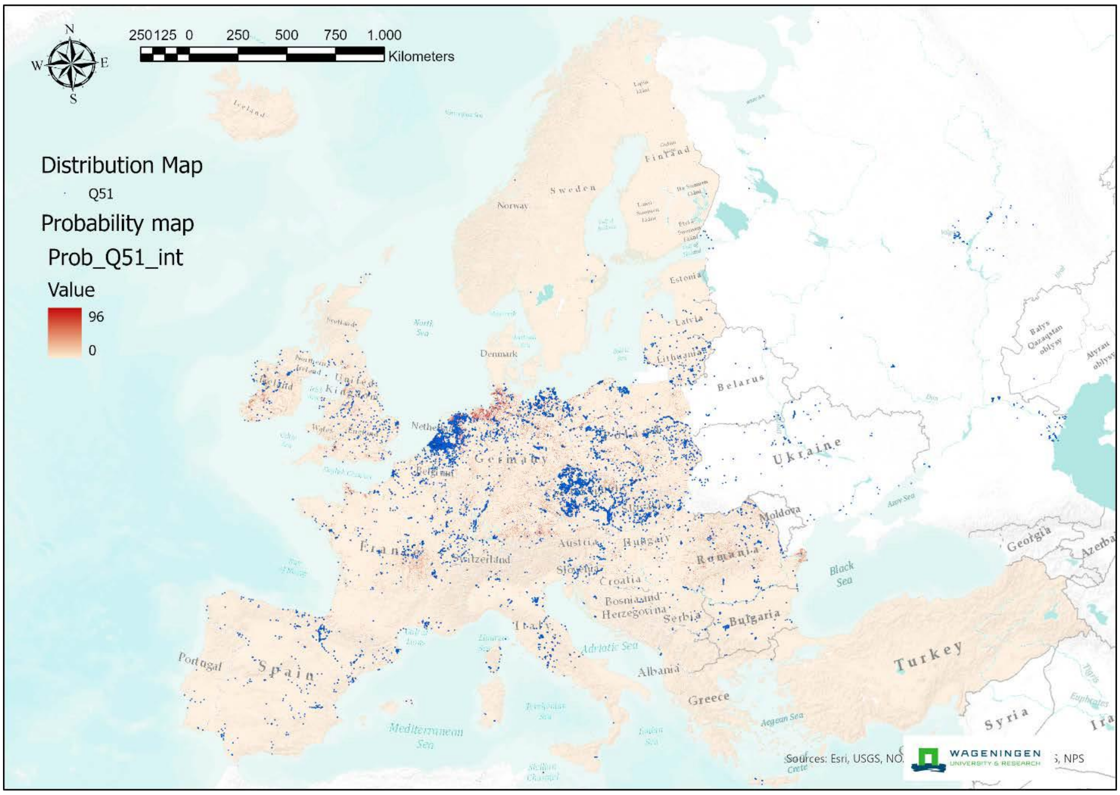


Figure 7: Probability maps overlaid with related in-situ vegetation plots at EU level

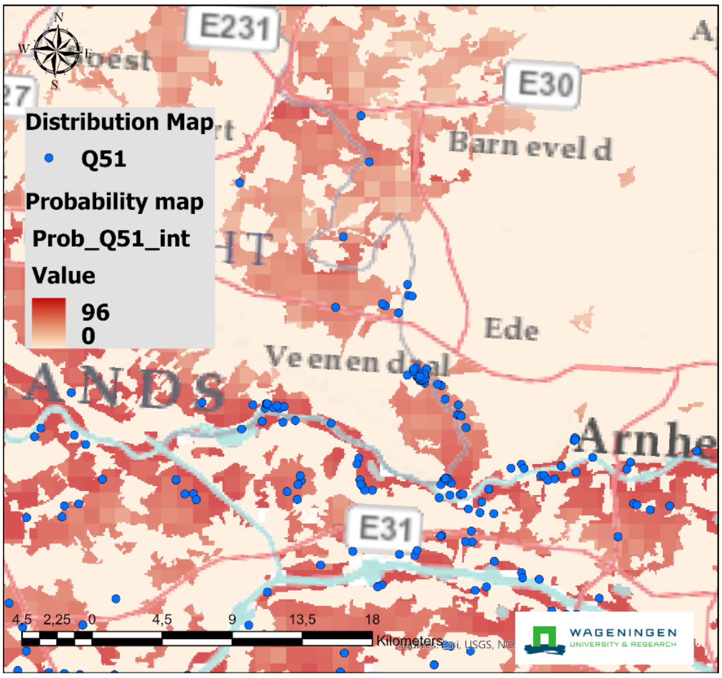


Figure 8: Localized "zoom-in" of the probability maps showing the real detail of the maps

2.3.2 The Extended wetland ecosystems layer

- **The 2012 baseline at EU-28 level**

Contrary to the EUNIS habitats maps, the Extended wetland ecosystems layer only comes as a combined map of all wetland ecosystems identified at EU-28 level, for the 2012 baseline (Figure 9). However, the map is also detailed for a few specific local examples, as to show the real details of the product (Figure 10).

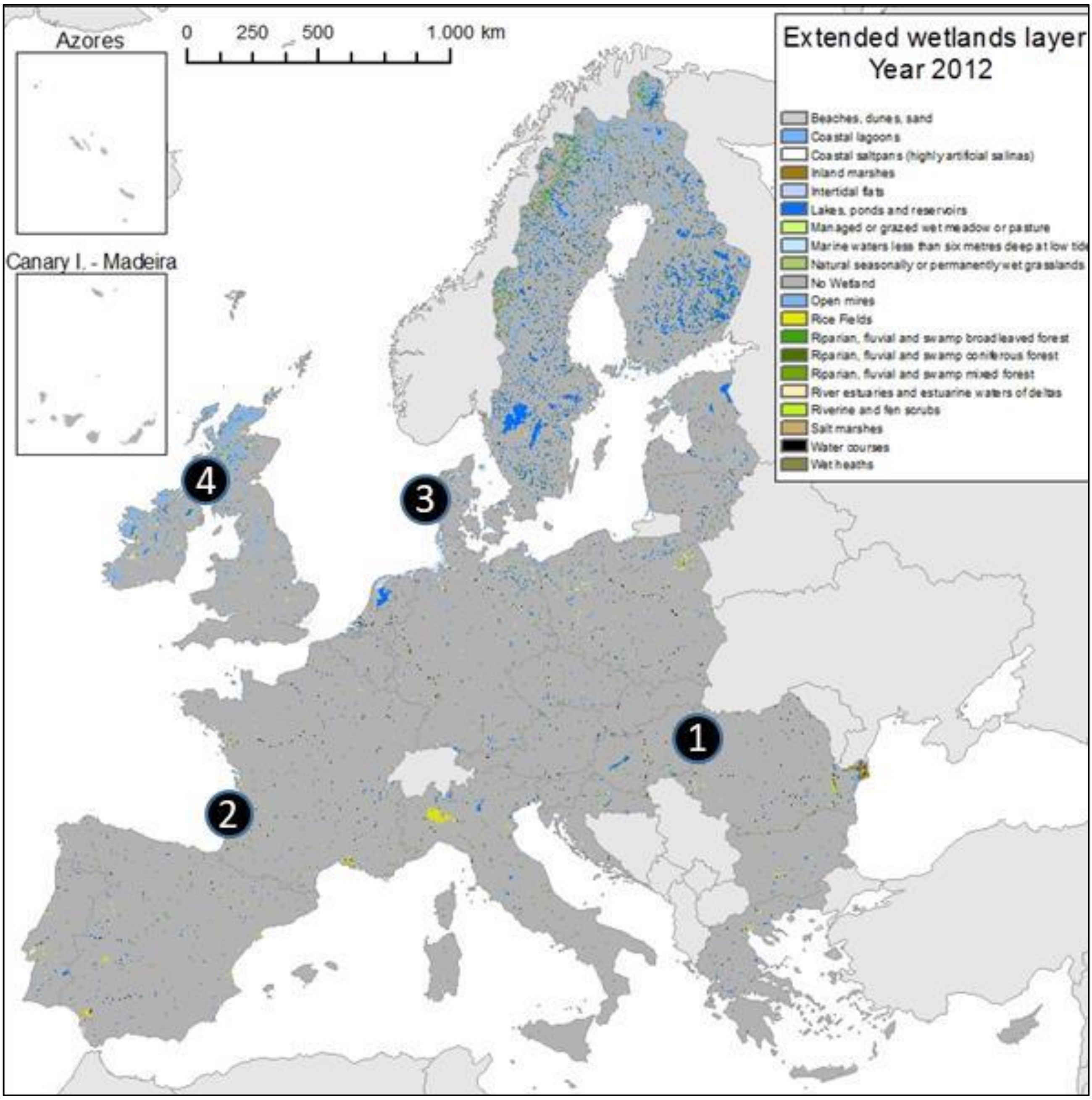


Figure 9: Extended wetland layer for 2012 covering 370,000 km2 of wetland habitats in EU-28

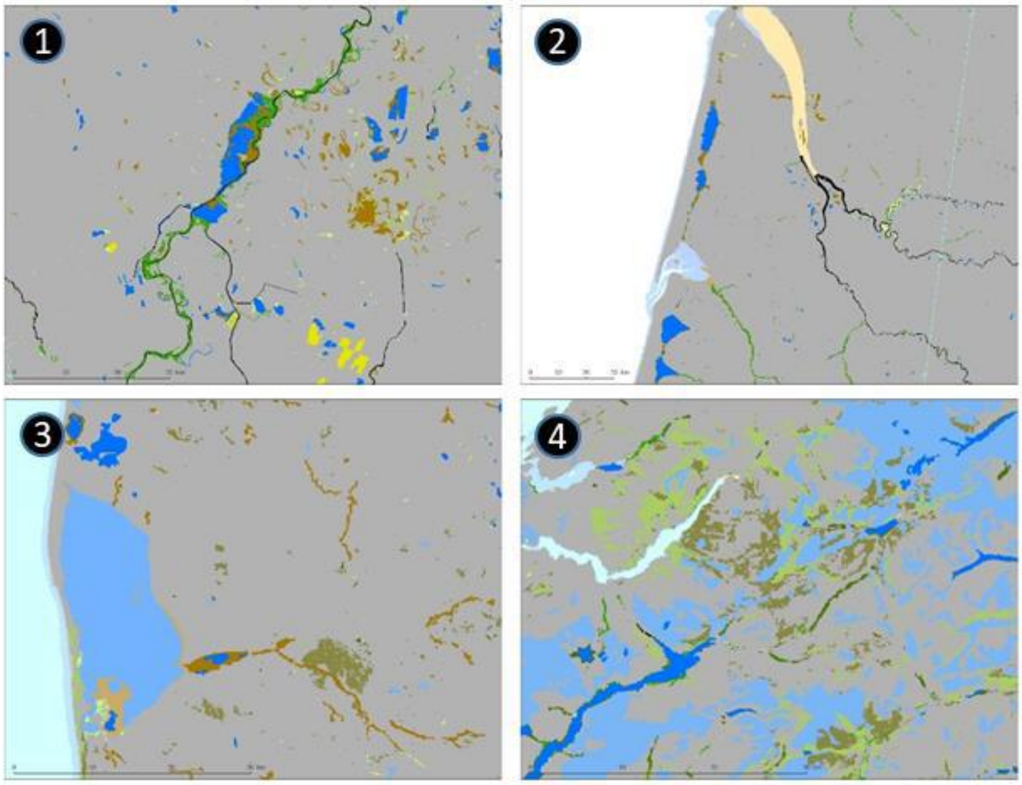


Figure 10: Extended wetland layer for 2012 for 4 specific contexts in Romania, France, Denmark and the UK

3 Toward a shared and multifunctional map of European wetland and coastal ecosystems

3.1 A common definition of European wetlands

A great diversity of wetlands exists, making the definition of a wetland ecosystem both challenging and sometimes controversial. As stated in Fitoka et al., 2017, the most widely accepted definition of wetlands is the one from the Ramsar Convention on Wetlands, made in 1971.

According to this text, wetlands are defined as: *"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six meters"*. Furthermore, wetlands *"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands"*.

3.1.1 The EUNIS wetland, coastal and marine habitats

- **Mires, bogs and fens, inland wetlands**

The wetland habitats belong to the EUNIS class "Mires, bogs and fens". They are defined as wetlands with the water table at or above ground level for at least half of the year, dominated by herbaceous or ericoid vegetation. They Include inland saltmarshes and waterlogged habitats where the groundwater is frozen, but excludes the water body and rock structure of springs (C2.1) as well as waterlogged habitats dominated by trees or large shrubs (F9.2, G1.4, G1.5, G3.D, G3.E).

In addition, habitats that intimately combine waterlogged mires and vegetation rafts with pools of open water are considered as complexes.

- **Coastal habitats**

Coastal habitats are those above spring high tide limit (or above mean water level in non-tidal waters) occupying coastal features and characterised by their proximity to the sea, including coastal dunes and wooded coastal dunes, beaches and cliffs. They include free-draining supralittoral habitats adjacent to marine habitats which are normally only affected by spray or splash, strandlines characterised by terrestrial invertebrates and moist and wet coastal dune slacks and dune-slack pools, but exclude supralittoral rock pools and habitats adjacent to the sea which are not characterised by salt spray, wave or sea-ice erosion (Table 1).

Table 1: List of the 37 EUNIS wetland and coastal habitat units (Level 3)

#	New code	Old code	New name
Coastal habitats (#19)			
1	N11	B1.1a	Atlantic, Baltic and Arctic sand beach
2	N12	B1.1b	Mediterranean and Black Sea sand beach
3	N13	B1.3a	Atlantic and Baltic shifting coastal dune
4	N14	B1.3b	Mediterranean, Macaronesian and Black Sea shifting coastal dune
5	N15	B1.4a	Atlantic and Baltic coastal dune grassland (grey dune)
6	N16	B1.4b	Mediterranean and Macaronesian coastal dune grassland (grey dune)
7	N17	B1.4c	Black Sea coastal dune grassland (grey dune)
8	N18	B1.5a	Atlantic and Baltic coastal Empetrum heath
9	N19	B1.5b	Atlantic coastal Calluna and Ulex heath
10	N1A	B1.6a	Atlantic and Baltic coastal dune scrub
11	N1B	B1.6b	Mediterranean and Black Sea coastal dune scrub
12	N1D	B1.7a	Atlantic and Baltic broad-leaved coastal dune forest
13	N1F	B1.7c	Baltic coniferous coastal dune forest
14	N1G	B1.7d	Mediterranean coniferous coastal dune forest
15	N1H	B1.8a	Atlantic and Baltic moist and wet dune slack
16	N1J	B1.8b	Mediterranean and Black Sea moist and wet dune slack
17	N21	B2.1a	Atlantic, Baltic and Arctic coastal shingle beach
18	N31	B3.1a	Atlantic and Baltic rocky sea cliff and shore
19	N32	B3.1b	Mediterranean and Black Sea rocky sea cliff and shore
Wetlands (#18)			
20	Q11	D1.1	Raised bog
21	Q12	D1.2	Blanket bog
22	Q21	D2.1	Oceanic valley mire
23	Q22	D2.2a	Poor fen
24	Q23	D2.2b	Relict mire of Mediterranean mountains
25	Q24	D2.2c	Intermediate fen and soft-water spring mire
26	Q25	D2.3a	Non-calcareous quaking mire
27	Q3132	D3.1	Palsa and polygon mires
28	Q41	D4.1a	Alkaline, calcareous, carbonate-rich small-sedge spring fen
29	Q42	D4.1a	Extremely rich moss-sedge fen
30	Q43	D4.1b	Tall-sedge base-rich fen
31	Q44	D4.1c	Calcareous quaking mire
32	Q45	D4.2	Arctic-alpine rich fen
33	Q46	-	Carpathian travertine fen with halophytes
34	Q51	C5.1a	Tall-helophyte bed
35	Q52	C5.1b	Small-helophyte bed
36	Q53	C5.2	Tall-sedge bed
37	Q54	C5.4	Inland saline or brackish helophyte bed

- **Coastal and marine wetland habitats**

Coastal Salt marshes habitats (M) can also be identified as coastal wetland ecosystems. They are defined as angiosperm-dominated stands of vegetation, occurring on the extreme upper shore of sheltered coasts and periodically covered by high tides. The vegetation develops on a variety of sandy and muddy sediment types and may have admixtures of coarser material. The character of the saltmarsh communities is affected by height up the shore, resulting in a zonation pattern related to the degree or frequency of immersion in seawater.

Their identification was the subject of another EUNIS mapping work, together with sparsely vegetated habitats (Table 2).

Table 2: List of the 17 EUNIS Salt marshes habitat units (Level 3)

#	New code	Old code	Habitat name	Distribution map	Suitability map
1	MA2	A2.5	Littoral biogenic habitat		
2	MA21	A2.5	Arctic Littoral biogenic habitat		
3	MA211	A2.5	Arctic coastal saltmarshes	x	-
4	MA22	A2.5	Atlantic littoral biogenic habitat		
5	MA221	A2.5	Atlantic saltmarsh driftline	x	x
6	MA222	A2.5	Atlantic upper saltmarshes	x	x
7	MA223	A2.5	Atlantic upper-mid saltmarshes and saline and brackish reed, rush and sedge beds	x	x
8	MA224	A2.5	Atlantic mid-low saltmarshes	x	x
9	MA225	A2.5	Atlantic pioneer saltmarshes	x	x
10	MA23	A2.5	Baltic hydrolittoral biogenic habitat		
11	MA232	A2.5	Baltic coastal meadow	x	x
12	MA24	A2.5	lack sea littoral biogenic habitats		
13	MA241	A2.5	Black Sea littoral saltmarshes	x	x
14	MA25	A2.5	Mediterranean littoral biogenic habitat		
15	MA251	A2.5	Mediterranean upper saltmarshes	x	x
16	MA252	A2.5	Mediterranean upper-mid saltmarshes and saline and brackish reed, rush and sedge beds	x	x
17	MA253	A2.5	Mediterranean mid-low saltmarshes	x	x

- **Other coastal habitats (littoral rock and sediment)**

Littoral rock includes habitats of bedrock, boulders and cobbles which occur in the intertidal zone (the area of the shore between high and low tides) and the splash zone. The upper limit is marked by the top of the lichen zone and the lower limit by the top of the laminarian kelp zone. There are many physical variables affecting rocky shore communities - wave exposure, salinity, temperature and the diurnal emersion and immersion of the shore. Wave exposure is most commonly used to characterise littoral rock, from 'extremely exposed' on the open coast to 'extremely sheltered' in enclosed inlets. Exposed shores tend to support faunal-dominated communities of barnacles and mussels and some robust seaweeds. Sheltered shores are most notable for their dense cover of fucoid seaweeds, with distinctive zones occurring down the shore. In between these extremes of wave exposure, on moderately exposed shores, mosaics of seaweeds and barnacles are more typical.

Littoral sediment includes habitats of shingle (mobile cobbles and pebbles), gravel, sand and mud or any combination of these which occur in the intertidal zone. They support communities tolerant to some degree of drainage at low tide and often subject to variation in air temperature and reduced salinity in estuarine situations. Very coarse sediments tend to support few macrofaunal species because these sediments tend to be mobile and subject to a high degree of drying when exposed at low tide. Finer sediments tend to be more stable and retain some water between high tides, and therefore support a greater diversity of species. Medium and fine sand shores usually support a range of oligochaetes, polychaetes, and burrowing crustaceans, and even more stable muddy sand shores also support a range of bivalves. Very fine and cohesive sediment (mud) tends to have a lower species diversity, because oxygen cannot penetrate far below the sediment surface. A black, anoxic layer of sediment develops under these circumstances, which may extend to the sediment surface and in which few species can survive. Some intertidal sediments are dominated by angiosperms, e.g. eelgrass (*Zostera noltii*) beds on the mid and upper shore of muddy sand flats, or saltmarshes which develop on the extreme upper shore of sheltered fine sediment flats.

Littoral sediments are found across the entire intertidal zone, including the strandline. Sediment biotopes can extend further landwards (dune systems, marshes) and further seawards (sublittoral sediments). Sediment shores are generally found along relatively more sheltered stretches of coast compared to rocky shores. Muddy shores or muddy sand shores occur mainly in very sheltered inlets and along estuaries, where wave exposure is low enough to allow fine sediments to settle. Sandy shores and coarser sediment (gravel, pebbles, cobbles) shores are found in areas subject to higher wave exposures.

Littoral sediment environments can change markedly over seasonal cycles, with sediment being eroded during winter storms and accreted during calmer summer months. The particle size structure of the sediment may change from finer to coarser during winter months, as finer sediment gets resuspended in seasonal exposed conditions. This may affect the sediment infauna, with some species only present in summer when sediments are more stable. These changes are most likely to affect sandy shores on relatively open shores. Sheltered muddy shores are likely to be more stable throughout the year, but may have a seasonal cover of green seaweeds during the summer period, particularly in nutrient enriched areas or where there is freshwater input.

3.1.2 MAES Ecosystem classes within the extended wetland layer

The MAES ecosystem types nomenclature initially limited the classification of wetlands to "inland wetlands" category, so coastal wetlands were classified as marine inlets and transitional waters (Table 3). Inland wetlands were described as *"predominantly water-logged specific plant and animal communities, supporting water regulation and peat-related processes. This class includes natural or modified mires, bogs and fens, as well as peat extraction sites."*

Table 3: Overview of a comprehensive classification of wetland ecosystems in Europe, including all the habitats linked to their hydro-ecological delimitation

Wetlands definition	What is included	Section	Available knowledge
Ramsar-based definition (extended wetlands)	MAES wetlands (inland marshes and peatbogs)	3.1	MAES assessment
			Art.17 assessment
	MAES Marine Inlets and Transitional Waters (coastal wetlands, lagoons, estuaries and other transitional waters)	3.2	Art.17 assessment
	MAES Rivers and Lakes	3.3	Art.17 assessment
	Beaches, Dunes and Sand		
	Managed and natural wet grasslands/pasture		
	Rice fields		MAES assessment for rivers and lakes
	Riparian, fluvial and swamp forests		
	Wet heaths		
	Riverine and fen scrubs		
	Marine waters < 6m deep		

However, areas that are currently treated as separate ecosystem types by MAES, are ecologically linked by their own water flows. Thus, water is released from upland peatlands into rivers, and then moves through marshes and lakes, before rivers issue into coastal wetlands such as estuaries with their saltmarshes and other coastal habitats (Table 4).

Table 4: Modified MAES nomenclature for the Extented wetland ecosystems layer

Modified MAES nomenclature	Modified MAES Class	Km^2	%
Rice Fields	2.1.3.1	7,665	1.6
Riparian, Fluvial and Swamp broadleaved forest	3.1	16,423	3.4
Riparian, Fluvial and Swamp coniferous forest	3.2	9,795	2.0
Riparian, Fluvial and Swamp mixed forest	3.3	2,269	0.5
Wet managed pasture and meadows	4.3.1	11,865	2.4
Wet natural grassland	4.3.2	5,050	1.0
Wet heaths	5.1.1.3	46,344	9.5
Riverine and fen scrubs	5.1.1.4	83	0.02
Beaches, dunes, sand	6.2.1	8,020	1.6
Inland marshes	7.1	13,898	2.8
Open mires	7.2	115,519	23.6
Salt marshes	8.1	5,529	1.1
Coastal lagoons	8.2.1	6,339	1.3
River estuaries and estuarine waters of deltas	8.2.2	3,654	0.7
Coastal saltpans (highly artificial salinas)	8.3	705	0.1
Intertidal flats	8.4	12,340	2.5
Water courses	9.1	13,470	2.8
Lakes, ponds and reservoirs	9.2	129,089	26.4
Marine Waters	10.1.1	80,527	16.5
Total		488,584	100

This extended definition of European wetlands according to their hydro-ecological dimension follows the Ramsar classification of wetland habitats that ensures the identification of transitional ecosystem types hydro-ecologically belonging to wetlands (Figure 11).

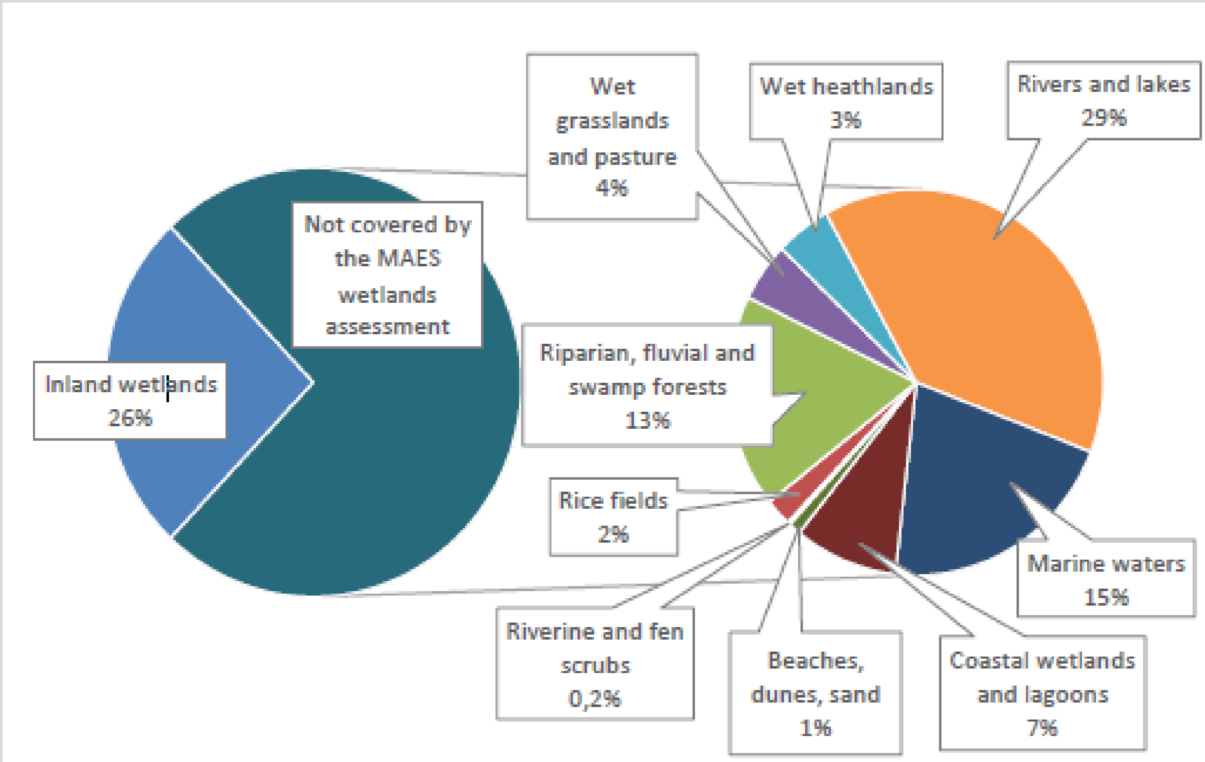


Figure 11: Extended wetland ecosystem layer at the EU-28 level: classes covered by the MAES Wetlands assessment (inland wetlands) and newly added ones are specified

- **Riparian, fluvial and swamp forest classes**

The riparian, fluvial and swamp forest classes represent MAES classes 3.1.1, 3.1.2, 3.2.1, 3.2.2, 3.3.1, 3.3.2.

The highest level of detail for the forest classes (level 3) can be achieved relying on the Copernicus RZP and N2K products. These products do not cover the entire study area, but focus on specific areas of interest (Riparian zones and N2K sites). In order to cover the rest of the areas, it was be possible to combine the forest CLC classes with a “water-related” product (WaW, GSWE). The WaW product was prioritised, since it is relative to the years 2009-2015, hence the water-wetness conditions could be considered valid for the period of interest (2000-2018).

On the other side, the GSWE product, although delivering a layer for each of the considered years, identifies only the water covered areas, not considering the “wetness” state which might be important for defining riparian or swamp forest areas. Alternatively, to simplify the approach, the considered forest classes were mapped relying on the only WaW product for the entire EU28 extent (hence not using the RZP dataset, which application should be anyways limited to the year 2012).

- **Managed and natural wet grassland, meadows or pastures**

These classes include MAES 4.3.1, 4.3.2 and EUNIS E3.

They can be imported from the ETM map (EUNIS E3). Alternatively, they could be mapped combining the corresponding CLC classes (2.3.1 “Pastures” and 3.2.1 “Natural grassland”) with the WaW layer. This last option would make the approach replicable for the whole time series (2000-2018).

- **Wet heaths**

Wet heaths fall under MAES 5.1.1.3 and EUNIS F4.1 categories.

This class can be imported from the ETM layer; alternatively, it can be derived from the combination of CLC 3.2.2 and WaW. This last option would make the approach replicable for the whole time series (2000-2018).

3.1.3 IUCN GEC/Ramsar/EUNIS/CLC/Art17 Crosswalk scheme for European wetlands

See Annex 1 - Draft overall crosswalk for EUNIS Wetland habitats and related Annex I habitat types according to Ramsar Wetland types.

3.2 Additional data for improving mapping of EU wetlands

Other potentially relevant sources of data that could be used to map wetland ecosystems were identified for improving the Extended wetland ecosystem map:

- GIS Lounge wetlands (point spatial database)
- CDDA layer on wetlands
- World Wetland Database (Greifswald University)
- National-Regional Inventories

In the case of several layers considered as good sources for mapping the extended wetland extent but with a lack of ecological dimension, the experts assessed their use for comparison with preliminary results from the initially proposed approach in selected study areas and, in the future, for possible improvements, if the comparison analysis shows feasible.

3.2.1 Ongoing and future experimental projects for habitat and ecosystem mapping

- **Combining the Extend wetland layer with the global surface water explorer product**

The extended wetland ecosystem layer baseline (Year 2012) could then be used in combination with the Global Surface Water Explorer (GSWE) raster data from JRC (https://global-surface-water.appspot.com/download), on the basis of which the wetland areas where there are being changes in terms of water coverage increase or decrease could be assessed.

It would be possible to assess the changes occurring in the sites and evaluate their performance in terms of conservation or allow highlighting activities of significant changes in order to trigger ad-hoc analysis and spotting potential infringements (indicators are currently being defined).

- **The Earth Observation for Biodiversity Modelling project (EO4Diversity)**

Within the ESA project 'Earth Observation for Biodiversity Modelling (EO4Diversity)', which started in October 2021 and will run for 18 months, a pilot study is included called 'EUNIS habitat modelling and mapping'.

The mapping and modelling of EUNIS Level 3 habitat types will be innovated by combining:

(i) high-resolution EO data, such as RS-EBVs (e.g., LAI, phenology, vegetation height, inundation) with
(ii) ESA and Copernicus high-resolution land cover data, soil and topography,
(iii) High-resolution climate data from CHELSA, and (iv) more than one million in situ vegetation plots from EVA.

State-of-art deep learning architectures that can handle the rich features enabled by EO data and derived products will be integrated into joint distribution models to predict all habitat classes as well as their spatial associations. The resulting EUNIS habitat suitability/probability maps can be used as a basis to improve the European Ecosystem Map.

3.2.2 Copernicus data and products

- **Corine Land Cover +**

The Corine Land Cover (CLC) maps have been produced at regular intervals from 1990 onwards. CLC has a wide variety of applications, underpinning various Community policies in the domains of environment, but also agriculture, transport, spatial planning, etc. The CLC land cover classification consists of an inventory of land cover in 44 classes, see Table 5.

Table 5: Changes in the Corine Land Cover maps over time

	CLC1990	CLC2000	CLC2006	CLC2012	CLC2018
Satellite data	Landsat-5 MSS/TM single date	Landsat-7 ETM single date	SPOT-4/5 and IRS P6 LISS III dual date	IRS P6 LISS III and RapidEye dual date	Sentinel-2 and Landsat-8 for gap filling
Time consistency	1986-1998	2000 +/- 1 year	2006+/- 1 year	2011-2012	2017-2018
Geometric accuracy, satellite data	≤ 50 m	≤ 25 m	≤ 25 m	≤ 25 m	≤ 10 m (Sentinel-2)
Min. mapping unit/width	25 ha / 100m	25 ha / 100m	25 ha / 100m	25 ha / 100m	25 ha / 100 m
Geometric accuracy, CLC	100 m	better than 100 m	better than 100 m	better than 100 m	better than 100 m
Thematic accuracy, CLC	≥ 85% (probably not achieved)	≥ 85% (achieved) [13]	≥ 85%	≥ 85% (probably achieved)	≥ 85%
Change mapping (CHA)	not implemented	boundary displacement min. 100 m; change area for existing polygons ≥ 5 ha; for isolated changes ≥ 25 ha	boundary displacement min.100 m; all changes ≥ 5 ha are to be mapped	boundary displacement min.100 m; all changes ≥ 5 ha are to be mapped	boundary displacement min.100 m; all changes ≥ 5 ha are to be mapped
Thematic accuracy, CHA	-	not checked	≥ 85% (achieved)	≥ 85%	≥ 85%
Production time	10 years	4 years	3 years	2 years	1.5 years
Documentation	incomplete metadata	standard metadata	standard metadata	standard metadata	standard metadata
Access to the data (CLC, CHA)	unclear dissemination policy	dissemination policy agreed from the start	free access for all users	free access for all users	free access for all users
Number of countries involved	26 (27 with late implementation)	30 (35 with late implementation)	38	39	39

CLC uses a Minimum Mapping Unit of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. Coordination and integration of national analyses for CLC map production is done by the EEA. Over time, the CLC mapping procedures have been updated and enhanced, resulting in shorter production time and higher resolution – both relevant considerations in ecosystem accounting.

The Copernicus program is working on a 2nd generation approach, known as CLC+. The approach is targeted to provide 3-yearly updates with a backbone of 10 m spatial resolution, and to join data from different sources (CLMS high resolution layers, countries and other) including (the 'CLC-Core'):

- Land cover components (LCC): abiotic, biotic and water classes
- Land use attributes / functions (LUA): primary production, industries, tertiary sector,
- transport networks, residential, other uses, etc.
- Further characteristics (CH): land management (i.e. agriculture or forest management measures or practices), spatial patterns, crop types activity, ecosystem types (i.e. EUNIS information), Height, Biophysical characteristics (i.e. phenology), etc.

The first dataset is expected to be available by end of 2021, with reference for the year 2018. The CLC+ concept should enable more flexible mapping towards ecosystem types, however such mapping has primarily focused per today on LULUCF and not yet on ecosystem accounting. The EEA states to continue its 'current coarse resolution (25 ha)' ecosystem accounts using the CLC-legacy layer, derived from CLC+. Simultaneously it targets to explore thematic land use improvements in the available data foundation, in particular from the CLC+ (1 ha) and other Copernicus program (i.e. High-Resolution Phenology to detect meadows or golf courses) and the combination with biodiversity data. The EEA also targets in the future to expand and refine the tiered approach for ecosystem extent accounts and add marine ecosystem types.

- **Copernicus – High resolution layers (HRL)**

Copernicus "High resolution layers" (HRL) provide a pan European land cover specific mapping based predominantly on Sentinel sensors. The product range covers five target land cover categories, provided as raster file types:

- Imperviousness (IMP)
- Forest (FOR)
- Grassland (GRA)
- Wetness and Water (WAW)
- Small Woody Features (SWF)

The Imperviousness and Forest layers cover three reference years (2012 / 2015 /2018) whereas the remaining products are only available for the years 2015 and 2018. From the reference year 2018 onwards, the products are available in an increased 10m resolution, earlier products feature a 20m resolution.

Naturally the WAW layer, which is produced from the combination of optical and radar data (Sentinel 1 / 2), features the thematically closest product for wetland mapping as it provides an aggregated time-series information on water presence. Thereby it is important to understand that the WAW layer is essentially a remote sensing product for a biophysical variable and is not intended to specifically map wetland as a habitat. As stated in chapter 2.1.3 the 2015 WAW layer was already utilised as ancillary information for the creation of the EUNIS probability layer. According to the user-guideline the WAW layer includes transitional coastal water bodies such as lagoons and estuaries. These elements are separated and delineated from sea water on the basis of a dedicated EEA coastline boundary layer. This boundary is harmonised across all HRL´s and does not necessarily correspond to the EUNIS definition (c.f. 3.1.1). This circumstance may therefore provide a potential source of error for mapping coastal wetlands.

With an improved resolution, the 2018 layer could be of special use where hygrophilous fringe vegetation occurs and thus especially for vegetation classes that follow linear landscape features such as rivers, rather than forming larger coherent patches. This may be especially relevant for temporarily waterlogged habitats which are, however, not part of the EUNIS wetland definition. An example for this would be the F9 class (EUNIS 2021 = S9 / Riverine and fen scrubs) which includes willow (*Salix spp.*) vegetation.

The WAW layer may also be deployed to support identifying riparian forest patches within terrestrial forest stands. For specifically improving EUNIS defined wetland classes (see 3.1.1) a combination

For this specific use-case, synergies with both the FOR, GRA and SWF layers could also be exploited. However, such approaches should always be accompanied by a detailed assessment in order to avoid introducing new sources of error. An example for this would be to consider the weaknesses of radar data in hilly terrain which may impact upon mapping accuracy in certain areas and therefore introduce localized error.

Whereas there are a variety of applications for the WAW layer for distinguishing semi-terrestrial from terrestrial vegetation, the potential for utilising the WAW layer for EUNIS specific wetlands is limited to specific applications.

- **Copernicus – High Resolution Vegetation Phenology and Productivity (HR-VPP)**

The High Resolution Phenology and Productivity (HR-VPP) product suite encompasses three major product groups all of which are provided at 10m resolution:

- **Vegetation indices**: This product group provides on a near real time basis pixel-level information on the following indices:
  - Leaf Area Index (LAI)
  - Fraction of Adsorbed Photosynthetically Active Radiation (FAPAR)
  - Normalized Difference Vegetation Index (NDVI)
  - Plant phenology index (PPI)
- **Seasonal trajectories** products are provided yearly after the end of the vegetation growing season. These are derived as a regular time-series of every 10 days by fitting a smoothing and gap filling function to the raw Plant Phenology Index, generated in the product group VIs;
- **Vegetation Phenology parameters**: product bundle are derived from the STs of the PPI index, on a yearly basis, after the end of the growing season. VPP metrics are provided for up to two growing seasons, being e.g. start of the season, end of season, seasonal productivity, etc

Due to the large amounts of data generated within the HR-VPP framework, direct data access shall be implemented via dedicated download tools (STATUS: October 2021). Data analysis can also be cloud based using dedicated Jupyter Notebooks.

In terms of wetland mapping phenological information can be used to support distinguishing persistent from non-persistent vegetation. Unlike non-persistent vegetation, persistent vegetation can be characterized by the presence of substantial amounts of biomass past the end of the growing season. Thereby the presence of non-persistent vegetation can also be used as an indication of salinity. This is especially relevant for the mapping of coastal wetland habitats.

- **Copernicus local component**

The local component product suite details specific thematic target areas at very high resolution (2.5m) and provides four major products:

- Urban Atlas
- Riparian Zones
- Natura 2000 (N2K)
- Coastal Zones

All generated products are made available as vector layers with a minimum mapping unit of 0.5 ha and cover a range of time steps partially dating back to 2006. All local component nomenclatures share a set of core classes essentially addressed to address MAES classification at level 2. This is then extended at higher levels to reflect the thematic content of the specific product.

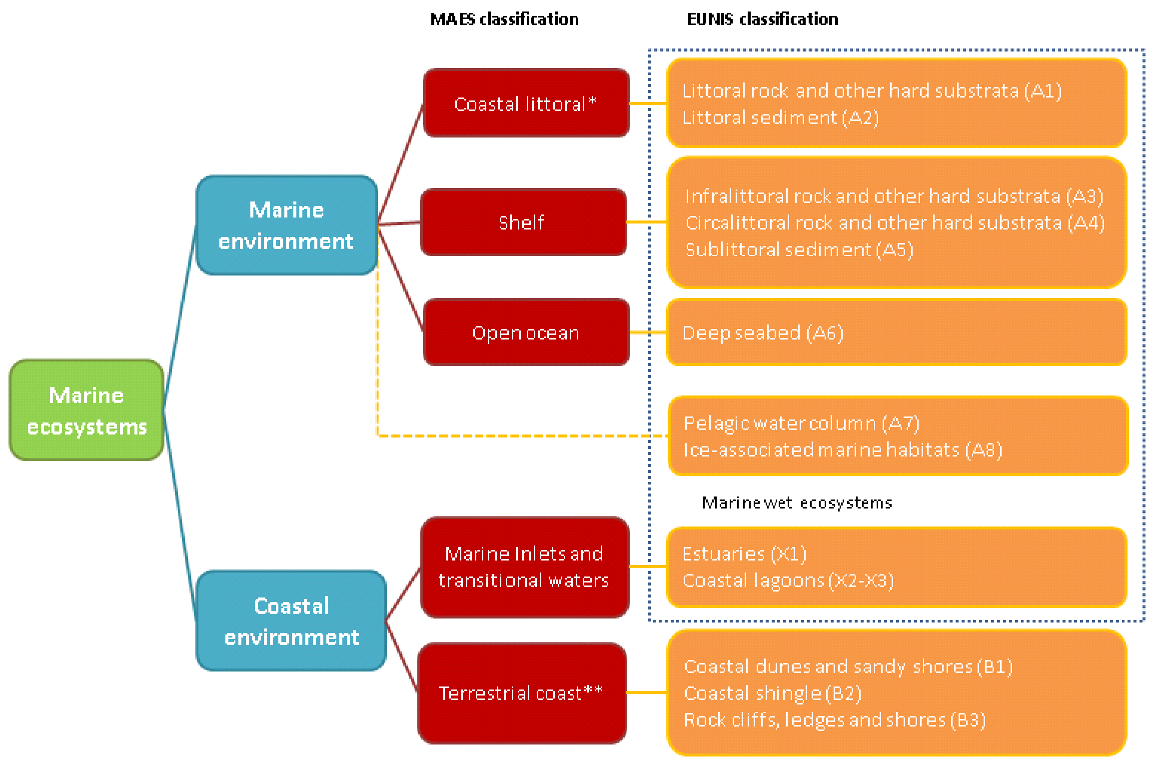
With regard to improving wetland mapping, both the riparian zones and coastal zones layer are likely the most relevant products. Although the N2K layer, which focuses on grassland rich Natura2000 sites, will likely feature substantial portions of wetland area.

Despite the limitations of the MAES nomenclature with regard to wetlands (c.f. 2.2.1), these layers feature a high potential to improve existing mapping products by providing pan European land cover information at very high resolution and for this reason have been utilised in the past.

3.2.3 Available datasets for mapping wetland marine & coastal habitats

Back in 2018, ETC/ULS developed a map of marine ecosystems (within task AP2018 -1.8.4.1) that was submitted to ETC/BD, further integrated into the EU Ecosystem Type Map v3.1 (ETM). Taking as a starting point this ETM v3.1 map, the goal of this sub-task is to explore the feasibility for updating and enhancing the mapping of wetland and marine habitats. This includes the revision and screening of potential improvements based on new or updated data sources - including the JRC “Seagrass map”- to be used as improvements of the methodology and inputs to be considered in the data integration between the terrestrial and the marine parts of the upcoming EU ecosystem map.

The marine and coastal environments can be defined and spatially delineated using the following EUNIS habitat classes (Figure 12).



*class name modified by ETC-SIA (original 'coastal areas')
** Not defined by MAES classification but by ETC-SIA to include the terrestrial habitats of coastal environment considered by EEA assessments

Figure 12: Conceptual framework including EUNIS and MAES classifications (Source: ETC-SIA)

The **land-sea interface** is a complex area to map, that still requires improvements in the understanding and in the method towards its accurate mapping. In this document, we refer to an approach to ensure a breakdown of this interface towards an improved mapping of important habitats, and to assess the feasibility of its mapping.

- **Defining the 'land-sea interface' ecosystems**

For the MAES initiative, Marine and coastal ecosystems were further refined in the dedicated typology into 4 main ecosystems:

- marine inlets and transitional waters;
- coastal waters;
- shelf waters, and;
- open ocean.

According to this typology, the '**marine environment'** encompasses all marine waters with salinity higher than 0.5 ‰, including waters at the land/sea interface defined by the nature of the substrate (littoral rocks or sediments) while the **'coastal environment'** is constituted of only the 'Marine inlets and transitional waters', defined as ecosystems on the land-water interface under the influence of tides and with salinity higher than 0.5 ‰ (salt marshes, salines, intertidal flats), which also include coastal lagoons, estuaries and other transitional waters, fjords and sea lochs, as well as embayments.

'Marine inlets and transitional waters' are also referenced as '**coastal wetlands'**, further defined as coastal and shallow marine systems that experience significant land-based influences, with diurnal fluctuations in temperature, salinity and turbidity, and affected by wave disturbance, and excluded the non-marine systems constituting the 'terrestrial coast' (Maes et al, 2013).

When considering the EUNIS habitat classification in complement to the MAES typology, **'Coastal areas'** could be defined as including some aquatic habitats effectively occurring adjacent to the coast, such as marine inlets and transitional waters, but also terrestrial habitats like sea rock cliffs, ledges and shores (B3), coastal shingle (B2) and coastal dunes (B1).

On the other hand, **'Marine areas'** could be characterised by marine waters and composed of habitats directly connected to the ocean, (below the high tide limit as defined by EUNIS). Marine ecosystems include 2 subdivisions, the seabed substrate and the water column, also differentiated according to their depths. The photic zone is the marine division close to the surface, of particular importance as it receives light and contains most of the primary productivity that supports marine food webs, including those in the deeper parts of Europe's seas. Salinity is also an important physico-chemical factor for species and their habitats in transitional and coastal waters (Howell, 2010).

The **land-sea interface** is however still not clearly mapped, and considers both terrestrial and marine linked habitats. Indeed, this 'land-sea interface' includes both the **Terrestrial coast,** comprising coastal dunes and sandy shores (B1), coastal shingle (B2) and rock cliffs, ledges, and shores (B3), but also intertidal habitats from the **Coastal littoral** comprising littoral rock and other hard substrata (A1) and Littoral sediment (A2), including coastal salt-marshes, mudflats and all hard, coarse and mixed sediment intertidal zones, as well as the habitat complexes Estuaries (X1) and Saline and brackish coastal lagoons (X2-X3) from the **Marine inlets and transitional waters.** However, intertidal habitats are, by definition, located "below the high tide limit", and considered as Marine habitats under the EUNIS classification.

This approach of including **Terrestrial coast** but excluding **Coastal littoral** was used in the development of the EU Ecosystem Type Map v3.1 and represents a different approach to the MAES definition of "coastal areas". For this purpose, the ETM v3.1 included a modified name to these areas, and referred to them as **coastal littoral ecosystems**, so a clear differentiation is made with the terrestrial stripe of coast, traditionally used in other EU assessments (i.e., SOER).

The work developed by ETC-ULS for mapping those coastal and littoral ecosystems (ETM v3.1), is the basis for the work presented below and includes the following steps:

- Classifying the coastal ecosystems, mainly terrestrial coast, based on Corine Land Cover;
- Classifying the marine ecosystem as follows:
  - Seven layers to differentiate water column depths, delineated for each of the European sea regions and based on bathymetry data, the measurements of the depth of water in oceans and the EUNIS classification;
  - The combination of these seven layers with six classes of seabed information, provided by the European Marine Observation and Data Network (EMODnet).
  - The combination of water column layers and seabed information resulted in 126 classes, for each European sea region.

Finally, to simplify the visualization, the information on water column and seabed is provided separately for each sea region.

- **Methodological approach for the EU ecosystem map v3.1.**

This document aims at improving the ETM (v 3.1) mapping of the coastal and marine ecosystem types, building on new/updated data sources as they became available. This analysis used as a primary data source the CLC for identifying the coastal ecosystems, and the European seabed habitats map (EUSeaMap) for identifying marine ecosystems.

The new generation of data for this improvement includes the **CLMS coastal zone** product and the **upgraded version of EUSeaMap,** which include the following improvements:

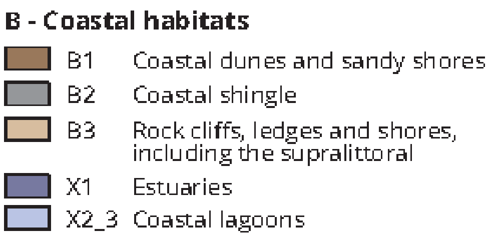
- Current version of EUSeaMap is at approximately 100 m (versus the previous version that was of 1km^2) and covers the EU marine full extent (the data used to produce the ETM v3.1 presented gaps for some EU seas), extending further into Norway and the Barents Sea. There have also been methodological refinements that improve the ensure improved accuracy of habitat classification in the current version.
- Coastal Zones 2018 status layer is at 10m spatial resolution (CLC, used to produce the ETM v3.1, is at 100m) and this product presents a tailored classification for covering the LU/LC specifications of coastal zones.

All the documentation regarding the work done for producing the EU marine ecosystem map 2012 (v.3.1) is here [Part A: ecosystem TYPE mapping | ETC Spatial Information and Analysis (europa.eu)](#).

For the development of the upcoming EU ecosystem coastal and marine map coastal, the marine ETM should be updated, as minimum, including these datasets in the methodological process because the higher resolution will enhance the modelled habitat maps; consequently, the resulting maps will be highly enhanced. There are additional improvements to include for updating the marine ecosystem map that are outlined in the next sections.

Updating the coastal part:

The European Ecosystem Type Map (ETM) v3.1 included as coastal ecosystem types:



The methodology of the mapping process to identify the coastal ecosystems in ETM v3.1 was based on Corine land cover (2012), HRLs (2012/2015) and the Copernicus local components available at that time (Urban Atlas, Riparian Zones and Natura 2000). Updated versions of most input datasets became available since then, but the most relevant opportunity to improve is the recently released Coastal Zones datasets (2012/2018).

The integration of this product into the ETM requires a crosswalk between the classes. As it was mentioned before, the ETM v3.1 already ingested the CLMS Local Components. So, the integration of Coastal zone will be in line with the approach used in the past for those products. Note that the ingestion of Coastal zone product into ETM will affect not only coastal ecosystems but all the LU/LC classes into a 10 km inland buffer zone.

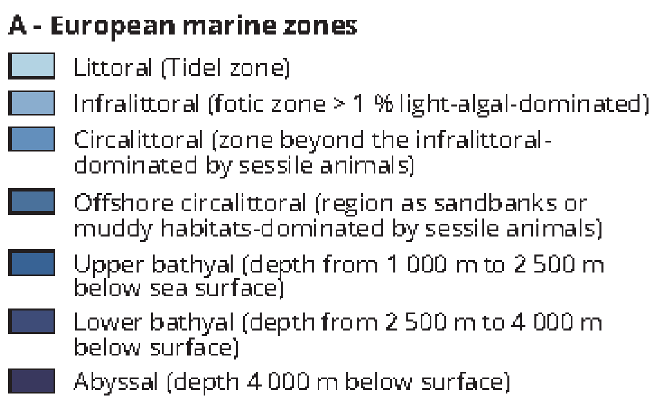
Additionally, a new version of the "Extended wetland ecosystem layer 2018" is ready to be published on the EEA SDI (under EEA QA/QC controls). Although the ETM provides a slightly modified classification of wetlands habitats, this layer could contribute to update/refine some classes of the coastal wetlands map since it integrates several ancillary spatial layers as input data. The metadata of the previous version could be consulted here.

Upgrade options - Coastal part

- Incorporate the new Copernicus Land Monitoring Service local product: Coastal Zones datasets.
- Cross-check with "Extended wetland ecosystem layer 2018"

Updating the marine part:

The European Ecosystem Type Map (ETM) v3.1 included as marine ecosystem types:



As summary, the classification used was based on the next parameters (Table 6):

Table 6: Parameters of marine ecosystem classification developed by ETC/ULS (2017)

Parameter	Value	Description
Sea region	1	Arctic
	2	Atlantic
	3	Baltic
	4	Mediterranean
	5	Black Sea
Sea zone	1	Littoral
	2	Infralittoral
	3	Circalittoral
	4	Offshore circalittoral
	5	Upper bathyal
	6	Lower bathyal
	7	Abyssal
	8	Estuaries
	9	Coastal lagoons
Ice coverage	0	no sea ice presence
	1	seasonal sea ice presence
	2	perennial sea ice
Substrate	0	undetermined substrate
	1	rock and biogenic
	2	biogenic
	3	coarse sediment
	4	mixed sediment
	5	sand
	6	mud

According to the methodology developed, each class is represented by a 4 digits numeric code:

- the first digit represents each sea region
- the second digit is for each sea zone
- the third digit provides information on the sea ice coverage
- the fourth defines the substrate

For example, class 1100 is Arctic littoral undetermined substrate, and 1526 is for Arctic Upper bathyal with perennial sea ice and mud sediment.

European seabed habitats map of EUSeaMap project produced broad scale modelled habitat maps following the EUNIS classification with some slight modifications. EUSeaMap project classifies the habitat at level 3, including energy at both wave and at seabed level discriminating infralittoral and circalittoral rock habitats into high, moderate, and low energy environments (McBreen et al., 2011). The ETM discriminated EUNIS level 2 classes for the marine environment, consequently energy parameters (wave and currents at seafloor) were not considered in this study.

Next sections summaries the datasets used to produce the ETM v3.1 for producing the marine ecosystems map and the opportunities to upgrade it. The analysis grounds very much on the approach of the previous version of the ETM focusing the developments on the ingestion of new datasets or new versions of those input data already used for ETM v3.1.

Sea regions:

The previous work used the version of the EEA dataset for European Sea Regions realized in 2013. The **upgrade option** is, simply, to **include** the updated dataset, realized in 2018. The improvement includes the agreement with the Marine Strategy Framework Directive (**MSFD**) **zoning** because this dataset compiles the marine regions and subregions listed in Article 4 of the MSFD, together with other surrounding seas of Europe.

Upgrade options - Sea regions

Incorporate the last sea regions dataset: Europe Seas - version 1, Dec. 2018

Seabed:

The physical nature of the seabed substratum influences the community types that develop above (McBreen et al., 2011 b). For this reason, it is extremely important to acquire reliable and accurate data on it. The main data source to produce ETM v3.1 for the seabed was the European seabed habitats map of EUSeaMap, 2017 version. EUSeaMap produced broad scale modelled habitat maps following the EUNIS classification with some slight modifications. This dataset did not cover the whole extent of the analysis at that time, and the rule was to use it as primary data source, where it was available, for seabed characterisation. Other data sources were used for filling the EUSeaMap gaps (MESHAtlantic, MEDINA, etc).

Last EUSeaMap versions, 2019 and 2021 (Figure 13), increased the extent of the mapped area including the Mediterranean Sea, Black Sea, Baltic Sea, and areas of the Northeastern Atlantic extending from the Canary Islands in the south to the Barents Sea in the north. EUSeaMap 2021 builds on previous iterations with an updated seabed substrate layer, provided by EMODnet Geology.

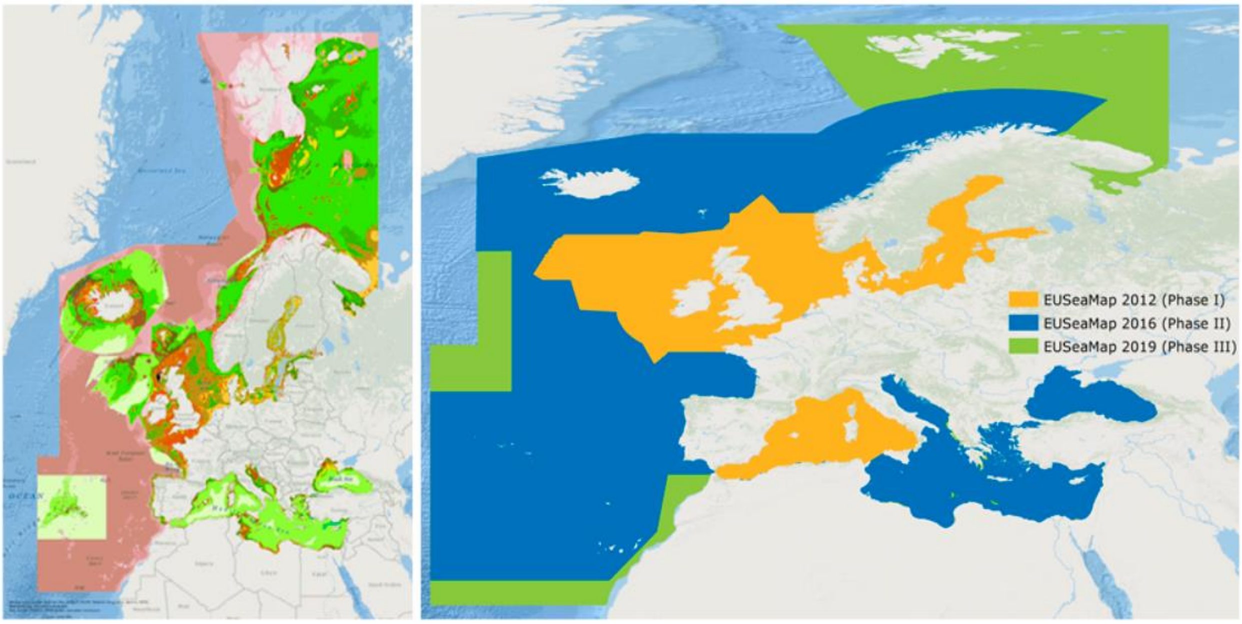


Figure 13: Overview of EUSeaMap 2021 (left) and coverage of the diferent EUSeaMap phases (right)

In addition, the inclusion of biogenic substrates has enabled to classify habitats to the new EUNIS 2019 classification system. Since 2019, the dataset is created at 100 metres (roughly); previous versions are at $1km^2$. The model used for mapping the EUNIS habitats includes the sublittoral zone only; due to the high variability of the littoral zone, a lack of detailed substrate data and the resolution of the model, it is difficult to predict littoral habitats at this scale. The next iteration will be in 2023. It will include updated depth and substrate data and for the first time will be extended to the Caspian Sea and some EU territories of the Caribbean.

UNEP-WCMC also developed [a specific product for seagrasses](#) showing their global distribution. It is composed of two subsets of point and polygon occurrence data, compiled by UNEP-WCMC in collaboration with many collaborators (e.g. Frederick Short of the University of New Hampshire), organisations (e.g. OSPAR), and projects (e.g. the European project Mediterranean Sensitive Habitats, MEDISEH), across the globe (Figure 14).

Figure 14: Sample of the Global Distributon of Seagrasses data (UNEP-WCMC)

Moreover, EMODnet Seabed Habitats portal provides modelled maps of specific habitats such as Posidonia oceanica in the Mediterranean Sea, Zostera marina in the Baltic Sea, cold water corals in the Atlantic Ocean, etc. These datasets are based on different classification models and provide habitat presence probability from 0 % to 100 % (Figure 15).

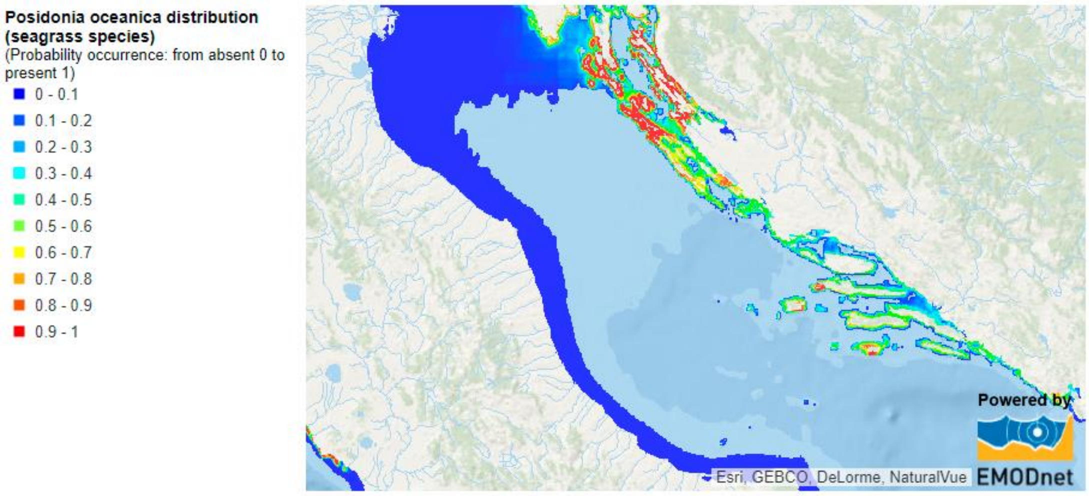


Figure 15: Posidonia oceanica probability map in the Adriatic Sea (EMODnet Seabed Habitats portal)

Upgrade options - Seabed
The new versions of the EUSeaMap offer important improvements to be considered for the incoming ETM. In addition, maps on seagrasses and other relevant habitats from EMODnet and UNEP-WCMC can be considered to refine the classification in certain geographic areas and for specific ecosystem types. Therefore, it is advisable to explore its potential inclusion in the methodology.

Sea depth:

The bathymetry can be used to discriminate the major divisions of coastal, shelf and open ocean. The shelf break occurs at variable depth; however, a general rule can be applied considering 200 m the average lower limit for the edge of the shelf (Davies et al., 2004). The EMODnet Bathymetry data products were used in the marine EMT v3.1. This is a Digital Terrain Models (DTM) that was, where possible and available, upon high resolution survey data sets, presenting a final resolution of 1/4 arc-minutes (15 arc-seconds ~ roughly 500 m). This dataset did not cover the whole extent of the analysis by then. For those areas where EMODNET bathymetry data was not available, GEBCO (General Bathymetric Chart of the Oceans) and others were used as input data (Figure 16).

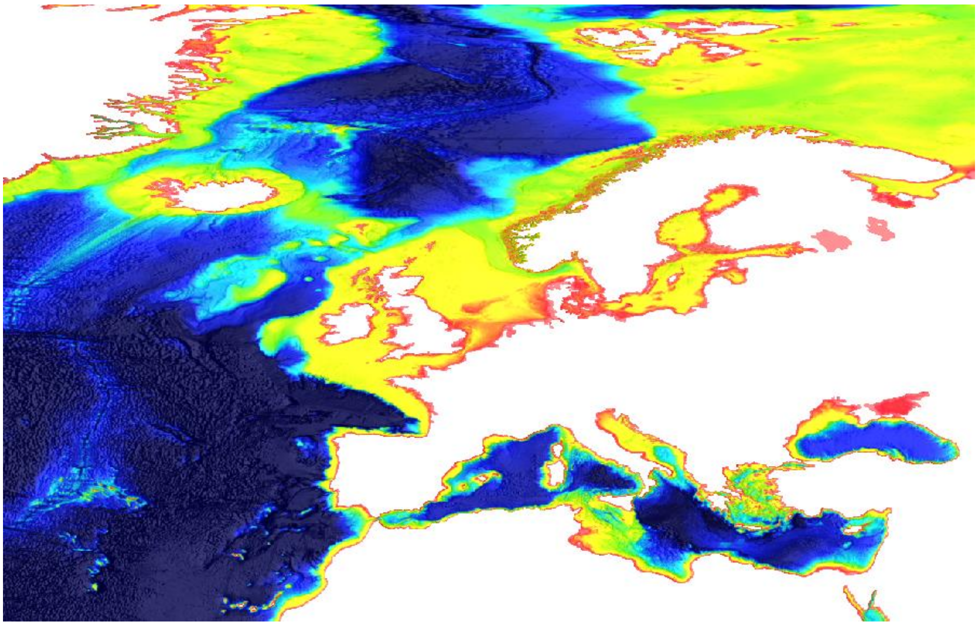


Figure 16: Overview of the EMODnet Digital Bathymetry 2020 (DTM)

Upgrade options – Sea depth

Newer versions of the EMODnet Digital Bathymetry (DTM) covers the full extent of Eu ecosystem type map. The 2020 DTM presents an improved spatial resolution respect to those used in 2015. This new release quadruples the resolution to 1/16 arc-minutes (circa 115 x 115 metres) by using the best available bathymetry data sets from an increasing number of data providers.

Light availability:

The euphotic zone provides a measure of the ocean depth below which light available is insufficient to support significant photosynthetic activity. It is the upper part of the water column, where most of the primary production occurs. The euphotic layer is the depth at which the visible light (400 – 700 nm range) reduces to 1 % of the light incident at the ocean surface. It is a measure of water quality, as well as an important variable to estimate water column primary production. This parameter was not included in the ETM v3.1 due to limitations of data source and resources. This parameter would allow the discrimination between infra and circa littoral ecosystems (A3 and A4 classes).

The Joint Research Center developed a specific product for the euphotic depth using MERIS data. The product is calculated according to a Quasi-Analytical Algorithm (QAA; Lee et al. 2007) in which vertical attenuation coefficient of the sub-surface light is modelled by the inherent optical properties of the water. The product is a monthly mean at 2 km resolution, covering the time period between May 2002 to September 2011.

The Global Ocean 3D Particulate Organic Carbon and Chlorophyll-a concentration, provided by the Copernicus Marine Service, consists of 3D fields of Particulate Organic Carbon (POC), Particulate Backscattering coefficient (bbp) and Chlorophyll-a concentration (Chla) at depth. This dataset infers the vertical distribution of Chla from surface ocean colour satellite observations of Chla and the relative position of the mixed layer and euphotic depths, with an horizontal resolution of 0.25° (~27-28 km), over 36 levels from the surface to 1000 m depth. Temporal coverage is so far 1998 to 2019.

Copernicus Marine Service also provides specific products on remote sensing reflectances and light attenuation coefficient for different European regional seas (North Atlantic, Baltic, Mediterranean and Black Sea). These datasets measure the ADG (volume absorption coefficient of radiative flux in sea water due to dissolved organic matter and non algal particles), APH (volume absorption coefficient of radiative flux in sea water due to phytoplankton) and ATOT (volume absorption coefficient of radiative flux in sea water); providing information on how the water turbidity affects the underwater light conditions, thus influencing primary production by phytoplankton and other algae in coastal waters. These products are remapped at nominal 300m (OLCI) and 1 Km spatial resolution using cylindrical equirectangular projection. Temporal coverage is from 2016 to present date (Figure 17).

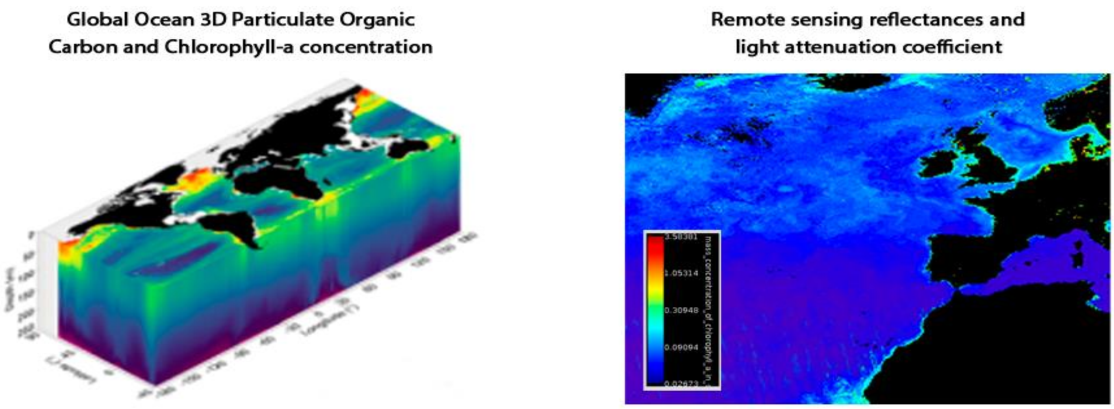


Figure 17: Conceptual framework including EUNIS and MAES classifications

Upgrade options – Light penetration / photosynthetic activity
Explore the potential of the JRC and Copernicus Marine Service products to be integrated in the ETM habitat classification methodology.

Sea ice:

Ice cover affects species distribution in coastal or shallow waters, but it has less influence than the physical parameters previously described (seabed sediment, depth, light penetration) when considering the broad extent of analysis (Cameron & Askew, 2011).

The ice cover dataset included for producing the marine ecosystem map v3.1 was generated data from MODIS, as it provides best available spatial (1km) and temporal resolution (from 2000 to 2014) by reflectance in the algorithm is stored as coded integers in the Sea_Ice_by_Reflectance SDS.

The parameter "ice cover" can be updated including values up to present but also including datasets from official repositories instead to be calculated by the user from satellite imagery. In this regards, the Copernicus Climate Change Service, concretely its [products related to the sea ice] could be a relevant source of data to be explored in depth. This dataset provides daily gridded data of sea ice edge and sea ice type derived from brightness temperatures measured by satellite passive microwave radiometers. Sea ice edge classifies the sea surface into open water, open ice, and closed ice depending on the amount of sea ice present in each grid cell. Sea ice type classifies ice-covered areas into two categories based on the age of the sea ice: multiyear ice versus seasonal first-year ice.

Both sea ice products are based on measurements from the series of Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave/Imager (SSM/I), and Special Sensor Microwave Imager/Sounder (SSMIS) sensors and share the same algorithm baseline. Sea ice edge data is provided at 12.5 km grid resolution, being true spatial resolution as resolved by sensor around 15 km. Sea ice type data is at 25 km resolution, with a true spatial resolution of 30-60 km. Temporal resolution is daily, with a 16-day latency, being available from 1978 to present date (Figure 18).

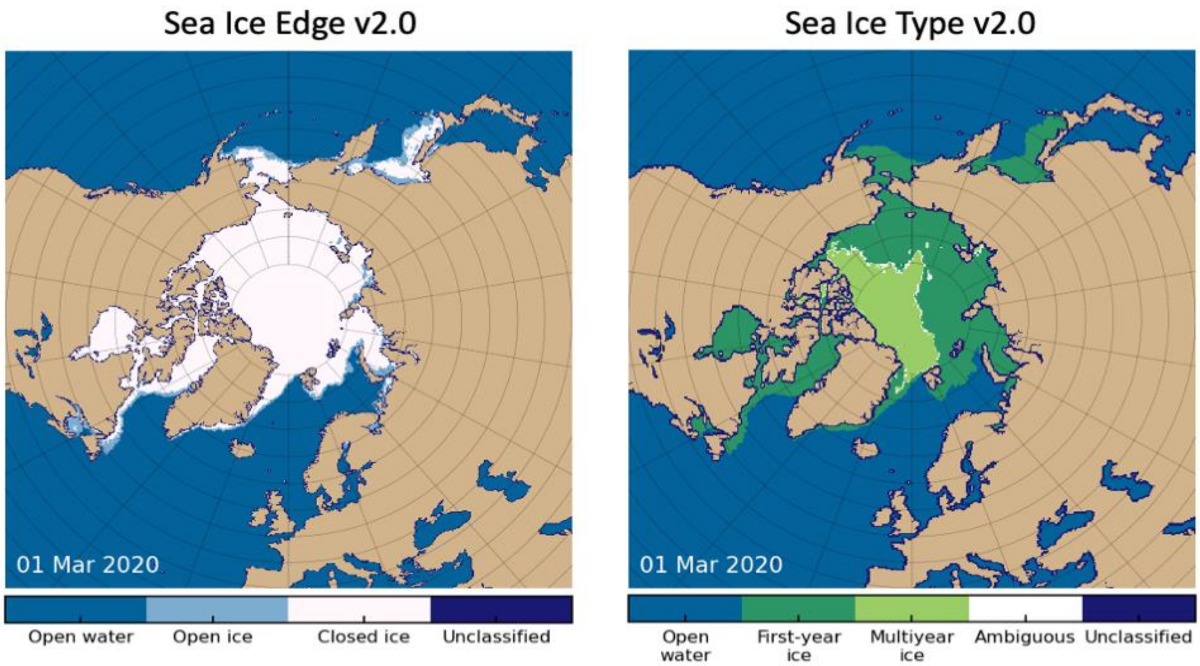


Figure 18: Map of the sea ice edge and type daily gridded data (Copernicus Climate Change Service)

Upgrade options – Sea Ice edge
Explore in depth the potential of the Copernicus Sea ice gridded data to be integrated into the ETM methodology. As data is available since 1978, it is possible to compare this product with the information derived from MODIS in the ETM v3.1 and assess its accuracy.

- **Conclusions**

A summary of the main actions that could be potentially implementing for updating and enhancing the EU marine ecosystem type map, already described in the different sections of the present report, is proposed as an ending note:

- **Incorporate the Coastal Zones datasets from CLMS;**
    - ***This allows to refine the classification of coastal belt of all European coasts and islands (10 km landwards);***
- **Use enhanced EUSeaMap datasets available:**
- **Extend the coverage to Canary Islands, the remaining Mediterranean areas (Adriatic, Ionian and Aegean Seas, and the Black Sea);**
- **Increase thematic reliability of resulting maps by the improvement of intermediate data (hydrodynamics models, seabed substrate layers, bathymetry, etc.);**
- **Refine working scale to 100 m pixel size;**
- **Incorporate maps on seagrasses and other relevant habitats from EMODnet and UNEP-WCMC;**
- **Incorporate euphotic depth related data from JRC and Copernicus Marine Service;**
- **Incorporate ice sea layer from Copernicus Climate Change Service.**

The main shortcoming found for EUSeaMap is that it does not cover the littoral zone; the classification simply does not cover the habitats there (from infralittoral to abyssal zone). Other available or future products offered by Copernicus Marine Service and Copernicus Land Service may be useful to cover this transitional area. Otherwise, a model could be defined to identify seabed substrate at 1st km from the coast using a combination of depth, slope, terrain curvature, and a measure of coastal exposure (Burrows et al., 2008). The combination of these variables performed well with a high degree of certainty (ROC-values > 0.8) in a model used to predict rocky shores in Norway (Bekkby et al., 2009). The methodology would need further development to be applied to the whole EU sea regions.

3.3 Technical requirements and case studies

3.3.1 Technical requirements for remote sensing of wetlands

This chapter provides a short synthesis of the general remote sensing specific challenges and requirements for wetland mapping initiatives. For a more comprehensive review of the use of various remote sensing sensors in the field of wetland mapping please refer to (Guo et al., 2017).

- **Sensor types and field of application**

In recent decades, remote sensing technology has been an indispensable tool for wetland mapping and monitoring (Guo et al., 2017). Wetland mapping can be targeted with a variety of different sensor types ranging from airborne imagery to RaDAR based systems (Table 7). Frequently a combination of different sensors is implemented and also recommended to achieve optimal mapping results (White & Lewis, 2013). Table 3.1 provides a basic overview of the field of application for different sensor types.

Table 7: Overview of remote sensing sensor types which can be utilized for wetland mapping (Guo et al., 2017)

Sensor type	Ground (Range) Resolution	Field of application
Aerial photography	< 1m	• Wetland plant community and/or species differentiation.
Coarse resolution	6000-7000m	• Wetland identification, frequently in combination with vegetation indices (NDVI etc.).
Medium resolution	100-1000m	• Class differentiation, • Flood dynamics • Biomass estimates.
High resolution	5-100m	• Wetland plant community and/or species differentiation. • Mapping verification/ improvement
Hyperspectral imagery	~1-30m	• Wetland plant community and/or species differentiation. • Determination of leaf chlorophyll / nutrient content.
RaDAR (Radio Detection and Ranging)	Heavily Platform / Band dependent (>10cm)	• Mainly used in cloud saturated areas (tropics) • Flood extent mapping • Identification of flooded vegetation • Biomass estimates
LiDAR (Light Detection and Ranging)	<10mm	• Optimisation of elevation data

While airborne as well as high resolution and hyperspectral systems are the most suitable sensors for wetland identification at the landscape level, these data usually can only cover smaller amounts of area and thus covering larger regions may be connected to high cost. Coarse/medium resolution data on the other hand may obtain larger spatial coverage, but is not likely to provide the level of detail required to ascertain narrow linear vegetation strips as they might be observed in the case of riverine vegetation and certain coastal habitats. This trade-off situation promotes the use of a multi-sensor approach.

- **Characteristics of wetland mapping**

Wetland mapping can be challenging due to the spectral proximity of land cover classes and between different wetland types (Maurer & Bauer, 2002). In addition, variations in terms of flooding dynamics with changing water levels over time can make wetland type distinction dependant on date or time of image acquisition. Gradually changing fluvial dynamics also inflict upon mapping accuracy over larger time periods.

Extracting species level information requires distinguishable vegetation pattern and optical imagery alone usually fails to identify vegetation types within wetlands due to signal saturation in dense vegetation cover (Morandeira et al, 2016). Therefore, oftentimes additional ancillary information such as in-situ vegetation plots, soil data or digital elevation models (DEM) is incorporated to distinguish classes and increase mapping accuracy by training and optimising spatial distribution models (c.f. 2.1).

Because wetlands occur as ecotones between terrestrial and aquatic ecosystems mapping scale can considerably affect the distinction of habitats (Figure 3.9) and emphasize should be put on the analysis of sub pixel spectral composition. While this is not a problem specific to remote sensing of wetlands and can evidently be reduced by the use of higher resolution imagery, it is certainly magnified by the occurrence of linear structures in wetland fringe vegetation.

Apart from relying on direct optical sensory, the indirect identification of wetlands habitats on the basis of biophysical and -chemical variables can also play a vital role in the mapping process. These variables may include:

- Soil moisture / water level
- Phenological cycles / variation
- Salinity

In this regard, hyperspectral and multispectral data of such variables can support estimating multiple vegetation specific parameters and thus identify properties and landscape specific patterns of wetland habitats (Mishra et al., 2015).

3.3.2 Recommendations for wetland mapping

From early developments until recent approaches there appears to be a general consensus among researchers to utilize data fusion techniques in order to improve wetland specific mappings (Guo et al., 2017; Maurer & Bauer, 2002; Mishra et al., 2015).

Combining different sources of information allows to reduce potentially detrimental effects of sensor specificities on the mapping result. Yet still, the choice of sensor still requires aligning a sensors´ strengths and weaknesses with the overall mapping target.

While only few mapping approaches aim at continental coverage (c.f. chapter 2) a multi-sensor approach may also be deployed for a pan-European mapping. However, the complexity of covering the extensive types of wetlands encountered within Europe may be a significant hurdle for such undertakings, requiring substantial research and computational effort as well as potentially incurring data acquisition cost.

In order to improve the status quo of mapping integrating the recent HR-VPP Copernicus product lineage, which now provides more detailed time series information, into future mapping initiatives may support disentangling phenological plant community characteristics in wetlands. While hyperspectral information is still largely only commercially available and may thus be less suitable for larger mapping projects, the increasing availability of non-commercial LiDAR information across Europe (JRC, 2021) is likely to provide a future cornerstone for wetland mapping in coastal habitats.

3.3.3 Local case study: Comparison of Ecosystem Type Map, Extended Wetland layer and localized EUNIS mapping along French Atlantic coast

- **Overview**

The present case study provides a short map comparison of the European Ecosystem Type Probability Map at EUNIS Level 2 (ETM), the newly released EUNIS habitat suitability maps (ETSM) and the Extended Wetland layer (EXT) with a dedicated localized EUNIS mapping product. The later reference mapping product stems from a study by Rapinel et al. 2021 which set out to map grassland habitats across France. Of the six EUNIS classes contained in the produced layer the class A2.5 (Coastal saltmarshes and saline reedbeds) was selected for analysis. The ETSM has been mapped using an updated EUNIS nomenclature. In the present case the thresholded product was used which is *"…a binary map based on the 10-percentile training presence. The 10-percentile training presence is a threshold which omits all regions with habitat suitability lower than the suitability values for the lowest 10 % of occurrence records. It assumes that the 10 % of occurrence records in the least suitable habitat aren't occurring in regions that are representative of the species overall habitat, and thus should be omitted."* (Hennekens, 2021).

At a resolution of approx. 250m, the resolution is quite coarse. Evidently, a higher resolution mapping product or actual field data would have been the preferable data source for this comparison. However, similar to the mapping approach for the ETM, Rapinel et al. 2021 also utilised vegetation plots as ancillary data. Therefore, the mapping is not based purely on topographic or biophysical variables.

- **Study area**

The target area includes all A2.5 class area mapped by Rapinel et al 2021. This class comprises roughly 2000 km² and is mainly located along the French Atlantic coast (Figure 19). The spatial distribution of the class is ranges from Quimper in the North until Bordeaux in the South. Larger coherent patches were mapped in the Breton Marsh (“Marais Breton”) which presents a renowned historic agriculturally utilized marshland.

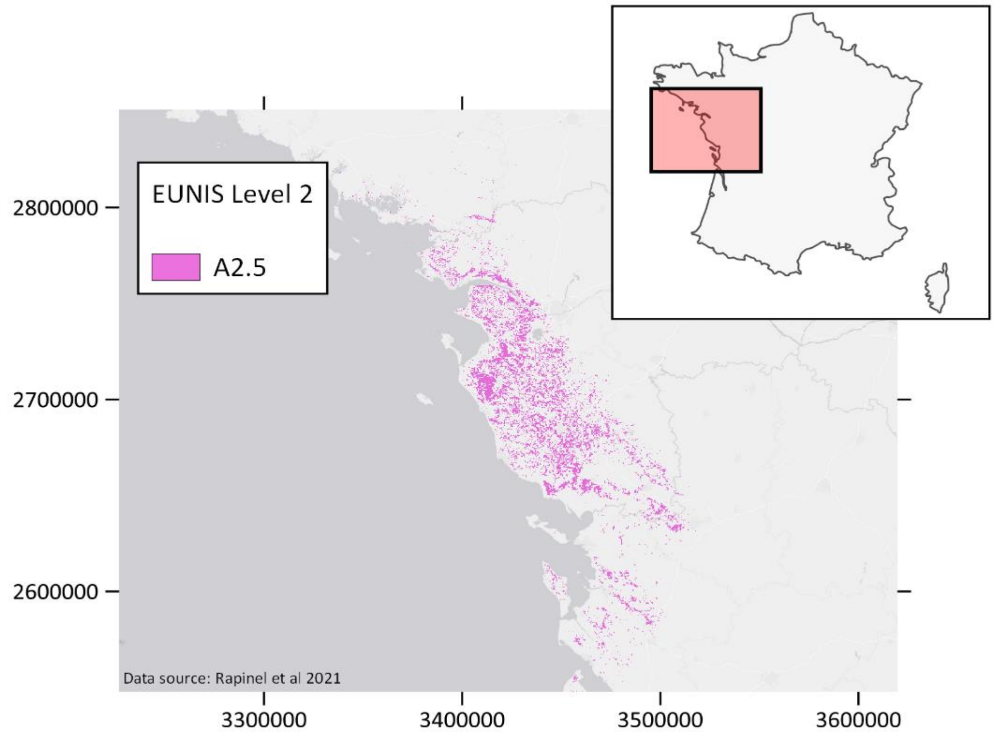


Figure 19: Overview of mapped EUNIS class A2.5 according to Rapinel et al 2021

- **Map comparison**

In order to compare both ETM, ETSM and EXT with the reference layer the class A2.5 reference layer was resampled to a resolution of 100m. Again, this is not ideal as this might introduce an additional source of error. However, this was deemed necessary to match the higher resolution comparison products. Subsequently the class A2.5 was overlaid with the ETM and EXT raster products. An accuracy assessment on the basis of e.g. randomized stratified sampling was not conducted due to the use of different classifications across all products. Despite the ETM being based on EUNIS classification the marine classes A1 - A8 are replaced by custom classification based on combined parameters on sea region, sea zone, substrate and ice coverage.

As the ETSM threshold product is a binary mapping the individual class coverage within the extents of the A.2.5 class can be seen in Table 8. While there is some overlap between the individual ETSM classes (not indicated here), the intersection with the A.2.5 class is generally low. All available “M” classes are located in close proximity to the coastline and the list of classes does not represent the full habitat extent of class A.2.5. Especially, habitat located further inland is not included.

Table 8: Cross tabulation of ETSM coverage of EUNIS A2.5 mapping (Rapinel et al. 2019)

EUNIS Habitat Suitability Maps (Thresholded	EUNIS A2.5
M221 (Atlantic saltmarsh driftlines)	3.72 %
M222 (Atlantic upper saltmarshes)	9.39 %
M223 (Atlantic upper-mid saltmarshes and saline and brackish reed, rush and sedge beds)	9.66 %
M224 (Atlantic mid-low saltmarshes)	7.48 %
M225 (Atlantic pioneer saltmarshes)	3.39 %

In total, 30 mapping categories from the ETM and 14 mapping categories from the EXT were identified within pixels designated as A2.5 by the reference layer. The majority of these classes covered less than 1 % of the study area and can therefore be treated as a likely result of the resampling and/or related to the mapping accuracy of these classes. Figure 20 displays the degree of class coverage for classes above a minimum threshold of 1 % total cover.

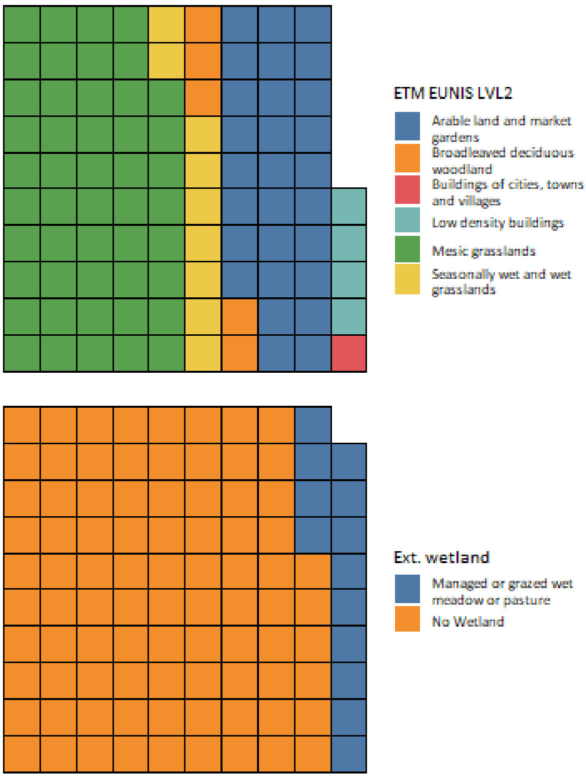


Figure 20: Waffle plots of EUNIS Level 2 Ecosytem type map (top) and Extended wetland layer (bottom) area proportions within EUNIS Class A2.5 mapped by Rapinel et al 2021. Classes of both overlay layers that did not exceed a 1 % area coverage threshold were removed

For the ETM, there is a notable complete absence of coastal habitats. The only class that is characterised by generally higher soil moisture is E3 (Seasonally wet and wet grassland) and only covers a small proportion of the total area (9%). Roughly, half of the area was designated as mesic grassland another third was mapped as cultivated arable land (and market gardens). Woodland and artificial area together amount to roughly 10 %.

In terms of classes the EXT is considerably less diverse, designating the vast majority of the area as “non-wetland” (86 %). The remainder is mapped predominantly as “Managed or grazed wet meadow or pasture”. Similar to the ETM the Extended wetland layer therefore mostly identifies the area mapped as A2.5 by Rapinel et al 2021 as terrestrial habitat.

The circumstance that both compared layers identify most of the area as terrestrial may be rooted in a similar product lineage (ETM used partially as input for the EXT) and their commonality with CLC. This similarity can be seen in Figure 21, where the classes D5 and “Inland marshes” feature a high spatial similarity. The ETM and EXT were not further assessed for spatial autocorrelation in the context of this exercise. Therefore, this degree of similarity must not necessarily be observed for all classes and different locations.

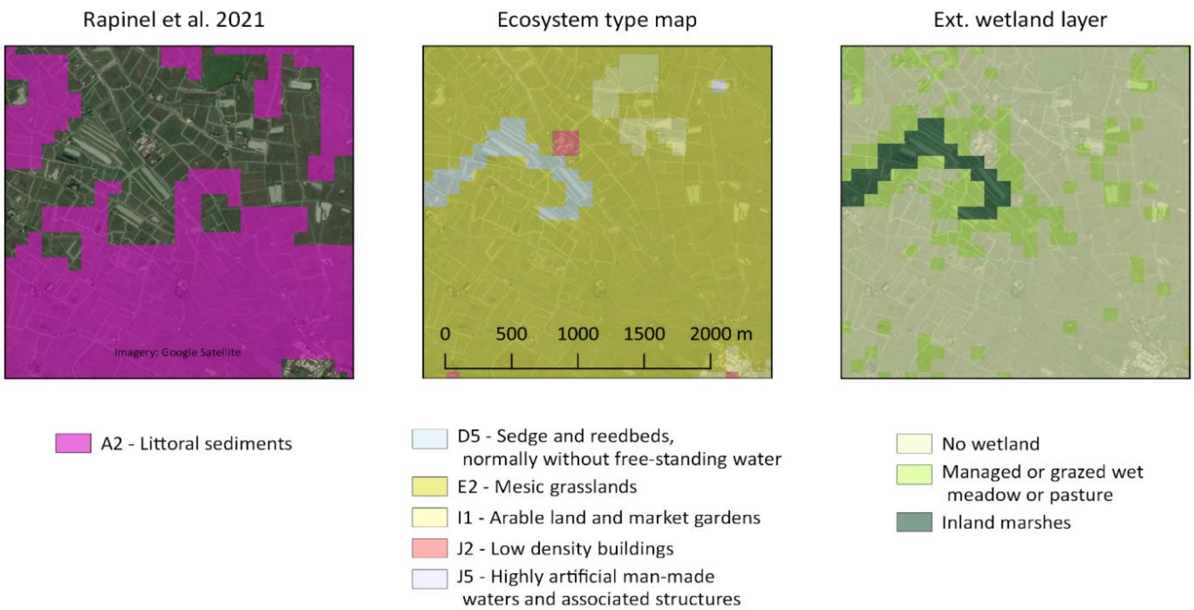


Figure 21: Example of the three compared mapping products showing a typical marshland landscape of the Breton marsh (WGS84: 46.95, -1.912)

For the greater area of the Breton marsh, it can be seen that all layers exhibit inconsistencies in terms of mapping agriculturally utilised marshland. This is interesting given the homogeneous landscape that characterises this area. The ETM is also accompanied by a dedicated reliability layer indicating both thematic and geometric reliability. With regard to thematic reliability large portions of the area were assigned with a very low reliability this also applies to geometric reliability albeit to a lesser degree.

- **Conclusion**

This brief exercise compared three wetland mapping products based on remotely sensed data and (partially) vegetation plot information. Because field data could not directly be accessed the comparison between the products remains relative and subject to spatial restrictions given by sensor resolution. Most of the area designated as A.2.5 by the mapping of Rapinel et al. 2021 was designated as non-wetland habitat by ETM, ETSM and EXT. Concerning the ETSM the comparison has to be considered incomplete as not all classes contained in the A.2.5 level were available for comparison.

A non-systematic review of core marshland areas along the French coast revealed that frequently adjacent homogeneous landscape units were mapped towards different classes. This applies to all products including the reference layer. This circumstance underlines the need for a better understanding of class composition and distinguishing variables for hygrophilous habitats.

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Annex 1 Draft overall crosswalk for EUNIS Wetland habitats and related Annex I habitat types according to Ramsar Wetland types