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**Preparatory Action for development and assessment of a European
broad-scale seabed habitat map**

EUSEaMap

Draft Final Report

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EMODnet
European Marine
Observation and
Data Network



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Executive Summary

A consortium of partners from across four Marine Regions (Baltic, North, Celtic and western Mediterranean Seas) has joined together to deliver the requirements for EC Tender MARE/2008/07. The EUSeaMap Partnership comprises government agencies and research institutions with proven national and international expertise in marine seabed mapping and modelling. The project will build upon the highly successful INTERREG MESH¹ and BALANCE² projects, by harmonising the MESH EUNIS seabed habitat maps for the North Sea and Celtic Seas with the seabed maps of the Baltic BALANCE project and extending the methodology to the western Mediterranean basin. Through expert application of the EUNIS classification and improved input data layers and seabed habitat modelling techniques, existing maps will be improved and refined, and their coverage seamlessly extended in the specified Marine Regions.

This Draft Final Report of EUSeaMap summarises the work of the project to date. Through a review of seabed habitat modelling and mapping in European waters, a consistent methodology has been developed across the partnership, which takes account of the diverse range of seabed habitats found in different Regions. Spatial data have been prepared for a suite of environmental variables, which form the basis of the model. This includes data provided by EMODNET geology and hydrography projects³. Biological data have been incorporated into the modelling process, through the development of ecologically-relevant thresholds. Models were run in three areas (Baltic, Western Mediterranean, North and Celtic Seas) to produce seabed habitat maps covering nearly 2 million square kilometres. All the models are structured to allow ready update of the maps, as new higher quality data become available in the future.

Three techniques have been developed for creating confidence maps associated with the seabed habitat maps. Confidence maps are important to enable the variation in quality and resolution of the input data layers to be visually reflected. The EUSeaMap pilot webGIS has been built, through which the final seabed habitat maps, environmental variables and confidence maps will be disseminated; additional functionality is in development ahead of the project completion in December.

In this final phase of the project a series of assessments to demonstrate the applications of the maps will be carried out to highlight benefits and weaknesses of such maps, including through stakeholder feedback. An assessment of further work required to refine the maps and to extend them to other parts of European seas will be undertaken.

¹ Development of a Framework for Mapping European Seabed Habitats (www.searchMESH.net)

² Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning (www.balance-eu.org)

³ Preparatory Actions for European Marine Observation and Data Network, No. MARE/2008/03, Lots 1 & 2

Table of Contents

1. Introduction	1
1.1. Background.....	1
1.2. Objectives.....	2
2. Review of Mapping and Modelling Seabed Habitats in Europe	3
2.1. Classification systems.....	3
2.2. International European modelling programmes	5
2.3. National marine habitat modelling programmes	10
2.4. National seabed survey programmes	17
2.5. EUSeaMap and future mapping	18
3. Rationale.....	19
3.1. Biological or depth zone.....	19
3.2. Substrate	22
3.3. Energy at the seabed.....	23
3.4. Salinity	25
3.5. Dissolved oxygen.....	26
3.6. Temperature	26
3.7. Ice cover	27
4. Methodology.....	28
4.1. Application of EUNIS	28
4.2. Modelling	31
4.3. Defining thresholds for habitats	32
4.4. Confidence	35
5. Data layers	36
5.1. Biological zone.....	39
5.2. Substrate	55
5.3. Energy at the seabed.....	62
5.4. Salinity	65
6. Modelling	66

6.1.	General principles	66
6.2.	Seabed habitat maps produced by the models	69
7.	Confidence – Assessing and showing certainty in the predicted maps ...	75
7.1.	Source data confidence.....	75
7.2.	Confidence by validation against surveyed habitats	76
7.3.	Confidence in boundaries using fuzzy thresholds.....	77
8.	Making data available	82
9.	Assessment of benefits.....	88
9.1.	Essential Fish Habitat	88
9.2.	Network of Marine Protected Areas.....	88
9.3.	Potential sites for sand and gravel extraction	96
9.4.	Potential sites for wind farms	96
9.5.	Tourist facilities	96
9.6.	Assessment of multiple uses in spatial planning	96
9.7.	Marine Strategy Framework Directive Initial Assessment.....	96
10.	Assessment of next steps	96
11.	Summary.....	97
12.	References	98
Appendix I.	Version Control	104
Appendix II.	EUNIS habitats – Western Mediterranean	105
Appendix III.	Publicity log	108
Appendix IV.	Data sources summary	110

List of Figures

Figure 1 BALANCE seabed habitat map.	7
Figure 2 MESH predicted seabed habitat map.	9
Figure 3 UKSeaMap 2010 predictive seabed habitat map (most detailed classes).	11
Figure 4 Overview of energy effects from water movement over the seabed due to waves (l) and currents (r).	24
Figure 5 Geographic extent of the EUSeaMap project.	28
Figure 6 Examples from the EUNIS hierarchy.	30
Figure 7 Illustration of raster based multicriteria evaluation.	31
Figure 8 Fuzzy thresholds, example using two classes.	34
Figure 9 Overview of photic depth (Zeu) as computed for the MERIS swath zone.	40
Figure 10 Comparison of 1% light contour from MERIS imagery (250m resolution) with seagrass bed outlines in Corsica.	42
Figure 11 Scatter plot of April mean Secchi depths vs. growing season (March to October) mean Secchi depths.	43
Figure 12 Water depth : Secchi depth ratio for the Baltic Sea.	46
Figure 13 Bathymetry of the Western Mediterranean.	47
Figure 14 Seabottom slope angle change observed in the western Meditteranean.	48
Figure 15 Bathymetry of the North Sea and Celtic Seas.	49
Figure 16 Coverages of four bathymetry maps used to make the BALANCE bathymetry map for the Baltic Sea map.	50
Figure 17 The BALANCE bathymetry map used in EUSeaMap.	51
Figure 18 Biological zones of the Western Mediterranean.	52
Figure 19 Biological zones of the Baltic Sea.	53
Figure 20 Biological zones of the North Sea and Celtic Seas.	54
Figure 21 Folk classification of sediment types, with aggregated groups to be used in EUSeaMap project.	56
Figure 22 EMODNET substrate index map, showing sources of substrate maps used to create harmonised substrate map.	57
Figure 23 Seabed substrate map of the EMODNET geology study area.	59
Figure 24 Western Mediterranean substrate index map, showing sources of substrate maps used to create harmonised substrate map.	60
Figure 25 Mediterranean substrate map compiled by the EUSeaMap project.	61
Figure 26 Simplified Wave Model layer for the Baltic Sea.	64
Figure 27 Baltic Sea salinity classes.	65
Figure 28 Module generating wave base ratio using peak wave period, T_p , as an input for the Baltic and Celtic/North sea models.	66
Figure 29 Visualisation of the North and Celtic Seas seabed habitat model in ArcGIS model builder interface.	67

Figure 30 Detailed view of a subsection of the North and Celtic Seas model, illustrating the inputs and processes that produce the energy classifications.....	67
Figure 31 EUSeaMap Toolbox.....	69
Figure 32 Modelled seabed habitats for the Baltic Sea, showing the four major salinity classes.	70
Figure 33 Legend for the modelled seabed habitats for the Baltic region, with four major salinity classes.....	71
Figure 34 Modelled seabed habitats for the North and Celtic seas.	72
Figure 35 Legend for the modelled seabed habitats for the North and Celtic regions.....	73
Figure 36 Modelled seabed habitat map produced by the model for the Western Mediterranean.....	74
Figure 37 Scores of sediment maps for northern part of western Mediterranean.	76
Figure 38 Scores of bathymetry maps for Italy and France.....	76
Figure 39 Example of a hard (left panel) and soft classification (right panel) of a fictitious habitat defined by a salinity range of 6-7 psu.	78
Figure 40 Illustration of the cell by cell process that uses fuzzy membership values to a) classify each grid cell using input data layers and b) retain the membership score for the output classification that gives a measure of associated certainty.....	80
Figure 41 Combined fuzzy membership scores from biological zonation and energy regime produced by the seabed habitat model for the North and Celtic Seas.	81
Figure 42 The EUSeaMap pilot webGIS, showing the EUSeaMap project regions and Welcome tab.....	83
Figure 43 WebGIS screenshot of seabed habitat maps for all basins, from the 'Model outputs' group. Map Layers tab is shown.	84
Figure 44 WebGIS screenshot of a zoom to part of the North Sea seabed habitat map, showing the Key tab.....	84
Figure 45 WebGIS screenshot of biological zone maps for all basins, from the 'Input layers' group.....	85
Figure 46 WebGIS screenshot of a zoom to part of the Western Mediterranean biological zones map, with Info pop-up.....	85
Figure 47 WebGIS screenshot of bathymetry data for the North, Celtic and Baltic Seas.	86
Figure 48 WebGIS screenshot of a zoom to the bathymetry data in the Baltic Sea, showing the Key tab and Info pop-up.....	86
Figure 49 WebGIS screenshot of functionality to add WMS layers.....	87
Figure 50 WebGIS screenshot of EMODNET biological data as WMS layers.	87
Figure 51 Boundary limits of the coverage considered for each EC country.	90
Figure 52 Distribution of the different classes of protection (MPAs, SCIs, and MPAs + SCIs by biological zones in the whole Western Mediterranean.	90
Figure 53 Percentage coverage of each network with respect to the spatial extension of each biological zone.	91

Figure 54 The percentage coverage of the total MPAs and Natura 2000 network with respect to the spatial extension of each biological zone in Spain, France and Italy.92

List of Tables

Table 1 Legend showing the most detailed classes in the UKSeaMap 2010 predictive seabed habitat model.....	12
Table 2 Comparison of full coverage seabed habitat modelling programmes in Europe.	14
Table 3 Limits of subtidal zones for EUSeaMap regions.....	21
Table 4 Example of EUNIS habitat types at level 3 and 4 which can be identified from the data layers seabed substrate, biological zone, and in the case of rock substrate types, by energy conditions.	32
Table 5 Physical data layers used in the construction of the EUSeaMap predictive seabed habitat model for the North Sea and Celtic Seas.	36
Table 6 Physical data layers used in the construction of the EUSeaMap predictive seabed habitat model for the Western Mediterranean.	37
Table 7 Physical data layers used in the construction of the EUSeaMap predictive seabed habitat model for the Baltic Sea.	38
Table 8 The values identified for the infralittoral-circalittoral boundary in the oligo- and mesohaline salinity zones in the Baltic Sea. The values are depth/Secchi depth ratio.....	44
Table 9 Biological zones used for mapping in the Western Mediterranean.....	52
Table 10 Biological zones used for mapping in the Baltic Sea.....	53
Table 11 Biological zones used for mapping in the North and Celtic Seas.....	54
Table 12 Error matrix for Italian ground truthing data.....	77

1. Introduction

1.1. Background

The importance of seabed habitat mapping has become increasingly apparent in recent years. Information on seabed habitats is essential both for the development of new economic activities and for assessing the impact of these activities on the marine environment. Management policies and actions, including marine spatial planning, need to be informed by the best-available data if they are to achieve long-term sustainable use and management of the marine environment and its resources. Whilst survey methods and technologies have improved dramatically in the fields of remote sensing and ground truthing, with advances such as multi-beam echo sounding and side-scan sonar able to provide highly detailed data on the seafloor, there are still many obstacles to providing full coverage maps of the seabed through these methods alone. Data collection can be prohibitively expensive and time consuming for full coverage mapping of large areas; methods that can use existing data to its highest potential to provide good coverage over areas otherwise poor in seabed habitat data are highly desirable. Developments in Geographical Information Systems (GIS) have made it possible to generate predictive seabed habitat maps over wide areas with continuous coverage.

To date there have been substantial efforts to map the marine seabed habitats of Europe at an international level but there remains a difficulty in comparing across regions at a European scale, arising from the differences in methodologies and classifications used. Some of these difficulties, such as variations in scale or local habitat anomalies, are a result of the intrinsic differences between the ecological and physiographic constitution of regions. There is now an implicit requirement for continuous mapping that can be applied across regions. The Marine Strategy Framework Directive (MSFD) states that, by 2012, "Member States shall make an initial assessment of their marine waters, taking account of existing data where available and comprising ... an analysis of the essential features and characteristics ... covering the physical and chemical features, the habitat types, the biological features and the hydro-morphology". Annex III of the Directive defines the list of elements against which the assessments must be made, and with reference to habitats calls for *"the predominant seabed and water column habitat type(s) with a description of the characteristic physical and chemical features, such as depth, water temperature regime, currents and other water movements, salinity, structure and substrata composition of the seabed"*.

1.2. Objectives

The overall objective of EUSeaMap is to use existing data to develop a prototype component of a continuous coverage European digital map of seabed habitats. The map itself will be a useful tool for marine management and will guide future efforts in mapping European seas. The specific objectives are to:

- Review and analyse existing full coverage marine habitat modelling and mapping efforts in terms of methods used, data requirements and applications;
- Develop a common methodology for full coverage seabed habitat modelling across Europe, specifically for the Baltic, North Sea, Celtic Seas and western Mediterranean Sea basins;
- Introduce better quality habitat maps through the use of best-available data and refined modelling processes;
- Make the digital map layers available to stakeholders and develop an on-line mapping tool to display the layers incorporating a site to make the data available to the public;
- Assess the benefits and constraints of using categories of the EUNIS marine habitat types, in comparison to the use of other regional variations and what shortcomings could be addressed by more accuracy and higher resolution;
- Demonstrate how the Marine Strategy Framework Directive Annex III requirements can be used in characterising the marine environment
- Contribute towards INSPIRE implementation standards; and,
- Determine the effort required to develop complete coverage of waters surrounding the European continent and that required to provide a more accurate, higher resolution survey-based map.

2. Review of Mapping and Modelling Seabed Habitats in Europe

The seabed is a complex environment, under the influence of a broad range of physical, chemical, geological and biological factors. Physical, or abiotic, variables such as topography, substratum and depth, influence, and at some scales are influenced themselves by, the variation of biological communities. These communities at the seabed are also affected by the nature of the water column itself: variables such as temperature, salinity and the energy exerted by water movements.

As discussed later in this section, the seabed environment has generally been classified in two ways: marine landscapes, which are defined by topographic and physiographic variables; and seabed habitats, defined by their abiotic characteristics which are relevant to the associated biological communities. Mapping of these seabed habitats can be achieved in two ways: survey of the seabed (with or without biology), or through modelling using abiotic variables and biological data.

This section reviews efforts to create full coverage maps of seabed habitats. Systems used to classify the marine environment, the differences in approaches used, data requirements and applications are discussed. Results of this review contributed to building our methodology. The focus is on those projects that have undertaken predictive seabed habitat modelling with international coverage, and hence are most relevant to the objectives of EUSeaMap.

2.1. Classification systems

In mapping and modelling seabed habitats it is clear that a system of components within which distinct units (classes) can be predicted is desirable. Consistent systems of this sort allow for comparison of maps from different sources, and provide a framework for standardised interpretation of raw data into maps. Classifications for the seabed in Europe have been developed since the early 1980s, e.g. CORINE⁴ (Commission of the European Communities 1991), ZNIEFF-Mer (Dauvin *et al.* 1994). The need for a structured approach to seabed habitat classification was recognised following the Marine Nature Conservation Review of UK (Hiscock & Connor 1991).

Classification systems were developed prior to the emergence of broad-scale mapping and modelling, but the latter has helped to inform revisions of the former through greater understanding of the abiotic variables that define the grouping of biological communities and geophysical habitat conditions.

⁴ <http://www.eea.europa.eu/publications/COR0-landcover>

A review of classification systems (Hiscock & Connor 1991; Connor *et al.* 1995) identified key requirements of a habitat classification system including that it should:

1. Be comprehensive (cover all habitat types in the geographic area);
2. Be truly hierarchical (i.e. have no duplication of units at the lower end of the scheme), with units of similar 'value' at each level;
3. Enable broad-scale, rapid use at higher levels and more refined, expert use at lower levels.

In response to these requirements, development of the Marine Habitat Classification for Britain and Ireland, within the EC BioMar project (1992-1996) led to the release of the first full working version in 1997 (Connor 1997; Connor *et al.* 1997), based on multivariate analyses of about 30,000 biological samples. Following extensive practical use, the acquisition of new data and further analyses to extend the classification, a fully revised version (Connor *et al.* 2004; www.jncc.gov.uk/MarineHabitatClassification) was released in 2004. The classification is now well established as a standard tool for nature conservation practitioners, industry regulators and those involved in environmental assessment, survey and management. Further additions to the classification, to cover offshore and deep-water seabed habitats, are anticipated in 2010.

2.1.1. EUNIS habitat classification development

The EUNIS habitat classification system (<http://eunis.eea.europa.eu/habitats.jsp>) was developed by the European Environment Agency in response to the recognised shortcomings of existing pan-European systems such as the CORINE and Palaeartic⁵ systems (Devillers, Devillers-Terschuren, & Vander Linden 1996). These systems did include the marine environment but with a limited coverage and suffered from a lack of consistent structure. EUNIS spans the terrestrial and marine environments, and is based on a similar set of principles as employed in the Marine Habitat Classification for Britain and Ireland. The latter had received wide input from European marine specialists during the BioMar project (Hiscock 1995) and offered a sound framework on which to add further types to cover the north-east Atlantic (from the OSPAR Convention), the Baltic Sea (from the HELCOM Convention), and the Mediterranean Sea (from the Barcelona Convention). The most recent version (2007) now also incorporates seabed habitats for the Black Sea. The additions to the Marine Habitat Classification for Britain and Ireland mentioned above, for offshore and deep-water habitats, will also be submitted to EUNIS.

2.1.2. Difference between habitats and marine landscapes

In what is often referred to as a 'top-down' approach, it is recognised that the distribution of habitats can be defined by geophysical variables, and hence also the spatial variation of the biological communities they support (Roff & Taylor 2000; Vincent *et al.* 2004; Connor *et*

⁵ http://www.naturalsciences.be/cb/databases/cb_db_physispal_eng.htm

al. 2006). The concept was developed initially for Canadian marine habitats (Roff & Taylor 2000), where it was demonstrated that oceanographic and geophysical data could be utilised to predict ecologically meaningful marine features at a scale where sufficient biological data are not available. Biological data can be used to generate the rules which are then applied to classify the oceanographic and geophysical data. Additionally, independent biological datasets can be used to validate the predictions based on the abiotic data.

The term ‘marine landscape’ has been widely used in this field to describe the units which are modelled. Marine landscapes work at a larger scale than seabed habitats and can be defined as “a suite of habitat types which occur together, often in a specific pattern, to form a topographically distinct feature” (Al-Hamdani & Reker 2007). The EUSeaMap project does not include a topographic element and therefore the term marine landscape is not used in this project. The units modelled by EUSeaMap are seabed habitats (see section 4.1 for definitions), and the approach used is referred to as seabed habitat modelling. EUSeaMap builds on the approach of MESH, which created a predictive EUNIS seabed habitat map for north-west Europe (Coltman *et al.* 2008). This work also did not include a topographic element, instead making use of the structure of the hierarchical EUNIS system to predict seabed habitat types based on abiotic variables, such as substrate type, depth, light levels and energy from currents.

2.2. International European modelling programmes

Modelling seabed habitats requires rules about where habitats are likely to occur, and not likely to occur. These rules rely on thresholds that can either be determined from direct analysis of biological data with the abiotic variables (e.g. to generate a range), or be based on thresholds which are part of seabed habitat classification systems. In the former approach, overlaying biological data with abiotic variables to determine the thresholds requires consistent coverage of biological community data, which is rarely available for all communities at an international scale. Furthermore, when thresholds generated directly from biological data in this way are then applied to abiotic data, the seabed habitats predicted usually cover overlapping areas; resolving these overlaps can be a very time consuming process, requiring expert knowledge of the seabed in an area. That overlaps occur is not surprising; they exist because the ranges of abiotic variables identified from the biological data are rarely mutually exclusive, which reflects the expected natural variation and gradual transitions from one habitat to the next. This is discussed further in section 4.3.1 below. However, this approach can be very successful regionally, and has been applied in the INTERREG IIIA funded HabMap⁶ project. The international modelling programmes discussed below both use thresholds which are based on seabed habitat classification systems – which themselves are derived from biological data and field measurements of

⁶ <http://habmap.org>

abiotic variables. Further analysis of these thresholds is often necessary to verify their appropriateness for use in a particular geographic area.

2.2.1. BALANCE

The BALANCE (Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) project was a Baltic Sea Region INTERREG IIIB co-funded programme comprised of 27 partners from 10 countries. It mapped marine landscapes and seabed habitats for the Baltic and Kattegat seas and parts of the Skagerrak strait.

The approach used by BALANCE built on the concepts proposed by Roff and Taylor and UK Irish Sea Pilot project (2004) and UKSeaMap (2006). The maps developed by BALANCE identified three different broad-scale characterisations of the marine environment; topographic features, such as sediment plains and troughs; physiographic features such as lagoons, estuaries, and archipelagos; and seabed features. This last characterisation used three primary environmental variables, sediment, photic depth and salinity, to spatially describe the seabed in terms of broad habitat conditions available (Al-Hamdani & Reker 2007; Figure 1).

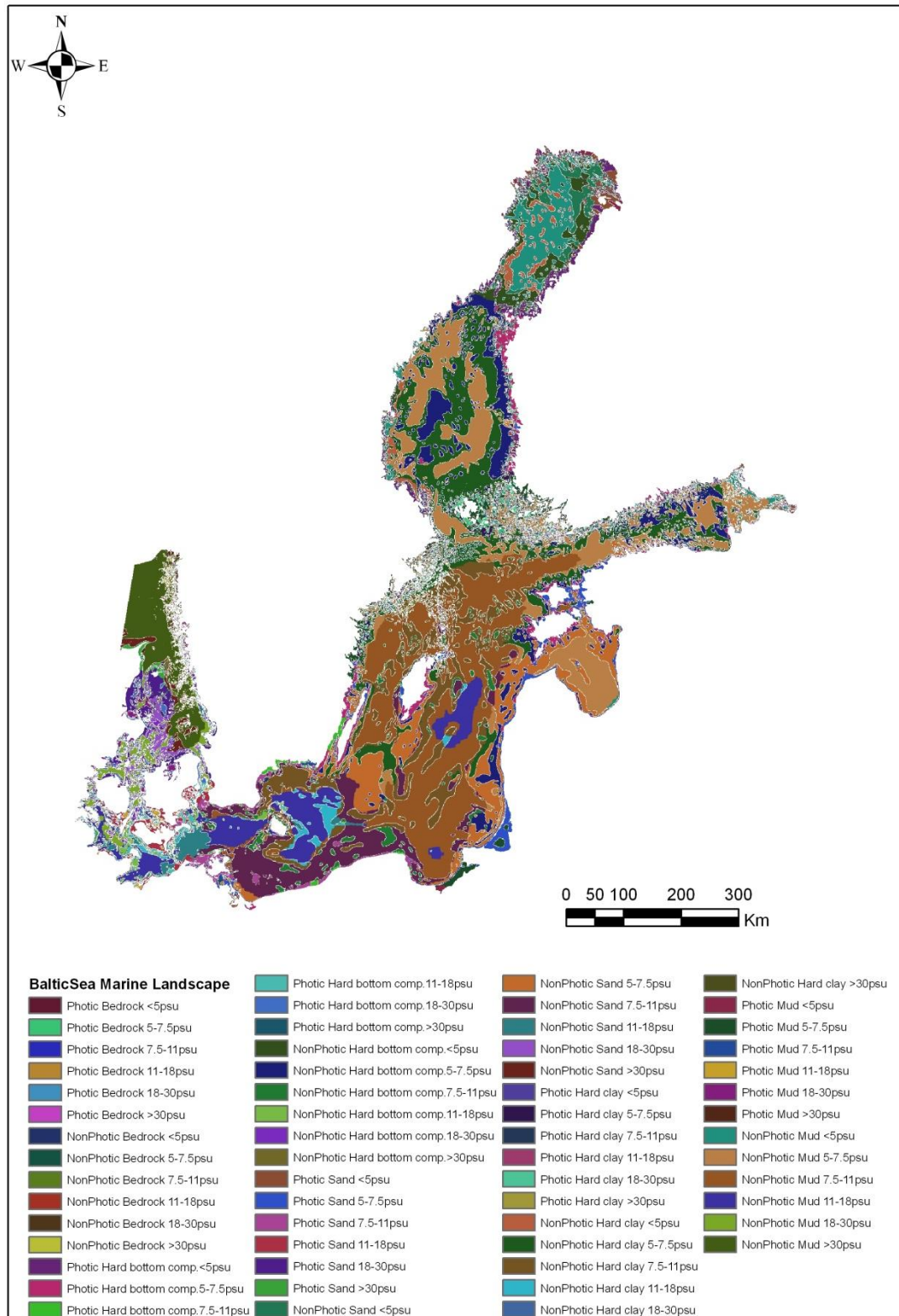


Figure 1 BALANCE seabed habitat map (Al-Hamdani & Reker 2007).

2.2.2. MESH

The Development of a Framework for Mapping European Seabed Habitats, or MESH (2004-2008), was a North West Europe INTERREG IIIB co-funded programme comprised of twelve

partners across Belgium, France, Ireland, the Netherlands and the UK. The geographical extent of the project was the partner countries' Exclusive Economic Zones (EEZ or equivalent), except for France where the southern boundary of the project area used the southern limit of the INTERREG north-west Europe area.

MESH produced a framework for seabed habitat mapping, with standardised and repeatable methods. A major aspect to the project arose from acknowledging the significant resource comprising existing seabed habitat maps that had been produced by a range of sectors for different purposes across the project area. However, these maps displayed a lack of cohesion in classifications, scales and techniques. Hence a key objective of the MESH project was to collate seabed habitat maps from across north-western Europe and harmonise them by converting to standard GIS data formats and translating them where possible to the EUNIS habitat classification scheme.

The patchy nature of these existing maps required the MESH project to use a second approach to create the first consistent, harmonised seabed habitat map for north-west Europe: predictive mapping. MESH refined methods used in the UKSeaMap project (Connor *et al.* 2006) and Irish Sea Pilot project (Vincent *et al.* 2004). MESH applied predictive mapping, or modelling, over a much larger area than had previously been attempted, using raster methods to optimise the data processing. In order that the modelled map produced by MESH was consistent with the collated seabed habitat maps from survey, and harmonised across five countries, the EUNIS classification scheme was used as the basis of the predictions. The final modelled EUNIS seabed habitat map was made from three core contributing layers – sediment, biological zone and energy – which were themselves produced from a range of other abiotic environmental variables (Figure 2).

MESH also developed an integrated formal procedure to assess the confidence of maps produced from surveys. This was the first time a systematic approach had been used in such a way to give a measure of confidence to seabed habitat mapping (MESH 2008; ICES 2007). The same confidence assessment system was not extended to apply to the modelled seabed habitat map.

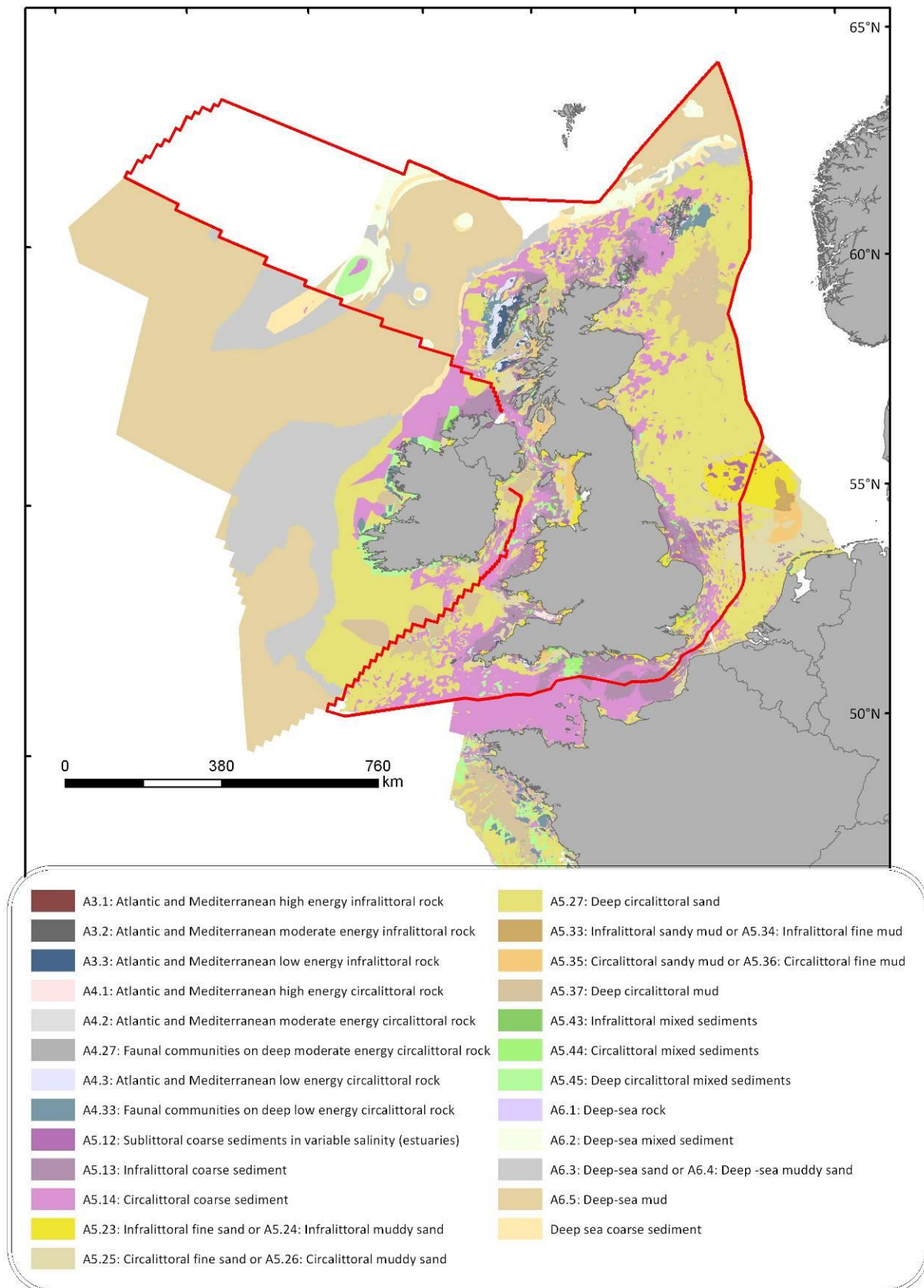


Figure 2 MESH predicted seabed habitat map. The map is a combination of EUNIS Level 3 and 4 habitats, showing the most detailed class available in each location (Coltman *et al*, 2008).

2.3. National marine habitat modelling programmes

Within Europe there have been a number of efforts to create full-coverage national maps of seabed habitats. With the aim of learning from these projects, which had similar aims to EUSeaMap, this review explores the approaches previously used, and Table 2 compares these national programmes with international programmes. There are many more projects which have created maps of specific seabed habitats, or maps of a particular local or regional geographic area. Transnational programmes such as CHARM⁷ and HERMES⁸ are focused on particular areas of countries' EEZs, or on particular habitats of interest, rather than attempting to model a full range of seabed habitats in a full-coverage. Similarly the OSPAR habitat mapping programme⁹ gathers point (and polygon) data for a specified list of threatened habitat types but does not have predictive elements to provide full coverage of OSPAR regions.

2.3.1. UKSeaMap 2010

UKSeaMap 2010 is a predictive seabed habitat mapping project. It aims to provide a full coverage predictive seabed habitat map for the UK marine area. Seabed habitat maps from survey data are estimated to cover approximately 10% of the UK marine area. There is a clear need to use the best available data to produce a map which shows the seabed habitats most likely to appear in the remaining 90%. Large scale environmental datasets are used to predict broad-scale habitats for UKSeaMap 2010 (McBreen *et al.* – in prep.).

In order to assess the value of map, UKSeaMap 2010 provides a full coverage confidence map for the predictive seabed habitat map. The confidence map is produced by combining confidence layers from the individual input datasets.

⁷ www.ifremer.fr/charm

⁸ www.eu-hermes.net

⁹ http://data.nbn.org.uk/hosted/ospar/ospar_text.html

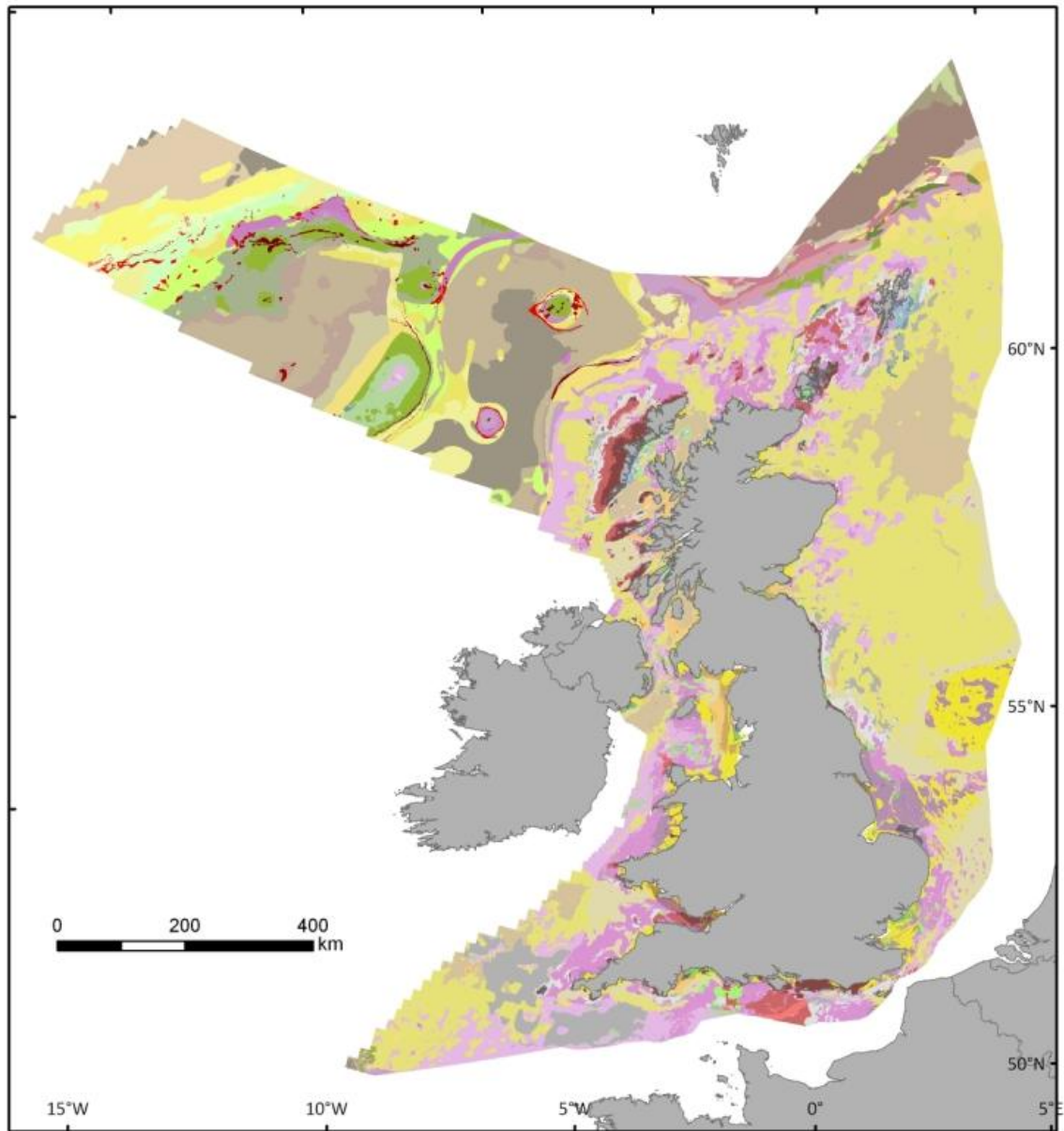


Figure 3 UKSeaMap 2010 predictive seabed habitat map (most detailed classes).

Table 1 Legend showing the most detailed classes in the UKSeaMap 2010 predictive seabed habitat model.

A3.1: Atlantic and Mediterranean high energy infralittoral rock	Arctic Upper bathyal coarse sediment
A3.2: Atlantic and Mediterranean moderate energy infralittoral rock	Arctic Mid bathyal coarse sediment
A3.3: Atlantic and Mediterranean low energy infralittoral rock	Arctic Slope sand and muddy sand
A3.22: Kelp and seaweed communities in tide-swept sheltered conditions	Arctic Upper bathyal sand and muddy sand
A3.31: Silted kelp on low energy infralittoral rock with full salinity	Arctic Mid bathyal sand and muddy sand
A3.32 Kelp in variable salinity on low energy infralittoral rock or A3.36: Faunal communities on variable or reduced salinity	Arctic Slope mud and sandy mud
A4.11: Very tide-swept faunal communities on circalittoral rock or A4.13: Mixed faunal turf communities on circalittoral rock	Arctic Upper bathyal mud and sandy mud
A4.12: Sponge communities on deep circalittoral rock	Arctic Mid bathyal mud and sandy mud
A4.27: Faunal communities on deep moderate energy circalittoral rock	Arctic Lower bathyal mud and sandy mud
A4.2: Atlantic and Mediterranean moderate energy circalittoral rock	Arctic Slope mixed sediment
A4.31: Brachiopod and ascidian communities on circalittoral rock	Arctic Upper bathyal mixed sediment
A4.33: Faunal communities on deep low energy circalittoral rock	Arctic Mid bathyal mixed sediment
A5.12: Sublittoral coarse sediments in variable salinity	Arctic Lower bathyal mixed sediment
A5.13: Infralittoral coarse sediment	Atlantic Slope rock or reef
A5.14: Circalittoral coarse sediment	Atlantic Upper bathyal rock or reef
A5.15: Deep circalittoral coarse sediment	Atlantic Mid bathyal rock or reef
A5.22: Sublittoral sand in variable salinity (estuaries)	Atlantic Lower bathyal rock or reef
A5.23: Infralittoral fine sand or A5.24: Infralittoral muddy sand	Atlantic Abyssal rock or reef
A5.25: Circalittoral fine sand or A5.26: Circalittoral muddy sand	Atlantic Slope coarse sediment
A5.27: Deep circalittoral sand	Atlantic Mid bathyal coarse sediment
A5.32: Sublittoral mud in variable salinity (estuaries)	Atlantic Lower bathyal coarse sediment
A5.33: Infralittoral sandy mud or A5.34: Infralittoral fine mud	Atlantic Upper bathyal coarse sediment
A5.35: Circalittoral sandy mud or A5.36: Circalittoral fine mud	Atlantic Slope sand and muddy sand
A5.37: Deep circalittoral mud	Atlantic Upper bathyal sand and muddy
A5.42: Sublittoral mixed sediment in variable salinity (estuaries)	Atlantic Mid bathyal sand and muddy sand
A5.43: Infralittoral mixed sediments	Atlantic Slope mixed sediment
A5.44: Circalittoral mixed sediments	Atlantic Upper bathyal mixed sediment
A5.45: Deep circalittoral mixed sediments	Atlantic Mid bathyal mixed sediment
Arctic Slope rock or reef	Atlantic Lower bathyal mixed sediment
Arctic Upper bathyal rock or reef	Atlantic Abyssal mixed sediment
Arctic Slope coarse sediment	

2.3.2. Germany: MarGIS

The MarGIS project predicted seabed communities for the German EEZ in the North Sea (Pesch *et al.* 2008). Abiotic measurements of salinity, temperature, silicate, nutrients and sediment grain size were converted to full coverage layers using interpolation techniques. Samples which identified different communities were then used to create a set of decision rules. The analysis was carried out using CART (Classification and Regression Trees). The decision rules generated were then applied to the full coverage layers derived from abiotic data, to predict the seabed communities which will occur in a particular area. The CART analysis showed bathymetry and sediment conditions to be important for the density and distribution of seabed species.

2.3.3. Belgium

For the Belgium part of the North Sea Degraer *et al.* (2008) predicted soft sediment macrobenthic communities. Their analysis selected two variables which were critical in determining the distribution of the communities: median grain size and sediment mud content. A model was built which predicted the chance of occurrence of each of four main macrobenthic communities. This model was used to create four community-specific seabed habitat suitability maps for the Belgian part of the North Sea. It was also attempted to translate these predicted habitats to EUNIS level 5 but not all were compatible with existing classes. A marine landscape map was also produced, based on seventeen input layers and resulting in eight marine landscapes (Verfaillie *et al.* 2009).

Table 2 Comparison of full coverage seabed habitat modelling programmes in Europe.

	BALANCE	Belgium	MarGIS	MESH	UKSeaMap
Area covered	Baltic sea	Belgian continental shelf	German EEZ	North-west Europe excluding NW approaches	UK continental shelf excluding NW approaches and North of 62 degrees
Time taken	3 years (2005 - 2007)	2 years (2005-2007)	6 years (1995 – 2000)	3 years (2004 - 2008)	1.5 years (2004 - 2006)
Classification scheme	No standard scheme - Marine landscapes identified in the course of project	Various: <ul style="list-style-type: none"> • Prediction of macrobenthic communities occurring on the Belgian shelf • EUNIS habitat classification for selected benthic communities • Marine landscapes ; full statistical approach 	No standard classification scheme – statistical prediction scheme for selected benthic communities	EUNIS habitat classification	No standard scheme - Marine landscapes identified in the course of project
Detail level (EUNIS equivalent)	Level 3 equivalent – physical only	Level 5 (or equivalent where communities did not fit EUNIS)	Level 5 & 6 equivalent - Biological communities	Levels 3 & 4	Level 3 equivalent – physical only
Input layers	3	<ul style="list-style-type: none"> • 2 (for habitat suitability modelling of macrobenthic communities) (Degraer et al. 2008) • 2 (for EUNIS habitat modelling) • 17 (Marine landscape modelling) (Verfaillie et al. 2009) 	11 <ul style="list-style-type: none"> • 1 Point map on benthic communities (Rachor and Nehmer 2003) • 10 raster layers on abiotic variables 	5	6 (for predictive mapping)

Highest input layer resolution	~600m	~80m (bathymetry) ~250 (other input layers, except as below) - Geostatistical interpolations of abiotic point data using bathymetry.	3.15 x 3.15 km - Geostatistical interpolations of abiotic point data	~250m	~250m
Lowest input layer resolution	7km	~1km (maximum Chlorophyll a concentration and maximum Total Suspended Matter)	182 point data on benthic communities (Rachor and Nehmer 2003)	12km	12km
Output Scale/Resolution	200m	250m	3.15km	0.0025° (~300m at Thames)	Fine – 0.02° to Coarse – 0.5° (~1.25km - 30km)
Method to define thresholds	Expert judgement	Statistical – Discriminant function analysis between biotic and abiotic datasets for habitat suitability maps and EUNIS classification maps Statistical - K-means cluster analysis between physical datasets for marine landscapes map	Statistical - Sample based decision tree (CART)	Expert judgement and some statistical testing	Expert judgement
Validation	Survey in study area with 4 marine landscapes to test ecological relevance of predicted types.	Used data from Macrodat database (University of Ghent) on macrobenthic communities	Not empirically	Used data from Marine Recorder translated to EUNIS, but not those point which were assigned biotopes by Habitat Matching Program. Validation carried out per polygon.	Table created to match UK&I codes to landscape types. Validation carried using data in UK&I scheme, per landscape type.

Confidence Assessment	No	Yes, using MESH confidence assessment scheme	No	Yes – but the MESH confidence assessment tool developed was only applied to surveyed habitat maps, not the modelled habitats.	Limited - Visualisation of validation results.
Strengths	<ul style="list-style-type: none"> • Collated, harmonized and provided access to large amount of data at international level 	<ul style="list-style-type: none"> • Multiple habitat schemes attempted (EUNIS translation, Marine landscapes) • Thresholds based on biological data • Nationally useful for e.g. marine spatial planning 	Thresholds based on association of biotic and abiotic data	<ul style="list-style-type: none"> • Standard and comparable predicted habitat units • Collated, harmonized and provided access to large amount of data at international level 	Variable resolution offshore
Limitations	<ul style="list-style-type: none"> • No standard classification scheme • Thresholds largely based on expert judgement rather than derived from biological data 	<ul style="list-style-type: none"> • No standard classification scheme • Requires large amount of biological community data 	<ul style="list-style-type: none"> • No standard classification scheme • Coarse resolution 	<ul style="list-style-type: none"> • Thresholds largely based on expert judgement rather than derived from biological data 	<ul style="list-style-type: none"> • No standard classification scheme • Thresholds largely based on expert judgement rather than derived from biological data

2.4. National seabed survey programmes

In addition to programmes that model seabed habitats, there are some large scale national seabed survey programmes in Europe. The primary focus of these programmes is on surveying and gathering datasets for the marine environment (in particular the seabed) rather than interpreting these datasets into seabed habitat maps. The Marine Area database for Norwegian coast and sea areas (MAREANO) and Integrated Mapping For the Sustainable Development of Ireland's Marine Resource (INFOMAR) programmes of Norway and Ireland respectively are two examples of these large scale survey programmes.

Smaller scale, local or regional surveys are reported yearly through National Status Reports to the ICES Working Group on Marine Habitat Mapping. Reports from this working group are available at <http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=104> . Although many of these surveys are part of wider programmes of work, the aims of the programmes are not seabed habitat mapping. For example, the Task Group for the Extension of the Portuguese Continental Shelf¹⁰ collects bathymetry, geophysical and geological data. Its aim is to prepare the submission for the extension of the Portuguese Continental Shelf beyond 200 nautical miles (in accordance with the United Nations Convention on the Law of the Sea (UNCLOS), to be presented to the Commission on the Limits of the Continental Shelf (CLCS). Biological data are not collected, and geological data are mainly collected through remote sensing (e.g. seismic, multi-beam echo sounder) rather than through direct sampling and analysis of the substrate (e.g. grabs, cores).

Another example of a national survey programme is Life⁺-funded seabed habitat project FINMARINET¹¹. It will carry out inventories of the seabed habitat types listed in the EC Habitats Directive Annex I, in Finnish territorial waters and the Finnish EEZ. The focus of survey effort will be in seven existing Natura 2000 areas. Although these surveys do collect biological information, the coverage of surveys is localised and does not aim to create a full-coverage seabed habitat map.

2.4.1. MAREANO

MAREANO is a national survey programme to map the seabed in Norwegian waters. The first phase of MAREANO began in 2005 and will deliver results for a revision of the Barents Sea management plan in spring 2010. Surveys are conducted to collect multibeam bathymetry and backscatter data together with a comprehensive, integrated biological and geological sampling programme. All results from MAREANO are integrated in the web portal, www.mareano.no. MAREANO also used GIS analyses to predict seabed habitats in

¹⁰ www.emepc.pt

¹¹ Inventories and planning for the marine Natura 2000 network in Finland

new areas. Testing these predicted seabed habitats with ground-truthing is planned in future cruises.

2.4.2. INFOMAR

INFOMAR was launched in 2006 as a follow on the successful Irish National Seabed Survey (INSS) which ran from 1999 to 2005. The INSS mapped over 80% of Ireland's offshore EEZ. INFOMAR aims to carry out integrated mapping over the entire shelf and coastal waters of Ireland. The mapping programme includes acquisition of multibeam bathymetry and backscatter data together with a comprehensive geological sampling programme. All results and raw data from INSS and INFOMAR are available for download and can be accessed at www.infomar.ie.

2.4.3. CARG

In Italy, a national geological cartographic project called CARG¹² (CARTografia Geologica) was initiated in 1988, with the aim of producing 652 geological and geothematic sheets at a scale of 1:50,000 covering the entire national territory. Recent initiatives to create equivalent marine maps have begun to produce geological seabed maps out to the limits of the continental shelf. To date 11 sheets have been printed, 27 are in press and another 31 are in the process of being concluded (ISPRA 2009).

2.5. EUSeaMap and future mapping

The efforts of these kinds of survey programmes mentioned are welcomed, and represent substantial and important improvements in data availability. It is evident however that, to date, there has been limited coordinated international attempts to map seabed habitats, particularly in common and comparable outputs. Most survey data has focused on geophysical mapping, and even though there are localised areas with substantial biological community data it is difficult to use these to know the distribution of broad scale seabed habitats over larger areas.

Biological sampling, at high intensity over large areas is not cost-effective because much baseline information over basic habitat differences can be obtained by assemblage of information on abiotic factors which determine many habitat types at broad scales. However since biological sampling is necessary in the long run for identifying and mapping communities which develop at fine scales, broad scale mapping effort is therefore crucial for pinpointing subareas where fine scale mapping should be carried out. To this effect broad scale initiatives provide a means to better plan fine-scale mapping studies thereby allowing future cost-effective fine-scale mapping efforts. Previous mapping programmes have shown

¹² http://www.apat.gov.it/site/it-IT/Progetti/Progetto_CARG_-_Cartografia_geologica_e_geotematica

that the approach to the mapping of seabed habitats under the EUSeaMap project is appropriate, especially because of common classification and data availability.

3. Rationale

As shown by the programmes outlined in the review (Section 2), the distribution of seabed habitats can be modelled by the use of wide coverage abiotic variables. Here the rationale behind the main variables used in the full coverage modelling of seabed habitats at large spatial scales is examined, with particular focus on their ecological relevance.

3.1. Biological or depth zone

There is, typically, a marked 'zonation' of communities from the top of the shore to the bottom of the deep sea. However, this zonation is not directly related to depth but to a range of linked factors, for example: the drying of the intertidal zone caused by low tides is greater at the top of the shore than the bottom; the amount of wave energy experienced at the seabed dissipates with depth; the degree of thermal stability increases with depth; the proportion of surface light reaching the sea floor decrease with depth.

Where the factors determining zonation are well understood, it may be possible to use bathymetry as a surrogate for the factor causing the zonation, although with increasing distance away from the 'tested' area, this relationship may become increasingly unreliable (and hence need further validation). These factors which change with depth also vary horizontally from region to region; thus their combination to give a pattern of biological zones is often complex. A factor which works well to define zones in one region (e.g. light) may not be appropriate in another region (e.g. where wave energy might be more important). There are particular differences between zonation in the Celtic and North Sea regions to the Mediterranean (which are illustrated in Table 3), whilst there is not common agreement on zonation in the Baltic (Backer et al. 2004, Isæus et al. 2007).

Very marked horizontal bands of zonation on most rocky coasts are related to the length of time the rock is exposed by the tide. In subtidal areas, changes in wave disturbance and light with increasing depth are the main factors responsible for structuring the vertical zonation. Zonation in sediment habitats is generally much less obvious than on rocky coasts. Shallow subtidal sediments reflect a high degree of wave disturbance, with high temperature and salinity fluctuations, followed by increasingly stable conditions in deeper waters.

3.1.1. Light

Light availability in the water column and at the seabed varies considerably, affecting in particular the depth to which macrophytes (kelp, seaweeds, seagrass, e.g. *Posidonia*) can grow. Light intensity decreases with depth due to the attenuating effects of scattering and absorption (by water molecules, suspended particulate matter, phytoplankton and coloured

dissolved organic matter) in the water column (turbidity). This attenuation tends to be higher in coastal waters, due to suspended and dissolved matter being washed down rivers, higher phytoplankton concentrations and suspension of sediment caused by wave action in shallow waters.

Light attenuation is the variable used to define the infralittoral zone, where irradiance from the sun is still sufficient to allow significant photosynthetic activity. On Atlantic coasts the decrease in light levels with depth is typically reflected in four zones (Hiscock 1996):

- Upper infralittoral dense kelp (*Laminaria*)
- Lower infralittoral sparse kelp, dense seaweeds
- Upper circalittoral sparse seaweeds
- Deep circalittoral encrusting algae only

In the Baltic, there is no kelp, but light levels are used to describe the infralittoral and circalittoral zones:

- Infralittoral dominance of erect macroalgae
- Upper circalittoral erect macroalgae may be absent or present, but not dominant
- Deep circalittoral encrusting algae only

In the Mediterranean, the differences in light levels reaching the bottom delimit four basic zones:

- Infralittoral seagrass and photophilic¹³ algae
- Upper circalittoral sciaphilic¹⁴ brown and red algal species
- Deep circalittoral survival of sparse sciaphilic algae originating from the upper circalittoral
- Abyssal no light and no plant life

Biological zoning in the Mediterranean is affected by different, but in some cases overlapping, variables to in the North and Celtic seas. In the Mediterranean the infralittoral zone starts at low tide level and extends down to the deepest limit of *Posidonia oceanica* growth. The lower limit of the infralittoral is therefore defined as the area up to which the light intensity is such that seagrasses (i.e. *Posidonia oceanica*) and photophilic algae can survive. This threshold value is estimated to be equivalent to 1% of the light irradiance reaching the bottom of the seafloor. In the case of soft bottoms the presence of a sea bottom dominated by muds also marks the end of the infralittoral zone and the beginning of the circalittoral (this may occur at depths less than 50m in areas close to river deltas).

¹³ Receptive to, or thriving in light conditions

¹⁴ Receptive to, or thriving in low light conditions

Table 3 Limits of subtidal zones for EUSeaMap regions.

Biological zone	Upper limit	Lower limit
Infralittoral (Atlantic & Mediterranean)	Lowest Astronomical Tide	Intersection of seabed and 1% surface light depth
Infralittoral (Baltic)	Lowest Astronomical Tide	2.5 ratio of depth/Secchi depth for mesohaline zones 1.6 ratio of depth/Secchi depth for oligohaline zones
Upper Circalittoral (Atlantic)	Intersection of seabed and 1% surface light depth	Maximum depth at which seabed is affected by waves
Upper Circalittoral (Mediterranean)	Intersection of seabed and 1% surface light depth	Intersection of seabed and average 0.01% incident light fraction
Upper Circalittoral (Baltic)	2.5 ratio of depth/Secchi depth for mesohaline zones 1.6 ratio of depth/Secchi depth for oligohaline zones	Position of deep halocline
Deep Circalittoral (Atlantic)	Maximum depth at which seabed is affected by waves	Shelf edge delimited by the slope angle change of the continental platform, or proxy (200m)
Deep Circalittoral (Mediterranean)	Intersection of seabed and average 0.01% incident light fraction	Shelf edge delimited by the slope angle change of the continental platform, or proxy
Deep Circalittoral (Baltic)	Position of deep halocline	n/a
Upper slope (Atlantic)	Shelf edge delimited by the slope angle change of the continental platform, or proxy (200m)	Top of the permanent thermocline, or proxy (750m)
Bathyal (Mediterranean)	Shelf edge delimited by the slope angle change of the continental platform, or proxy	Shelf slope break delimited by the slope angle change of the continental platform, or proxy
Bathyal (Atlantic)	Top of the permanent thermocline, or proxy (750m)	Shelf slope break delimited by the slope angle change of the continental platform, or proxy (2,700m)
Abyssal (Atlantic & Mediterranean)	Shelf slope break delimited by the slope angle change of the continental platform, or proxy (2,700m for Atlantic)	n/a

The circalittoral zone starts from the lower limit of the infralittoral until the maximum depth where multicellular photosynthetic forms can exist. The assemblages found in this zone are therefore characterised by the predominant presence of sciaphilic algal communities. The

lower limit of the circalittoral also coincides with the external margin of the continental shelf, identified on the basis of the slope break (usually found within the 130 and 200m depth range). The circalittoral can also be divided into upper circalittoral and lower circalittoral on the basis of the amount of light reaching the seabed. In the upper circalittoral the light reaching the bottom is estimated to range between 1% - 0.01% of the surface light thereby allowing the photosynthesis of multicellular algae. The light reaching the bottom in the upper circalittoral is sufficient to allow the photosynthesis of different brown algae communities such as the Fucales (deep water *Cystoseira* and *Sargassum* spp.), Laminariales, Desmarestiales and Sporochnales as well as red algal (rhodophycean) species. Characteristic communities present in this zone are the coralligenous assemblages consisting of more or less massive bioconstructions formed by coralline algae as well as Rhodolith (maerl beds) consisting of loose lying, living or dead, coralline red algae, usually aggregated into masses on shell gravel mixed with coarse sand. The lower circalittoral instead is characterised by having less than 0.01% of the surface light reaching the seabed and multicellular algae are therefore generally not present in great quantities as light becomes more and more a limiting factor. Another characteristic of the circalittoral zone is that the bottom temperature ranges from 18 down to 13.5°C; temperature is discussed further in section 3.6)

The deep sea areas of all regions are difficult to delineate; possible additional zonation could split this into Bathyal and Abyssal zones. These are typically split using depth or slope as a proxy, but there is ongoing discussion as to how best to define these limits for different regions. The slope angle change adjacent to the base of the continental shelf is often used to mark the beginning of the abyssal plain, but other surrogates such as depth and thermoclines may be more appropriate in some regions.

3.2. Substrate

Seabed community types are strongly influenced by the physical nature of the seabed. Seabed (or benthic) species live on the surface or within the sediment. These species are referred to as epifauna and infauna respectively. Species are mostly confined to the top 30cm or so of sediment, but a few species may burrow to 1m or more. Species composition is particularly influenced by the substratum type (e.g. sediment particle size) and its composition (mixtures of different particle sizes). Its structure (e.g. topography, porosity), origin (geological, biological) and mobility further influence the biology.

Seabed substrata vary from solid rock, boulders, cobbles and pebbles, through to gravels, sands and muds. Additionally the seabed may be composed of material of biogenic and anthropogenic origin (e.g. shells, calcareous skeletons, tree-trunks, concrete). The type of sediment is mainly determined by the dynamics of water movement as a result of waves and currents.

Many species are quite specific in their preference for particular types of seabed, although the degree of specificity varies markedly between species. At the community level (i.e. a combination of species and their relative abundances into a recognisable community type), there is generally a very high degree of correlation to the physical nature of the seabed, most easily expressed as the substratum type. It is for this reason that the EUNIS classification places considerable emphasis on substratum in its higher level structure.

Seabed communities can be classified into two broad categories: namely those associated with hard substrata (epifaunal communities) and those of soft substrata (infaunal communities – with or without associated epifauna). There is, however, a complete gradation between the two, as many areas of seabed comprise mixtures of hard and soft substrata. Dealing satisfactorily with these mixtures is a major challenge in seabed habitat classification schemes, with substratum mobility adding further complexity to the issue.

For mapping and modelling seabed communities, it is necessary to know the relative proportions of the different substrata which make up the seabed in an area and to delineate areas of consistent composition. Some areas of seabed are quite homogeneous in substrate type, whilst other areas are much more heterogeneous. This is partly a function of the scale of the area being considered. For instance, mosaics of rock and sediment at a coarse scale of mapping may be mapped as separate seabed types at a fine scale.

There are a number of schemes to distinguish different types of seabed sediment; those especially used by different national geological agencies include the Wentworth (1922) particle-size classification and the Folk scheme (1954). These schemes are generally useful for broad-scale seabed habitat mapping and modelling, but have a number of limitations. In particular, the boundaries between classes may not be established with relevance to their effects on the communities. Further research is required to better understand the relationship between communities and the Folk classes of sediment (and other similar schemes).

3.3. Energy at the seabed

Energy exerted on the seabed can be characterised in a variety of ways that account for effects due to waves or tidal currents, or their combined effects. For example, waves can be characterised by their height, period, or orbital velocity of water particles that varies with depth. Currents can be characterised by measures such as tidal current magnitude or kinetic energy over a tidal cycle. One variable common in ocean modelling to capture the effects of both waves and tides and also their combined effect on the seabed is bed shear stress. Bed shear stress is a measure of the force exerted by waves and/or currents on sediments by the water movement over the seabed. Bed shear stresses are functions of several wave and current variables, in addition to sediment information (grain size), and fluid dynamic effects like the creation of near bed boundary layers (Figure 4) need to be taken into account. These measures are important factors that define the stability of the seabed and hence determine the suitability of the seabed for different communities (Boyd 2002), but they are

also complex hydrological processes to model and their relationship with the biological communities on the seabed are difficult to define clearly.

Energy regimes resulting from wave action and tidal currents have similar, but not always the same, effects on biological community character. Their relative importance varies significantly from one place to another, being quite different in a macrotidal¹⁵ system such as the Channel compared to wind-dominated areas such as the Western Mediterranean. In coastal areas, the two variables typically work together; their separate effects are often difficult to distinguish and for simplicity they are combined for application in the EUNIS classification scheme. These energy levels are applied only to rocky habitats in the EUNIS classification, because sediment types typically reflect the hydrodynamic regime of an area of sediment (i.e. high energy gives coarse sediments, low energy fine sediments). The influence of waves is greatest on the shore and in the infralittoral zone. In the circalittoral zone tidal currents have a more marked influence. With increasing depth, movement of particles in the water column caused by waves decrease; the depth below which waves have a negligible influence is known as the wave base. Hence below the wave base currents have the only effect.

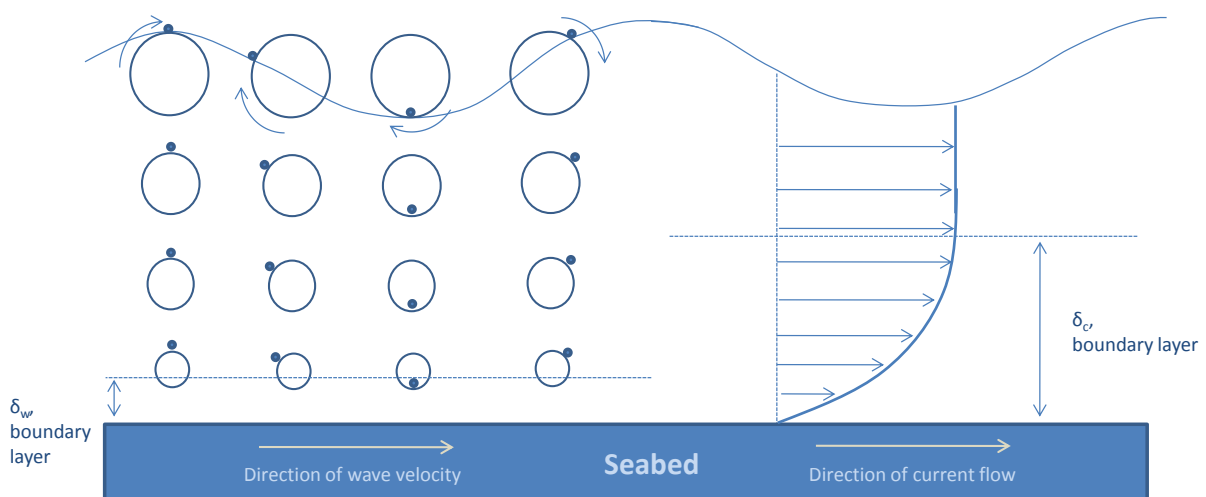


Figure 4 Overview of energy effects from water movement over the seabed due to waves (l) and currents (r).

3.3.1. Waves

An assessment of the exposure to waves, from all directions and all seasons, can be used as a disturbance indicator. Wave statistics such as significant wave height (H_{sig}), peak wave period (T_p), significant wave height for a return period of 50 years (H_{50}), combined with

¹⁵ In macrotidal areas the difference between mean high water springs and mean low water springs is between 4m and 6m.

water depth, can give estimates of the wave orbital velocity at the seabed which can be contoured to show regional variations.

Wave action affects seabed communities in coastal areas, with variations due to the aspect of the coast (with respect to prevailing winds), the fetch (distance to nearest land), degree of open water offshore and depth of water adjacent to the coast (Hiscock 1996). This can manifest itself either by influencing the type of sediment available (coarse sediments on exposed coasts and fine sediments on sheltered coasts), or by directly affecting epifaunal communities, especially on rocky habitats. Its effects vary both horizontally (along shore from exposed coasts to sheltered inlets) and vertically (dissipating with increased depth).

Marked differences in community types result from different wave exposures along rocky coasts. Exposed shores are usually animal-dominated (mussels and barnacles), whilst sheltered shores are algal-dominated (furoids). Such differences can occur over only tens of metres at certain sites, such as opposite sides of a headland. In the subtidal a similar pattern is exhibited, but is masked by tidal current influence with increasing depth.

3.3.2. Tidal currents

Bottom currents have a marked influence both on the sediment type (and hence the communities) and the communities themselves which live on rocky habitats. Strong offshore currents affect many coasts and have a particularly marked influence on communities below the infralittoral zone, with lessening effects in shallow water and on the shore (where the influence of wave action predominates). However constricted sections of some inlets, particularly the narrows in sealochs, can have very strong currents which affect both the shallow subtidal and the lower shore zones, significantly increasing species richness.

In estuaries and sealochs strong currents can lead to coarser sediments than would normally be expected in sheltered areas. The lower shore of some inlets by the main channel can have tide-swept sands and gravels with distinctive communities.

3.4. Salinity

Salinity separates marine systems, in their broadest sense, from freshwater systems (at 0.5‰). It then distinguishes brackish (stable lowered salinity) and estuarine (unstable variable salinity) conditions, from fully marine conditions. Brackish and estuarine conditions are mostly confined to coastal areas, except in the Baltic Sea where low salinities extend throughout the sea to the Kattegat and Skagerrak, before changing to more marine conditions in the North Sea.

Slight reductions in salinity (in the range 33-35‰) lead to loss of some species, with this becoming increasingly marked below 30‰ in the highly variable salinity regimes of estuaries. A series of estuarine 'zones' are described in the literature (McLusky 1993) to reflect the highly variable and increasingly reduced salinity regimes of estuaries.

Brackish-water communities in the Baltic Sea and lagoons differ markedly to estuarine communities, as salinity regimes vary on monthly or yearly timescales rather than daily. Distinct communities are developed in particular salinity regimes.

3.5. Dissolved oxygen

The vast majority of marine species are totally dependent on the availability of oxygen for essential life processes. The majority of marine waters are sufficiently oxygenated to support marine species at the seabed. Areas of fully or partially deoxygenated water can occur naturally (e.g. some fjordic basins with restricted water exchange) or from anthropogenic pressures (e.g. organic enrichment, eutrophication). The effects of eutrophication on benthic communities will depend on the energy conditions at the seabed. In areas with strong tidal currents, high levels of eutrophication may be tolerated by benthic species (e.g. parts of the Channel), whereas in areas with similar levels of eutrophication but a lack of strong tidal currents (e.g. parts of the Baltic), the benthic communities will be very different because of the greater effect of deoxygenation. Deoxygenation has a significant effect on seabed communities, through marked reductions in species diversity as a result of partial deoxygenation, to eventual dominance of bacterial growths in fully deoxygenated water.

3.6. Temperature

Water temperature and its degree of variation (or stability) are important in characterising broad-scale temperature regimes at a European scale. Species are generally adapted to both absolute temperatures and to the fluctuations they experience on daily to annual timescales. Coastal and shelf seas are generally subject to seasonal variations in temperature, with these being increasingly more pronounced in shallower waters. Deep sea habitats, in contrast, are subject to much more stable temperatures, with marked differences between Arctic, Atlantic and Mediterranean basins.

Temperature is a significant element in defining biogeographic changes and hence bioregions. There are a number of biogeographic classifications for European waters including Dinter (2001), ICES (2004) and UNESCO (2009). EUNIS has not (yet) explicitly built biogeographic regions into its marine classification, although its use of major sea regions (Atlantic, Baltic, Mediterranean and Pontic [Black Sea]) in the higher levels provides a proxy (which also relates to salinity regimes). Temperature variation in EUNIS is considered at lower levels (levels 5, 6) to reflect biogeographic variation within the same functional habitat type, although this is not consistently applied (e.g. for types around Britain and Ireland). In deep sea areas, UNESCO (2009) and Howell (in prep.) both suggest splitting the deep sea by biogeography before using depth to delineate between the major deep sea biological zones: upper slope, bathyal, abyssal and hadal. Depth is recommended, rather than temperature, as it acts as a proxy for all environmental variables.

3.7. Ice cover

Permanent ice provides a habitat in its own right, whilst the seasonal ice found in the Baltic affects seabed habitats by covering or scouring the seabed and thus affects species survival, favouring ephemeral species (e.g. *Enteromorpha intestinalis*). There can be a tendency for deoxygenation in shallow basins subject to ice cover. Furthermore, ice cover reduces the amounts of light reaching the seabed annually, hence reducing the available growth period. Large parts of the Baltic Sea are covered by sea ice for extended periods of the year, especially in the northern part. In the very cold winters even the inner Danish waters freeze over. Thus ice cover has an influence on species in coastal or shallow waters, but compared to sediment, salinity and light it is less important in determining species distribution at a broad-scale.

Using data from Metria/Sweden and Leppäranta *et al.* (1988), the BALANCE project presented three categories for ice cover, in units of days per year:

0-90 days of ice cover

91-150 days of ice cover

>150 days of ice cover

There are many other abiotic variables that affect community type. Most of these however influence at fine scales, such as localised methane and sulphide seeps (that lead to vents, pockmarks and other seabed features), dissolved inorganics and acidity of the sediment and water column. Others such as rock type and sediment stability are difficult to obtain at a wide geographical coverage. Therefore these are not considered further for this project.

4. Methodology

The limits of the EMODNET projects were agreed between the various consortia to be based on ICES ecoregions¹⁶ primarily. These ecoregions are likely to inform the MSFD boundaries once agreed and, with the addition of EEZs as a secondary layer where appropriate, cover the obvious interpretation of the regions described in the tender specification for the project. For the EUSeaMap project regions (Figure 5) the Celtic and North Sea areas extend to the limits of the UK continental shelf also, as this area was covered under the MESH project and for consistency and comparability was felt should be included.

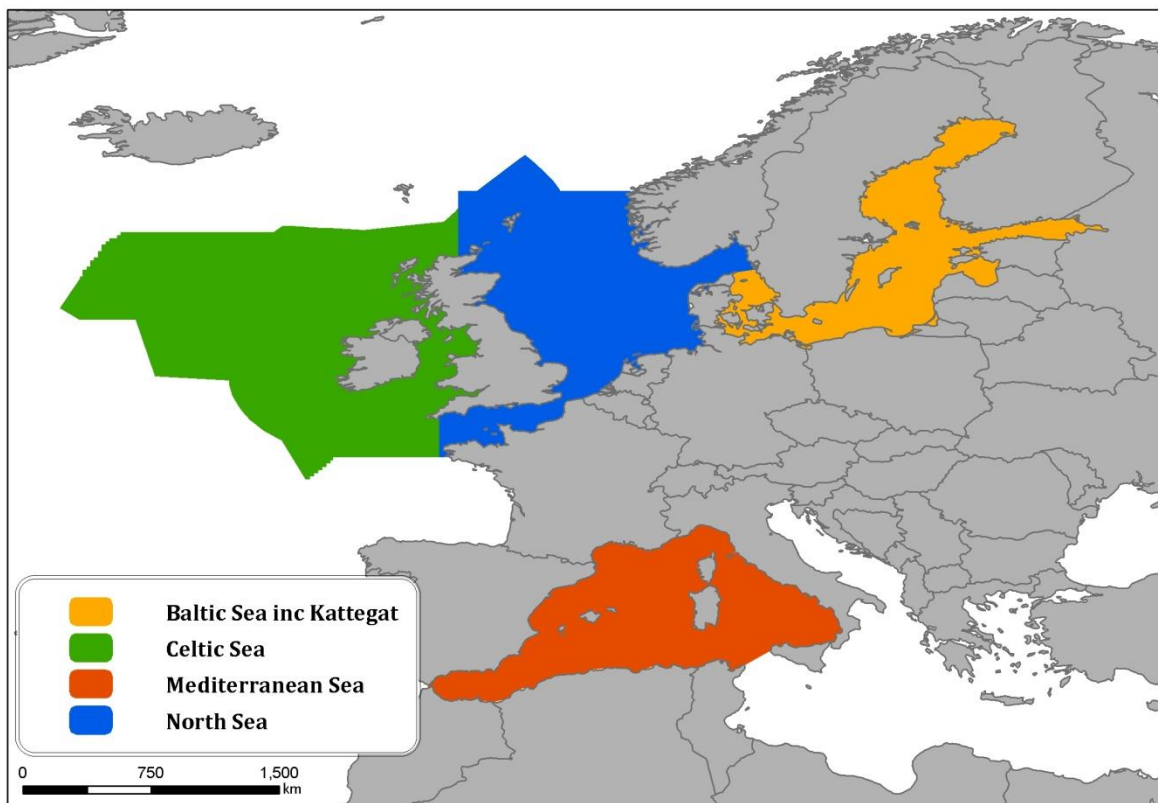


Figure 5 Geographic extent of the EUSeaMap project. Regional basins are defined by ICES ecoregions with additional areas where EEZs extend beyond these.

4.1. Application of EUNIS

As the only consistent system to classify European seabed habitats, EUNIS and its spatial application through modelling are at the core of this project. Although the structure of EUNIS will be followed, the precise terminology used for different levels of the hierarchy will not be adopted. EUNIS defines a habitat as *“plant and animal communities as the*

¹⁶ <http://www.ices.dk/aboutus/icesareas.asp>

characterising elements of the biotic environment, together with abiotic factors [...] operating together at a particular scale". This use of the term habitat to include both biotic and abiotic elements is in common with many policy mechanisms (e.g. Habitats Directive, OSPAR Convention list), and is usually referred to in scientific terminology as a biotope (Olenin and Ducrotoy 2006). For the purposes of this report however it is helpful to separate habitat, in its original meaning, the "*abiotic environment [...] which contributes to the nature of the seabed*" (Connor *et al.* 2004) from the biotic 'community'. The term biotope will be used to describe the combination of a habitat and an associated community of species, as defined by Connor *et al.* (2004) and Olenin and Ducrotoy (2006).

EUNIS classifies habitats on a seven-tier hierarchical scale. At level 1, habitats are separated into marine habitats (EUNIS code: A) and others (terrestrial and freshwater). At level 2, EUNIS identifies the marine habitats based on depth and substrate type, permanent or non-permanent water cover, ice-cover and characteristics of the pelagic water column (EUNIS codes: A1 – A8) (Davies, Hill & Moss 2004). Level 3 habitats are further classified based on criteria involving abiotic variables such as the actual substrate nature (i.e. coarse sediment, sand, sandy mud), energy levels (moderate, high, low energy), temperature, light, salinity and plant cover. Differentiations between habitats based on the components of the biological communities begin to appear at level 4 in rocky environments (e.g. A3.11: Kelp with cushion fauna and foliose red seaweeds; Figure 6). However the inclusion of biological communities at level 4 is not universal across the system. Figure 6 shows that in sediment environments level 4 can be reached using only physical data, e.g. A5.35: circalittoral sandy mud.

The upper levels of the marine classification of EUNIS are primarily defined using abiotic variables (substrate, depth, etc.) which are categorised in a way in which is relevant to the biological communities they support. For instance, as seen in section 3.2, substratum is separated into classes for rock, sand, gravel and mud because they support markedly different communities. The particular combinations of the abiotic variables lead to different biological communities such that it becomes possible to model the distribution of seabed habitats using data for a number of environmental variables, using the structure of EUNIS levels 1 to 3 as the basis for defining the relationship between habitat and their abiotic characteristics. Modelling using these abiotic variables enables the prediction of EUNIS habitat types to level 3 or 4. The current structure of EUNIS is not always best suited to such top-down modelling processes, so the predictive ability is not strictly linked to a single level in EUNIS (e.g. not all types at level 4 can be predicted on abiotic data alone). This may reflect sensible differences in biological character or it may reveal inconsistencies in the current structure of EUNIS. Similarly, the modelling process results in producing some seabed habitat types that do not feature in EUNIS currently. It is hoped that EUSeaMap may inform where there are gaps or inconsistencies in the EUNIS structure.



Figure 6 Examples from the EUNIS hierarchy. The example on the left is a sediment environment and illustrates that level 4 can be attained by modelling using physical data layers only. The example on the right is a rocky environment and shows that to predict to level 4 of EUNIS cannot be done with physical data alone and requires community data.

4.2. Modelling

This project will develop the techniques used in similar projects (UKSeaMap 2006, BALANCE 2007, MESH 2008), which “recognised the strong correlation between environmental parameters and ecological character, such that mapping environmental parameters in an integrated manner can successfully be used to produce ecologically relevant maps” (Connor *et al.* 2006). The approach used is an application of what is commonly referred to as multicriteria evaluation: the combination of several variables through the use of layers in a Geographical Information system (GIS) that can determine a meaningful modelled output (Figure 7). The main data layers to be used here are: a) seabed substrate, b) biological zones (also referred to as depth zones), and c) energy conditions at the seabed. These data layers are divided into classes equivalent to the EUNIS level 3 types. Division is made by using specific thresholds which are defined either from literature and expert judgement, or through testing against field data.

In practical terms, this process can be performed in a raster based GIS: in EUSeaMap ESRI® ArcMap™ 9.2/9.3 with Spatial Analyst extension has been used. The raster input data layers contain grid cells with continuous values. These values can be assigned to classes according to where they fall within a defined set of thresholds for a given variable. If several variables are considered as distinct grid layers, these grids can be stacked within a GIS to construct combinations of these classes, in the form of a code for each grid cell. These codes can be translated to a EUNIS habitat code where possible (Table 4), since the primary layers equate to the variables used at the top levels of EUNIS. As the building blocks of EUNIS, these variables will form an integral part of the EUSeaMap model.

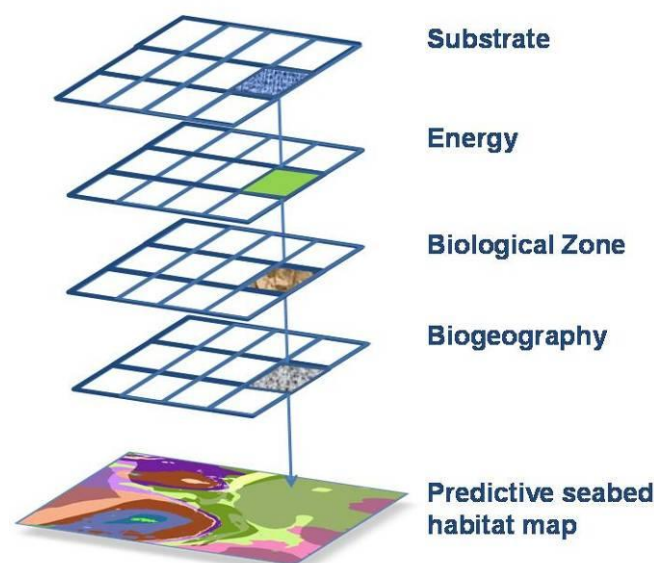


Figure 7 Illustration of raster based multicriteria evaluation.

Table 4 Example of EUNIS habitat types at level 3 and 4 which can be identified from the data layers seabed substrate, biological zone, and in the case of rock substrate types, by energy conditions. Note that some combinations from the modelling process do not have an equivalent EUNIS habitat type.

Biological zone	Seabed substrate						
	Rock/Reef			Coarse Sediment	Sands and muddy sands	Muds and sandy muds	Mixed sediment
	Energy						
	High	Moderate	Low				
Infralittoral	A3.1	A3.2	A3.3	A5.13	A5.23 or A5.24	A5.33 or A5.34	A5.43
Cirralittoral	A4.1	A4.2	A4.3	A5.14	A5.25 or A5.26	A5.35 or A5.36	A5.44
Deep ciralittoral	A4.27	A4.27	A4.33	A5.15	A5.27	A5.37	A5.45
Deep Sea	A6.1	A6.1	A6.1	No code	A6.3 or A6.4	A6.5	A6.2

Data sets in the raster format are used (rather than the vector format) because it is much more economical in terms of data storage, and also because the majority of the source data layers are generated in this format. Additionally, the raster form is ideal to carry out map algebra, i.e. the combination of a series of pixel maps.

The working or nominal resolution was chosen as approximately 250m, since this level of resolution is generally available for most datasets. It should be noted that whilst this is the case in the coastal zone for the two key base layers (substratum and depth), it does not hold true in deep offshore areas where data tend to be found at coarser resolutions. However, one way to express the fact that source layers are not as detailed as the nominal resolution is by associating a confidence map to the final map.

The GIS modelling process is a combination of pre-processing modules that are needed to go from the original data to the input layers for the core model. The whole process will be thoroughly documented, since the value of the model is in its updating capabilities when improved data sets become available. As part this process updating the confidence map along with the modelled map is of course required.

4.3. Defining thresholds for habitats

Crucial to the EUSeaMap seabed habitat modelling process is the structure of EUNIS, which informs the application of ecologically-relevant thresholds to environmental variables. These thresholds must classify the variables in a way that can be translated to the predictive units, in this case the level 3 and 4 EUNIS habitat types. In some cases the definition of a seabed habitat lends itself naturally to a clearly defined threshold, and perhaps one that is

easily quantifiable. In the case of seabed substrate it is easy to conceive areas of rock or sand. However, the concept of what constitutes 'low energy' is not one that is easily well developed for seabed habitats. Exploring these thresholds is a key step in the modelling process. Thresholds can be determined in a variety of ways; arbitrary, intuitive, using expert judgement or through a variety of more complex analytical means.

For example, Infralittoral Rock and Circalittoral Rock in EUNIS (types A3 and A4) differentiate themselves by the type and degree of vegetation cover observed in the different communities that develop in the infralittoral and circalittoral zone. The infralittoral zone is in fact characterised by communities dominated by seagrasses and photophilic species of algae such as kelp and photophilic red, green and brown algae, while the circalittoral, and in particular the upper circalittoral of some European seas, is characterised by reduced light levels supporting sparser vegetation communities dominated by sciaphilic brown and red algae. Scientific literature for northern European seas suggested that the infralittoral boundary with the circalittoral zone could be determined on the basis of the estimated 1% of surface light levels reaching the seabed but previous attempts to statistically validate the boundary in MESH revealed the threshold was better placed at 2.3% using the available light data. This has been further explored in EUSeaMap and is described in more detail in section 5.1.1 below.

Similar validation of thresholds for other abiotic data and across different geographic areas will give the highest possible confidence in the output maps. Each of the input variables will be examined and the thresholds used previously (in the MESH and BALANCE projects) will be reviewed. Although this is a potentially large task, the project will focus on the thresholds for those variables considered most critical in each Region. Fine-scale biological data (community types or biocenoses) will be used in selected areas to help validate the thresholds.

4.3.1. Fuzzy classifiers

Previous efforts to model full coverage seabed habitats at large spatial scales (section 2.2 and 2.3 above) have used multicriteria evaluation with Boolean logic: a habitat falls into a distinct, finite class for each contributing variable used in the model. In other words, the thresholds are 'hard' boundaries between classes in the input variables, and hence these hard boundaries are reproduced in the final habitat map. However, this use of classical set theory is often inadequate to represent the natural variation that would be expected in the relationships between habitats and environmental variables (Yanar & Akyürek 2004). In reality one habitat does not make such a sharp transition to another.

To include this notion of variability within our model, the concept of fuzzy logic has been used in EUSeaMap. When ecological thresholds cannot be defined to classify a habitat distinctly with a specific value (e.g. a temperature threshold of 9.0°C rather than 9.1°C) such

thresholds can be described as fuzzy. In this case, a given class is defined by a range of values marking the low and high end of acceptance criteria for membership to that class. A function transforms the continuous environmental variable to a membership value from 0 to 1, with one being the maximum membership to a class possible. A pixel grid cell will then be classified as being located somewhere along this continuum rather than simply present or absent in the class. Figure 8 illustrates an example of how membership function for classes can be set up. The habitat models will then calculate, for each category of each variable, the measure of membership to the category.

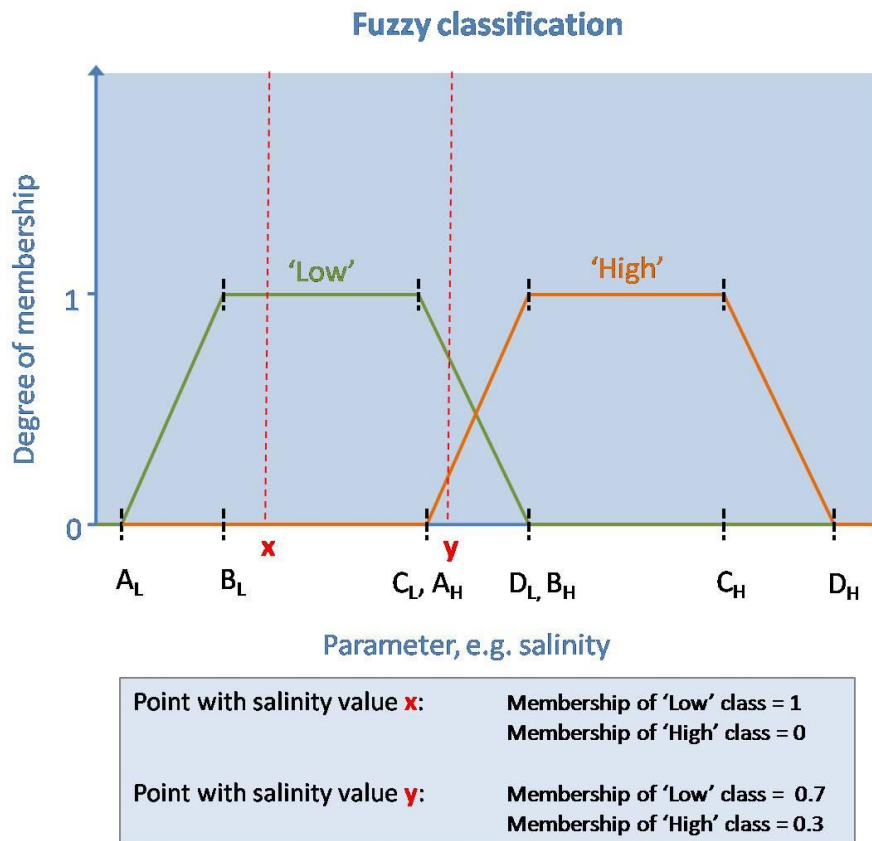


Figure 8 Fuzzy thresholds, example using two classes.

4.4. Confidence

An important part of the EUSeaMap project is to provide an assessment of confidence in the final modelled seabed habitat maps, commensurate with the intended uses of the map. Confidence is defined as a statement about how reliable a map user thinks the map is, given its purpose¹⁷. This is not a mathematical definition like accuracy or uncertainty, but is a judgement made by the map-user and may therefore vary for any map. However, this judgment can be supported by evidence from:

- Accuracy measures
- Supporting maps showing underlying evidence used to interpret map
- Evaluation of all contributing data
- Independent validation
- Expert opinion
- User support

Previous projects have followed this definition, and the MESH project developed a tool to assess the confidence in seabed habitat maps, at www.searchmesh.net/confidence. The tool evaluates a map by scoring factors according to agreed rules. The approach received positive feedback in international fora, including from the ICES Working Group on Marine Habitat Mapping (WGMHM)¹⁸ and OSPAR Marine Protected Areas, Species and Habitats (MASH)¹⁹ group. The output of the tool is a qualitative measure of confidence in a seabed habitat map. To date, this method has been used only to assess the confidence of surveyed habitat or substrate maps, for example where remote sensing data and ground-truthing data have been interpreted to produce mapped seabed types. It has not yet been applied to broad scale predictive maps.

Another approach is to analyse the uncertainties associated with the contributing data layers statistically and obtain a quantitative, probabilistic measure of confidence. This is a complex process, particularly as each variable used in the construction of the modelling layers needs to be examined against sufficient field data. Finally, a third method involves the use of fuzzy classifiers to determine the likelihood of occurrence of a seabed habitat. Further consideration of the approaches available to achieve this is given in section 7.

¹⁷ MESH definition

¹⁸ <http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=104>

¹⁹ www.ospar.org

5. Data layers

During the course of project meetings it was decided which variables should be priorities in terms of developing improved data layers and thresholds applied to these data layers. Key data layers were considered to be light attenuation, energy (effects due to waves and currents), substrate and bathymetry. Progress is summarised in the following section, with detailed descriptions of the methods used to produce the data layers in the Technical Appendices accompanying this report. A full list of data sets collected to contribute to the development of these data layers is presented in Appendix IV.

As EUSeaMap represents the first time such a modelling approach has been tried at this scale for the western Mediterranean, much attention was given to the identification of seabed habitats that could be modelled in the Mediterranean. The seabed habitats were identified by screening them from the overall Mediterranean benthic habitats list identified within the framework of the UNEP-MAP Barcelona Convention²⁰ which describes all the benthic habitats present in the Mediterranean. This habitat list and the corresponding EUNIS habitat types were analysed so as to identify those seabed habitat types which could be mapped at our working resolution of ~250m. The list was then further examined and for each habitat the approximate variable thresholds for the input data layers (substrate, biological zone and energy) which characterise and influence the presence of each were identified. Appendix II indicates the EUNIS habitat types to be modelled for the Mediterranean and the variable values which determine their occurrence. Table 5, Table 6 and Table 7 outline the physical data layers prepared for the EUSeaMap predictive seabed habitat model in each basin.

Table 5 Physical data layers used in the construction of the EUSeaMap predictive seabed habitat model for the North Sea and Celtic Seas.

North & Celtic sea data layers	Organisation	Source(s)	Resolution
Bathymetry	SeaZone	Coastal Digital Elevation Model	30m
	Intergovernmental Oceanographic Commission (IOC) (of UNESCO) and the International Hydrographic	GEBCO ²¹	30 arcsecond

²⁰ <http://www.unepmap.org/>

²¹ General Bathymetric Chart of the Oceans: www.gebco.net

	Organization (IHO). EMODNET Hydrography project partners	EMODNET hydrography DEM	15 arcsecond
Light	ESA	MERIS on ENVISAT platform	1km
Substrate	EMODNET Geology partners	EMODNET Geology substrate map (version 20100830)	1:1,000,000
Waves	NOC DHI	ProWam MIKE21 Spectral wave model (from the coast out to 6km from the coast)	12.5km ~100m
Currents	NOC	POLCOMS CS20 ²² POLCOMS CS3 POLCOMS North East Atlantic	1.8km (2007 version) 10km (2007 version) 35km (2007 version)

Table 6 Physical data layers used in the construction of the EUSeaMap predictive seabed habitat model for the Western Mediterranean.

Western Mediterranean data layers	Organisation	Source(s)	Resolution
Bathymetry	Intergovernmental Oceanographic Commission (IOC) (of UNESCO) and the International Hydrographic	GEBCO	30 arcsecond

²² Run 11 was used.

	Organization (IHO).		
	EMODNET Hydrography project partners	EMODNET hydrography DEM	15 arcsecond
Light	ESA	MERIS on ENVISAT platform	1km
Substrate	Various	Various – collated by EUSeaMap partners	From 1:10,000 - 1:1,000,000
Waves	PREVIMER	WAVEWATCH III	10km
Currents	PREVIMER	MENOR	1km

Table 7 Physical data layers used in the construction of the EUSeaMap predictive seabed habitat model for the Baltic Sea.

Baltic Sea data layers	Organisation	Source(s)	Resolution
Bathymetry	BALANCE project partners	BALANCE bathymetry	1:250,000 - 1:1,000,000
Light	ESA	In Kattegat & Skagerrak: MERIS on ENVISAT platform	1km
	ICES, SYKE ²³	In Baltic Proper: Secchi depth data	200m
Substrate	EMODNET Geology partners	EMODNET Geology substrate map (version 20100830)	1:1,000,000
Salinity & halocline	DHI	MIKE3 Classic 3D Hydrodynamic	3nm

²³ Finnish Environment Institute

		Model	
Waves	Aquabiota	Simplified Wave Model	25m
	DHI	MIKE21 Spectral Wave Model	3nm

5.1. Biological zone

Biological zone maps have been prepared for each basin by integrating bathymetry with information about light attenuation through the water column (all basins), wave attenuation through the water column (North Sea and Celtic Seas), the position of the deep halocline (Baltic), manual interpretations of slope values and bathymetry (Western Mediterranean), and information about depth zonation in deep sea communities (North Sea and Celtic Seas). The following sections describe the preparation these biological zone maps, and present the maps.

5.1.1. Light attenuation

On Atlantic coasts the infralittoral zone is where favourable light conditions enable the development of kelp forests, whereas in the Mediterranean and Baltic the infralittoral 'reference' seabed habitat is that of *Posidonia oceanica* seagrass meadows and *Fucus* respectively. This lower depth boundary varies with turbidity and can reach around 45 and 50 metres respectively for the Atlantic and the Mediterranean.

Sciaphilic algal communities forming coralligenous communities and rhodolith (maerl) beds are able to thrive in very low light levels, making the 0.01% light threshold relevant to define the lower limit of the upper circalittoral zone.

There are two ways of assessing light levels in the water column. The first is by using the very simple "Secchi disc" method which is still the standard method used in oceanography cruises. While somewhat over-simplistic, this method enables comparisons between basins and also makes it possible to benefit from historic data sets. In the Baltic Sea where high concentrations of detritic matter in the ocean are a drawback to using satellite imagery, it can be a valuable alternative, as explained in the section on the Baltic below.

The second method uses satellite observations of the diffuse attenuation coefficient of the down-welling spectral irradiance at wavelength 490 nm (K_{d490}) or the diffuse attenuation coefficient for the down-welling photosynthetically available radiation (K_{dPAR}), which is an effective method to provide large extent maps of light attenuation at high spatial and temporal resolution. Several models are commonly used to derive the K_{d490} and K_{dPAR} maps from ocean colour satellite sensors, such as the Medium Resolution Imaging Spectrometer

Instrument (MERIS) aboard the European Envisat satellite, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and the Moderate Resolution Imaging Spectroradiometer (MODIS). Most of these existing models have been calibrated on open ocean waters and provide good results in these areas, but tend to underestimate the attenuation of light in turbid coastal waters.

The infralittoral zone can be determined by intersecting the depth data layer with these light attenuation values and using a pre-defined threshold. The 1% threshold is still the subject of discussion in the scientific community and it is within the remit of this project to attempt to validate it with suitable ground-truth data for both the Atlantic and the Mediterranean. This fraction (Fr) of surface light which reaches a given depth is computed using the formula:

$$Fr = e^{-h/D_m}$$

where h is the depth and $D_m = K_{PAR}^{-1}$, sometimes referred to as mean penetration depth.

For EUSeaMap, an improved K_{PAR} layer has been estimated from radiance measured by the MERIS sensor (Saulquin *et al.*, in prep.).

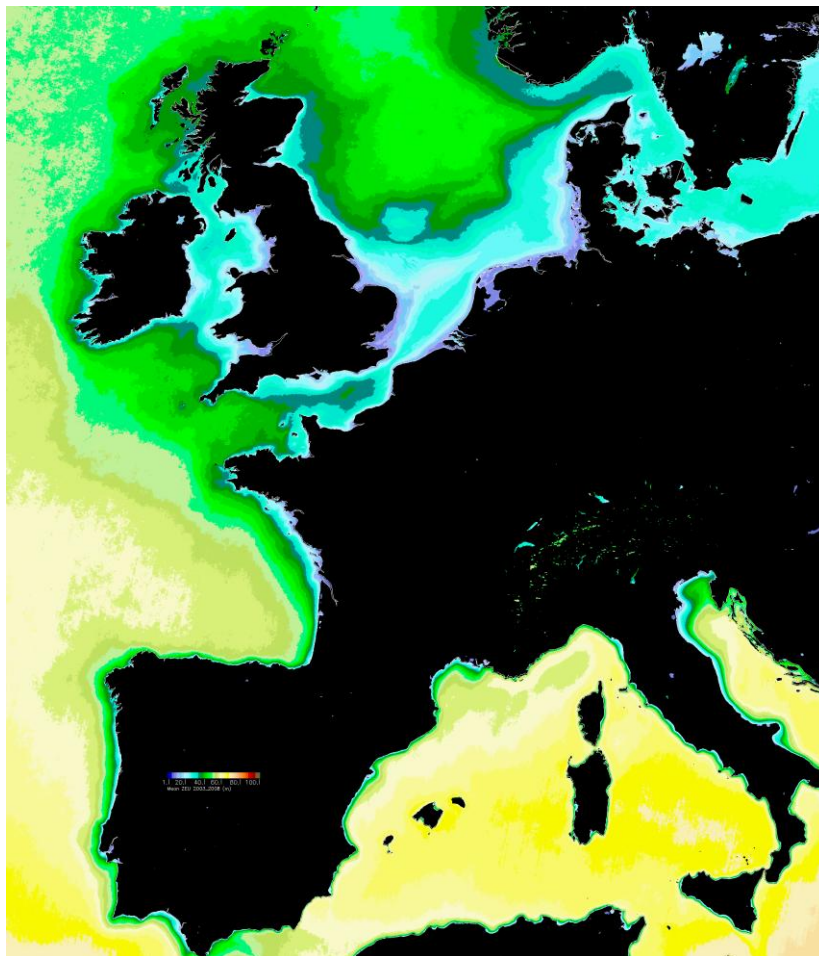


Figure 9 Overview of photic depth (Zeu) as computed for the MERIS swath zone.

The validity of the 1% light threshold implemented with satellite imagery was checked with a comparison to ground-truth data. In the Atlantic, acoustic measurements of kelp forest from 2007 surveys in Brittany at a number of sites (Abers, Héaux de Bréhat, Triagoz, Méloine, Molène, Ile de Groix - Méléder *et al.* 2010) were plotted against the photic zone as derived from the 1km resolution K_{PAR} . The distribution of kelp habitats around the UK coast was examined. This was carried out using 4km resolution light data (K_{d490} values) from the MODIS instrument on NASA's Aqua satellite and bathymetry data from GEBCO and SeaZone Hydrospatial to calculate values for the fraction of surface light reaching the seabed. Data showing the spatial distribution of kelp habitats were extracted from the UK's database of seabed habitat samples (Marine Recorder). These kelp habitat data were intersected with the data layer showing the fraction of light reaching the seabed, derived from 4km resolution MODIS data. Using the first quartile value of the fraction of incident light reaching the seabed where kelp habitats were found, the threshold was identified as 1% of surface light. A similar analysis by the MESH project identified the threshold as 2.36%. However, this work used 9km resolution data which may be responsible for the different result. Higher resolution data (250m) from the MERIS satellite have recently become available: and EUSeaMap plans to use these higher resolution data to again test the infralittoral-circalittoral boundary in the Atlantic.

In the Mediterranean pristine *Posidonia* beds in Corsica mapped in recent years were deemed suitable for such a comparison (as opposed to more degraded continental ones, whose limits are heavily impacted by anthropological activities) (Figure 10). There is generally good agreement between the two sets of data, which seems to confirm the soundness of the threshold definition. Full details of the preparation of the light layer and threshold testing for all basins is described in the Technical Appendix for light (in preparation).

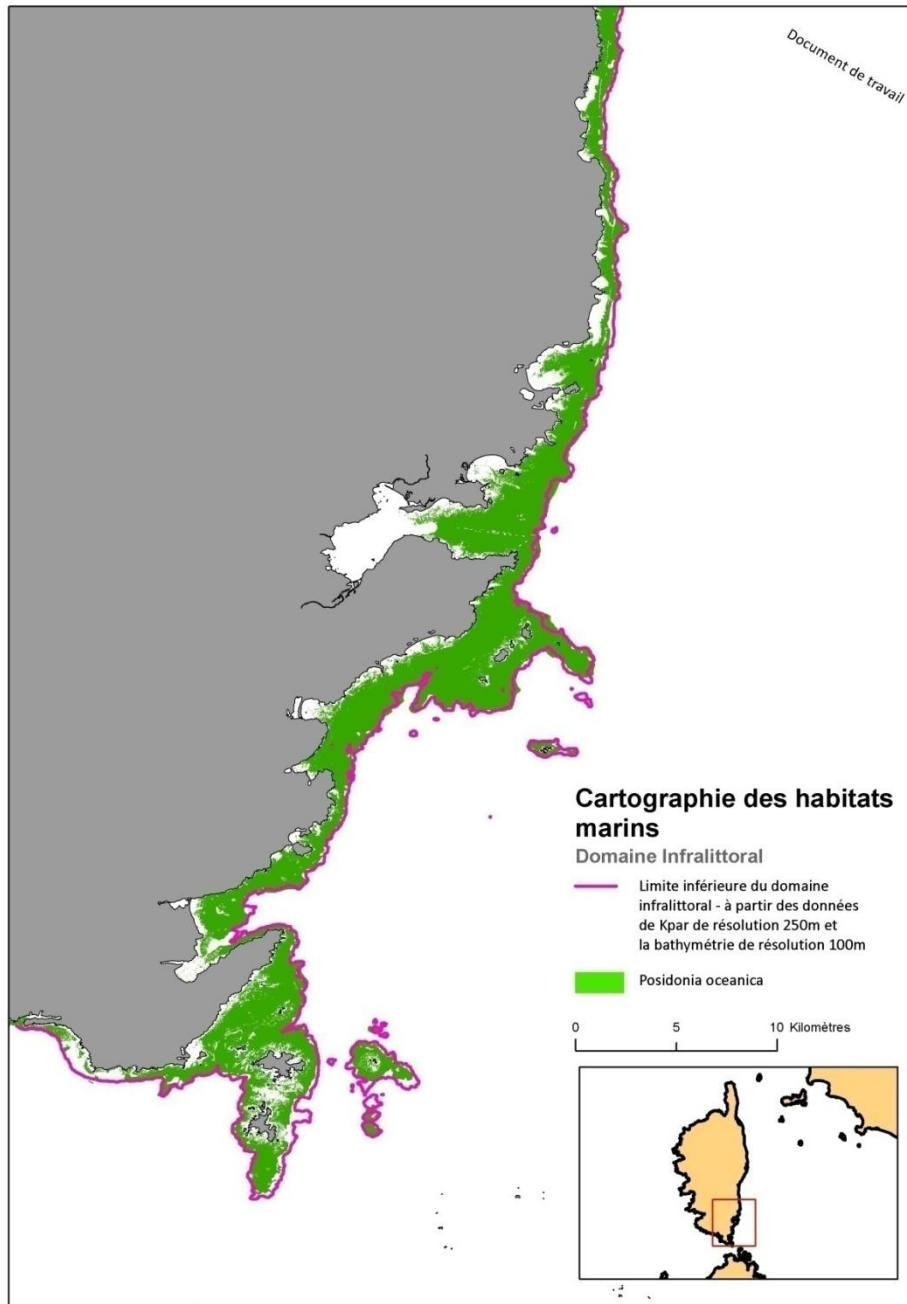


Figure 10 Comparison of 1% light contour from MERIS imagery (250m resolution) with seagrass bed outlines in Corsica.

Some research questions still remain with regard to the use of such imagery. So far mean annual values over a multiple year period have been used; it would be interesting to also look at monthly or seasonal values. Discussions in meetings revolved around the seasonality for threshold testing, e.g. March – end of June to cover recruitment and growth period, but there are many conflicting opinions in the literature. For example, the winter period might be important with respect to the length of time for which species need to store light energy, or perhaps a ratio of summer to winter means is best to examine. There is a need to consider differences between regions for species (*Posidonia*, *Fucus* and *Laminaria*). It was

also suggested to seek for means corrected for seasonal variability.

Due to high amounts of coloured dissolved organic matter, frequent cloud cover and a lack of optical field data for sea-truthing, remote sensing of the optical properties of the Baltic Sea at a regional scale is difficult (Kratzer *et al.* 2003). An alternative approach, which was successfully applied earlier (Al-Hamdani & Reker 2007, HELCOM 2009), is using Secchi depth data. The method described in Al-Hamdani and Reker (2007) was refined, and additional data were incorporated²⁴, to produce a Secchi depth raster for the Baltic Sea.

At many of these locations, Secchi depths had been measured repeatedly, and monthly means were calculated. The main growing season from March to October was covered with at least one measurement per month at 277 locations. For these, “growing season means” were calculated, which were strongly correlated to the monthly means from April to October. Thus, a linear regression function was determined for each of these months (R^2 ranging from 0.77 to 0.86; Figure 11). For the locations where data were not available for the whole March to October period, but at least for one of the months between April and October, the growing season mean was estimated based on the month with the best-fitting regression line.

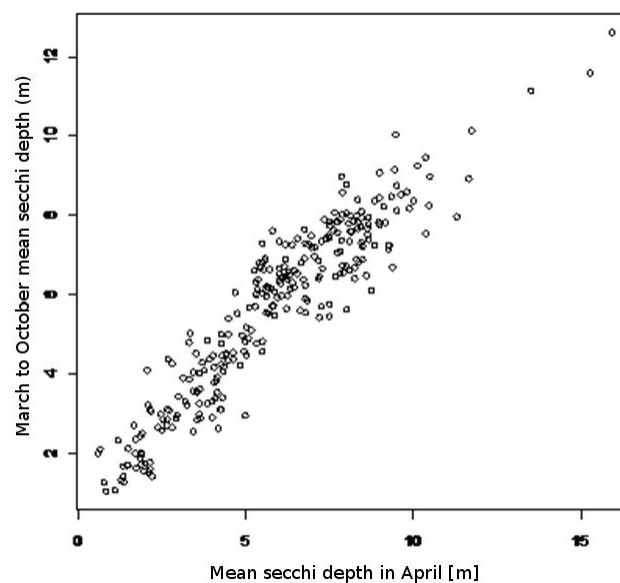


Figure 11 Scatter plot of April mean Secchi depths vs. growing season (March to October) mean Secchi depths, n=277.

However, this approach neglects inter-annual variability, and the density of data points was spatially very variable. To avoid pseudo-patchiness, the study area was subdivided into squares with a side length of 10km. For each square, the growing season means of all data points within were averaged and assigned to the points' mean centre. A Secchi depth raster

²⁴ Secchi depth data were obtained via the International Council for the Exploration of the Sea (ICES): Aarup's collection (Aarup 2002) covering 1902 to 1998 and additional data covering 1999 to 2008. The Finnish Environment Institute (SYKE) provided further data points for 2000 to 2008.

with a spatial resolution of 200m was then interpolated from the mean centres based on local trend surfaces. Cross-validation showed a mean error caused by the interpolation of below 1m and without a clear spatial pattern. Finally, a low pass filter was applied.

To derive euphotic zone depths from Secchi depths, conversion factors ranging from 1.7 to 3.5 have been suggested in literature (Al-Hamdani and Reker, 2007, and references therein; Holmes 1970). In EUSeaMap, the analyses of thresholds for light were done separately for (1) oligohaline, (2) mesohaline and (3) polyhaline and fully marine zones, since the biological communities used to define the thresholds differ greatly between these salinity zones. In the oligo- and mesohaline parts of the Baltic Sea proper (inside Öresund and the Danish Belts), the ratio between Secchi depth and depth was used to map the thresholds. In the polyhaline and fully marine parts of the Baltic Sea area (Kattegat and Skagerrak), the $K_{d_{PAR}}$ layer produced from MERIS data was used to map the thresholds between infralittoral and circalittoral and between upper and lower circalittoral.

The oligo- and mesohaline zones lack kelp communities, which are used to define the lower threshold of the infralittoral in the Atlantic EUNIS. Instead, the threshold was defined by the deepest occurrence of algal-dominated biotopes.

The field data set used to set the threshold values came from a total of 902 diving transects from the Swedish and Finnish coasts. The method used to collect these transect data is designed to monitor depth distribution of organisms and the data were therefore expected to be well suited to defining the depth-related light thresholds.

The deepest finding of biotopes dominated by macroalgae was recorded for each transect and used in the analyses. The depth/Secchi depth ratio for the deepest recording was calculated as the ratio between the depth recorded during the inventory and the Secchi depth taken from the interpolated data layer.

Table 8 The values identified for the infralittoral-circalittoral boundary in the oligo- and mesohaline salinity zones in the Baltic Sea. The values are depth/Secchi depth ratio.

	Statistic	Value (D/SD)
Oligohaline	75 percentile	1.2
Oligohaline	max	2.0
Mesohaline	75 percentile	1.8
Mesohaline	max	3.2

The maximum depth/Secchi depth ratio recorded was used as the lower limit of the fuzzy threshold, after removing one or a few extreme outliers apparently resulting from errors in the Secchi depth layer. The 75 percentile was used as the upper limit of the fuzzy threshold for the transect data. The percentile levels were chosen as the expected fraction of the data

Version 1

that is likely to show the deepest occurrence of macroalgae and the resulting threshold values were examined and judged to give a reasonable result (Table 4).

The wide fuzzy threshold results in a large uncertainty around the light thresholds derived from the Secchi depth layer. It was also clear from the analyses that the defined thresholds tend to overestimate the depth distribution in some regions while underestimating it in other regions. For instance, the depth of the infralittoral is underestimated in offshore areas of the Baltic Proper, in some parts of the Eastern Baltic Proper and some coastal areas in the Bothnian Bay. This means that the mapping of the biological zones in the Baltic Sea could be greatly improved by a better light layer for the Baltic Sea, for instance produced from MERIS data.

In the polyhaline and fully marine zones, the lower threshold of the infralittoral was mapped using the 1% fraction of surface light as developed for the North and Celtic Seas. The relevance of this threshold in the Kattegat and Skagerrak was tested using the depth limit of kelp (*Saccharina latissima*, *Laminaria digitata* and *L. hyperborea*) in 198 diving transects. Only three of the transects (<2%) had presence of kelp below 1% light from the $K_{d_{PAR}}$ layer, indicating that this threshold is relevant in the Polyhaline salinity zone as well.

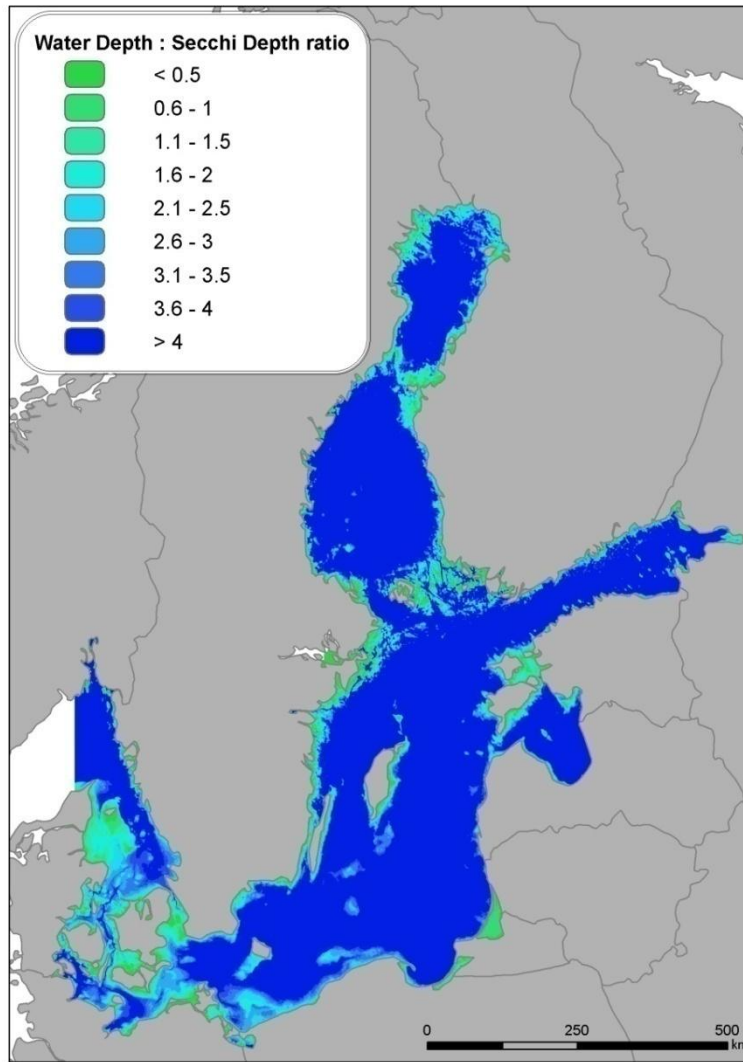


Figure 12 Water depth : Secchi depth ratio for the Baltic Sea.

5.1.2. Bathymetry

Bathymetry is one of the key deliverables for EUSeaMap from the EMODNET hydrography project. The DTM being developed by the EMODNET Hydrography consortium will be a minimum of a quarter minute resolution, with the latest half minute resolution GEBCO (General Bathymetric Chart of the Oceans) release incorporated for areas where sufficient data cannot be made available. The EMODNET Hydrography project covers the North and Celtic Seas and the Western Mediterranean. An initial draft of this dataset for the North and Celtic Seas was received in May 2010 (Figure 15). The preparation of the North Sea and Celtic Seas DTM is described in more detail in the Hydrography project Interim Report.

In the Western Mediterranean, EUSeaMap partners are also partners in the EMODNET Hydrography project. The projects have elaborated a Mediterranean global DTM with a resolution of 0.0027 decimal degrees (Figure 13). This DTM has been elaborated from twelve partial DTMs. One DTM was used for the French margin and one for the Italian margin. Ten

Version 1

DTMs were used for the Spanish margin and areas beyond French, Spanish or Italian waters (deep zones):

- Alborán Sea
- Catalan Continental Margin
- South of Ibiza Island – Balearic Islands
- South of Formentera Island – Balearic Islands
- Strait of Gibraltar
- East Mediterranean Margin
- ZEEE – Spanish Exclusive Economic Zone – Balearic Islands
- IBCM – South Alborán Sea
- IBCM – Deep zone Mediterranean Sea
- IBCM – Deep zone Tyrrhenian Sea

The data processing has been different in each case; these have been conditioned by the data source and format of the original data.

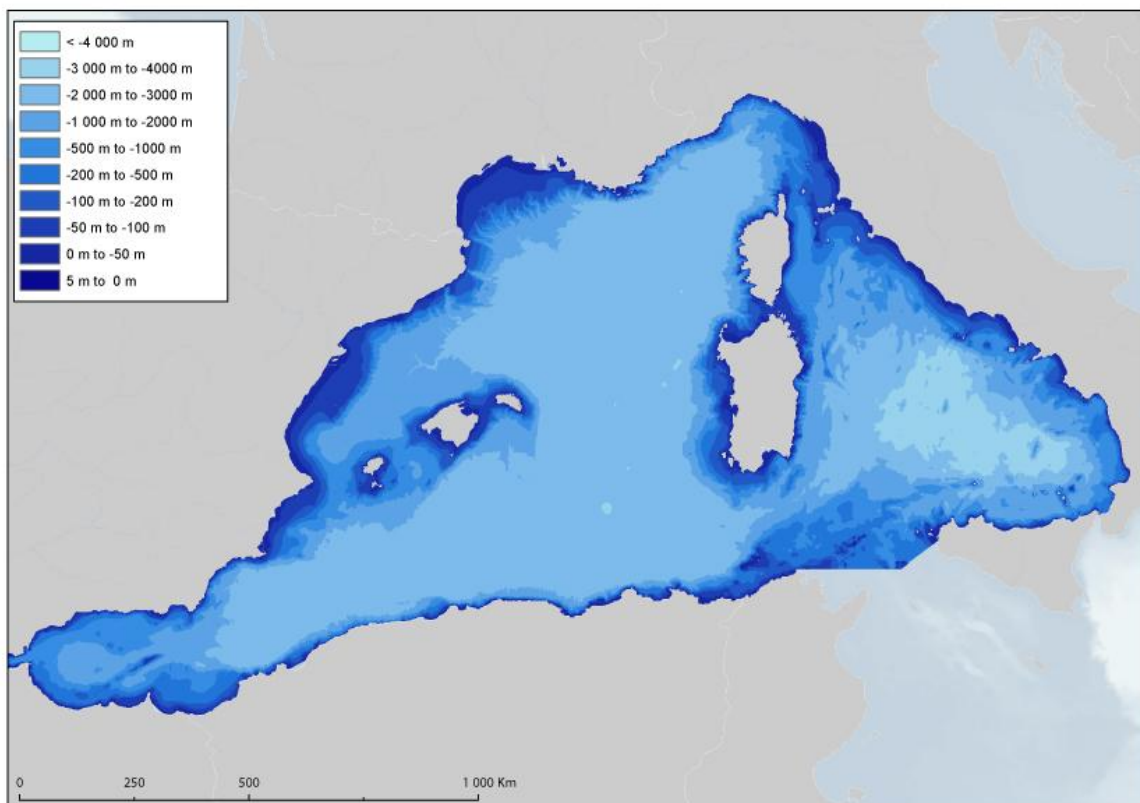


Figure 13 Bathymetry of the Western Mediterranean.

In the Western Mediterranean, bathymetry is the abiotic variable that was used to identify the threshold value to delimit the boundary between the lower circalittoral and the bathyal biological zone, and between the bathyal and the abyssal zone. In fact in both these biological zones it is the change in bottom slope angle, resulting from physical-geological constraints operating on the seafloor over time, that actually contributes to different

environmental conditions influencing the formation of discrete biological communities of the bathyal and abyssal biological zones

The lower limit of the deep circalittoral and beginning of the bathyal zone coincides with the external margin of the continental shelf and can be identified on the basis of the angle break in bottom slope followed by the higher seabed inclination of the continental slope. Bibliographic information reports this break as occurring between 110-260m (Carpine, 1970) with a median value range occurring between 170-210m. The lower limit of the bathyal zone and beginning of the abyssal zone instead coincides with the gentle sloping seabed angle change occurring just after the base of the continental slope. Bibliographic information reports this as occurring in the depth range 2500-3000m. Given the reported heterogeneity in depth range it was decided that the continental shelf edge limit and the continental slope angle change be identified manually

The manual identification of relevant changes in seabottom slope angle revealed more than one feature needing consideration for the definition of the circalittoral/bathyal and bathyal/abyssal boundaries. In particular, a first rupture of slope change (shelf break) was observed in continental shelf area at shallower depths than expected and prior to the point of the continental shelf edge. The shelf edge limit was identified for a good part of the basin but in some instances no shelf edge limit was identifiable due to the absence of a strong change in bottom slope angle. An alternative bathyal basin limit was identified in areas occurring at shallower depths where the seabottom angle changed from steep inclination to a mild one but at shallower depths than where the continental margin would be expected. The cartographic information on the different identified slope angle changes and topographic features is displayed in Figure 14 below.

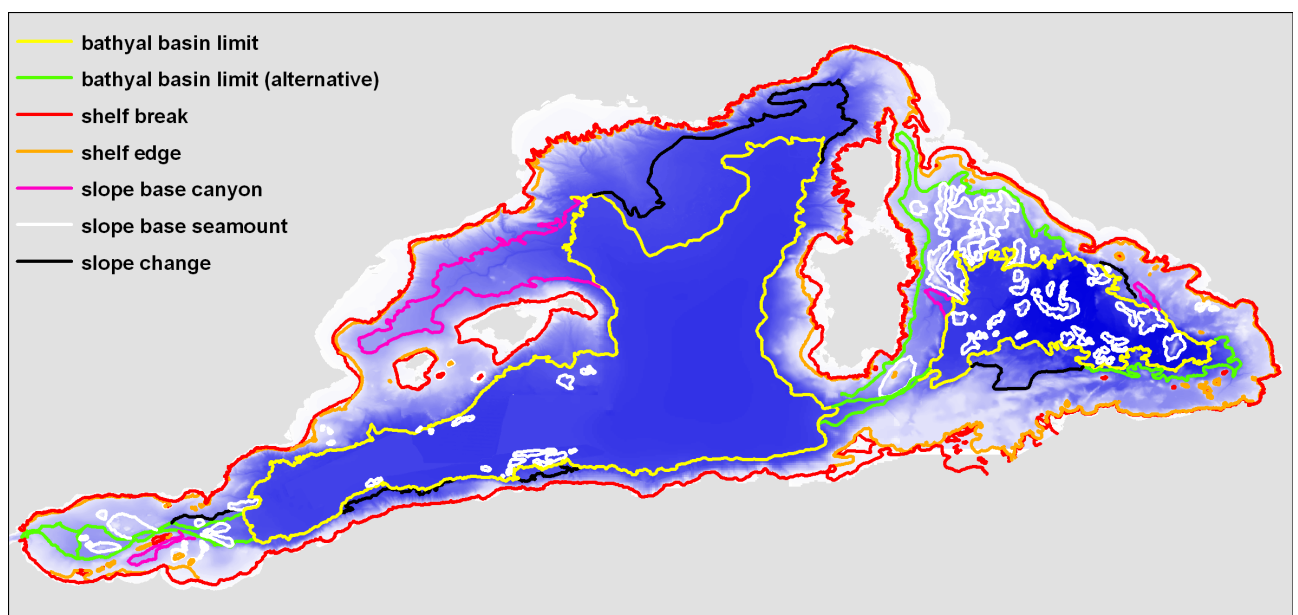


Figure 14 Seabottom slope angle change observed in the western Mediterranean.

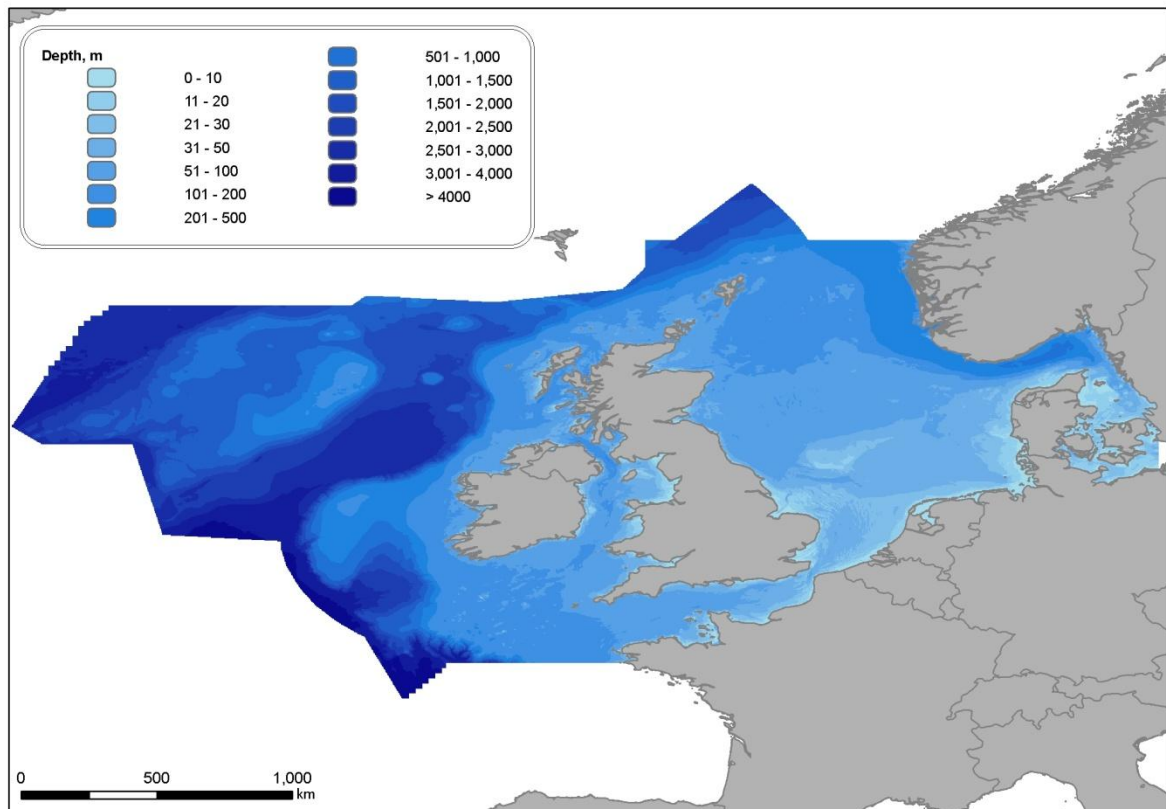


Figure 15 Bathymetry of the North Sea and Celtic Seas.

The Baltic Sea region is not included within the extent of the EMODNET hydrography project. For this region, bathymetry data collated for the BALANCE project was used. The BALANCE bathymetry layer was compiled from three regional bathymetry maps, these are:

- The Swedish 1:500,000 scale map
- The Swedish 1:50,000 scale map
- The Finnish 1:50,000 scale map
- The Danish 1:500,000 scale map

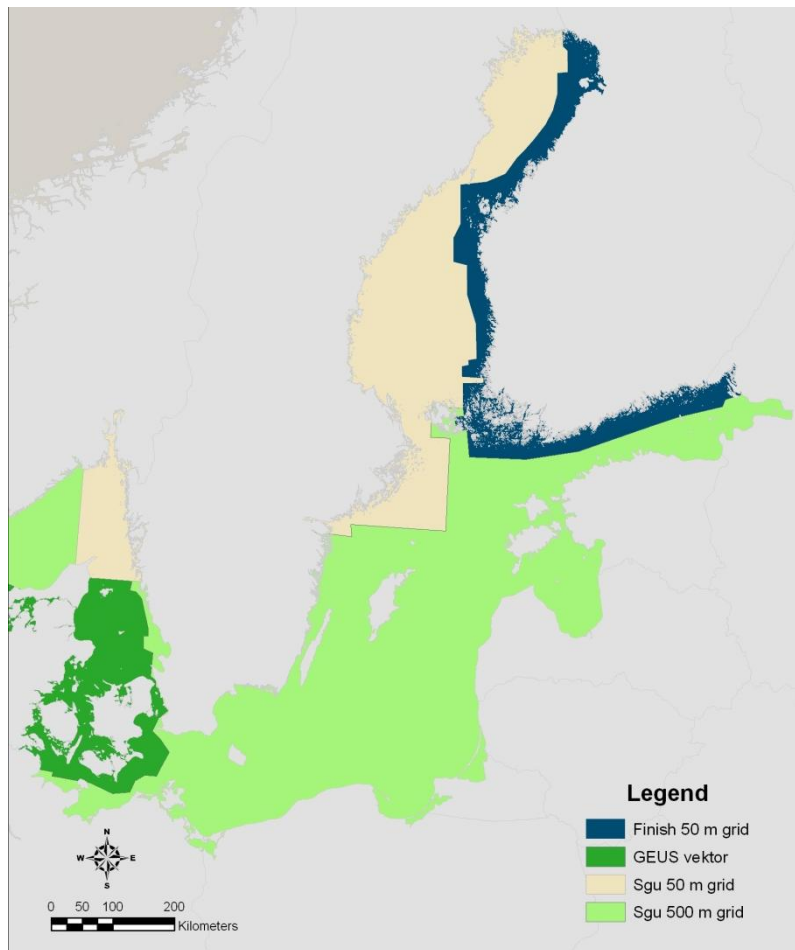


Figure 16 Coverages of four bathymetry maps used to make the BALANCE bathymetry map for the Baltic Sea map.

Joining bathymetry maps from different sources is not a straightforward task. Differences in bathymetry values at borders between maps are readily shown in the merged map. It is also difficult to produce reasonable values for slope from such compiled maps. Therefore care was taken to inspect the border zone of each two different maps and try to merge them by finding the average value at the overlap if they do not match.

Another problem was to join maps of different resolution; this immediately appears at the joint border so in some areas it was decided to under-sample the high resolution map to match it with the neighbouring low resolution one. In other occasions the high resolution map was used as it is, and others it was replaced by a lower resolution map.

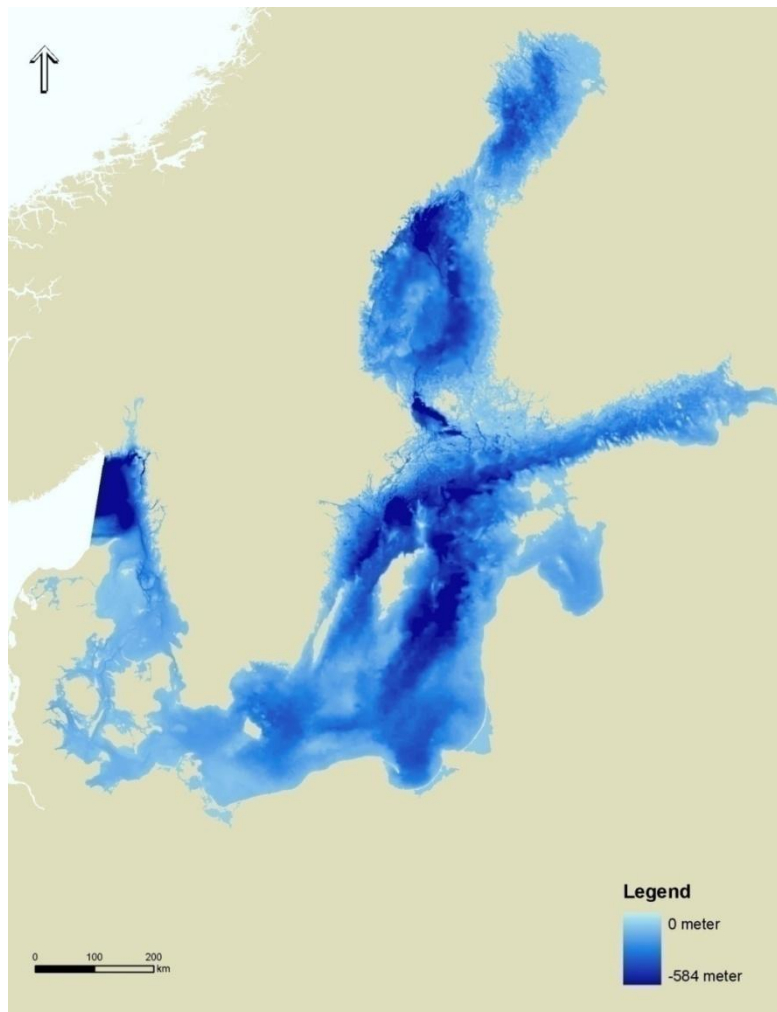


Figure 17 The BALANCE bathymetry map used in EUSeaMap.

5.1.3. Biological zone maps

Tables 9, 10 and 11 show the zones used to create each biological zone map for each basin. Figure 18, Figure 19 and Figure 20 show the resulting maps.

Table 9 Biological zones used for mapping in the Western Mediterranean.

Biological Zones of the Western Mediterranean	Upper limit	Lower limit
Infralittoral	0m	1% light reaches the seabed
Upper circalittoral	1% light reaches the seabed	0.01% light reaches the seabed
Deep circalittoral	0.01% light reaches the seabed	Shelf edge (manual delineation)
Bathyal	Shelf edge (manual delineation)	Slope change (manual interpretation)
Abyssal	Slope change (manual interpretation)	n/a

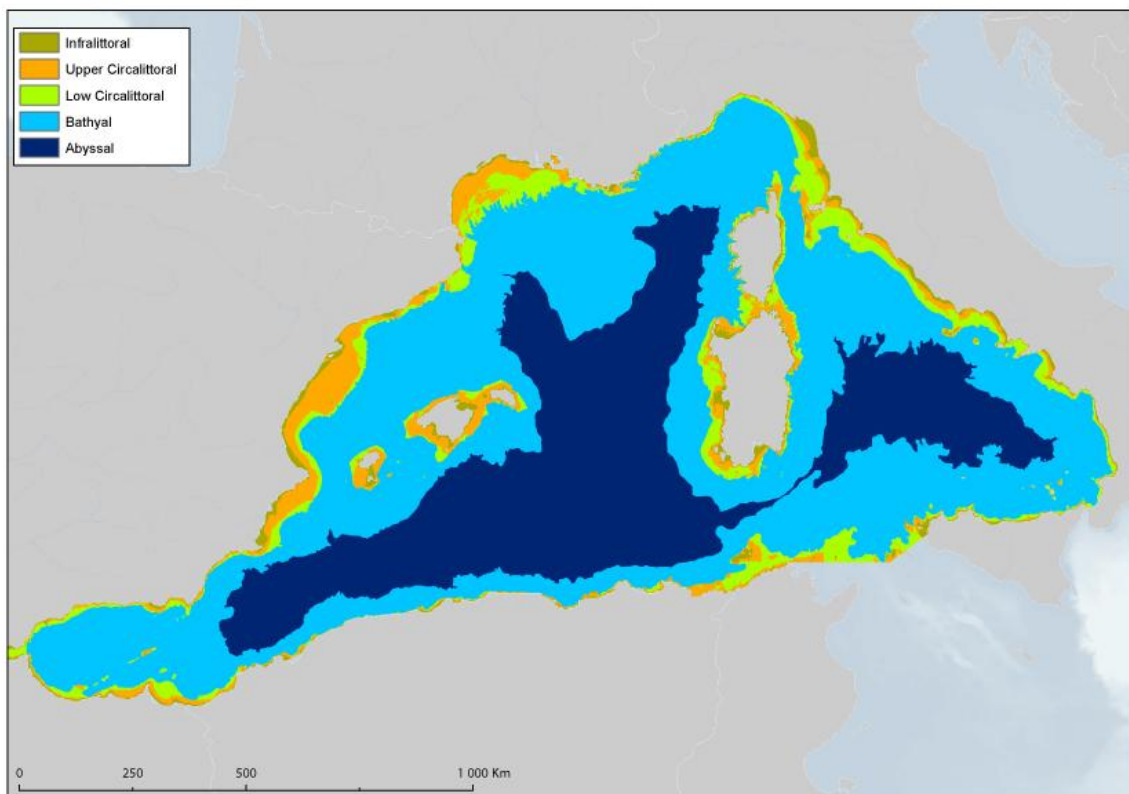


Figure 18 Biological zones of the Western Mediterranean.

Table 10 Biological zones used for mapping in the Baltic Sea.

Biological Zones of the Baltic Sea	Upper limit	Lower limit
Infralittoral	0m	2.5 ratio of depth/Secchi depth for mesohaline 1.6 ratio of depth/Secchi depth for oligohaline
Upper circalittoral	2.5 ratio of depth/Secchi depth for mesohaline 1.6 ratio of depth/Secchi depth for oligohaline	Position of deep halocline
Deep circalittoral	Position of deep halocline	n/a

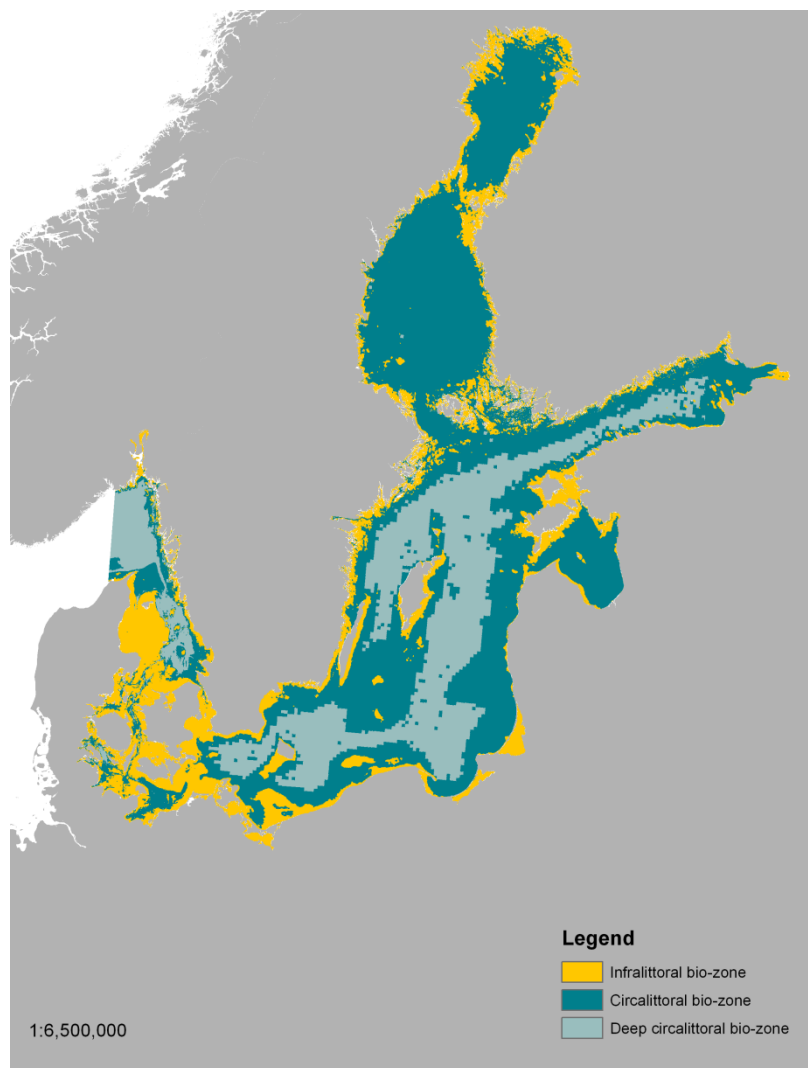


Figure 19 Biological zones of the Baltic Sea.

Table 11 Biological zones used for mapping in the North and Celtic Seas.

Biological Zone of North and Celtic Seas	Upper limit	Lower limit
Infralittoral	0m	1% light reaches the seabed
Circalittoral	1% light reaches the seabed	Wave base
Deep circalittoral	Wave base	200m
Upper slope	200m	750m
Upper bathyal	750m	1,100m
Mid bathyal	1,100m	1,800m
Lower bathyal	1,800m	2,700m
Abyssal	2,700m	

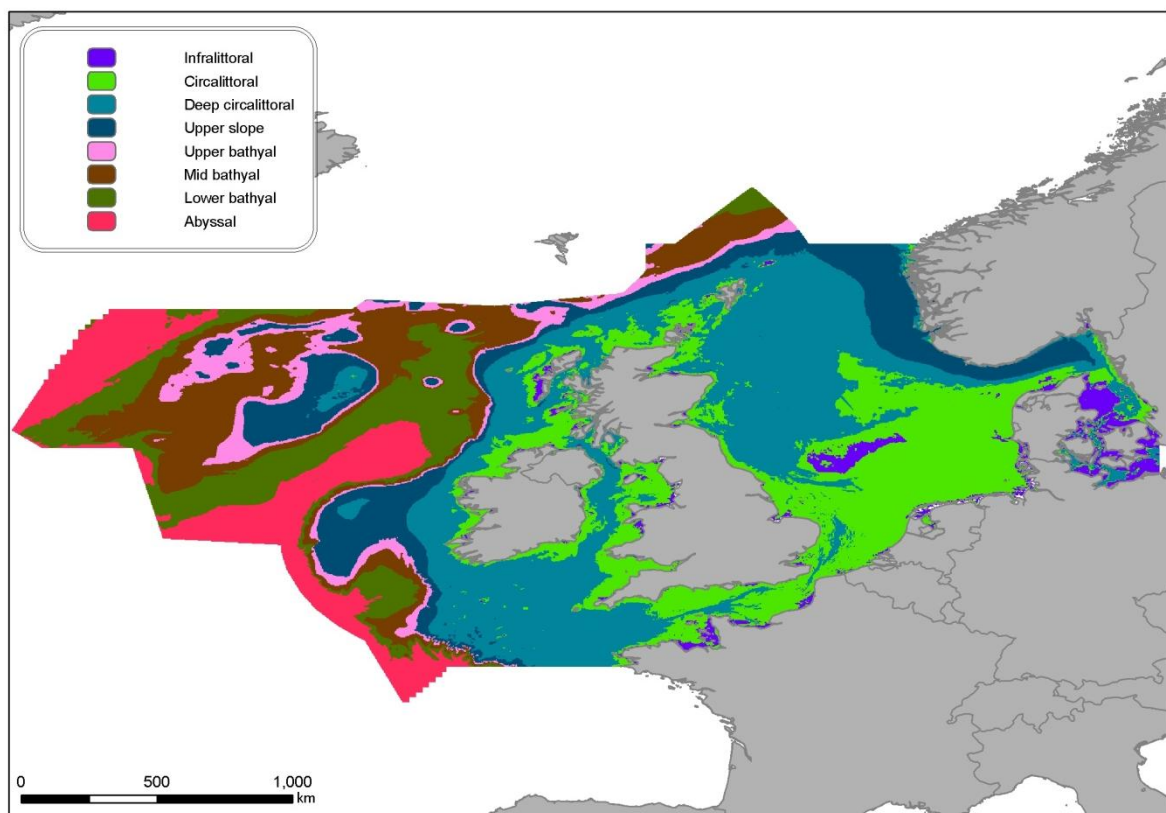


Figure 20 Biological zones of the North Sea and Celtic Seas.

5.2. Substrate

With the EUSeaMap project covering such a wide extent, there exists a potentially very large number of data sources, in particular for substrate maps. Therefore it was important to work with an appropriate sediment classification scheme that could not only relate to EUNIS but also be achievable in terms of collation and harmonisation. In previous projects the Folk classification has been preferred as the categories can be modified to many existing data sets and these then amalgamated to reflect the substrate types in the EUNIS classification.

For the North Sea, Celtic Seas and Baltic Sea, tests were carried out on the relationship between biological communities (benthic samples classified to EUNIS scheme) and results of particle size analysis (PSA) at the same locations. A clear relationship was not found between substrate and biological communities at EUNIS level 4, or at progressively more detailed levels in the EUNIS hierarchy. At EUNIS level 3, there are strong relationships between the biological communities and the PSA data. Our results indicated that the classes previously used in UKSeaMap and subsequently in MESH were still the most appropriate divisions of the Folk classification (Figure 21) to predict EUNIS habitat types. These four broad sediment types, plus hard substrate, form the basis of the EUSeaMap model. Through discussions with EMODNET geology lot, it was agreed that a draft seabed substrate data for these regions would be delivered at the end of January 2010. The map includes six substrate types; hard substrates, with till²⁵ also shown as this was considered by the group a particularly relevant substrate type for Baltic and northern North Sea regions. The resulting map represents the first continuous harmonised substrate map over such a large area of northern Europe, extending from the Baltic out to the Atlantic off the west coast of Ireland.

²⁵ Unsorted glacial deposits with no stratification.

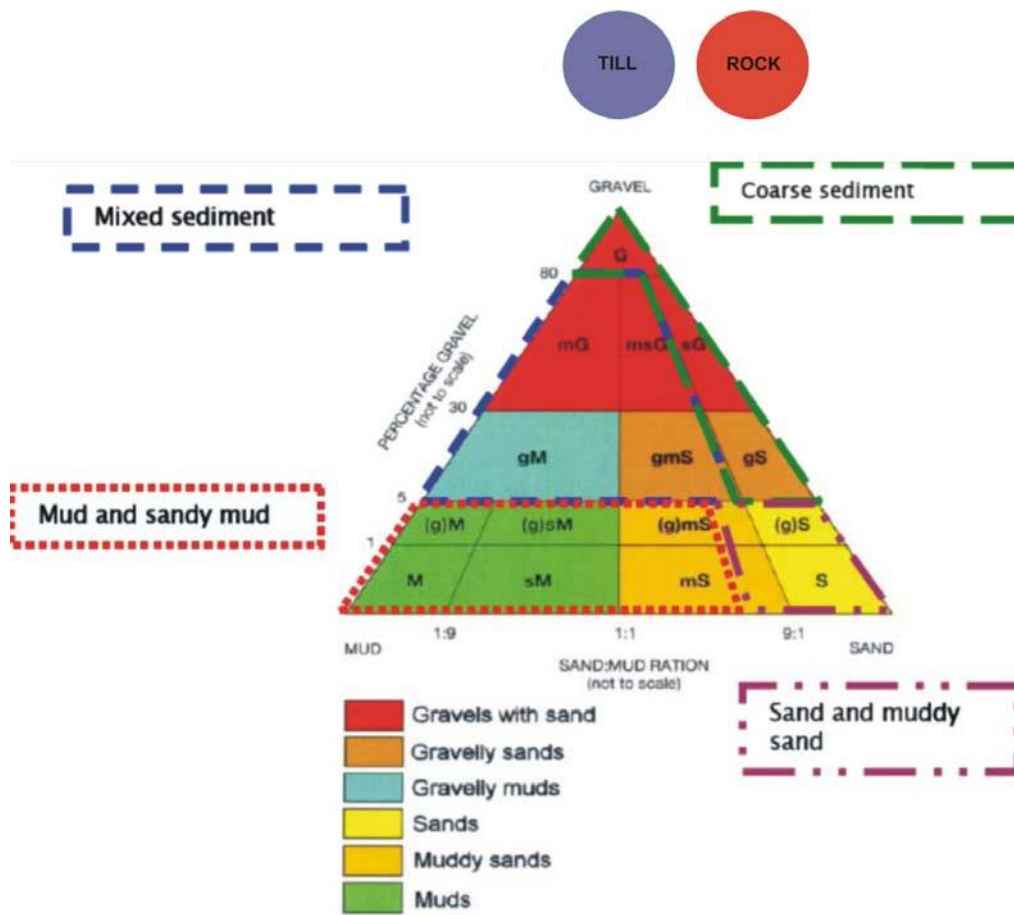


Figure 21 Folk classification of sediment types, with aggregated groups to be used in EUSeaMap project. Note the modified ratio threshold for the category Sand and muddy sand, and that boulders are included with rock.

The first draft of EMODNET sediment map was delivered to EUSeaMap by June 2010. The map was a result of integration and harmonisation of data from 17 organisations from all partner’s countries (Figure 22). Each partner submitted a substrate map of their national waters including the EEZ. The submitted shapefile contains attribute table containing information about the metadata.

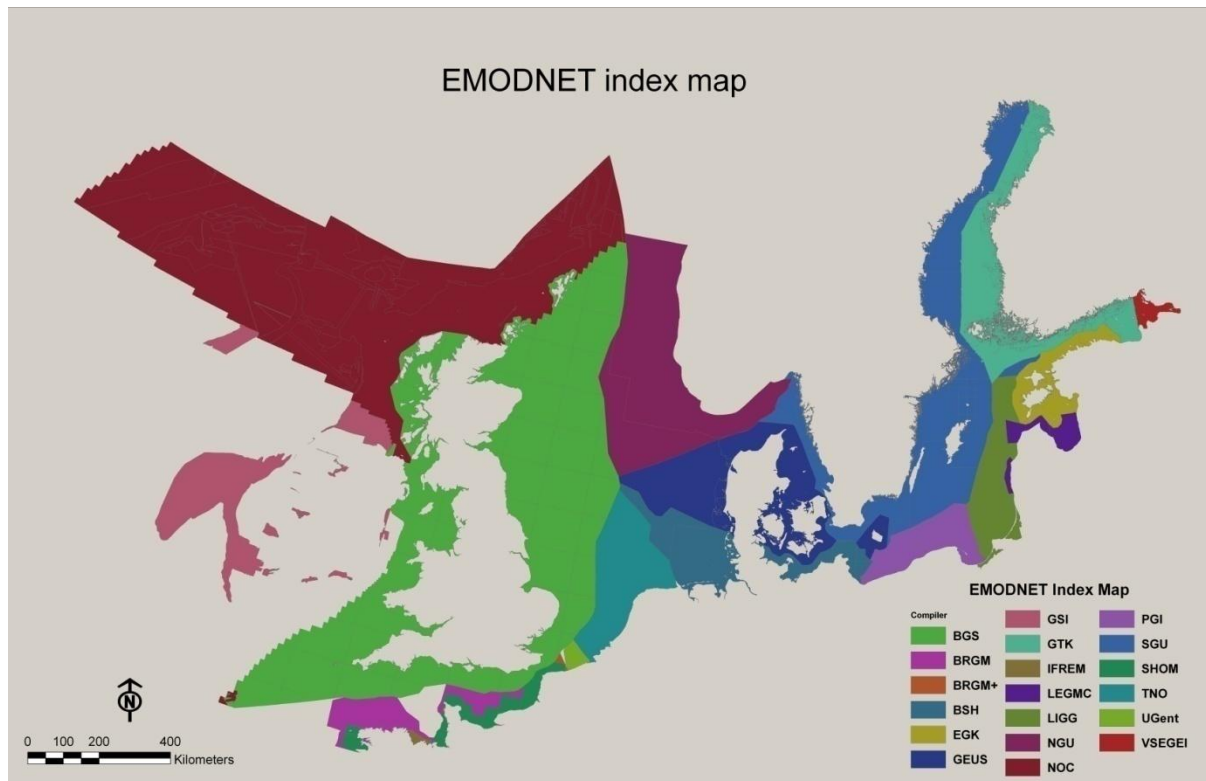


Figure 22 EMODNET substrate index map, showing sources of substrate maps used to create harmonised substrate map.

In the EMODNET Geology project more than 200 maps were harmonised to a one continuous map. Methodologies used for producing these maps differed enormously, with remote-sensing methods varying from poor to full-coverage, and positioning systems ranging from advanced systems (0-5m accuracy) to Nautical Charts (>100m accuracy). Gaps were found in a few areas such as the Channel and the Celtic Sea. These differing methods were captured in the attribute table of the index map, which was used by EUSeaMap to create confidence maps.

The current seabed substrate map was produced on the basis of EUSeaMap requirements. Due to the challenging timeline, the substrate reclassification scheme is simplified and provides an estimate of the substrate from the uppermost 30cm of the sediment column. The BALANCE approach was adapted to reclassification due to its simplicity and transparency (Al-Hamdani et al. 2007). The approach is based on surface material (that is sometimes predicted). At the kick-off meeting in Edinburgh it was decided to include 4 substrate classes on the basis of the modified Folk triangle (mud to sandy mud; sand to muddy sand; coarse sediment; mixed sediment) and take into account 3 additional classes (boulder, till/diamicton, bedrock) (Figure 21). The aim was to compile one seabed substrate map that includes all seven classes. Only two boulder fields were defined from the study area. Due to their small spatial coverage boulders were merged with bedrock for EUSeaMap modelling.

The numerous European national and international sediment datasets are very diverse. Traditionally, European countries have conducted their marine geological surveys according to their own national survey and interpretation standards.

Substrate classifications also vary as different nations have interpreted their data according to national classification schemes. The seabed surface sediment maps that were not originally in the Folk classification system were reclassified. The first step in the reclassification was to analyze the surface material. In ideal cases the substrate content was examined from the actual surface samples and grain-size analysis. If this was not possible, an expert-based prediction of the surface sediments was made.

The predicted surface sediments were then compared with the modified Folk classification system to find the best fit. In addition, differences in national grain-size classification schemes were identified. Harmonization of national categories into one classification scheme is essential for interoperability. Unfortunately, the substrate reclassification is not unambiguous in every case. In particular, the definition of the mixed sediment class turned out to be difficult. During the project meeting in Rovaniemi it was found that the term 'mixed sediment' had been interpreted different by the partners during the harmonizing process. For example, the following seafloor types and sediments have been identified as 'mixed sediment': patchy seafloor; glacial clay; bimodal grain size distribution.

The seabed substrate attribute table shows that large portion of the maps is reclassified to the modified Folk system based on expert-based prediction, especially in the Baltic Sea area.

The EMODNET Geology project provides data at 1:1 million scale. If not originally compiled at this scale, more detailed maps were generalized. The EMODNET project followed the cartographic principles established in the MESH project²⁶. Accordingly the smallest cartographic unit (polygon) on a map of the scale 1:1 million is about 4 km². Thus all sediment polygons less than 4 km² were eliminated.

The generalization procedure was implemented in ArcGIS environment and followed GTK's guidelines (Väänänen *et al.*, 2007). This method raises the issue of the deletion of important information. It is important to be aware of these issues to try to improve the generalization methodology in future projects. For example, partners could generalize their data individually or could be separate layers that show heterogeneity and special features.

²⁶ <http://www.searchmesh.net/default.aspx?page=1635>

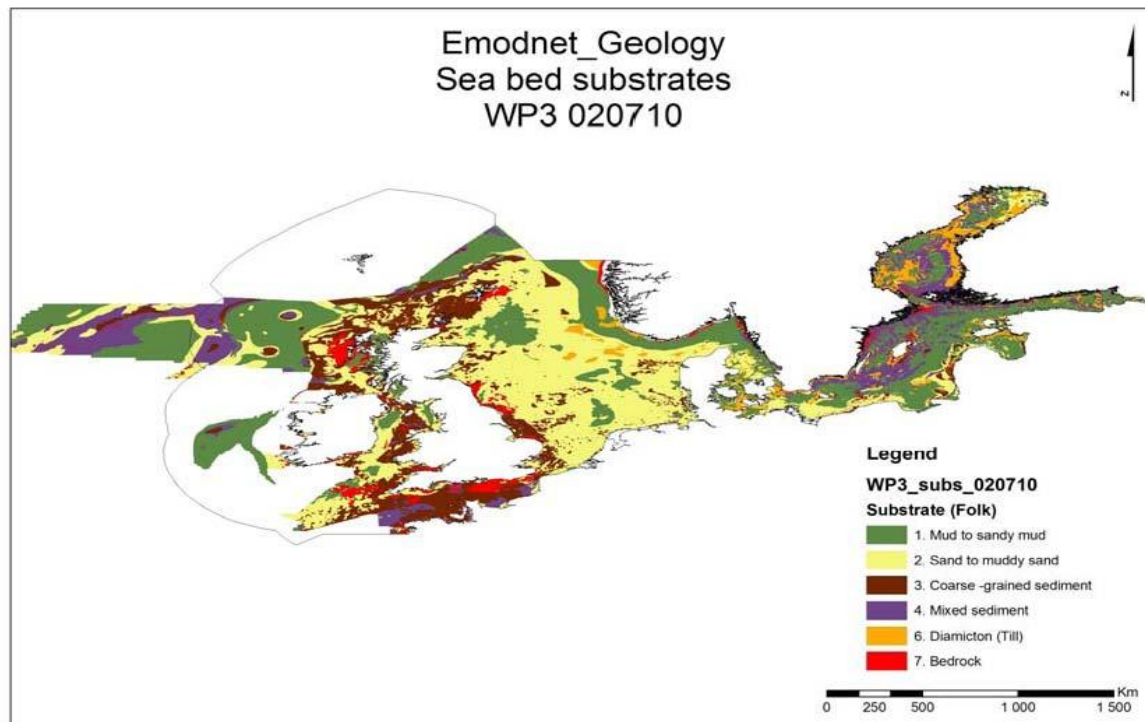


Figure 23 Seabed substrate map of the EMODNET geology study area.

The Western Mediterranean is not part of the EMODNET Geology project; instead in this region standardising sediment data have been created within the EUSeaMap, to create seabed substrate information which is essential for seabed habitat modelling. Generally there are fine-scale sediment maps around the coasts of France, Spain and Italy. In areas without detailed mapping, sediment distribution maps from the IOC International Bathymetric Chart of the Mediterranean (IBCM) have been used.

Partners converted their maps into an agreed classification as follows: coarse and mixed sediment, sand, muddy sand, sandy mud, mud, rock. In the Mediterranean, *Posidonia* and *Cymodocea* are often mapped as substrate types on geological maps. Rather than lose this useful biological information, classes for *Posidonia* and *Cymodocea* have been retained in the final Mediterranean substrate map (Figure 25). The raw data used to make the fine-scale sediment maps are not available to this project, so the conversions are being made through expert interpretation of the map classes themselves, rather than examination of grain size or % composition data.

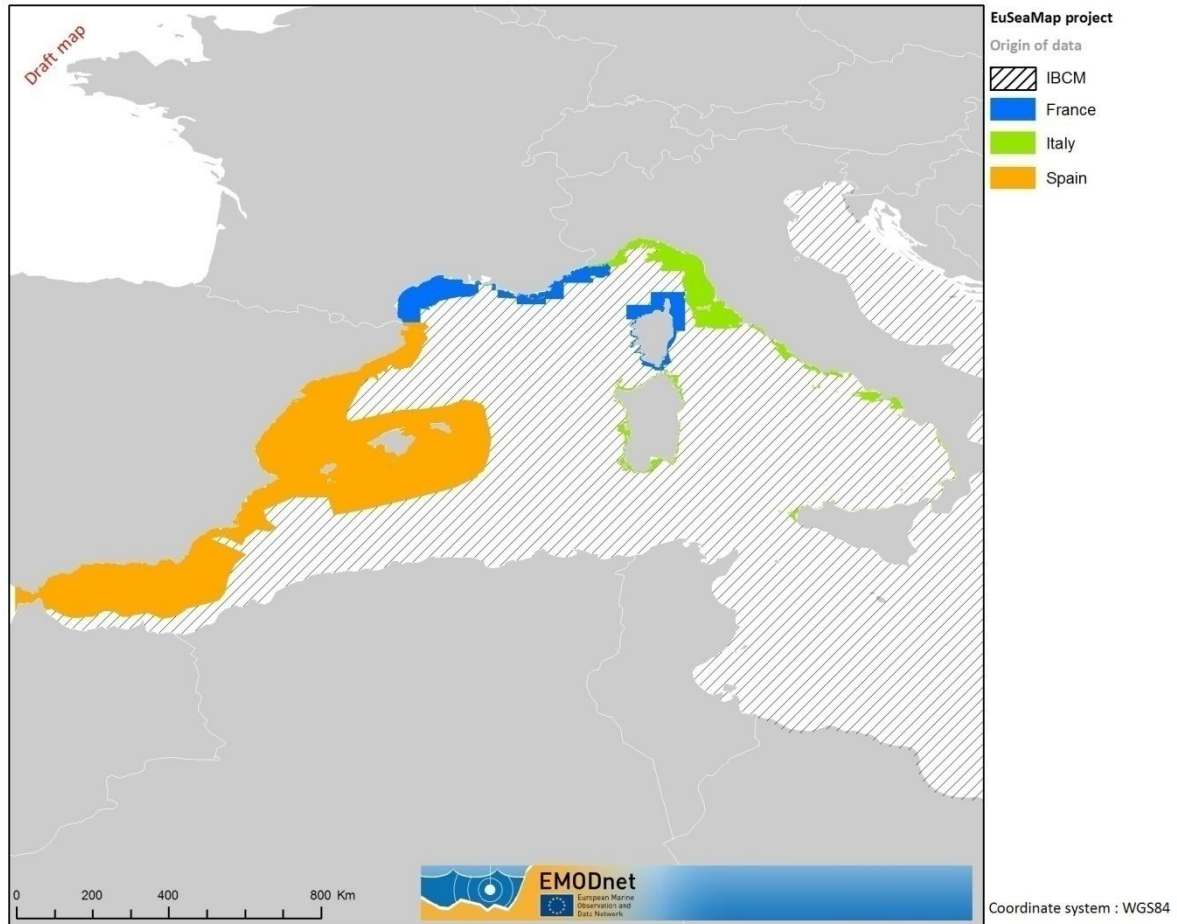


Figure 24 Western Mediterranean substrate index map, showing sources of substrate maps used to create harmonised substrate map.

The substrate map for Western Mediterranean seas was prepared using different cartographic sources derived by previous work. Therefore, coverage of substrate data for these waters represents an assemblage of different information collected at different scales and/or projections, with different methodologies and for different objectives. Much effort was put into standardising the different sediment classifications used to make the various collated substrate maps. The raw sediment sample data were rarely available, and as such EUSeaMap needed to rely on re-classification of interpreted polygons into the agreed classification. The data were acquired from different source formats; some of them were available in electronic format (i.e. ESRI™ shapefiles, images) while others were available as printed maps and have been digitised.

The sources collated for Italian waters are the following:

- GIS Natura
- Quaderno ICRAM
- Atlante habitat Liguria – Regione Liguria
- ENEA – Cartografia sedimentologica dei mari Toscani
- ENEA – Carta bionomica dei mari Toscani
- ISPRA (exICRAM) – Elba

Version 1

- Il Mare del Lazio
- CARG

The sources collated for French waters are the following:

- SHOM
- BRGM
- Perpignan University
- Lima
- MedBenth database (seagrass meadows)

These sources (plus Spanish and deep water sources) are detailed in Appendix IV and in the Technical Appendix describing the preparation of substrate data layers (in preparation). This Technical Appendix will include a brief description of the project; the geographic region covered; data attributes; original projection; original scale; year of the data; original sediment classification and how this was converted into the 6 agreed Folk categories for the Mediterranean (Rock, Sand, Coarse Sand or Gravel, Muddy Sand, Sandy Mud, Mud).

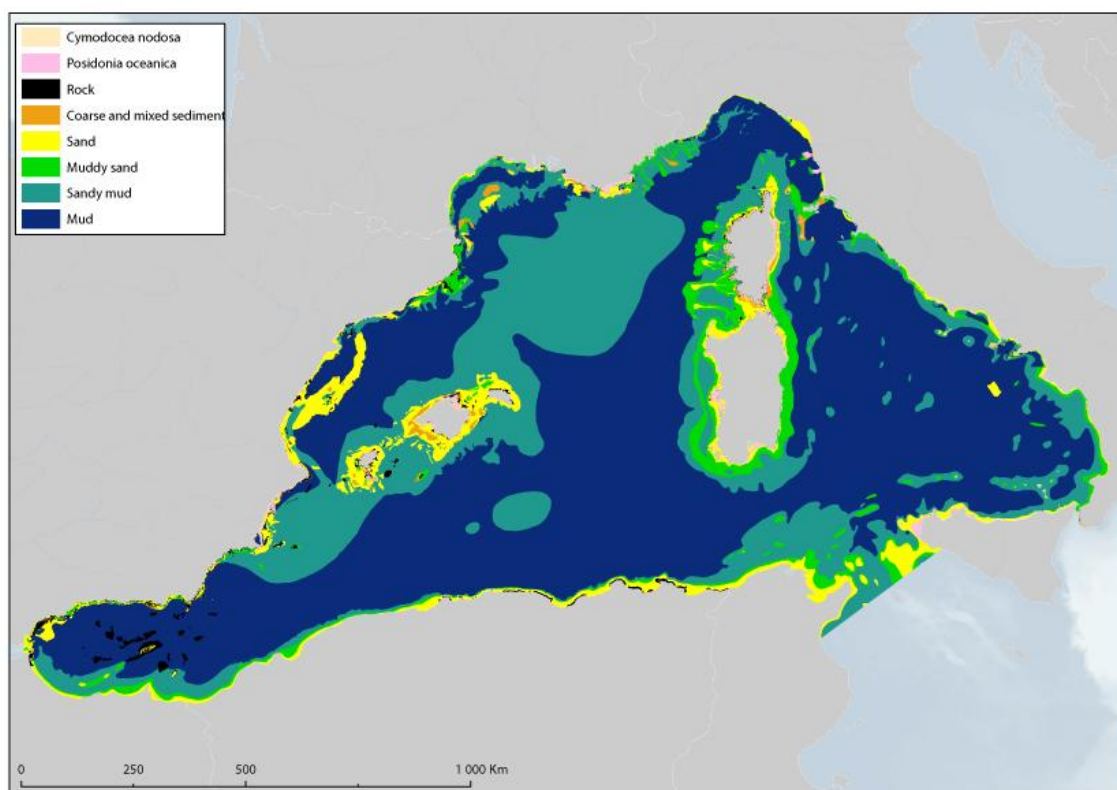


Figure 25 Mediterranean substrate map compiled by the EUSeaMap project.

5.2.1. Priority seabed habitats

Some seabed habitats are recognised as remarkable or priority habitats. This is the case of some OSPAR priority habitats²⁷, such as seagrass or maerl beds, or other seabed habitats

²⁷ OSPAR Convention Annex V provides a list of threatened and/or declining habitats in the North East Atlantic.

such as kelp forest. In EUNIS these seabed habitats are found at level 4 (kelp communities) and below, which means the modelling process used here will not allow for them to be identified in the final maps. This is one of the drawbacks of modelling the full range of seabed habitats over such a large geographic area. Developing rules for predicting community level information for all priority habitats, or all EUNIS level 4 habitats, requires more extensive research than is possible in the scope of this contract. However, there are two instances of seabed habitats which have been included in the final map.

In the Mediterranean, seagrass beds (*Posidonia oceanica* and *Cymodocea nodosa*) are seabed habitats of conservation interest, and are important to consider in EUSeaMap. The motivation behind this lies in the fact that the variables that influence both of these seagrass habitat types are known (i.e. sediment types, light requirements, salinity) but it is difficult to know the size and extent of the largely anthropological limiting factors that may greatly determine the absence of such a seabed habitat in an area (e.g. chronic exposure to environmental degradation aspects such as river run-offs, pollution, localised thermal and freshwater inputs, continuous illegal trawling/dredging activity and anchoring pressure). There is a difficulty in accommodating seagrass patches of relatively small area with respect to the coarseness of the map with a cell size of ~6 ha. However, a key characteristic of *Posidonia oceanica* is that the species engineers the substrate, to the extent that in existing Mediterranean sediment maps *Posidonia* beds are in fact mapped as a substrate type in their own right. This opens the possibility to include *Posidonia* beds as an additional substrate type, and thus preserve it through the modelling process.

5.3. Energy at the seabed

In EUNIS, energy appears at level 3 for rock habitats (Table 4), but is not applied to sediments because sediment types typically reflect the hydrodynamic regime of an area of sediment. Thus the focus of EUSeaMap is on the way rock is affected by energy from currents and waves. Although the Soulsby (1997) method to combine wave and current data has been used for bed-shear stress layers, this method was developed for sediment environments rather than rock. For this reason, EUSeaMap partners developed data layers for alternative variables for energy at the seabed independently from substrate type. Full-coverage data for these variables are themselves obtained through a process of modelling. The subsequent combination of energy resulting from waves, and from tides, may be carried out as part of the system of rules in the model: some seabed habitats may have particular wave conditions, others particular tidal conditions, others a combination of the two.

A number of variables can serve as measures of energy, and temporal resolution is an important issue to consider. Maximum wave energy structures seabed habitats through its destructive powers, but a storm wave may only affect the seabed in a particular place every 10 or 20 years. It is important to filter out major events by taking high percentile statistics over as long periods as possible. Energy levels resulting from tidal currents on the seabed are a more constant force throughout the year. For example there is evidence in the Baltic

that it is these average conditions which structure communities. The project has been working to develop layers based on these considerations.

Under a specific contract for the project, energy layers have been produced for the North and Celtic seas. Energy layers are built on NOC²⁸ wave (ProWAM at a resolution of 12.5km) and current models (the CS20, CS3 and NEA models at resolutions of 1.8km, 10km and 35km respectively). These were all processed to populate a 1km resolution grid, with a high resolution DHI Spectral Wave model used to augment the coastal areas where the ProWAM model resolution was inadequate. In the northern part of the western Mediterranean basin (roughly north of Balearic Islands) an energy model was built on PREVIMER²⁹ wave and current models (WAVEWATCH III at resolution of 10km and MENOR model at 1km respectively). The Mediterranean model was run at a time step of three hours for a period of three years (2001 and 2007-2009). Methods used to combine the effects of waves and currents for bed shear stress were based on Soulsby (1997). The energy layers developed for the Mediterranean were eventually not used in the seabed habitat model after threshold analysis showed that the models were too coarse and there were insufficient field biological data available to be able to classify energy regimes in the Mediterranean.

In the Baltic, tidal currents make a smaller contribution to energy at the seabed, with current velocities generally falling in the 'low' category for work applied in the Celtic and North Seas (Al-Hamdani & Reker 2007). In order to develop an appropriate input data layer for energy at the seabed caused by currents, EUSeaMap has modelled patterns of currents at the seabed, using data for the period 2004-2009. The model (MIKE 3 HS) has a resolution of ~5.5km. Two wave models have been developed for the Baltic: a coastal wave exposure model; and a model to be applied away from the coast.

This dual approach is necessary because in coastal areas with a complex coastline, particularly archipelagos, the wave exposure can vary at a small spatial scale in a way that is poorly described by large-scale oceanographic models. In order to better describe energy at the sea bed in such areas of the Baltic Sea, the oceanographic wave model is complemented with a simpler fetch based model, SWM (Simplified Wave Model). The method is called simplified since it uses the shoreline and not the bathymetry as input for describing the coastal shape. This is an adaptation to the fact that bathymetry data of sufficient spatial resolution is often unavailable or confidential and therefore of restricted use. The model away from the coast is a spectral model with a resolution of ~5.5km, built using data from the period 2006-2009. This wave model extends into the North Sea, which provides EUSeaMap with the opportunity of comparing the outputs of two wave models in the same place, using field data and biological data.

²⁸ National Oceanography Centre (formerly Proudman Oceanographic Laboratories, Liverpool and National Oceanography Centre Southampton).

²⁹ PREVIMER Coastal observations and forecasts www.previmer.org

The coastal wave exposure model covers the Baltic coast using the Simplified Wave Model (SWM; Isæus 2004). SWM was calculated with the software WaveImpact 1.0, as described in Isæus (2004). Winds blowing over the water surface will generate waves in the direction of the wind. The distance from a coast to the nearest land in a particular direction is known as fetch, so the larger the fetch, the larger the waves; winds blowing over long distances can have significant effects on local wave exposure regimes. These important effects are captured through the use of a series of nested grids. The wave exposure was calculated for mean wind conditions represented by hourly wind data³⁰ for period 2002-2007. A total of 26 wind stations were used, and the wind data were divided in sixteen compass directions, each representing an angular sector of 22.5°.

The coastal fetch based model was merged with the oceanographic model to provide continuous coverage for the region. Regression analysis was used to recalculate wave height statistics from the oceanographic model as equivalent to SWM outputs and the two layers merged in GIS (Figure 26).

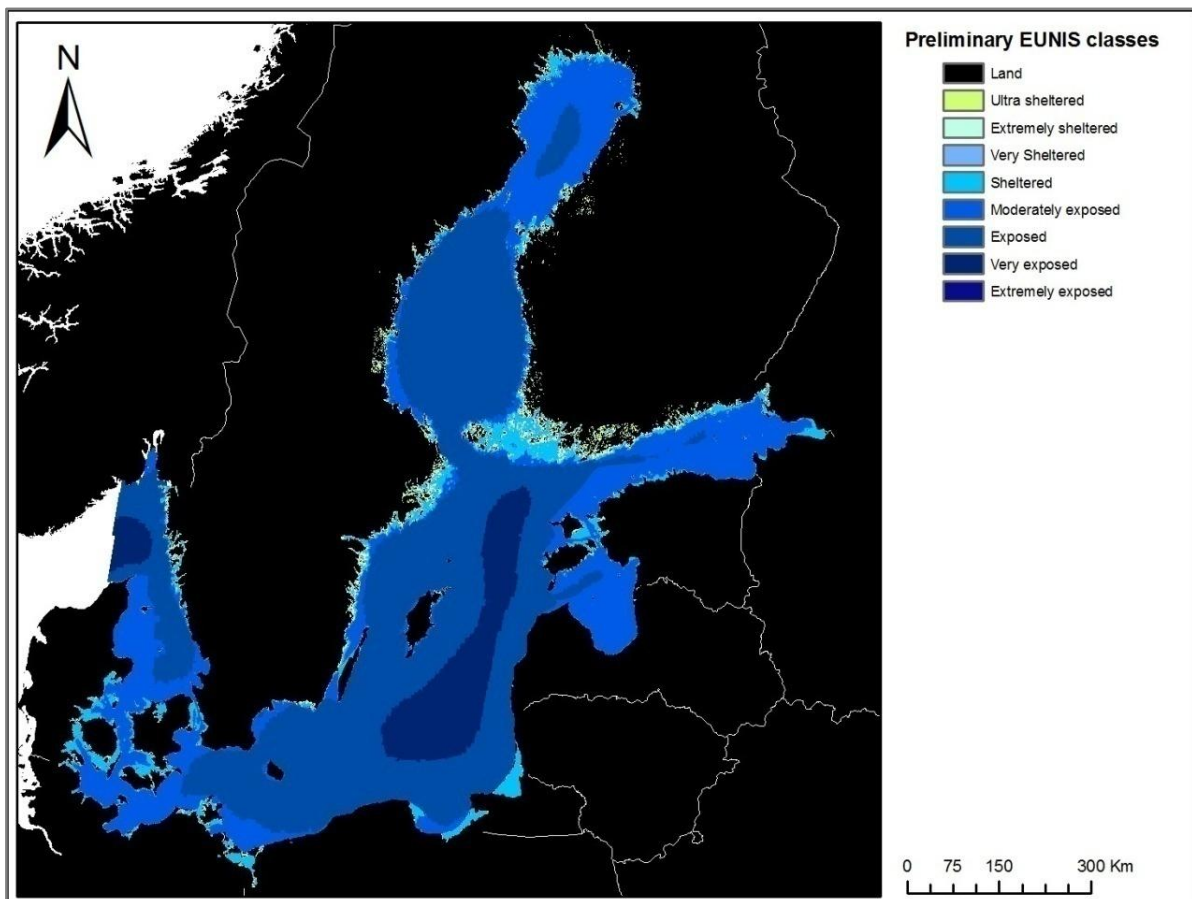


Figure 26 Simplified Wave Model layer for the Baltic Sea. SWM values for open sea areas are derived from recalculated significant wave height.

³⁰ Wind data were retrieved from the British MET Office Unified Model, by the Interdisciplinary Centre for Mathematical and Computational Modelling, University of Warsaw.

5.4. Salinity

In the Baltic, salinity regime is of particular importance to the distribution of biological communities, but was considered a secondary variable in the marine landscape modelling of the BALANCE project (Al-Hamdani & Reker 2007). Therefore in this project salinity has been estimated using calibrated and validated hydrodynamic model data averaged over several years (2000 – 2008), at a scale of ~5.5km. In addition to average values, the variance of salinity has been calculated. The variance of salinity is a good indicator of conditions favoured by species with relatively high tolerance.

From modelled temperature and salinity, density data layers have been developed reflecting biological conditions generated by stratification. Based on several years of 3D hydrodynamic modelling, the likely position of the deep halocline has been mapped, below which the Baltic Sea is classified as deep circalittoral.

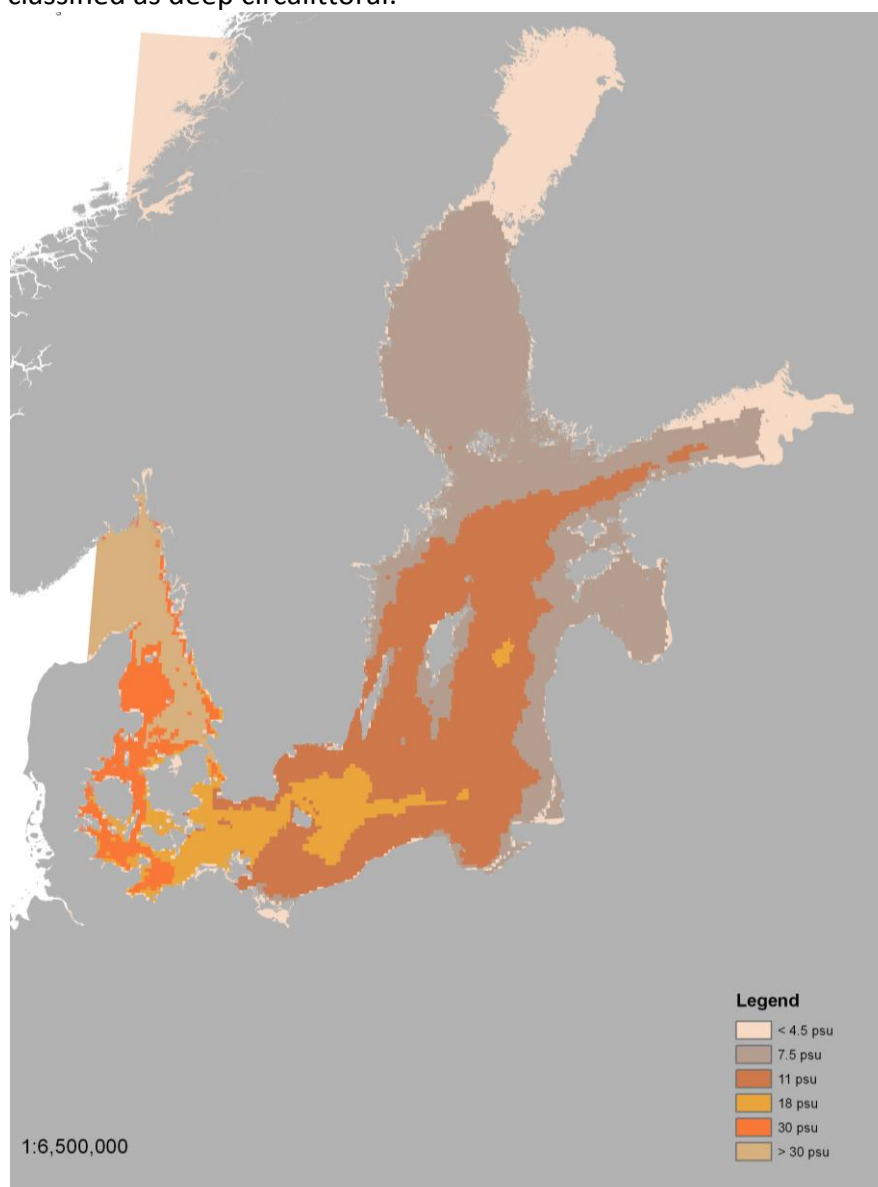


Figure 27 Baltic Sea salinity classes.

6. Modelling

6.1. General principles

Models were built using ModelBuilder in ESRI™ ArcGIS 9.2/9.3 with Spatial Analyst extension. Spatial Analyst™ is an extension of ArcGIS™, in which rasters can be combined through the use of ‘map algebra’. ModelBuilder allows design of models by graphically joining together ArcGIS™ tools, using the output of one tool as the input to another tool. Models designed through ModelBuilder can be saved and executed multiple times. This ensures that the modelling process is repeatable and as new or more detailed datasets become available in the future they can be easily incorporated into the model to produce new versions of the EUSeaMap predictive seabed habitat maps.

Two pre-processing steps were not included in the model as they are computationally heavy: calculating the fraction of light reaching the seabed using K_{PAR} and bathymetry data layers, and, in the Baltic and Celtic/North models, wave base was calculated in a separate model from peak wave period and bathymetry (Figure 28). The models output a seabed habitat map ESRI™ shapefile which is then joined to MS Excel spreadsheet containing the attributes associated with each gridcode value. This post-processing step is done outside of the model. Figure 29 and Figure 30 show images of the model for north and Celtic seas; a detailed explanation of the GIS modelling will be included in the Technical Appendix for modelling (in preparation).

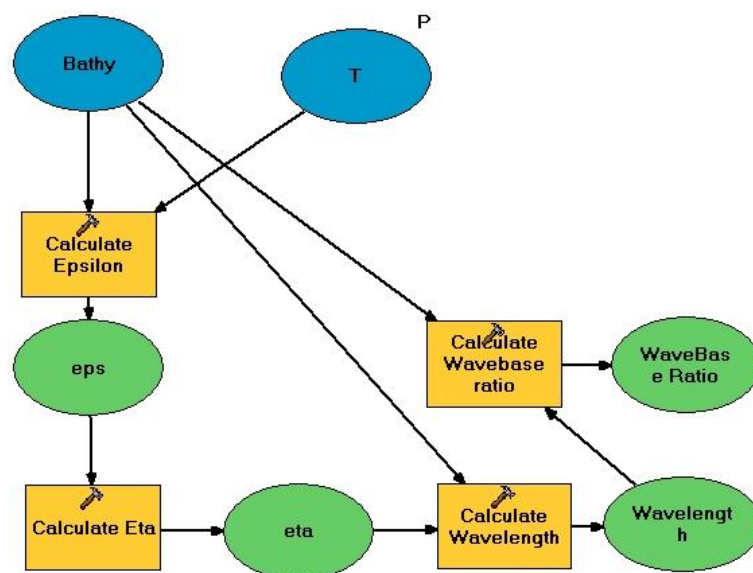


Figure 28 Module generating wave base ratio using peak wave period, T_p , as an input for the Baltic and Celtic/North sea models.

Because of the issues of resolution discussed below, because of storage considerations, and because of the fact that each basin has its own unique biological and physical specificity (e.g. only Baltic Sea takes account of salinity), three models have been made: one for Baltic Sea, one for North/Celtic Seas, and one for Mediterranean Sea.

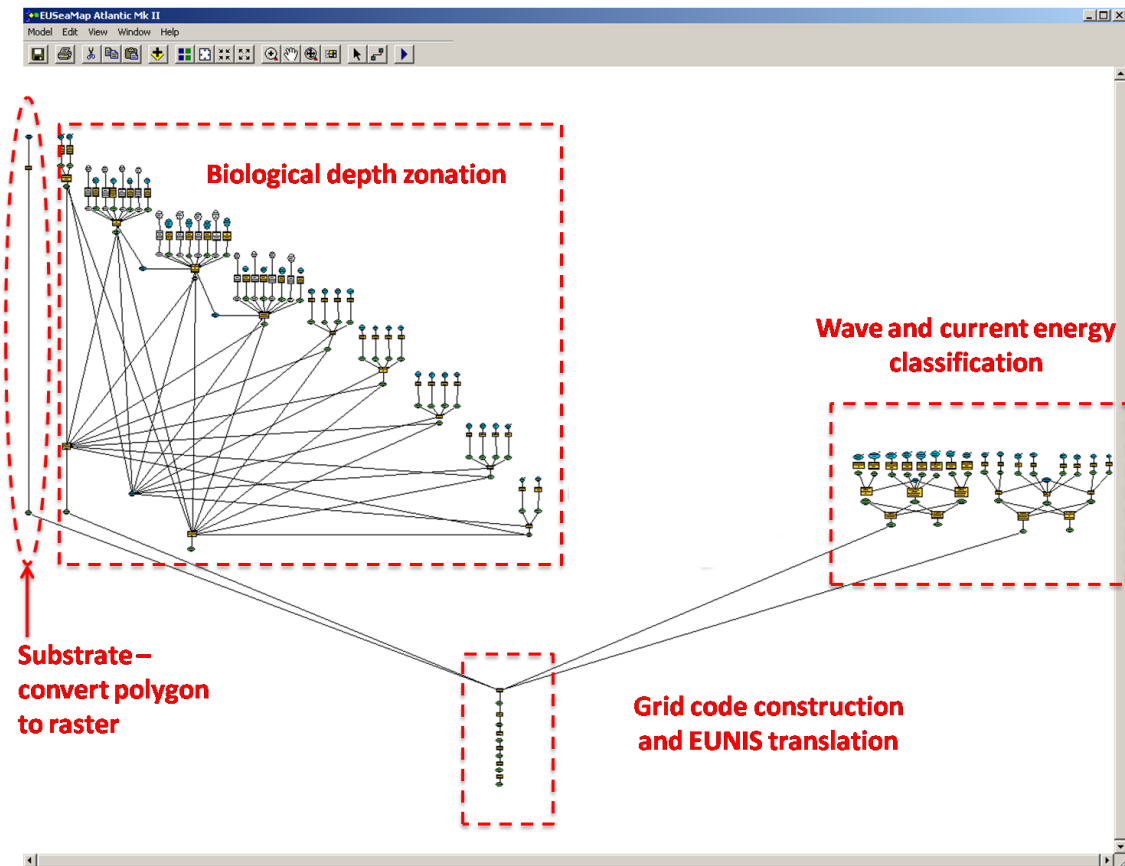


Figure 29 Visualisation of the North and Celtic Seas seabed habitat model in ArcGIS model builder interface.

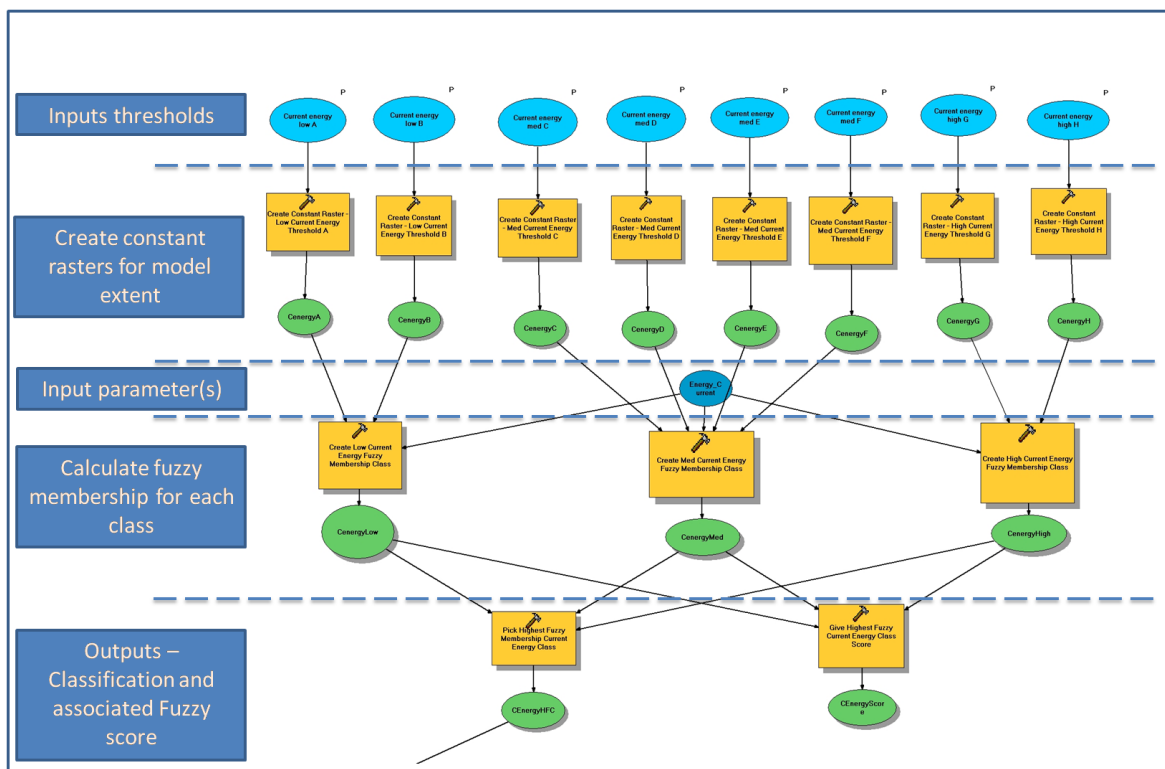


Figure 30 Detailed view of a subsection of the North and Celtic Seas model, illustrating the inputs and processes that produce the energy classifications.

6.1.1. Resolution

The contract states that the outputs must be in geographic coordinates (Lat/Long). The WGS84 datum will be used. Some data layers are already generated in geographic coordinates, although for example in the Baltic many modelled layers are in the UTM32 projected coordinate system. The problem of converting these layers (and associated resampling effects) will be avoided because ArcGIS™ Raster Calculator does not need to have all layers in the same projection (section 6.1.3).

Whilst geographic coordinates have many advantages to the end user, when converted to a projected coordinate system (e.g. Cartesian or polar coordinate system), the difference in cell size between the northern regions and the Mediterranean can be significant. Therefore it was decided to use variable cell sizes to minimise the difference in cell size when end users may be working in projected systems: in the Mediterranean, 0.0027 decimal degrees (which equates to a cell area of ~69,000m² or 230x300m) and in the Celtic, North and Baltic seas, 0.0030 decimal degrees (which equates to a cell area of ~55,611m² or 167x333m).

The EEA recommends for pan-European mapping the usage of a Lambert Azimuthal Equal Area (LAEA) for mapping at scales smaller or equal to 1:500,000. Therefore it is advisable to render EUSeaMap products both in projected and non-projected form. Partners agreed that the project will proceed at ~250m resolution. This means in theory that it will be possible to predict seabed habitats which only occupy a 250m grid cell, but are surrounded by a different habitat type. Cartographers often systematically remove such isolated pixels which are detrimental to the quality of the map due to the 'salt and pepper' effect they create. This is an issue of scale and purpose which is currently being addressed as part of work to prepare final seabed habitat maps.

Modelling will be carried out in raster mode, which means all data layers have to be expressed in pixels before running the model. The raster format is the original format of most data layers (depth DTM, imagery for light, physical models for energy), while the vector format is commonly found for sediment maps. It will be necessary to convert the sediment layer into 250m cells, which brings about specific technical issues related to the respective sizes of the individual polygons and final cell. A crude conversion only based on the position of the cell centroid within polygons can be refined to look for the polygon having majority coverage within the cell.

6.1.2. Using projections in the models

The ESRI® ArcGIS™ Spatial Analyst™ has been successfully tested within its modelling mode on a small area in Brittany. Raster calculator is able to execute functions using input layers in different projections (e.g. Lat/Long WGS84 and LAEA ETRS89), working with them 'on the fly'. There was very close agreement between results produced by converting all layers to the same projection before executing a function, and results produced by working 'on the fly'. It is possible to deal with different datums as well, but this is not desirable and should

be avoided because datum conversion is a complex operation that implies approximations when computed in real time.

Once all layers are in raster form, regardless of their spatial characteristics (coordinates of origin, resolution, extension), the raster calculator computes the output map at any specified resolution by resampling layers to the final cell size. The output extension is merely the intersection of all inputs extensions.

6.1.3. Repeatability

One of the main challenges of the project was to build reusable models, i.e. models that could be run at any time by persons with limited experience in computer programming and/or the use of ArcGIS™ ModelBuilder. Therefore an ArcGIS™ toolbox, called "EUSeaMap" (Figure 31), has been developed. This toolbox is composed of three toolsets (one toolset per basin), and each toolset contains at least one model, which is the main one, and which is the one that has to be loaded by the user. The toolset can also contain other models or scripts, but they are not stand-alone: they are loaded by the main model.

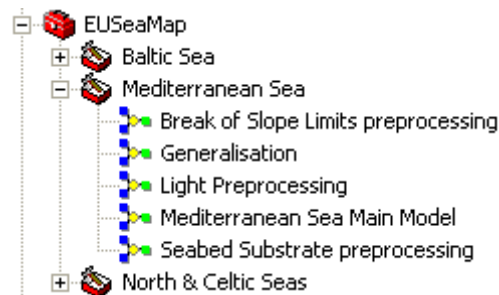


Figure 31 EUSeaMap Toolbox. It contains three toolsets (one per region), and each toolset contains at least one model, the main one. Here Mediterranean Sea toolset is opened. The main model is "Mediterranean Sea Main Model". The other models are not stand-alone, but are loaded by the main one.

In order to update the model with an updated input, for example an updated bathymetry layer, a user can simply replace the input grid file with the new one. The file structure as well as file naming adopted in EUSeamap models is documented in the Technical Appendix on Modelling (in preparation).

6.2. Seabed habitat maps produced by the models

6.2.1. Baltic

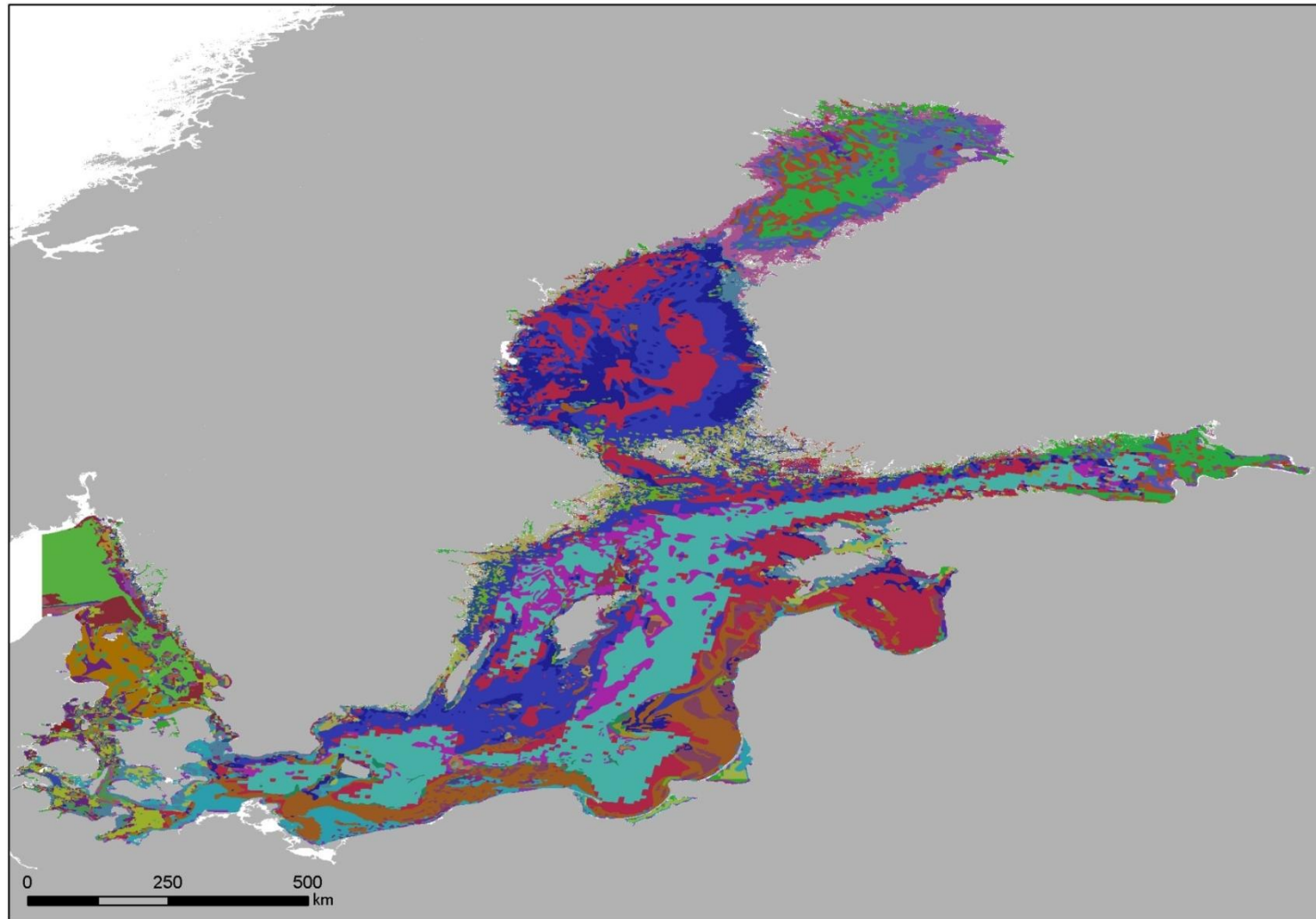


Figure 32 Modelled seabed habitats for the Baltic Sea, showing the four major salinity classes.

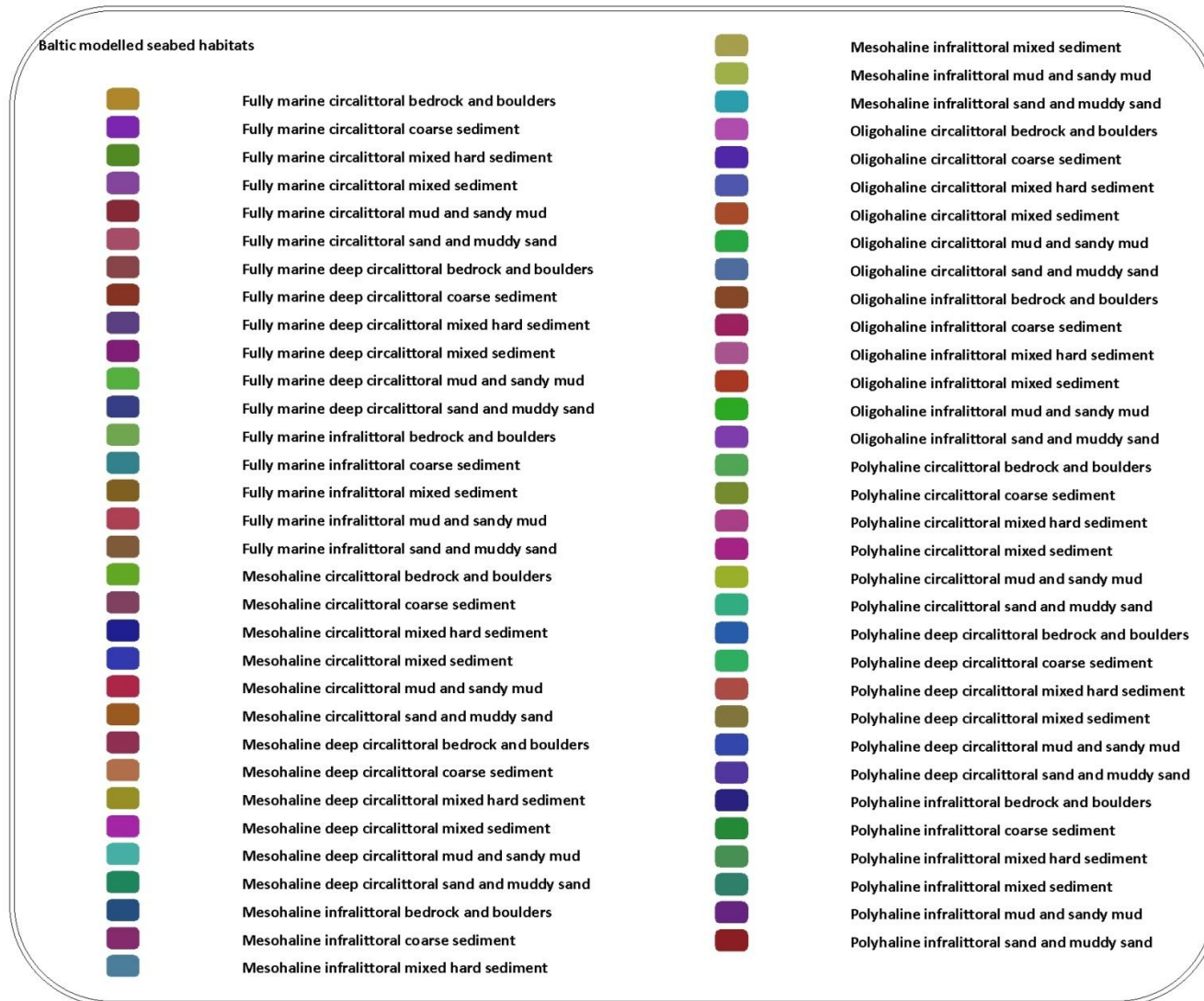


Figure 33 Legend for the modelled seabed habitats for the Baltic region, with four major salinity classes.

6.2.2. North & Celtic Seas

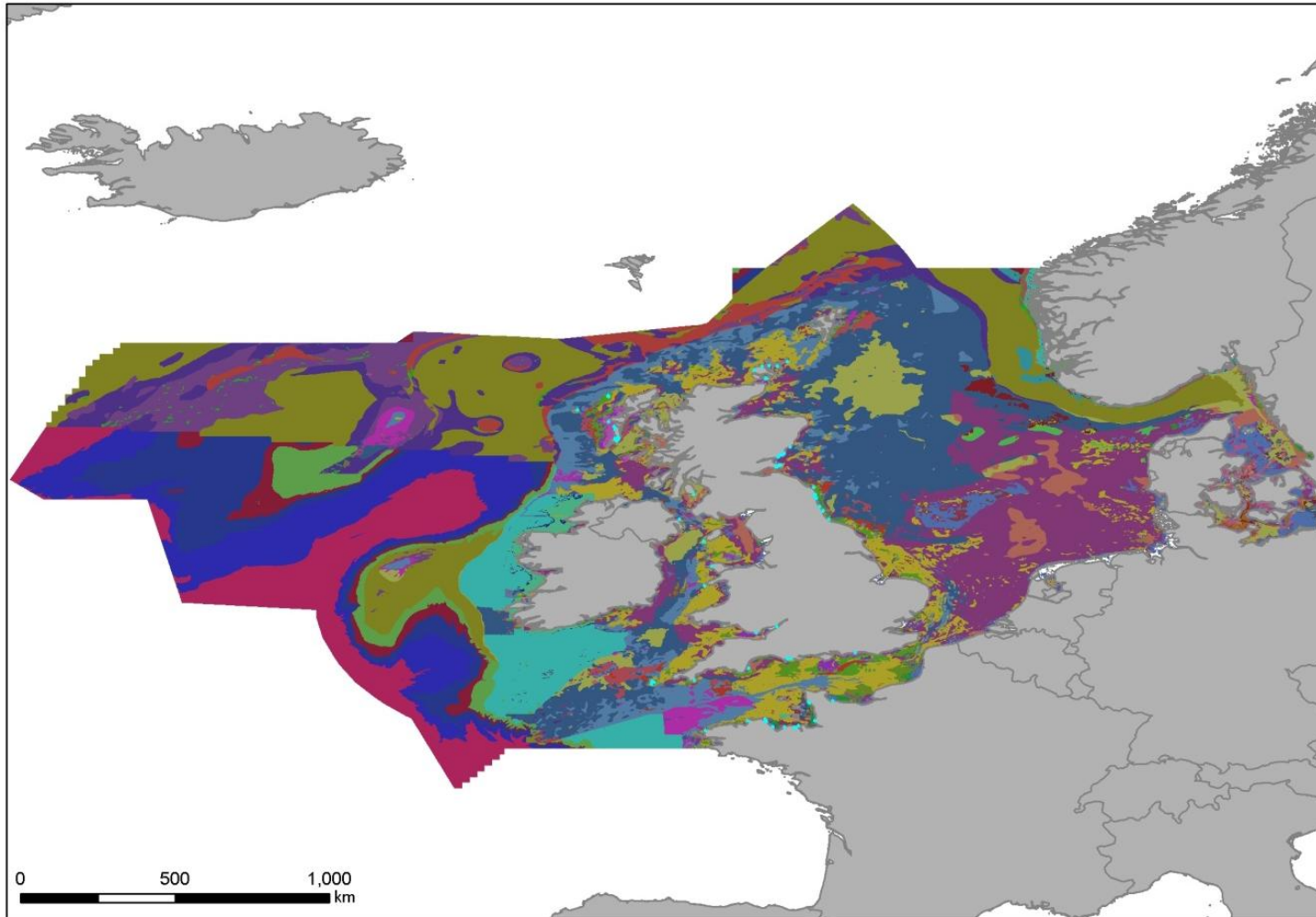


Figure 34 Modelled seabed habitats for the North and Celtic seas.

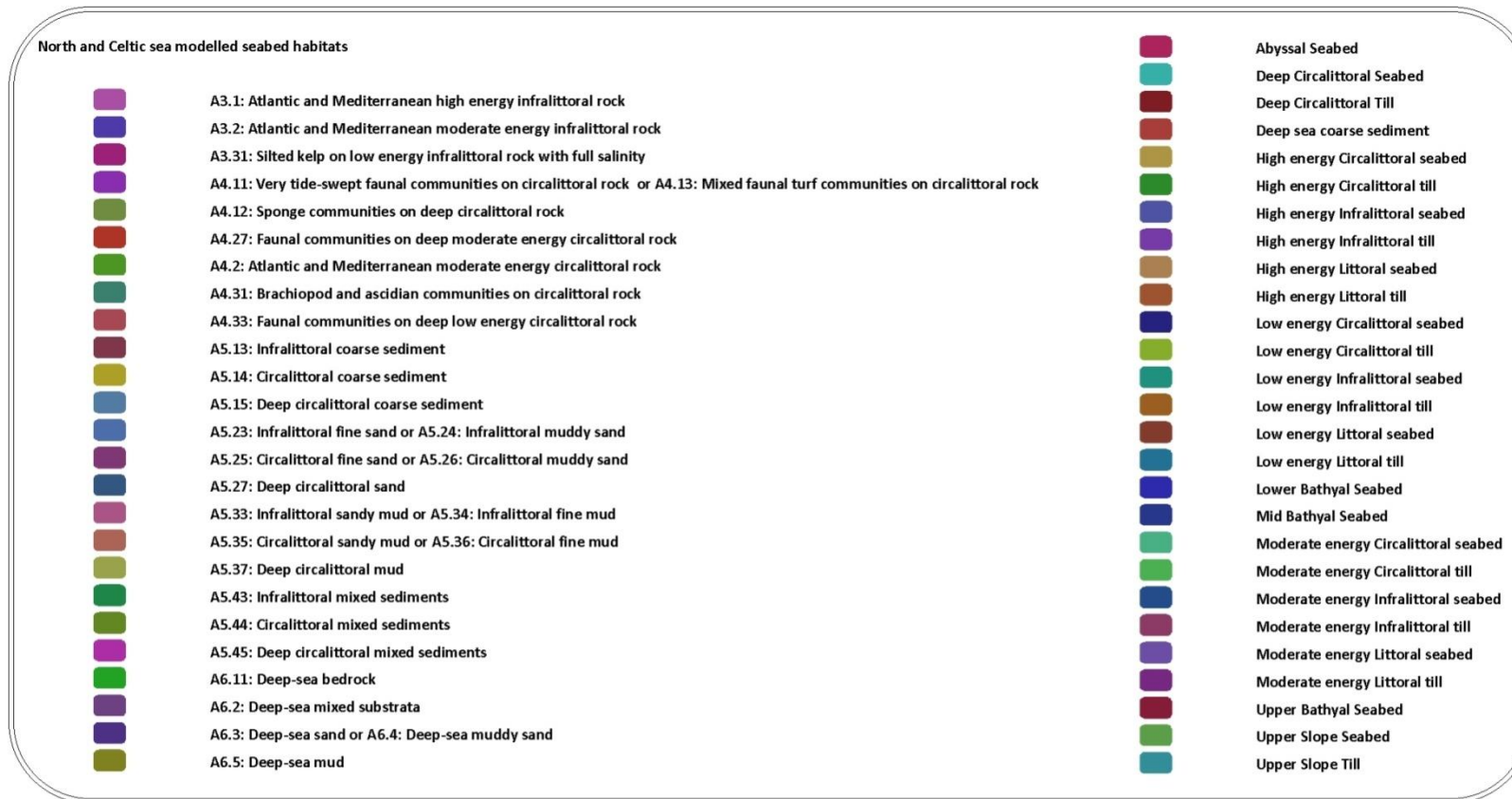


Figure 35 Legend for the modelled seabed habitats for the North and Celtic regions.

6.2.3. Western Mediterranean

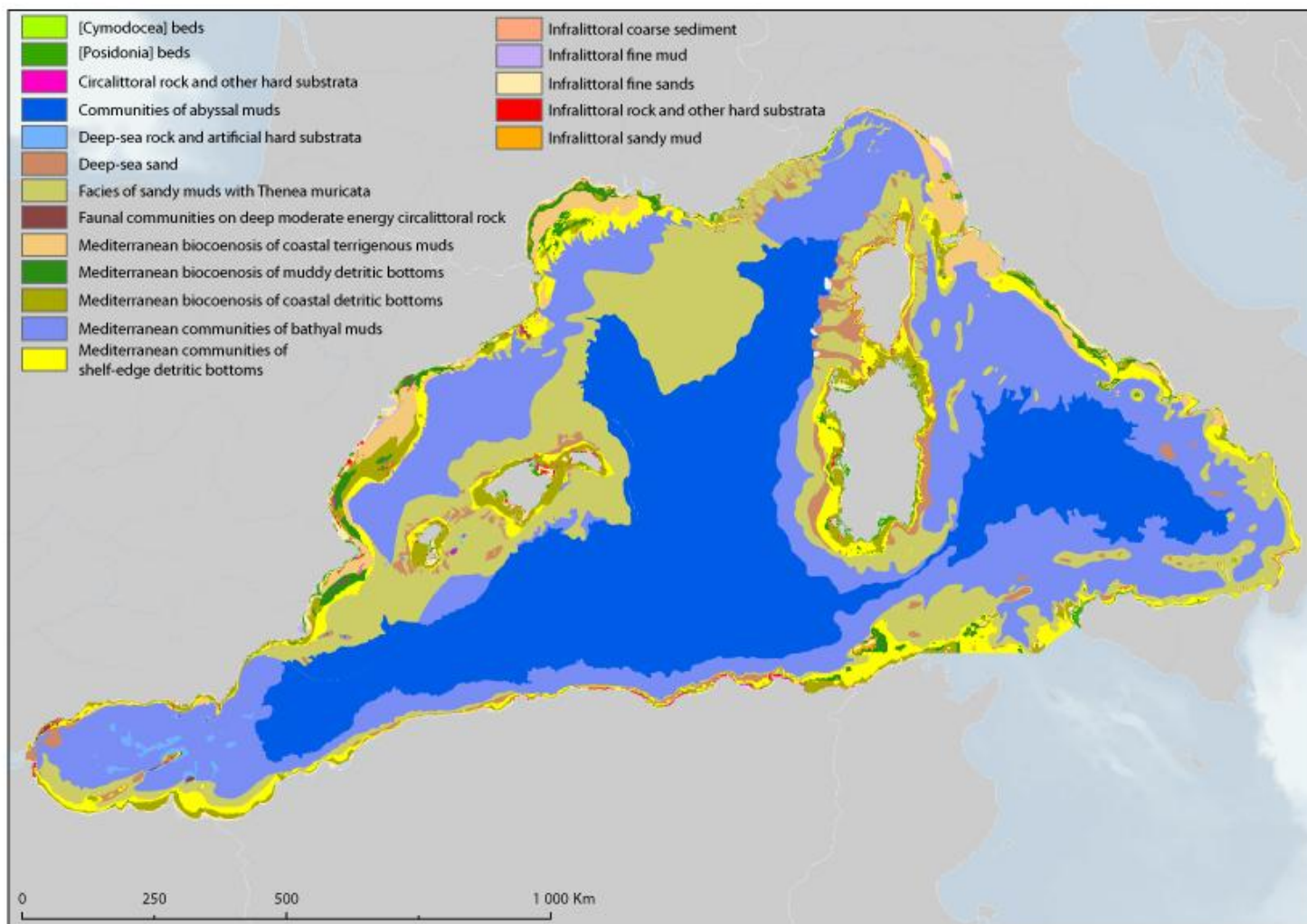


Figure 36 Modelled seabed habitat map produced by the model for the Western Mediterranean.

7. Confidence – Assessing and showing certainty in the predicted maps

A spatial assessment of confidence in the EUSeaMap modelled seabed habitats is considered to be a final product alongside the seabed habitat maps themselves. It is important that seabed habitat maps, both interpreted and modelled, reflect that they are a version of reality, and acknowledge the uncertainties in the data that have been used to construct them. Confidence maps are an effective way of achieving this. EUSeaMap has explored three methods to display confidence in the maps, as discussed in section 4.4 above:

1. Assessment of source data layers, either quantitative or qualitative
2. Quantitative assessment, using fuzzy classifiers, of the membership of a given location (grid cell) to a particular habitat type based on the conditions at that location in relation to the habitat thresholds.
3. Assessing modelled seabed habitat maps against recent habitat maps from surveys

7.1. Source data confidence

Statistically analysing the uncertainties associated with the contributing data layers to obtain a quantitative, probabilistic measure of confidence is a complex process, particularly as each variable used in the construction of the modelling layers needs to be examined against sufficient field data. Given the variety of data sources across the EUSeaMap basins, it was felt that computing a probability of occurrence of each input parameter, including sourcing sufficient *in situ* data required for such calculations, was beyond the scope of this contract.

However it is important that the final confidence map can show which data sets require improvements in future, and where. This was achieved by simply assessing the confidence value of two key layers, namely substrate and bathymetry and computing a weighted sum of the two scores. The MESH confidence assessment tool was slightly modified, in liaison with the EMODNET Geology project and applied to EUSeaMap source layers. Figure 37 and Figure 38 show the application of this index to a variety of six types of maps in the northern part of the western Mediterranean basin, with scores varying from 30 in the central Mediterranean (IBCM map) to 80 for some detailed coastal maps. For bathymetry the confidence assessment developed in the EMODNET Hydrography lot was not yet ready for use so the Project has to develop its own method. Three features of DTMs were selected that are thought to account for most of their quality: resolution, vintage and data origin.

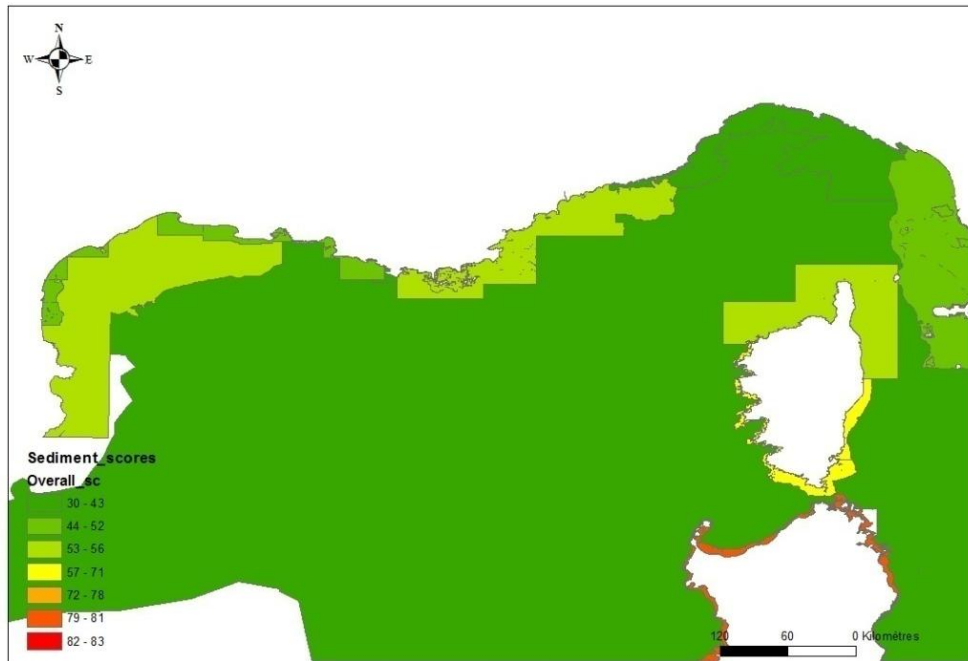


Figure 37 Scores of sediment maps for northern part of western Mediterranean.

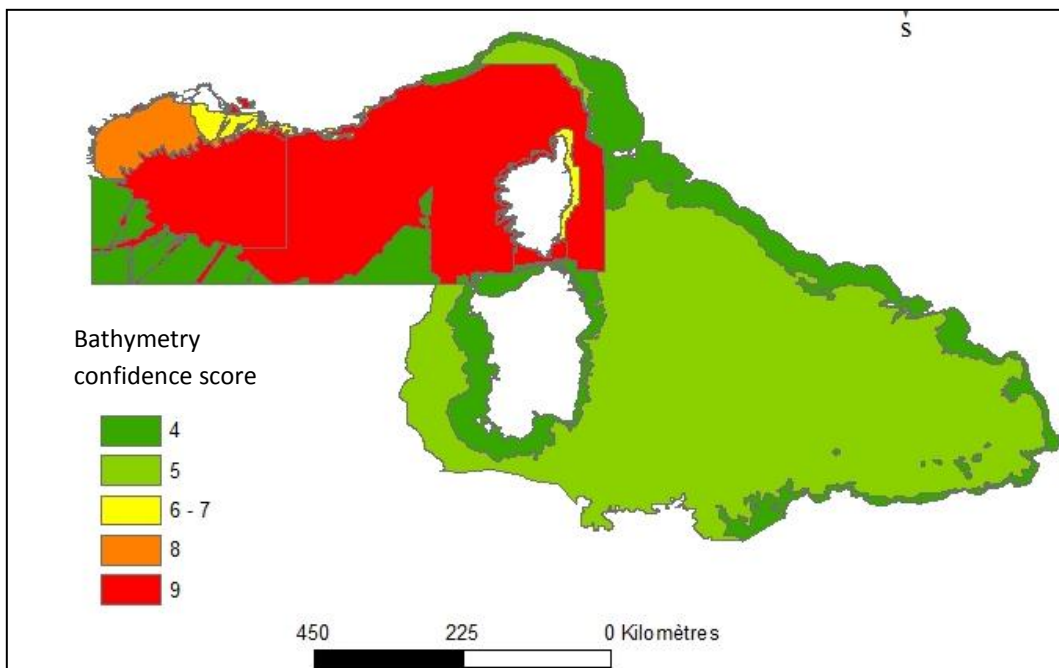


Figure 38 Scores of bathymetry maps for Italy and France. A maximum score is 9, from scoring 3 for each of resolution, vintage and data origin.

7.2. Confidence by validation against surveyed habitats

This test was only run in the Mediterranean where both the final modelled map and ground truth data were available in due time for this report. Among the 18 modelled classes, only eight classes were represented in ground truth data (Table 12).

Version 1

The comparison was run in a stepwise way, firstly using only the 79 survey points from Italy and secondly adding biocenosis polygons centroids from both Italy and France. The first step yielded a percentage of 52% and the second one 47%. Part of this 5% overall discrepancy originates in rocky points being absent from the first set (no A3 and A4 codes in ground truth data). In the second table, from 33 rocky points, only two fit with the model, which contributes greatly to this discrepancy between the two statistics.

This assessment would need to be refined in a project update, when more ground truth samples from the three contributing countries have been collated. Another strand of improvement is when the final model is run with 250m resolution light pixels, the improvement of the extent of the infralittoral zone along the coast will reduce the misfit between the model and the coastal rocky observations.

Table 12 Error matrix for Italian ground truthing data (79 sample points). Overall classification accuracy is 51.9%.

Class Name	References Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Class 0	0	2	0	---	---
A5.13	0	3	0	---	---
A5.23	12	14	11	91.67%	78.57%
A5.33	0	1	0	---	---
A5.38	15	17	4	26.67%	23.53%
A5.39	30	17	13	43.33%	76.47%
A5.46	16	19	10	62.50%	52.63%
A5.47	3	2	0	---	---
A6.511	3	3	3	100.00%	100.00%
TOTAL	79	79	41		

7.3. Confidence in boundaries using fuzzy thresholds

In addition to assessing the input layers to the model, fuzzy thresholds are also regarded as a useful tool in describing and quantifying any uncertainties underlying the predicted seabed habitats through the classification of abiotic variables. Although in many cases the evidence for an ecological threshold does not allow for an unambiguous classification of a given grid cell to only one class, this so-called specification error (Alonso 1968) is typically transferred to the final habitat map without further consideration. Obviously, the amount of bias in the final map will depend on the number of specification errors in the input layers. Through the application of fuzzy or 'soft' classifiers to the input layers a measure of this potential bias can be visualised (Figure 39).



Figure 39 Example of a hard (left panel) and soft classification (right panel) of a fictitious habitat defined by a salinity range of 6-7 psu. The differences can be observed in the boundary zones of the habitat, where the soft classification results in a gradient of habitat membership.

In the EUSeaMap project, fuzzy classifiers were implemented in the models for all input variables except substrate, which as a discrete variable, with only a preclassified map available to use, is not compatible with the fuzzy approach. Where possible, inflection points for input variables that mark the upper and lower bounds of a class' range (such as those illustrated in Figure 8) were derived from threshold analysis using the prepared data layers and biological data collated by partners in the project group. If sufficient data was not available, arbitrary ranges were used around 'hard' classifier values to illustrate uncertainty around the thresholds between classes. The derivation of the thresholds used in the model are outlined in detail in the technical appendices associated with each input variable (in production for the final report).

In the process of deriving each grid cell's classification, the models calculate fuzzy membership values for each class within the biological zones. In the North, Celtic and Baltic Sea models fuzzy memberships are also calculated for each energy class, and salinity class (Baltic only). The membership scores associated with the final classification of each grid cell give an indication of certainty that the grid cell belongs to that class (Figure 40). A cell with a score of near 1 is well within the range of the variable used to define the class; a cell with a lower score is nearer the threshold, and is likely to be in a transitional zone for the predicted

Version 1

seabed habitat. These scores can be combined simply through multiplication and give a good visual indication of certainty at or near the boundaries of the final output seabed habitat types. Figure 41 is an example of a confidence map produced using these fuzzy membership scores, combining those scores from both the biological zonation and energy classification of the North and Celtic sea model. The result shows clearly the varying certainty around class boundaries that subdivide the substrate map to produce the final seabed habitat map.

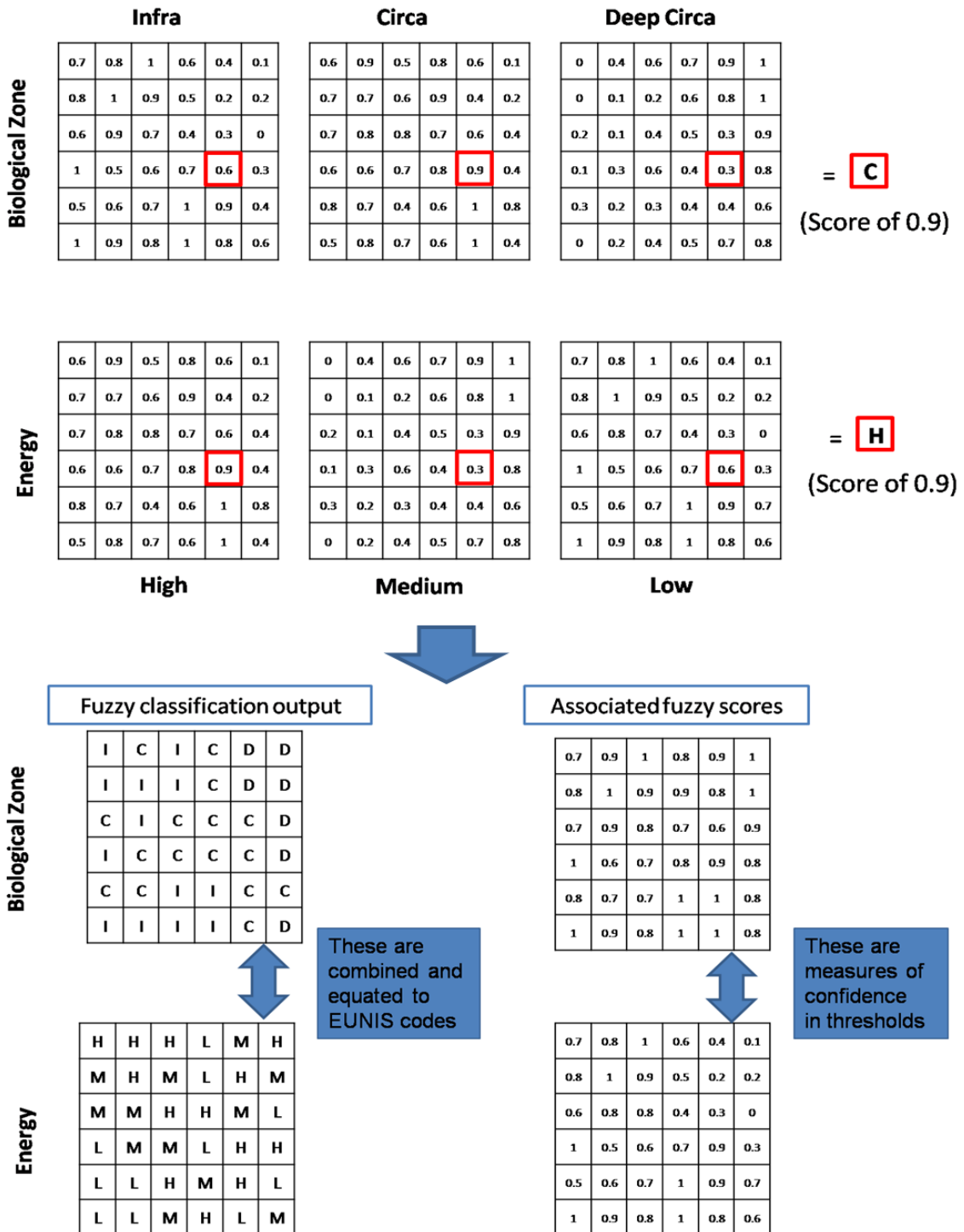


Figure 40 Illustration of the cell by cell process that uses fuzzy membership values to a) classify each grid cell using input data layers and b) retain the membership score for the output classification that gives a measure of associated certainty.

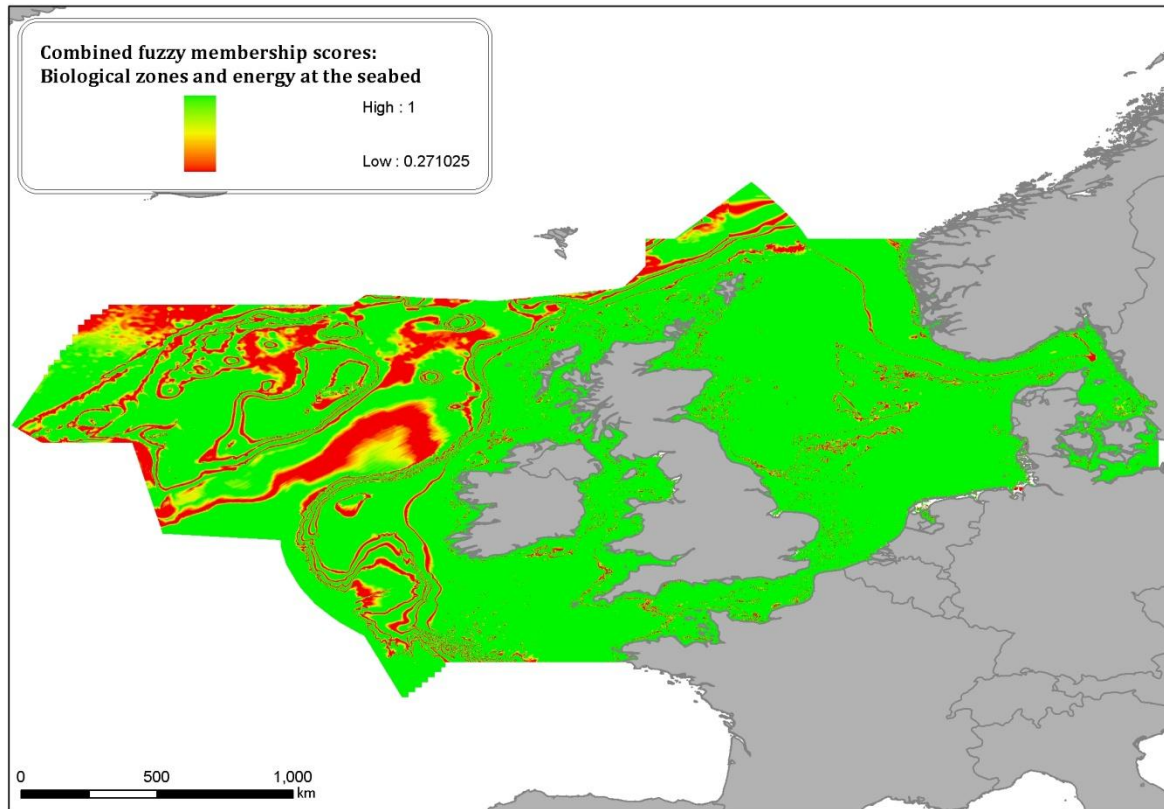


Figure 41 Combined fuzzy membership scores from biological zonation and energy regime produced by the seabed habitat model for the North and Celtic Seas.

8. Making data available

The modelled seabed habitat map will be available free of charge to users. An interactive web mapping portal (a webGIS) will allow users to view and query the data. This can be beneficial for individuals who do not have access to desktop GIS software. The modelled seabed habitat map will be downloadable from the webGIS. This will enable those who have desktop GIS software to analyse the data in more detail, possibly in combination with their own data. Another route through which the data will be made available is Web Mapping Services. This provides a 'live link' to the data, either directly to a desktop GIS, or to another internet server which hosts a different webGIS, such as the European Atlas of the Seas or the other EMODNET portals.

The input data layers used to model the seabed habitats will be available on the webGIS. In some cases access to view the data layers may be restricted because of licence constraints. This restricted access will be managed through a user registration system as an integrated part of the webGIS. Where possible, these input data layers will also be downloadable in a variety of formats (e.g. ASCII, in addition to proprietary ESRI formats) and available through Web Mapping Services.

The data will conform to Open GIS Consortium³¹ standards for exchange of geographical information. This is necessary for Web Mapping Services to function; the system is developed using MapServer which is itself compliant with Open GIS Consortium standards. The metadata will meet the ISO19115 and ISO19119 standards, and SeaDataNet common vocabularies will be used where appropriate in the metadata and data formats. This will be implemented by entering metadata in the CAMIOON catalogue. This is not yet available to EUSeaMap.

A prototype webGIS has been built, using the open source software MapServer and the OpenLayers API. Base mapping is provided by Open Street Map, using the 'Google' projection. The modelled seabed habitat maps are soon to be loaded onto the webGIS. Test data layers are currently loaded on the EUSeaMap webGIS, such as the predicted EUNIS seabed habitat map created by MESH. As background layers are finalised, they will be loaded onto the webGIS.

The webGIS currently has the following functionality:

- Standard GIS functions of pan, zoom (in, out, back to previous extent, to full extent), query attributes
- Tool to select map objects
- Tool to print map to .pdf
- Individual layers downloadable

³¹ www.opengeospatial.org

Version 1

- Legend
- Mechanism for users to send comments and receive feedback by email
- Mechanism for users to add WMS layers from a standard list or to add their own WMS layer (user enters URL)

A login system for users to access restricted datasets has been developed. Functionality for several different methods of data download have been developed; these can be applied to different data layers as appropriate, depending on access restrictions. All EUSeaMap products will be freely available to download, with users only needing to enter an email address so that they can be informed of updates, and so that usage of the download facility can be monitored.

The ability for the webGIS to search a central EMODNET WMS registry, based on keywords, can only be enabled when the central registry is in place. This is not anticipated until after January 2011. Hence, EUSeaMap will use the first part of maintenance phase of this project to implement this part of the development: January 2011-March 2011. The live public launch of the webGIS is now planned to coincide with the release of the final report in December 2010, when the background and foreground data layers will be available. Online instructions will be available for the public launch, to allow users to use the webGIS efficiently as well as to understand the EUSeaMap aims and methods used to create the modelled seabed habitat maps.

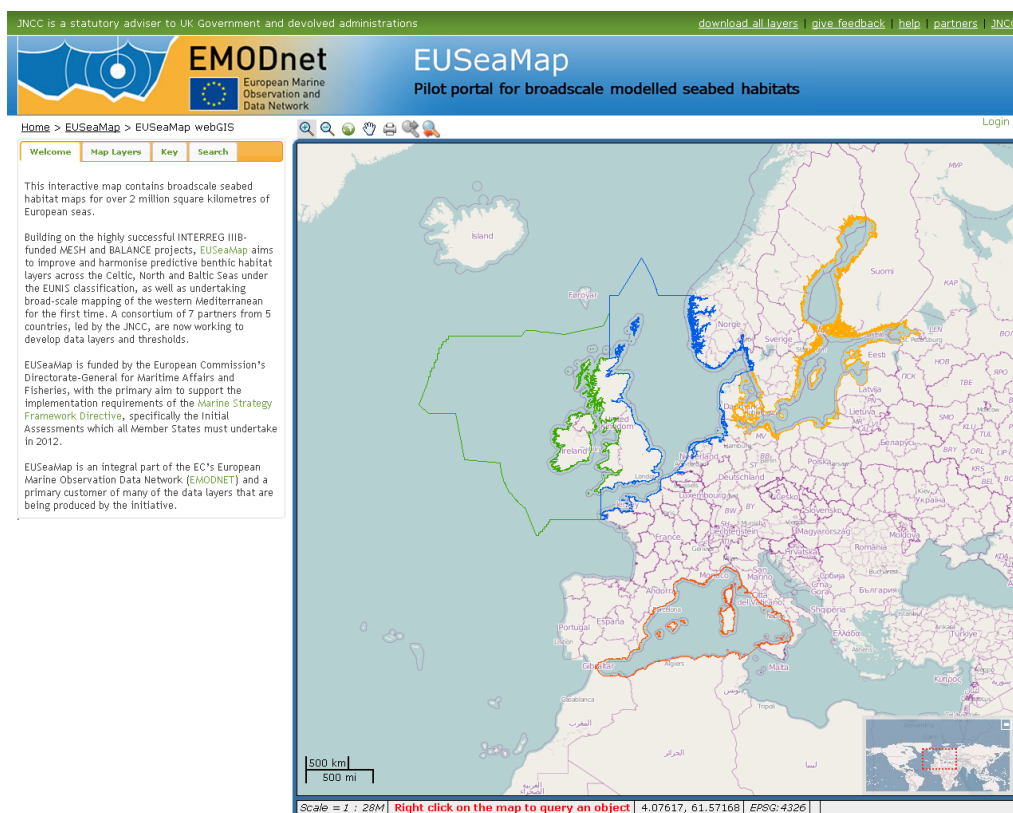


Figure 42 The EUSeaMap pilot webGIS, showing the EUSeaMap project regions and Welcome tab.

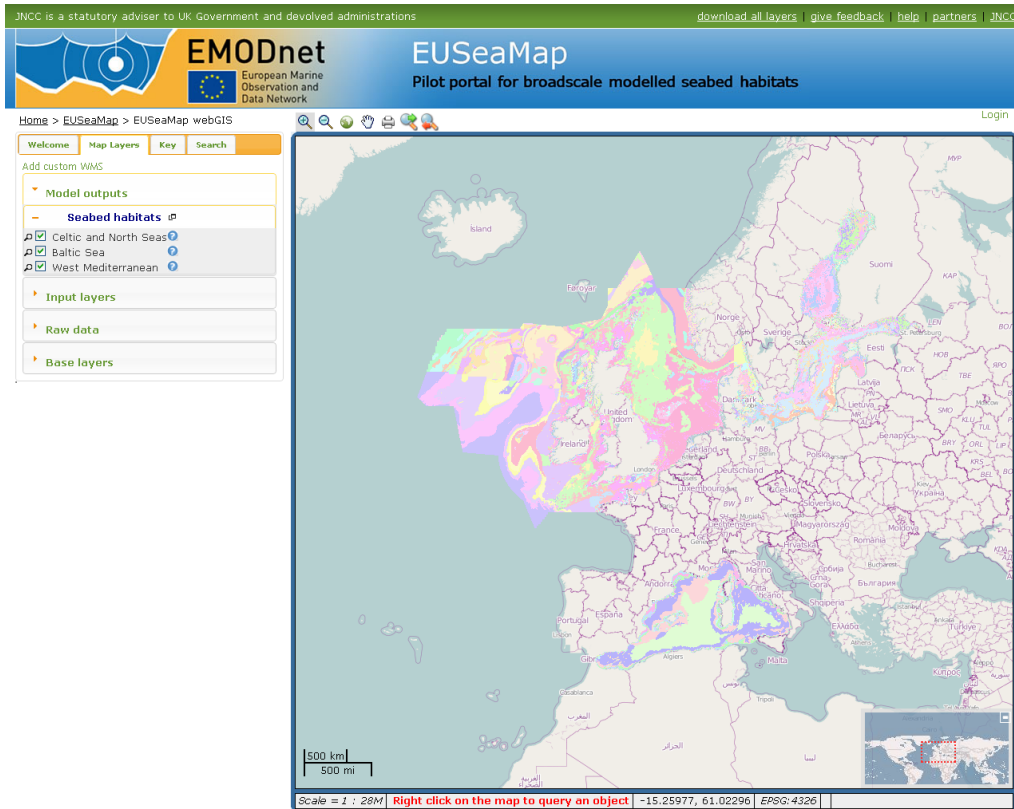


Figure 43 Seabed habitat maps for all basins, from the 'Model outputs' group. Map Layers tab is shown.

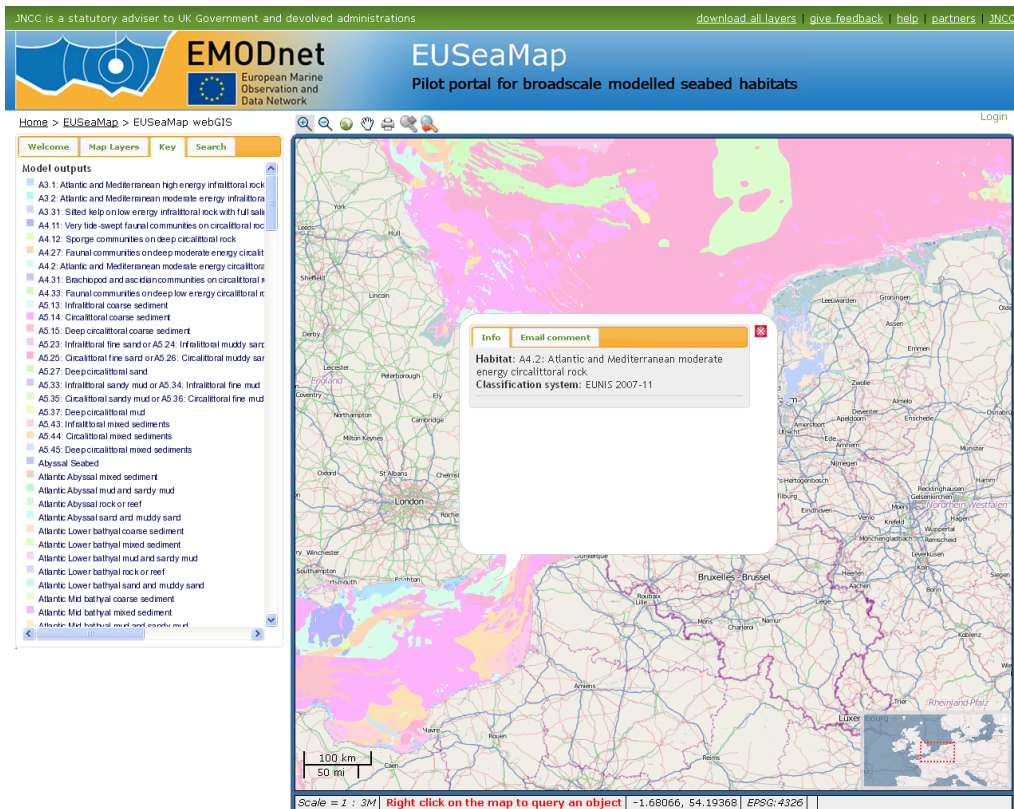


Figure 44 A zoom to part of the North Sea seabed habitat map, showing the Key tab. The Info pop-up is reached by right-clicking on the map and has a facility to comment on the layer via email.

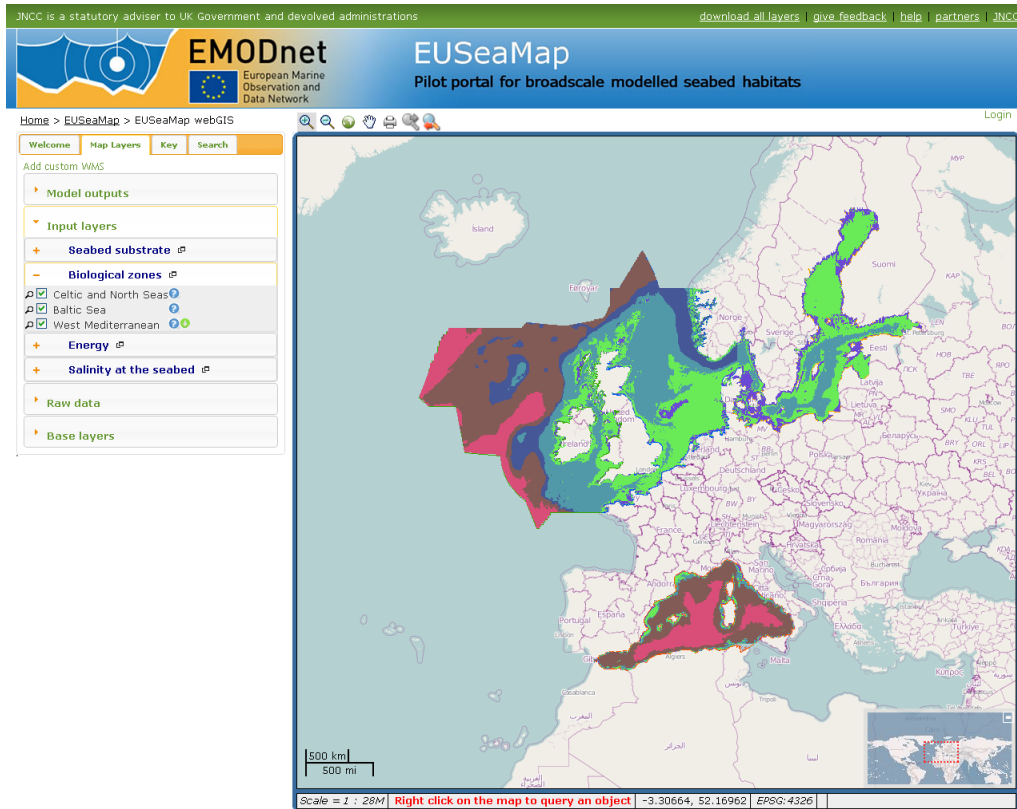


Figure 45 Biological zone maps for all basins, from the 'Input layers' group. Map Layers tab is shown.

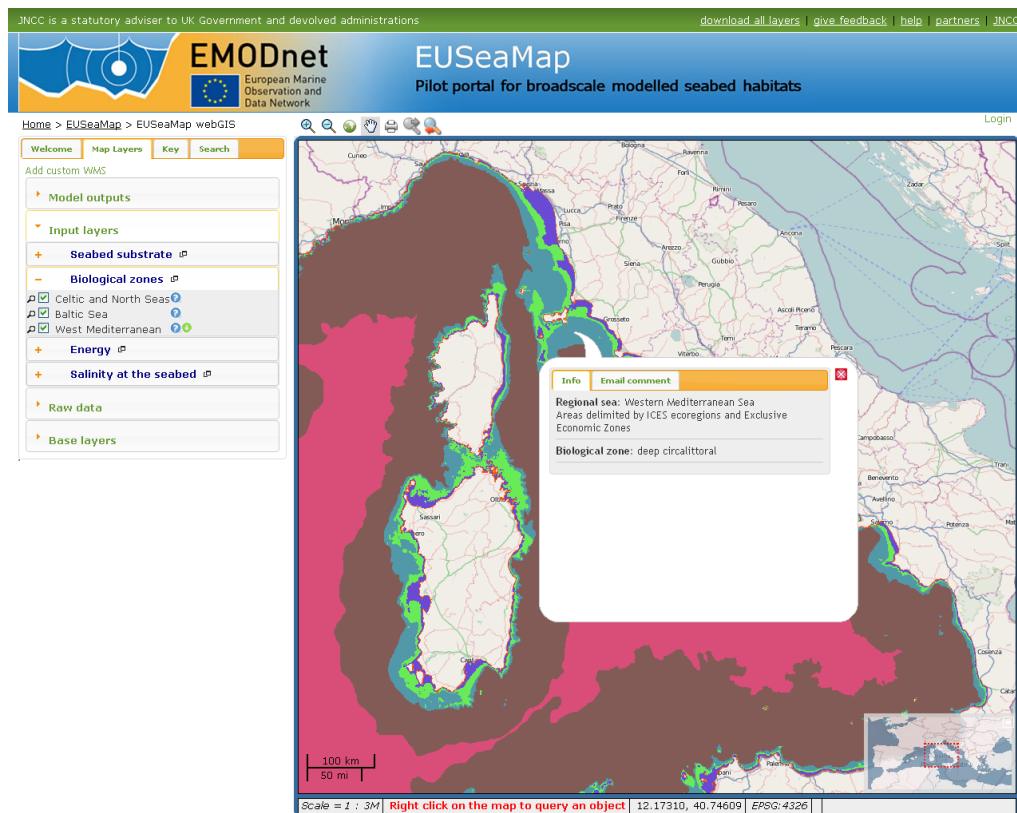


Figure 46 A zoom to part of the Western Mediterranean biological zones map, with Info pop-up. Note the green download button and blue help button next to the layer name, and location window in lower right corner.

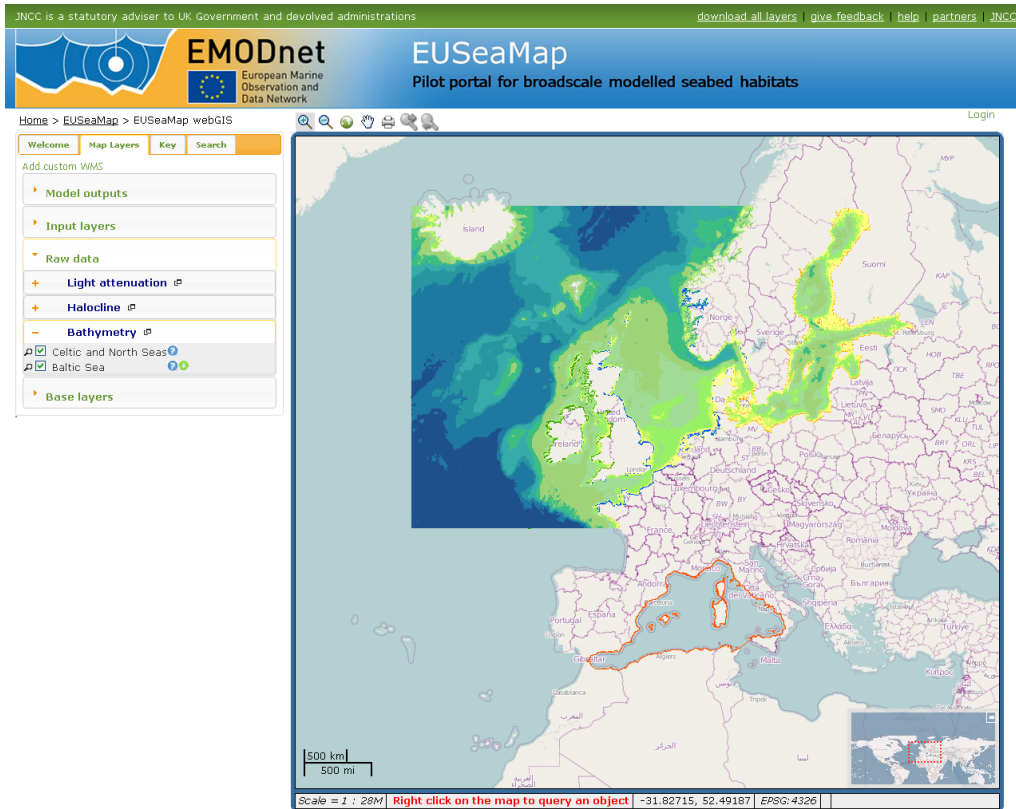


Figure 47 Bathymetry data for the North, Celtic and Baltic Seas.

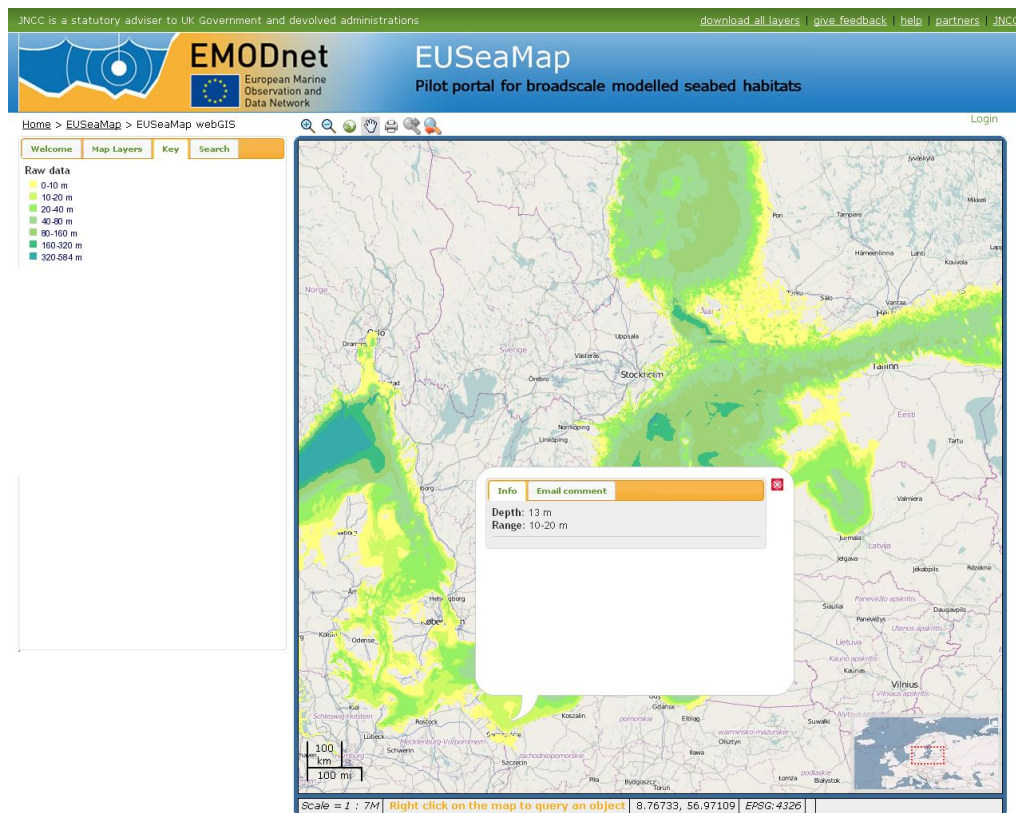


Figure 48 A zoom to the bathymetry data in the Baltic Sea, showing the Key tab and Info pop-up.

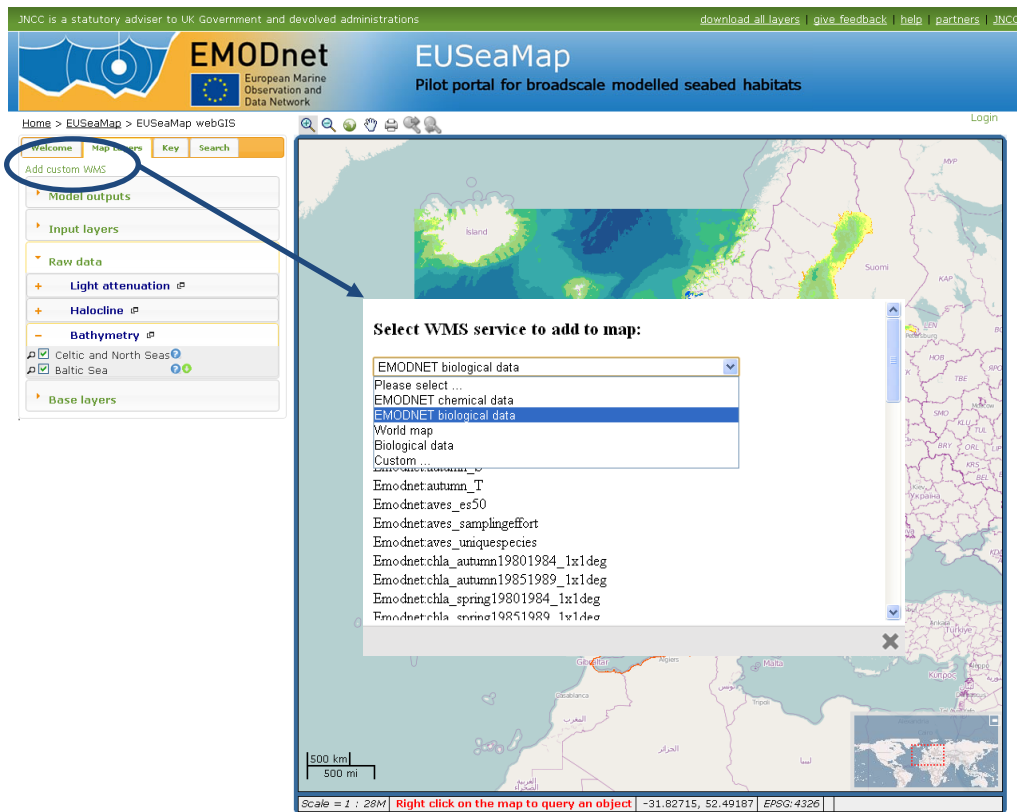


Figure 49 Users have the ability to add from EMODNET WMS layers or to add their own layer by pasting in a URL of a WMS ('Custom...' option). This functionality is still under development.

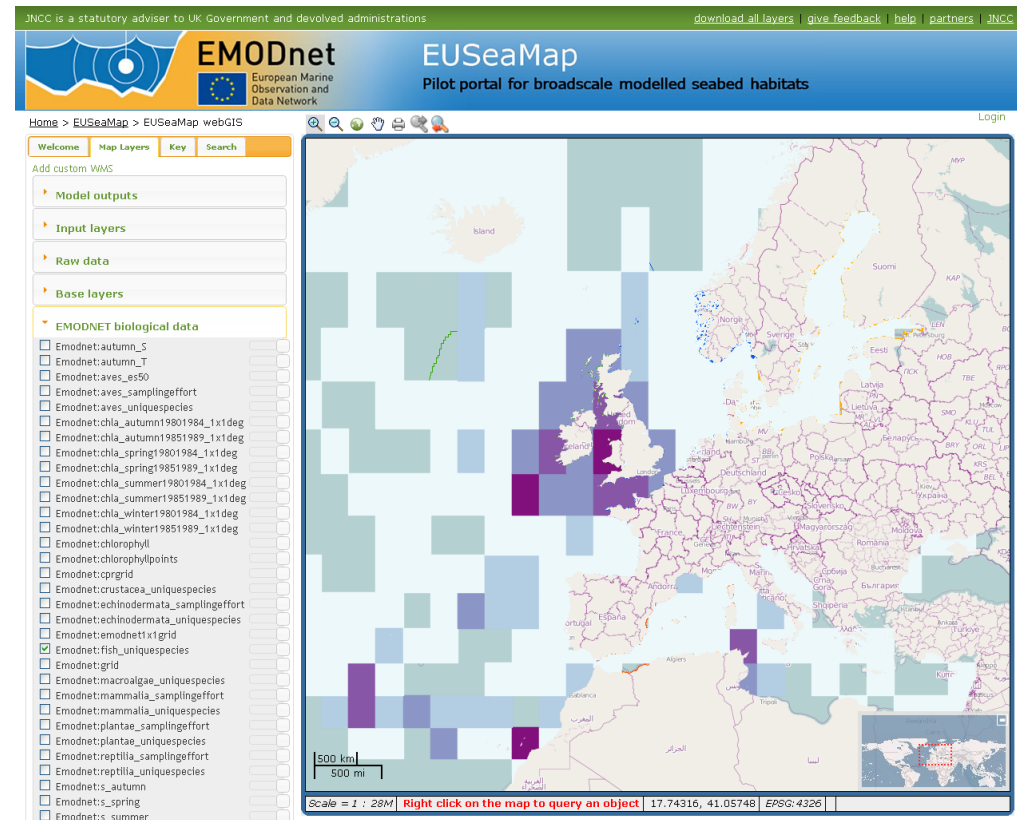


Figure 50 Having selected EMODNET biological data (in Figure 49), a list of available layers appears in the Map Layers tab.

9. Assessment of benefits

The following sections will be part of the Final Report. Draft text has been prepared for the Network of Marine Protected Areas application. Analysis is underway using the outputs of the seabed habitat models.

9.1. Essential Fish Habitat

9.2. Network of Marine Protected Areas

The present contribution is centred on the evaluation of the usefulness of the modelled seabed habitat map with respect to the existing scenario of Marine Protected Areas present in the EC countries of the Western Mediterranean Sea. In particular the modelled seabed habitat map will be used to first define and describe the representativity of the existing network of MPAs with respect to the modelled biological zones and habitat typologies and then subsequently evaluate the map's usefulness in identifying potential gaps with respect to the conservation objectives identified by international instruments ratified by the EC Member States.

The MPA distribution in the Western Mediterranean was evaluated by taking into account the following cartographic datasets:

- a) The CDDA - European inventory of nationally designated areas which holds information on protected sites established under different legal frameworks in all European countries (contains areas designated as national parks, regional parks, wildlife corridors, Natura 2000 sites, national and regional marine protected areas etc.) (<http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-3> ; uploaded version: 30 Oct 2008; CDDA boundaries_v8_2009)
- b) Natura 2000 ecological network of protected areas, set up for species and habitats according to the 1979 Birds Directive and the 1992 Habitats Directive (<http://www.eea.europa.eu/data-and-maps/data/natura-2000> ; uploaded version September 2010)

The CDDA dataset was screened so as to retain only the marine areas subject to protection regimes and also which foresee amongst their objectives the conservation of marine benthic habitats. This therefore allowed the exclusion of those marine areas protected under other legal frameworks whose protection objectives are independent of seabed habitat characterisation such as fishing reserve areas or areas for the protection of pelagic resources such as the International Mediterranean Sea Cetacean Sanctuary.

Moreover, the CDDA was updated to include marine protected areas established since the date of the CDDA last uploaded version by including cartographic information on the

Version 1

following typologies of marine protected areas obtained from the following official national sources and databases. In cases in which cartographic information derived from the central government authorities overlapped with existing CDDA areas the latter was substituted with data obtained from national authorities.

France: Agence des Aires Marines Protegees – This source allowed to add cartographic information on natural marine parks (updated database version 02/2010), national, regional and Corsican natural reserves (updated database version 12/2009), national parks (updated database version 08/2009) .

(<http://www.aires-marines.fr/localisation-des-aires-marines-protegees-par-categorie.html>)

Spain: Spanish Ministry of the Environment – This source of information allowed addition of cartographic information on marine reserves of central government competence

Spain: Autonomous Region of Catalunya – This source of information allowed access to the establishment decrees and respective cartographic information of the following regional marine protected areas: Freus de Ibiza, Badia de Palma, Isla del Toro, Migyorn de Mallorca, Islas Malgrats, Nord de Menorca.

Italy: Italian Ministry of the Environment – this source of information allowed to access the establishment decrees and respective cartographic information of national marine protected areas not present in the CDDA October 2008 dataset.

The above mentioned cartographic datasets therefore allowed the production of two shapefiles relating to the Natura 2000 network and other Marine Protected Areas. These shapefiles were analysed in most cases, separately and together but it is important to keep in mind that in the latter case the values of the total coverage are not the sum of Natura 2000 network and MPAs because in some cases there is a partial overlap of distinct geographic areas present in both datasets.

The shapefiles were therefore analysed in the two following ways:

- spatial coverage of the two networks separately and together so as to define the MPA distribution and how representative it is with respect to the modelled biological zones and marine habitats of the Western Mediterranean
- spatial coverage of the network so as to pinpoint the usefulness and limits of the modelled habitat map will be analysed by considering the conservation requirements/targets set out under different legal/environmental frameworks:
 - usefulness to the purpose of identifying the state of the art and gaps of protected areas according to the EC Habitats Directive
 - usefulness to the purpose of identifying the state of the art of protected areas and gaps according to the conservation targets set by regional conventions (Barcelona Convention)

In the absence of an official shapefile delimiting the territorial waters' extension, the spatial marine delimitation used by the EC for the national assessment within the framework of the Article 17 reporting (Habitats Directive 92/43) was used to carry out some of the calculations by country level (Spain, France, Italy). The boundary delimitations of the spatial coverage considered for the elaborations of each EC country are reported in Figure 51.

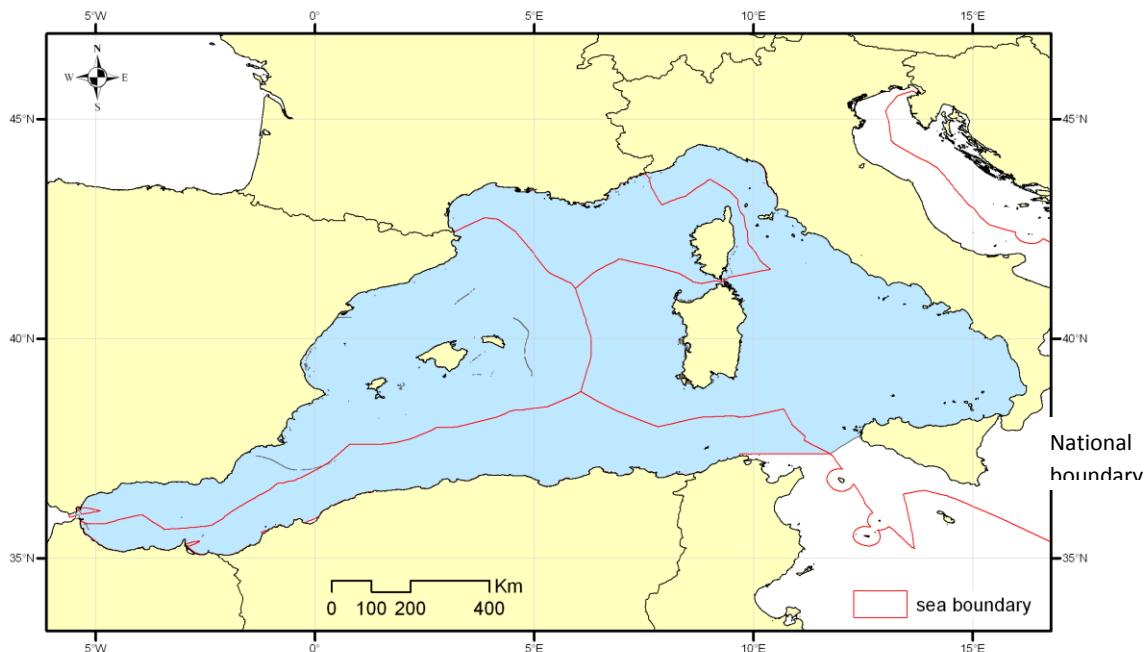


Figure 51 Boundary limits of the coverage considered for each EC country.

9.2.1. Spatial coverage of the entire network in the Western Mediterranean sea EC countries

Total MPA, N2000 (SCIs), and total protected area coverage (%) in the basin

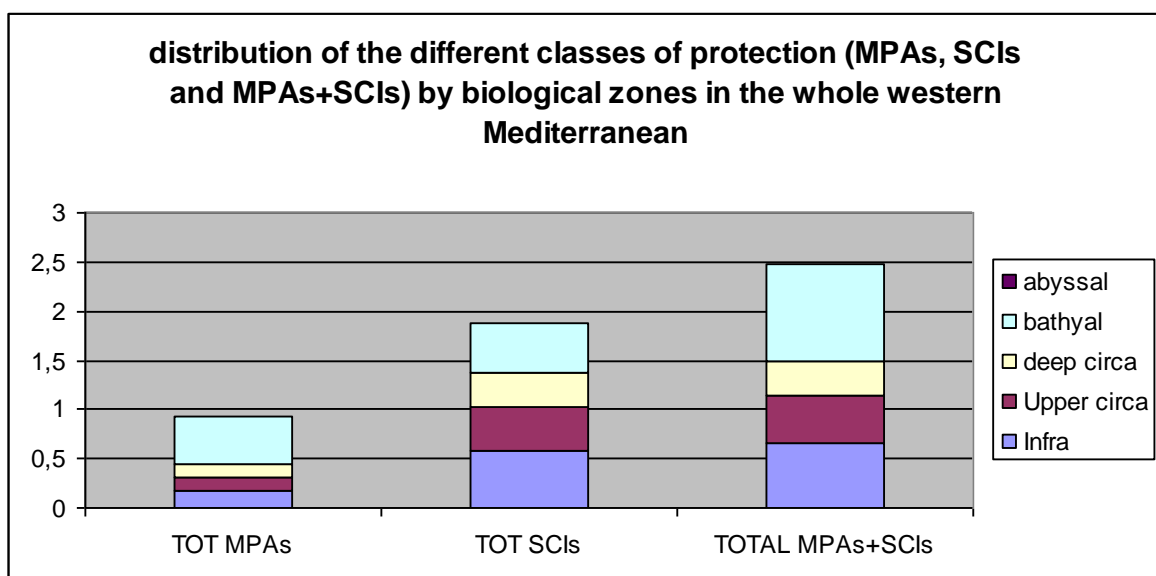


Figure 52 Distribution of the different classes of protection (MPAs, SCIs, and MPAs + SCIs) by biological zones in the whole Western Mediterranean.

Version 1

Figure 52 shows that, with respect to the total modelled map, protected area coverage ranges from 0.9 – 2,5% of the entire study area. Furthermore each histogram shows how the protection percentage cover with respect to the entire study area is distributed throughout the biological zones. Even though these percentages appear low, with respect to the IUCN and CBD 10% coverage target (IUCN 2003, CBD 2004, Coad *et al.* 2009), it must be remembered that the above analysis indicates only the protection effort of the three Member State Countries of the Western Mediterranean and is calculated by considering waters beyond these countries' national jurisdiction, thereby taking into account not only international waters but also the national waters of the north African western Mediterranean countries. Further elaborations will be done to calculate the percentage of cover in the respective 3 EC Member Countries.

MPA distribution and the percentage coverage in each biological zone

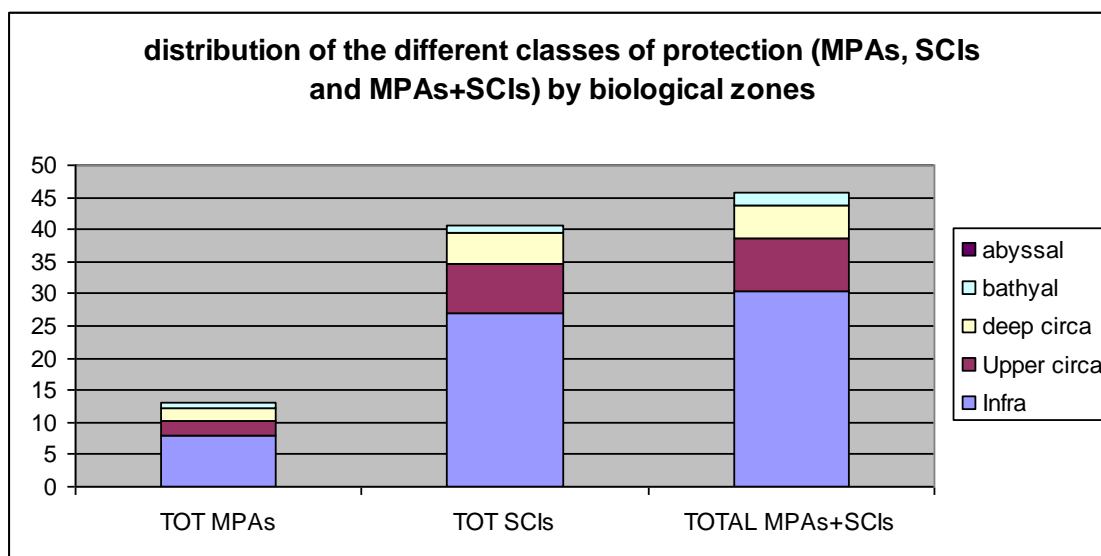


Figure 53 Percentage coverage of each network with respect to the spatial extension of each biological zone.

Figure 53 shows the percentage coverage of each network with respect to the spatial extension of each biological zone in the whole study area of the western Mediterranean. It is evident that the highest protection effort has been exerted in the infralittoral zone followed by the circalittoral and a minor amount of the abyssal zone. This is surely reflective of a coastal approach to protection but is also influenced by the spatial protection limitation determined by the jurisdiction over the territorial waters. Future elaborations will be carried out taking into account the territorial waters' extension.

The percentage coverage of the total MPAs and Natura 2000 network with respect to the spatial extension of each biological zone in Spain, France and Italy (territorial waters interpreted as being the Article 17 spatial extension) is reported in Figure 54.

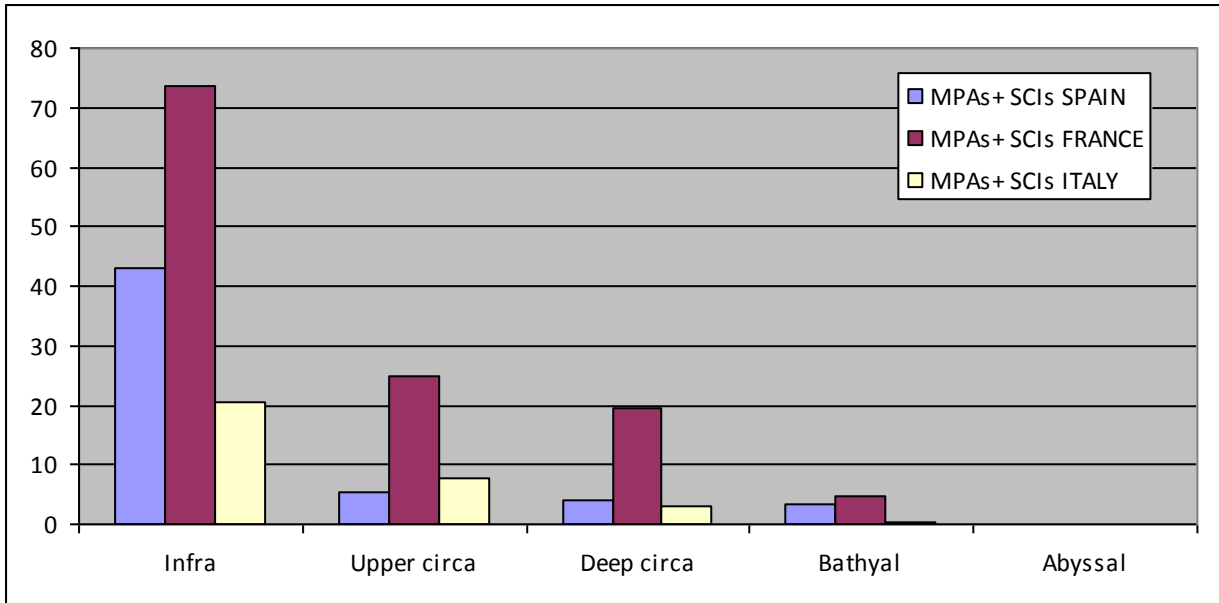


Figure 54 The percentage coverage of the total MPAs and Natura 2000 network with respect to the spatial extension of each biological zone in Spain, France and Italy.

9.2.2. Evaluation of the modelled seabed habitat map with respect to conservation requirements/targets

Usefulness for the state of the art of protected areas according to the EC Habitats Directive

The EUSeaMap habitat map consisting in 18 modelled habitat types and 2 assembled habitats (Posidonia and Cymodocea meadows) is analysed in terms of its usefulness to the purpose of the conservation targets defined within the framework of the EC 97/42 Habitats Directive. Most of the marine habitats defined by the Directive and present within the Mediterranean consist of habitat features composed of various type of sub-habitat types.

The only two Habitats Directive marine habitat types that can be connected to the list of EUSeaMap habitats are: Posidonia meadows (Directive habitat 1120) and reefs (Directive habitat 1170). Since the EC Habitats Directive requests that an adequate percentage of sites of community interest be elected by MS to contain specific habitat types with predetermined optimal percentage cover, the EUSeaMap habitat map was used to determine its applicability in determining the coverage of the existing Natura 2000 network for these two habitat types.

1) Posidonia meadows

The EUSeaMap did not model Posidonia meadows but compiled all the cartographic information available for this habitat type. The existing network of Natura 2000 sites was therefore evaluated against the mapped distribution of Posidonia meadows (EUNIS habitat code A5.535) to evaluate the coverage of the meadow distribution in all the sites. The modelled habitat map allows evaluation of the percentage of Posidonia meadows included in the existing Natura 2000 network for each of the countries involved as indicated in table 1 below and testifies that the EUSeaMap is a useful tool for the purpose of evaluating protection effort provided by the existing network in terms of percentage inclusion of this habitat. In fact the French and Spanish data show that these countries have included over 60% of the habitat's coverage in their networks which is compliant with EC Habitats Directive requirements for this priority habitat of Community importance. It must be remembered that the

Version 1

Italian waters considered in this application only regard those which are encompassed in the western Mediterranean and that the percentage cover of this mapped habitat in the Natura2000 network indicated below is only partially representative of the entire national situation.

EUNIS habitat code	% coverage in Natura 2000 network (all SCIs)		
	Italy	France	Spain
A5.535	22.4%	78.7%	61.9%

The 250m pixel size scale of the EUSeaMap is able to give a far better habitat coverage estimate with respect to the 10km grid cell reported for by countries in the EC cartographic requirements specified within the framework of the Habitats Directive Article.17 reporting obligations. Despite the drawbacks with which the *Posidonia* data was extrapolated into a 250m pixel resolution map, the usefulness of the map to this extent is crucial as a tool for Europe and can be considered an advance with respect to prior available cartographic tools.

2) Reefs:

The EC Habitats Directive habitat “Reefs” can be interpreted as encompassing different hard substrate communities composed of non-biogenic substrata or hard substrate communities resulting from biogenic concretions of various sorts. Though the modelled habitat types present in the EUSeaMap model do not contemplate the mesolittoral rocky habitats, it is possible to use the modelled habitat types relating to hard bottom communities of each of the biological zones listed below to evaluate the overall coverage of hard bottom communities in the Natura2000 network of each country and then relate this to the Directive habitat 1170 Reefs.

EUNIS habitat code	EUNIS habitat name	% coverage in Natura 2000 network (all SCIs)		
		Italy	France	Spain
A3	Infralittoral rock and other hard substrata	32.1%	66.7%	34.2%
A4.26	Mediterranean coralligenous communities moderately exposed to hydrodynamic action (we intend Coralligenous beds)	10.1%	63.3%	11.9%
A4.27	Faunal communities on deep moderate energy circalittoral rock	5.2%	49.7%	7.2%

A6.1	Deep-sea rock and artificial hard substrata (only bathyal)	39.0%	65.0%	2.8%
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Further elaborations will be done to indicate the percentage of total coverage of all rocky habitats per country, so as to evaluate the approximate coverage present according to the gross habitat "Reef".

Usefulness for the state of the art of protected areas according to the Barcelona Convention

The modelled habitat map will be analysed in terms of spatial coverage of the Barcelona Convention habitat types, in particular the capacity to model the biocenosis, associations/facies of conservation interest identified within the framework of the UNEP MAP Barcelona Convention. Most habitats identified by the Barcelona Convention as being worthy of conservation interest are not described in the map because an analysis of their distribution would require a fine scale habitat map. However, some specific habitat types are present in the map and an evaluation of their distribution with respect to ALL MPA distribution will be carried out.

Examples of seabed habitats for which percentage of inclusion in all MPA is observed:

- 1) *Cymodocea nodosa*
- 2) *Posidonia meadows*
- 3) Coralligenous communities
- 4) Deep water corals (deep water rock lower circalittoral, bathyal)

Usefulness for an evaluation of the distribution of marine protected areas according to the MSFD

The Marine Strategy Framework Directive, and its relative technical documents, indicates that all marine habitats should be given adequate protection in order to maintain good marine environmental status. This may imply their inclusion in marine protected areas. The percentage cover of each modelled seabed habitat in the total MPA and Natura 2000 network with respect to each country's national waters (as defined by the Article 17 cartographic reporting obligations) is listed in the table below. Habitats which are present in each country with over 50% coverage in the total protected area network are highlighted in bold.

EUNIS habitat code	% coverage in each country								
	Italy			France			Spain		
	N2000	Other MPAs	Total Coverage	N2000	Other MPAs	Total Coverage	N2000	Other MPAs	Total Coverage
A3	32.1%	41.4%	60.7%	66.7%	18.3%	69.1%	34.2%	15.0%	42.1%
A5.13	6.4%	4.4%	9.8%	79.7%	19.2%	80.5%	35.5%	5.9%	36.8%
A5.23	12.4%	11.0%	17.3%	83.8%	1.4%	83.8%	31.9%	6.1%	34.4%
A5.33	12.2%	2.7%	12.7%	57.0%	1.2%	57.0%	68.7%	2.4%	68.8%

Version 1

A5.23	9.0%	3.0%	11.2%	55.9%	0.6%	55.9%	49.6%	0.6%	50.0%
A5.34	0.1%	0.5%	0.6%	47.2%	0.0%	47.2%	38.3%	0.8%	38.8%
A5.535	22.4%	18.6%	31.9%	78.7%	2.1%	79.5%	61.9%	8.2%	62.6%
A5.531	7.0%	0.7%	7.1%	0.0%	0.0%	0.0%	100.0%	87.5%	100.0%
A4.26	10.1%	5.1%	11.4%	63.3%	4.4%	64.4%	11.9%	6.2%	12.7%
A5.46	6.9%	6.6%	9.3%	55.0%	11.2%	55.2%	6.9%	1.3%	7.0%
A5.38	4.6%	2.3%	6.1%	15.5%	0.5%	15.5%	1.8%	0.3%	1.8%
A5.39	1.4%	0.4%	1.8%	1.9%	0.0%	1.9%	2.0%	0.2%	2.1%
A4.27	5.2%	0.5%	5.4%	49.7%	0.3%	49.9%	7.2%	12.3%	15.1%
A5.47	3.3%	2.8%	3.9%	23.0%	5.6%	23.0%	3.7%	0.7%	4.0%
A5.39	1.7%	1.5%	1.8%	4.1%	0.0%	4.1%	0.7%	0.0%	0.7%
A6.1	39.0%	2.4%	41.5%	65.0%	0.0%	65.0%	2.8%	40.6%	41.5%
A6.3	1.4%	0.9%	1.9%	17.5%	0.0%	17.5%	2.1%	0.5%	2.3%
A6.511	0.5%	0.5%	0.9%	4.5%	0.0%	4.5%	1.2%	0.0%	1.2%
A6.51	0.0%	0.0%	0.0%	0.9%	0.0%	0.9%	0.1%	3.8%	3.9%
A6.3 (Abyssal)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
A6.52	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Stakeholder involvement

Stakeholder involvement was sought by contacting the UNEP-MAP RAC SPA secretariat which is responsible for the implementation of the Protocol for Specially Protected Areas and Biodiversity of the Barcelona Convention. UNEP MAP RAC SPA as asked to evaluate the potential application of the EUSeaMap modelled habitat map in the Mediterranean Sea and with respect to the analysis of Mediterranean Marine Protected Area networks.

9.3. Potential sites for sand and gravel extraction

9.4. Potential sites for wind farms

9.5. Tourist facilities

9.6. Assessment of multiple uses in spatial planning

9.7. Marine Strategy Framework Directive Initial Assessment

10. Assessment of next steps

This section will be completed in the Final Report.

11. Summary

This Draft Final Report of EUSeaMap summarises the work of the project to date. Through a review of seabed habitat modelling and mapping in European waters, a consistent methodology has been developed across the partnership, which takes account of the diverse range of seabed habitats found in different Regions. Spatial data have been prepared for a suite of environmental variables, which form the basis of the model. This includes data provided by EMODNET geology and hydrography projects³². Biological data have been incorporated into the modelling process, through the development of ecologically-relevant thresholds. Models were run in three areas (Baltic, Western Mediterranean, North and Celtic Seas) to produce seabed habitat maps covering nearly 2 million square kilometres. All the models are structured to allow ready update of the maps, as new higher quality data become available in the future.

Three techniques have been developed for creating confidence maps associated with the seabed habitat maps. Confidence maps are important to enable the variation in quality and resolution of the input data layers to be visually reflected. The EUSeaMap pilot webGIS has been built, through which the final seabed habitat maps, environmental variables and confidence maps will be disseminated; additional functionality is in development ahead of the project completion in December.

In this final phase of the project a series of assessments to demonstrate the applications of the maps will be carried out to highlight benefits and weaknesses of such maps, including through stakeholder feedback. An assessment of further work required to refine the maps and to extend them to other parts of European seas will be undertaken.

³² Preparatory Actions for European Marine Observation and Data Network, No. MARE/2008/03, Lots 1 & 2

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Appendix I. Version Control

Build status:

Version	Date	Author	Reason/Comments	Sections
0.1	12 September 2010	EUSeaMap	Initial Release	All
0.2	8 October 2010	EUSeaMap	Comments from NC and text from partners incorporated	All
1.0	13 October 2010	EUSeaMap	Final amendments, release to EC	All
				All

Amendments in this release:

Section Title	Section No.	Amendment Summary

Distribution:

Copy	Version	Issue Date	Issued To
Electronic	1.0	13 Oct 2010	Iain Shepherd, DG-Mare, European Commission
Electronic	0.2	8 Oct 2010	JNCC
Electronic	0.1	10 Sept 2010	JNCC

Appendix II. EUNIS habitats – Western Mediterranean

EUNIS Habitat code	EUNIS Level	EUNIS name (in parenthesis eventual notes)	Barcelona Code	Barcelona Convention name	Zone	Light	Bathymetry (or slope where appropriate)	Substrate	Energy conditions	Bottom temp
A3	2	Infralittoral rock and other hard substrata	III.6.	HARD BEDS AND ROCKS (intended as biocenosis of infralittoral algae)	INFRA	>1% surface light - <i>in situ</i> data	1-45 max	bedrock, boulders and cobbles / ROCK		
A5.23	4	Infralittoral fine sands	III.2.	FINE SANDS WITH MORE OR LESS MUD	INFRA	>1% surface light - <i>in situ</i> data	0-45	fine homogenous granulometry and well sorted fine sands / SAND / MUDDY SAND		
A5.13	4	Infralittoral coarse sediments	III.3	COARSE SANDS WITH MORE OR LESS MUD	INFRA	>1% surface light - <i>in situ</i> data	0-45	COARSE & MIXED SEDIMENT		Eurithe
A5.33	4	Infralittoral sandy mud		<i>No corresponding Barcelona Convention habitat type</i>	INFRA			SANDY MUD		
A5.34	4	Infralittoral mud		<i>No corresponding Barcelona Convention habitat type</i>	INFRA			MUD		
A4.26	4	Mediterranean coralligenous communities moderately exposed to hydrodynamic action (we intend Coralligenous beds)	IV.3.1	Coralligenous biocenosis	UPPER CIRCA	<1% surface light >0.01% - <i>in situ</i> data	25-100	ROCK		13-18
A5.46	4	Mediterranean biocenosis of coastal detritic bottoms	IV.2.2.	Biocenosis of the coastal detritic bottom	UPPER CIRCA	<1% surface light >0.01% - <i>in situ</i> data	below P. oceanica until the break of continental slope, lower depth is 100 meters	gravel, sand and shell debris / COARSE & MIXED SEDIMENT/ MUDDY SAND / SAND	medium constant current	

A5.38	4	Mediterranean biocoenosis of muddy detritic bottoms	IV.2.1.	Biocenosis of the muddy detritic bottom	UPPER CIRCA	<1% surface light >0.01% - <i>in situ</i> data	below P. oceanica until beginning of continental slope	very sandy mud or muddy sand, compact mud rich in shell debris, gravel and sand present but with constant mud predominance / SANDY MUD	sedimentation slow; low energy	
A5.39	4	Mediterranean biocoenosis of coastal terrigenous muds	IV.1.1.	Biocenosis of coastal terrigenous muds	CIRCA	<1% surface light	25 – continental shelf	pure mud of fluvial origin, fine and rapid settling, more or less clayey, can be both soft or sticky mud / MUD	low to medium	
A4.27	4	Faunal communities on deep moderate energy circalittoral rock	IV.3.3.	Biocenosis of shelf-edge rock	DEEP CIRCA	0	120-180	hard substrata / ROCK		
A5.47	4	Mediterranean communities of shelf-edge detritic bottoms	IV.2.3.	Biocenosis of shelf-edge detritic bottom	DEEP CIRCA	0	-80 m to shelfbreak	detritic, high abundance dead shells, bryozoans and coral skeletons which are calcareous debris of quaternary thanatocenosis; higher proportion of fine sand and mud rather than gravel / COARSE & MIXED SEDIMENT / MUDDY SAND / SAND / SANDY MUD	medium - high	
A6.1	3	Deep-sea rock and artificial hard substrata	V.3.	HARD BEDS AND ROCKS	BATHYAL	0	from the shelf-break (150-250m) to	ROCK		

Version 1

							the beginning of the abyssal plain			
A6.51	4	Mediterranean communities of bathyal muds	V.1.1.	Biocenosis of bathyal muds	BATHYAL	0	from the shelf-break (150-250m) to the beginning of the abyssal plain	fluid to compact mud (Clayey usually compact, yellowish or bluish, sometimes a bit sandy / MUD		
A6.511	5	Facies of sandy muds with <i>Thenia muricata</i>	V.1.1.1.	Facies of sandy muds with <i>Thenia muricata</i>	BATHYAL	0	from the shelf-break (150-250m) to the beginning of the abyssal plain	SANDY MUD		
A6.3	3	Deep-sea sand	V.2.	SANDS	BATHYAL		from the shelf-break (150-250m) to the beginning of the abyssal plain	MUDDY SAND		
A6.1	3	Deep-sea rock and artificial hard substrata		<i>No corresponding Barcelona Convention habitat type</i>	ABYSSAL	0		ROCK		
A6.52	4	Communities of abyssal muds	VI.1.1.	Biocenosis of abyssal muds	ABYSSAL	0	abyssal plain	MUD		
A6.3	3	Deep-sea sand		<i>No corresponding Barcelona Convention habitat type</i>	ABYSSAL			SAND		

Note: *Posidonia oceanica* and *Cymodocea nodosa* beds will not be modelled but will appear in the map as they enter as special "substrate" types

Appendix III. Publicity log

The EUSeaMap project, for large scale cartography of European seabeds Definition of the process to model habitat distribution in the western Mediterranean - Presentation at Progetto CARG, Rome, Italy, 29-30 September 2009.

EUSeaMap: Towards common spatial seabed data - Presentation at the Maritime and coastal information systems, Europe - EEA/EIONET workshop, Trieste, Italy, 18-19 November 2009

EUSeaMap: modelling European seabed habitats - Information paper and presentation at OSPAR Working Group on Marine Protected Areas, Species and Habitats (MASH) in Vilm, Germany, 24-26 November 2009.

EUSeaMap project: Modelling European seabed habitats - Information poster presented at GeoHab 2010, Wellington, New Zealand, 4-7 May 2010.

EUSeaMap project: Modelling European seabed habitats - A focus on the western Mediterranean. Information poster to be presented at 39th CIESM (The Mediterranean Science Commission) in Venice, Italy, 10-14 May 2010. Published as: Tunesi L., Agnesi S., Cameron A., Coltman N., Hamdi A., Lopez V., Mo G., Populus J., Sanz alonso J., Sartoretto S., Connor D., 2010 - EUSeaMap project: modelling European seabed habitats - a focus on the western Mediterranean. *Rapp. Comm. int. Mer Médit.*, 39: 686.

EUSeaMap: Modelling European seabed habitats - Presentation at Mesh-Atlantique kick-off meeting, Lisbon, Portugal, 31 May 2010.

Estimation of the diffuse attenuation coefficient K_{dpar} using MERIS satellite reflectances for European coastal waters - Paper presented at the 2010 European Space Agency (ESA) Living Planet Symposium in Bergen, Norway, 28 June - 2 July 2010.

EUSeaMap: Modelling European seabed habitats - Information made at Pegaso meeting "Cases Bouches du Rhône" and Work Package 3 meeting, Marseille, France, 14 September 2010.

Modélisation spatiale des habitats benthiques à l'échelle continentale - Presentation at ESRI France user conference, Versailles, France, 28-29 September 2010.

Development of EUNIS habitat classes for the Baltic Sea - Paper to the Workshop for the Biotope Experts of the Project for Completing the HELCOM Red List of Species and Habitats/Biotopes, Second Meeting, Stockholm, Sweden, 4-5 October 2010.

Prospects for a seabed and habitat map of Europe - Presentation at the EurOcean 2010 conference (David Connor), Ostend, Belgium, 12-13 October 2010.

Appendix IV. Data sources summary

Region: Baltic sea						
Model Layer	Variable	Data Set	Date	Source	Resolution/Scale	Owner of Intellectual Property Rights
Substrate	Sediment	EMODNET Geology	NA	EMODNET Geology (Various)	1:1,000,000	Public access
Biological depth zone	Bathymetry	GEBCO_08 Grid	NA	The GEBCO_08 Grid, version 20090202, www.gebco.net	30 arcsecond grid	
Biological depth zone	Bathymetry	BALANCE	NA	BALANCE	Sources: 1:250,000 to 1:1,000,000 Raster: 250m grid	GEUS, GTK, SGU (joint)
Biological depth zone	Bathymetry	EMODNET Hydrography DTM	NA	EMODNET Hydrography DTM	15 arcsecond grid	Public domain
Biological depth zone	Light	Light secchi data (ICES/Aarup 2002, ICES, SYKE)	1980 - 2008	Aarup, T. (2002). Transparency of the North Sea and Baltic Sea – a Secchi depth data mining study. <i>Oceanologia</i> 44 (3):323–337. More recent data from ICES (1999-2008) and SYKE (2000-2005)	Source: 5738 points; Raster: 200m grid	Public domain (raster)
Energy	Wave energy at seabed	DHI	2006 - 2009	DHI spectral model	3 nm grid 9 nm grid east of 18 E	
Energy	Tidal energy at seabed	DHI	2004 - 2009	DHI spectral model	3 nm grid 9 nm grid east of 18 E	

Version 1

Energy	Wave exposure	SWM	2010	Aquabiota Water Research	25 m grid	Aquabiota Water Research, freely available
Other	Salinity at seabed	DHI	2000 - 2008	MIKE 3 Classic, 3D hydrodynamic model	3 nm grid	
Other	Temperature at seabed	DHI	2000 - 2008	MIKE 3 Classic, 3D hydrodynamic model	3 nm grid	
Other	O ₂ /POC/Chl	BALANCE	2000 - 2008	MIKE 3 Classic, HD + ECOLAB	3-9 nm grid	
Other	Ice cover	BALANCE	1963 - 1980	Metria/Sweden and Leppäranta et al. 1988		
Other	Bottom stratification frequency	DHI	2000 - 2008	MIKE 3 Classic, 3D hydrodynamic model	3nm grid	
Other	Stratification strength Brunt-Vaisala Frequency	DHI	2000 - 2008	MIKE 3 Classic, 3D hydrodynamic model	3nm grid	

Region: Celtic sea						
Model Layer	Variable	Data Set	Date	Source	Resolution/Scale	Owner of Intellectual Property Rights
Substrate	Sediment	DigSBS250 seabed sediments (2010 update), with NOC deep sea dataset (MB105) and BGS rock layer (MB0103)	NA	Cooper, R., Long, D., Doce, D., Green, S. and Morando, A.. 2009. Creating and assessing a seabed sediment data layer for UKSeaMap 2010. British Geological Survey Commercial Report, CR/09/168. 15pp.	1:250,000	BGS and JNCC (joint)
Substrate	Sediment	Larsonneur	NA	Vaslet D, Larsonneur C, Auffret J-P, 1979. Les sédiments superficiels de la Manche. 1/500 000ème. Carte géologique de la marge continentale française. BRGM/CNEXO	1:500,000	Ifremer
Substrate	Sediment	EMODNET Geology	NA	EMODNET Geology (Various)	1:1,000,000	Public domain
Biological depth zone	Bathymetry	GEBCO_08 Grid	NA	The GEBCO_08 Grid, version 20090202, www.gebco.net	30 arcsecond grid	
Biological depth zone	Bathymetry	SeaZone DTM	NA	SeaZone Hydrospatial Coastal DTM	1 arcsecond grid	SeaZone Ltd.
Biological depth zone	Bathymetry	EMODNET Hydrography DTM	NA	DTM - built from composite surveys and DTMs	15 arcsecond grid	Public domain
Biological depth zone	Light	MERIS	2003 - 2008	Détermination de KdPAR, Kd490, et de la profondeur euphotique à partir de données satellitaires. Contrat Ifremer n° 022-791, 2009.	0,015° * 0,01° tif (~1km)	Ifremer/ACRI
Biological depth zone	Wavebase	MB102	2000 - 2004	NOC ProWAM and ABPMer bespoke coastal model (based on DHI MIKE Spectral Wave) from Data contract MB102: Accessing and developing the required biophysical datasets and datalayers for Marine Protected Areas network planning and wider marine spatial planning purposes	300m grid	Defra

Version 1

Energy	Wave energy at seabed	MB102	2000 - 2004	NOC ProWAM and ABPMer bespoke coastal model (based on DHI MIKE Spectral Wave) from Data contract MB102: Accessing and developing the required biophysical datasets and datalayers for Marine Protected Areas network planning and wider marine spatial planning purposes	300m grid	Defra
Energy	Tidal energy at seabed	MB102	2000 - 2004	NOC CS30, CS3 and NEA tidal models from Data contract MB102: Accessing and developing the required biophysical datasets and datalayers for Marine Protected Areas network planning and wider marine spatial planning purposes	300m grid	Defra
Other	Temperature at seabed	Met Office Atlantic Margin Model	2003 - 2007	Met Office/NCOF operational Atlantic Margin Model, running AMM in hindcast mode. http://www.ncof.co.uk/Coastal-Seas-Modelling.html		MET

Region: North sea						
Model Layer	Variable	Data Set	Date	Source	Resolution/Scale	Owner of Intellectual Property Rights
Substrate	Sediment	DigSBS250 seabed sediments (2010 update), with NOC deep sea dataset (MB105) and BGS rock layer (MB0103)	NA	Cooper, R., Long, D., Doce, D., Green, S. and Morando, A.. 2009. Creating and assessing a seabed sediment data layer for UKSeaMap 2010. British Geological Survey Commercial Report, CR/09/168. 15pp.	1:250,000	BGS and JNCC (joint)
Substrate	Sediment	EMODNET Geology	NA	EMODNET Geology (Various)	1:1,000,000	Public domain
Biological depth zone	Bathymetry	GEBCO_08 Grid	NA	The GEBCO_08 Grid, version 20090202, www.gebco.net	30 arcsecond grid	
Biological depth zone	Bathymetry	SeaZone DTM	NA	SeaZone Hydrosatial Coastal DTM	1 arcsecond grid	SeaZone Ltd.
Biological depth zone	Bathymetry	EMODNET Hydrography DTM	NA	DTM - built from composite surveys and DTMs	15 arcsecond grid	Public domain
Biological depth zone	Light	MERIS	2003 - 2008	Détermination de KdPAR, Kd490, et de la profondeur euphotique à partir de données satellitaires. Contrat Ifremer n° 022-791, 2009.	0,015° * 0,01° tif (~1km)	Ifremer/ACRI

Version 1

Biological depth zone	Wavebase	MB102	2000 - 2004	NOC ProWAM and ABPMer bespoke coastal model (based on DHI MIKE Spectral Wave) from Data contract MB102: Accessing and developing the required biophysical datasets and datalayers for Marine Protected Areas network planning and wider marine spatial planning purposes	300m grid	Defra
Energy	Wave energy at seabed	MB102	2000 - 2004	NOC ProWAM and ABPMer bespoke coastal model (based on DHI MIKE Spectral Wave) from Data contract MB102: Accessing and developing the required biophysical datasets and datalayers for Marine Protected Areas network planning and wider marine spatial planning purposes	300m grid	Defra
Energy	Tidal energy at seabed	MB102	2000 - 2004	NOC CS30, CS3 and NEA tidal models from Data contract MB102: Accessing and developing the required biophysical datasets and datalayers for Marine Protected Areas network planning and wider marine spatial planning purposes	300m grid	Defra
Other	Temperature at seabed	Met Office Atlantic Margin Model	2003 - 2007	Met Office/NCOF operational Atlantic Margin Model, running AMM in hindcast mode. http://www.ncof.co.uk/Coastal-Seas-Modelling.html		MET

Region: Western Mediterranean sea						
Model Layer	Variable	Data Set	Date	Source	Resolution/ Scale	Owner of Intellectual Property Rights
Substrate	Sediments/geology	“Geological Map of the Italian Seas”	2005-2008	CARG - Geological Cartography. sheets number 464, 465, 466, 467, 484, 485, 486 (in press).	1:25,000- 1:50,000	ISPRA
Substrate	Hard bottom/ seagrasses	Atlante degli habitat marini della Liguria.	1973-2006	Diviaco G., Coppo S. 2006. Atlante degli habitat marini della Liguria. Descrizione e cartografie delle praterie di Posidonia oceanica e dei principali popolamenti marini costieri. Regione Liguria. Catalogo dei beni naturali n°6: 205pp + 83 Tavole	1:10,000	Regione Liguria
Substrate	Sediment	Atlante della cartografia bionomica dell'ambiente marino costiero della Liguria. Agnesi S., Piccione M.E., Tunesi L. CD	1971-1996	In: Tunesi. L. Piccione M.L., Agnesi S. 2002. Progetto pilota di Cartografia bionomica dell'ambiente marino costiero della Liguria. Proposta di un sistema informativo geografico per la gestione di cartografie bionomiche e sedimentologiche. Quaderno ISPRA n° 2: 112pp	1:50,000	ISPRA
Substrate	Substrate (Seagrasses)	Carta Bionomica dei mari Toscani	1985-1993	Bianchi, Cinelli, Morri . 1993. In: Atti Convegno “Lo stato degli ecosistemi marini del tirreno toscano” Grosseto 2-4 Dicembre 1993. Atti della Società Toscana di Scienze Naturali. Memorie – Serie A, Supplemento Vol CII, anno 1995.	1:250,000	ENEA, Regione Toscana

Version 1

Substrate	Sediments/geology/seagrasses	Carta della distribuzione dei sedimenti e delle praterie di Posidonia oceanica (3 carte - Lazio settentrionale, centrale e meridionale)	1989-1990	G.D. Ardizzone, G.B. La Monica, R. Raffi. In: Il mare del Lazio, 1994 - Regione Lazio	1:100,000	Regione Lazio
Substrate	Sediment	Carta Sedimentologica dei Mari Toscani.	1993	Ferretti O., Immordino F., Manfredi Frattarelli F.1993. In: Atti Convegno "Lo stato degli ecosistemi marini del tirreno toscano" Grosseto 2-4 Dicembre 1993. Atti della Società Toscana di Scienze Naturali. Memorie – Serie A, Supplemento Vol CII, anno 1995.	1:250,000	ENEA, Regione Toscana
Substrate	Sediments/geology/seagrasses	GIS Natura	1990-2004?	BD Natura 2000. AA. VV., 2005. GIS Natura: il GIS delle conoscenze naturalistiche in Italia. DVD. Politecnico di Milano - Ministero dell'Ambiente e della Tutela del Territorio, Direzione Protezione della Natura.	1:250,000	MATTM
Biological depth zone	Bathymetry	Carte Nautiche dell'Istituto Idrografico della Marina	NA	Dati dell'Istituto Idrografico della Marina	1:100,000	Istituto Idrografico della Marina
Biological depth zone	Bathymetry	EMODNET Hydrography DTM	NA	DTM - built from composite surveys and DTMs	15 arcsecond grid	Public domain
Biological depth zone	Bathymetry	GEBCO_08 Grid	NA	The GEBCO_08 Grid, version 20090202, www.gebco.net	30 arcsecond grid	
Biological depth zone	Bathymetry	Depth DTM for Golfe du Lion and Région PACA	2009	Etude pour la réalisation d'un Modèle Numérique de terrain pour les façades méditerranée et Corse. Contrat Ifremer n° 2009-2-20694022	250m grid	SHOM and Ifremer
Biological depth zone	Light	MERIS	2007 - 2009	Détermination de KdPAR, Kd490, et de la profondeur euphotique à partir de données satellitaires. Contrat Ifremer n° 022-791, 2009.	0,0038° * 0,0027° tif (~250m)	Ifremer/ACRI

Biological Depth Zone	Light	MERIS	2003 - 2008	Détermination de KdPAR, Kd490, et de la profondeur euphotique à partir de données satellitaires. Contrat Ifremer n° 022-791, 2009.	0,015° * 0,01° tif (~1km)	Ifremer/ACRI
Depth Zone /Substrate	Bathymetry / Substrate	Estudio de la Plataforma Continental Española (ESPACE project)	1999-2007	Sanz, J.L.; Tello, O.; Hermida, N.; Fernández-Salas, L.M.; Pastor, E.; Rivera, J.; González, J.L.; Cubero, P.; Godoy, D.; Alcalá, C.; Contreras, D.; Torres, A.; Alfageme, V.M.; Pérez, J.I.; Redondo, B.C.; Velasco, D; González, F. Estudio de la Plataforma Continental Española. Cartographic Serie. Sheets: 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57. 33 maps	1:50,000.	Instituto Español de Oceanografía (IEO) / Secretaría General de Pesca Marítima (MAPA)
Depth Zone /Substrate	Bathymetry / Substrate (inc. Meadows)	Estudio de la Plataforma Continental Española (ESPACE project)	1999-2009	Sanz, J.L.; Tello, O.; Hermida, N.; Fernández-Salas, L.M.; Pastor, E.; Rivera, J.; González, J.L.; Cubero, P.; Godoy, D.; Alcalá, C.; Contreras, D.; Torres, A.; Alfageme, V.M.; Pérez, J.I.; Redondo, B.C.; Velasco, D; González, F. Estudio de la Plataforma Continental Española. Cartographic Serie. Sheets: 10, 11, 43, 44, 45, 46, 58, 59, 60, 61 (un published)	1:50,000.	Instituto Español de Oceanografía (IEO) / Secretaría General de Pesca Marítima (MAPA)
Depth Zone/ Substrate	Bathymetry / Substrate	Cartas de pesca del mar de Alborán. (CARPEMA project)	2002-2007	Cartas de pesca del Mar de Alborán. Sheets:MA-1, MA-2; MA-3; MA-4, MA-5; MA-6; MA-7; MA-8; MA-9; MA-10, MA-11; MA-12; MA-13	1:200,000.	Instituto Español de Oceanografía / Secretaría General de Pesca Marítima
Depth Zone	Bathymetry	Plan Hidrográfico y Oceanográfico de la Zona Económica Exclusiva Española. Baleares	1999	Instituto Hidrográfico de la Marina / Instituto Español de Oceanografía. Sheets:9, 10, 11, 13, 14, 15. 18 maps	1:200,000	Instituto Hidrográfico de la Marina
Substrate	Substrate	Mapa del Cuaternario de España	1996	Instituto Tecnológico y GeoMinero de España	1:1,000.000.	Instituto Tecnológico y GeoMinero de España

Version 1

Depth Zone/ Substrate	Bathymetry/Substrate	Mapa geologico de la plataforma continental española y zonas adyacentes a 1:200.000.	1990-2004	Mapa geologico de la plataforma continental y zonas adyacentes a 1:200.000. Sheets: 32/25-FIGUERAS, 35/42-BARCELONA, 41/42-TORTOSA/TARRAGONA, 72/73-ALICANTE, 79-MURCIA, 84/85-S.ALMERÍA/GARRUCHA Y CHELLA/LOS GENOVESES	1:200,000	Instituto Tecnológico y GeoMinero de España (ITGE)
Depth Zone/ Substrate	Substrate	Mapa geomorfológico de España y del margen continental.	2005	Mapa geomorfológico de España y del margen continental.	1:1,000,000	Instituto Geológico y Minero de España (IGME)
Depth Zone/ Substrate	Bathymetry/ Substrate (inc. Meadows)	Plan de Ordenación del Litoral	1988- 2000	Cartografía para el plan de Ordenación del Litoral. Dirección General de Costas. Tramos de Valencia y Barcelona	1: 25,000	Dirección General de Costas. Ministerio de Obras Públicas
Depth Zone/ Substrate	Bathymetry/ Substrate (inc. Meadows)	Sistema de Información Geográfica del IEO. SIGFOMAR and SIDFOMAR Projects	1998-2010	Sistema de Información Geográfica del IEO. SIGFOMAR and SIDFOMAR Projects (1995-2009). Sanz, J.L.; Tello, O.; Hermida; N., Pastor, E.; Cubero, P.; López, V.; Lobato, A.	Cartographic synthesis of several confidence and scale maps incorporated to a GIS on Spanish continental margins.	Instituto Español de Oceanografía (IEO)
Depth Zone	Bathymetry	Continental margin of Cataluña. Grid		Canals, M. (Synthesis of several works). Unpublished	250 m grid	M. Canals, Departamento de Estratigrafía, Paleontología y Geociencias Marinas. Universidad de Barcelona - UB
Depth Zone	Bathymetry	BALCOM project grid (Columbretes, Ibiza and Formentera islands margin study)		Acosta, J. et al. (unpublished)	20 m grid	Instituto Español de Oceanografía (IEO)

Depth Zone	Bathymetry	Deep Sedimentary Environment of the South Balearic Margin project (SBAL-DEEP). DTM	2005 & 2008	Bathymetric grid data unpublished. Camerlenghi, A. Morphogenesis of the SW Balearic continental slope and adjacent abyssal plain, Western Mediterranean Sea Angelo Camerlenghi; Daniela Accettella; Sergio Costa; Galderic Lastras; Juan Acosta; Miquel Canals; Nigel Wardell (2008). Morphogenesis of the SW Balearic continental slope and adjacent abyssal plain, Western Mediterranean Sea. Int J Earth Sci (Geol Rundsch) Costa, S., Accettella, D., Lastras, G., Camerlenghi, A., Acosta, J., Canals, M., Ceramicola, S., Rebesco, M., Wardell, N., (2006). Shallow sediment deformation, sediment sliding and mud volcanoes in the SW Balearic continental margin and abyssal plain (OGS-Explora Cruise SBALDEEP). 3rd ESF-EUROMARGINS conference. (2007). EGU General Assembly	200 m grid	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)
Depth Zone	Bathymetry	Hercules and TARIK projects.	1980-1997	Sanz, J.L. et al. (unpublished data). Several papers	1:25.000 - 1:100.000	Instituto Español de Oceanografía (IEO)
Depth Zone/ Substrate	Bathymetry	SAGAS project (El Sistema del Arco de Gibraltar: Procesos Geodinámicos	2004-2008	Ercilla, G (grid unpublished). Several papers	100 m grid	CMIMA (barcelona). CSIC
Depth Zone/ Substrate	Bathymetry	MARSIBAL Project (Estudios Geológicos y Geofísicos Integrados en Márgenes y Cuencas del Sur de Iberia). Grid	2001-2005	Comas, M. (grid unpublished). Several papers	50 m grid	IACT (Granada). CSIC
Depth Zone	Bathymetry	Morpho-Bathymetry of the Mediterranean Sea. DTM	2008	CIESM - IFREMER. Morpho-Bathymetry of the Mediterranean Sea	1:3,000,000	CIESM - IFREMER

Substrate	Substrate	IBCM-Sed		IBCM. Unconsolidate bottom surface sediments (ICBM sed). www.ngdc.noaa.gov/mgg/ibcm	1 : 1,000,000	IOC - IBCM
Substrate	Sediments/geology	Carte des formations superficielles sous-marines entre Port-Barcarès et Saint-Cyprien (Pyrénées Orientales)	1986	AUGRIS C. , MEAR Y., « Carte des formations superficielles sous-marines entre Port-Barcarès et Saint-Cyprien - Pyrénées Orientales », 1986, Ifremer, Université de Perpignan, Région Languedoc-Roussillon.	1:20 000	Ifremer, Université de Perpignan, Région Languedoc-Roussillon
Substrate	Sediments/geology	Cartographie des plates-formes sous-marines de la Corse entre 0 et 100m de profondeur - LIMA 1	2001 and 2004	GUENNOC P., PALVADEAU E., PLUQUET F., MORANDO A., VAIRON J. (2001) - LIMA, Cartographie des plates-formes sous-marines de la Corse entre 0 et 100m de profondeur, BRGM/RP-51523-FR, 53 p., 16 fig., 6 tabl., 4 pl., 9 cartes (hors texte). et PLUQUET F., GUENNOC P., GARLAN T., PALVADEAU E., (2004) - La plate-forme sous-marine de Corse : cartographie « historique » des formations superficielles à partir des levés anciens du SHOM (1884-1891), Bull. Soc. Sci. hist. nat. Corse, 606-607, 111-132.	1: 100 000	BRGM, OEC, DIREN Corse, Agence de l'Eau Rhône Méditerranée & Corse, Ifremer, SHOM
Substrate	Sediments/geology	Carte géomorphologique du précontinent languedocien	1973 and 1986	GOT H., 1973, « Etude des corrélations tectonique-sédimentation au cours de l'histoire quaternaire du précontinent pyrénéo-catalan ». Thèse d'Etat de l'Université de Montpellier, 295 p. ALOISI J.C. 1986, Sur un modèle de sédimentation deltaïque. Contribution a la connaissance des marges passives ». Thèse d'Etat de l'Universite de Perpignan, 178 p. et Annexes.	1:250 000	Université de Perpignan

Substrate	Sediments/geology	Cartes G	2009	6822G - Abords Nord de Bastia - Pluquet F., Guennoc P. ; 6822G - Abords Nord de Bastia - Pluquet F., Guennoc P. ; 6969G - Du Cap Corse à la Punta di d'Acciolu, Golfe de Saint-Florent - Pluquet F., Guennoc P. ; 6970G - De Punta di d'Acciolu à Capo Cavallo - Pluquet F., Guennoc P.	1:50 000	SHOM
Substrate	Sediments/geology	Cartes géologiques de la France à 1/50 000	1975 to 1994	Cartes géologiques de la France à 1/50 000 : Feuille 1017 - LE GRAU DU ROI - 1993 ; Feuille 1018 - SAINTES MARIES DE LA MER - 1975 ; Feuille 1019 - ISTRES - 1975 ; Feuille 1020 - MARTIGUES MARSEILLE - 1977 ; Feuille 1024 - FREJUS CANNES - 1994 ; Feuille 1040 - AGDE - 1978 ; Feuille 1044 - AUBAGNE MARSEILLE ; Feuille 1047 - SAINT TROPEZ CAP LARDIER ; Feuille 1061 - NARBONNE - 1982 ; Feuille 1063 - LA CIOTAT - 1977 ; Feuille 1065 - HYERES PORQUEROLLES - 1976 ; Feuille 1079 - LEUCATE - 1982 ; Feuille 1091 - PERPIGNAN - 1988 ; Feuille 973 - MENTON NICE	1:50 000	BRGM
Substrate	Sediments/geology	Cartes géologiques de la France à 1/250 000	1979 and 2001	Cartes géologiques de la France à 1/250 000 : Feuille 38 - MONTPELLIER - 2001 ; Feuille 39 - MARSEILLE - 1979 ; Feuille 40 - NICE - 1979	1:250 000	BRGM
Substrate	Posodonia and Cymodocea	Étude des sédiments superficiels marins, des herbiers à phanérogames et des peuplements à Caulerpa taxifolia de Menton au Cap d'Ail	2001	BELSHER, T., HOULGATTE, E., 2000. Étude des sédiments superficiels marins, des herbiers à phanérogames et des peuplements à Caulerpa taxifolia de Menton au Cap d'Ail. Éditions Ifremer 43 p. et 3 cartes	1:7 500	Ifremer, Bureau d'Etude Géologique - Brest
Substrate	Posodonia and Cymodocea	Cartographie des biocénoses marines entre Antibes et Cap d'Ail	2007	HOLON F., DESCAMP P., 2007. CARTOGRAPHIE ET ANALYSE DES BIOCENOSES MARINES ENTRE ANTIBES ET	1:5 000	Communauté d'Agglomération Nice Côte d'Azur, Conseil Général

				CAP D'AIL. Contrat Communauté d'Agglomération Nice-Côte d'Azur.		des Alpes-Maritimes, Région PACA, Agence de l'Eau Rhône Méditerranée & Corse, Andromède Environnement
Substrate	Posodonia and Cymodocea	Cartographie des biocénoses marines - Contrat de Baie des Golfes de Lérins	2008	HOLON F., DESCAMP P., 2008. ETUDE DE L'ÉCOLOGIE MARINE - ETUDE COMPLÉMENTAIRE AU CONTRAT DE BAIE DES GOLFES DE LÉRINS. Contrat ANDROMEDE / Ville de Cannes	1:10 000	Ville de Cannes, Conseil Général des Alpes-Maritimes, Région PACA, Agence de l'Eau Rhône Méditerranée & Corse, Andromède Océanologie
Substrate	Posodonia and Cymodocea	Cartographie des biocénoses marines du littoral des Maures	2004	Création de l'Observatoire Marin du littoral des Maures. Contrat SIVOM du Littoral des Maures, 1997, CETIIS, 174p; Etude préalable à la mise en place de l'Observatoire marin du littoral des Maures le long des côtes de Ramatuelle - Etat de la connaissance du milieu, synthèse bibliographique, 2004, SIVOM du Littoral des Maures, Agence de l'Eau RM&C, SAFEGE CETIIS.	1:80 000	SIVOM du Littoral des Maures, Agence de l'Eau Rhône Méditerranée & Corse, SAFEGE CETIIS
Substrate	Posodonia and Cymodocea	Carte des biocénoses benthiques ou types de fond de la zone Natura 2000 de l'île du Levant (Hyères - Var)	2007	RUITTON S., BONHOMME D., BONHOMME P., CADIOU G., EMERY E., HARMELIN J.G., HERVE G., KANTIN R., 2007, Etude et cartographie des biocénoses du milieu marin de l'île du Levant (Var - France). Phase 3 - Rapport final, Contrat Parc national de Port-Cros & GIS Posidonie - Ifremer, GIS Posidonie Publ. : 1 - 163	1:5 000	Parc national de Port-Cros, DIREN PACA, GIS Posidonie, Ifremer
Substrate	Posodonia and Cymodocea	Cartographie de la prairie à Posidonia oceanica et des principaux faciès sédimentaires marins du Parc national de Port-Cros (Var - France -	2001	Carte de l'Herbier à Posidonia oceanica et des principaux faciès sédimentaires des fonds sous-marins du Parc National de Port-Cros, 2001, Parc National de Port-Cros, DIREN PACA, Ifremer, Bureau d'étude Géologique (Brest).	1:7 500	Parc national Port-Cros, DIREN PACA, Ifremer, Bureau d'étude géologique (Brest), Centre d'océanologie de Marseille

		Méditerranée)				
Substrate	Posidonia and Cymodocea	Carte des biocénoses benthiques ou type de fond de la zone Natura 2000 de l'île de Porquerolles (Hyères - Var)	2007	RUITTON S., BONHOMME D., BONHOMME P., CADIOU G., EMERY E., HARMELIN J.G., HERVE G., KANTIN R., ZIBROWIUS H., 2007. Etude et cartographie des biocénoses du milieu marin de l'île de Porquerolles (Var - France). Phase 3 - Rapport final, Contrat Parc national de Port-Cros & GIS Posidonie - Ifremer, GIS Posidonie Publ. : 1 - 153.	1:5 000	Parc national de Port-Cros, DIREN PACA, GIS Posidonie, Ifremer
Substrate	Posidonia and Cymodocea	Cartographie de l'herbier de Posidonie et des fonds marins environnants de Toulon à Hyères (Var, France)	1993	PAILLARD M., GRAVEZ V., CLABAUT P., WALKER P., BLANC J.J., BOUDOURESQUES C.F., BELSHER T., URSCHELER F., POYDENOT F., SINNASSAMY J.M., AUGRIS C., PEYRONNET J.P., KESSLER M., AUGUSTIN J.M., LE DREZEN E., PRUDHOMME C., RAILLARD J.M., PERGENT G., HOAREAU A. & CHARBONNEL E., 1993. - Cartographie de l'herbier de Posidonie et des fonds marins environnants de Toulon à Hyères (Var - France). Reconnaissance par sonar latéral et photographie aérienne. Notice de présentation. Ifremer & GIS Posidonie Publ., Fr. :1-36 + 3 cartes annexes.	1:10 000	Région PACA, Agence de l'Eau Rhône Méditerranée & Corse, Ifremer, GIS Posidonie

Version 1

Substrate	Posodonia and Cymodocea	Cartographie des biocénoses marines de la rade de Toulon	2001	BERNARD G., DENIS J., DENEUX F., BELSHER T., SAUZADE D., BOUDOURESQUE C.F., CHARBONNEL E., EMERY E., HERVE G., BONHOMME P., 2001. Etude et cartographie des biocénoses de la rade de Toulon - Rapport de synthèse final. Contrat d'étude pour le Syndicat Intercommunal de l'Aire Toulonnaise, IFREMER et GIS Posidonie. IFREMER publ., La Seyne, fr. : 1-150.	1:10 000	Toulon Provence Métropole, Région PACA, DIREN PACA, Conseil Général du Var, Agence de l'Eau Rhône Méditerranée & Corse, GIS Posidonie, Ifremer
Substrate	Posodonia and Cymodocea	Les Biocénoses Benthiques de la Baie de La Ciotat	2003	Etude du patrimoine marin environnant les domaines départementaux de l'île verte et du Muges - phase 1 (Etat de la connaissance), 2003, Conseil général des Bouches du Rhône, GIS Posidonie, Ifremer, Philippe Clabaut Consultant	1:30 000	Conseil général des Bouches du Rhône, Ifremer, GIS Posidonie, Philippe Clabaut Consultant
Substrate	Posodonia and Cymodocea	Cartographie des habitats marins - Plan de gestion de la rade de Marseille	2007	Cartographie des habitats marins - Plan de gestion de la rade de Marseille, 2007, Ville de Marseille, Agence de l'Eau RM&C, DIREN PACA, Conseil Régional PACA, Conseil Général des Bouches du Rhône, Marseille Provence Métropole, BCEOM	1:5 000	Ville de Marseille, Agence de l'Eau Rhône Méditerranée & Corse, DIREN PACA, Conseil Régional PACA, Conseil Général des Bouches du Rhône, Marseille Provence Métropole, BCEOM
Substrate	Posodonia and Cymodocea	Cartographie des biocénoses marines de la Côte Bleue - L'Herbier à Posidonia océanica	2003	Cartographie des biocénoses marines de la Côte Bleue - Volet n°1 : L'Herbier à Posidonia océanica, Février 2003, Agence de l'eau RMC, Région PACA, DIREN PACA, Gis Posidonie, Ifremer, Centre d'Océanologie de Marseille, Parc Marin de la Côte Bleue	1:25 000	Agence de l'Eau Rhône Méditerranée & Corse, Région PACA, DIREN PACA, Gis Posidonie, Ifremer, Centre d'Océanologie de Marseille, Parc Marin de la Côte Bleue

Substrate	Posodonia and Cymodocea	Fonds et recouvrement sédimentaire du golfe de Fos	1975	BLANC J.-J., ROUX M., VERNIER E. Fonds et recouvrement sédimentaire du golfe de Fos et ses annexes, 1975, Centre national pour l'exploitation des océans, Centre d'Océanologie de Marseille, Laboratoire de géologie marine et sédimentologie appliquée, .	1:25 000	Centre d'Océanologie de Marseille, CNEXO
Substrate	Posodonia and Cymodocea	Etude et cartographie du milieu marin du site Natura 2000 « Posidonies de la Côte Palavasienne »	2008	HOLON F., DESCAMP P., 2008. ETUDE ET CARTOGRAPHIE DU MILIEU MARIN DU SITE NATURA 2000 « POSIDONIES DE LA COTE PALAVASIENNE », ANDROMEDE ENVIRONNEMENT 2008. Rapport final. Contrat DIREN & Andromede Environnement. Andromede publ., Fr. : 1-104 + annexes.	1:2 000	DIREN Languedoc-Roussillon, Andromede Environnement
Substrate	Posodonia and Cymodocea	Localisation des habitats naturels présents dans l'enveloppe de référence du site Natura 2000 « Posidonies du Cap d'Agde » - Atlas	2008	DUPUY DE LA GRANDRIVE R., FOULQUIE M., BLOUET S., Janvier 2008. Document d'objectifs du site Natura 2000 « Posidonies du Cap d'Agde ». Atlas. ADENA, 20 cartes, 24 p.	1:25 000	ADENA, DIREN Languedoc-Roussillon, Agence de l'Eau Rhône Méditerranée & Corse, Conseil Régional du Languedoc-Roussillon, Université de Nice, CNRS-EPHE Université de Perpignan, GIS Posidonie, Ville d'Agde
Substrate	Posodonia and Cymodocea	Carte des habitats du site Natura 2000 « Posidonies de la Côte des Albères » Phase I : Inventaire et analyse de l'existant	2004	LICARI M.L., LENFANT P., AMOUROUX J.M., DUPUY DE LA GRANDRIVE R., LABRUNE C., FOULQUIE M., ROCHEL E., BONHOMME P., CADIOU G., 2004. Document d'objectifs site Natura 2000 « Posidonies de la Côte des Albères » Phase I : Inventaire et analyse de l'existant, volume 3 : cartes, 60p.	1:25 000	Réserve Naturelle Marine de Cerbère-Banyuls, GIS Posidonie, Ecole Pratique des Hautes Etudes, Observatoire océanologique de Banyuls, ADENA, Conseil Général des Pyrénées-Orientales, DIREN Languedoc-Roussillon

Version 1

Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : de Saint Florent à Bastia, de Bastia à Campoloro, de Campoloro à Solenzara, de Solenzara à Porto-Vecchio, de Porto-Vecchio à Senetosa, de Senetosa aux îles Sanguinaires, des îles Sanguinaires à Capu Rossu, de Capu Rossu à la pointe de La Revellata et de la pointe de La Revellata à Saint Florent.	1997	PASQUALINI V., 1997. Caractérisation des peuplements et types de fonds le long du littoral corse (Méditerranée, France). Thèse Doct. « Ecologie marine », Univ. Corse : 1 - 165	1:20 000	Equipe Ecosystèmes Littoraux - Université de Corse
Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : baie de Tizzano	1997	FERNANDEZ C., PERGENT-MARTINI C., PASQUALINI V., 1997. Etude de faisabilité d'un mouillage organisé dans la baie de Tizzano - Approche environnementale. Contrat Mairie de Sartène/GIS Posidonie N°9702, GIS Posidonie - Centre de Corse édit., Corte	1:20 000	Mairie de Sartène, GIS Posidonie, Université de Corse
Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : lagune de Biguglia, lagune de Diana, lagune d'Urbinu,	1999 and 2000	PERGENT-MARTINI C., FERNANDEZ C., PASQUALINI V., PERGENT G., SEGUI C., TOMASZEWSKI J.E., 2000. Les étangs littoraux de Corse : Cartographie des peuplements et types de fonds. Contrat Equipe Ecosystèmes Littoraux - Université de Corse & IFREMER, N° 99 3 514004 : 1-33	1:10 000	Equipe Ecosystèmes Littoraux - Université de Corse, IFREMER
Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : région de Pianottoli-Caldarello : îles Bruzzi, région de Porto-Vecchio : îles Cerbicale, île Lavezzu,	2001	VELA A., PERGENT-MARTINI C., PASQUALINI V., LEONI V., PERGENT G., 2001. Parc Marin International des Bouches de Bonifacio, Etat de référence des herbiers à Posidonia oceanica, Contrat GIS Posidonie & O.E.C. : 1-35	1:12 000	Office de l'Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse

Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : Est de la lagune de Biguglia, Nord du port de Campoloro, Nord de l'embouchure du Fium'Orbu, marine de Sisco, Est du port de Solenzara,	2004	PERGENT G., ABIVEN T., HAUDEN S., MIMAUULT B., PASQUALINI V., PATRONE J., PERGENT-MARTINI C., 2004. Mise en oeuvre d'un Réseau de Surveillance Posidonies le long du littoral de la Corse. Première phase : Cap Corse / Porto-Vecchio. Contrat Office de l'Environnement de la Corse et GIS Posidonie Centre de Corse, GIS Posidonie Publ., Corte : 1-108	1:5 000	Office de l'Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse
Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : falaises de Bonifacio, îles Moines	2004	PETRAGALLO S., MIMAUULT B., PASQUALINI V., PERGENT-MARTINI C., PERGENT G., 2004. Etat de référence des principaux peuplements et types de fonds du Parc Marin International des Bouches de Bonifacio. Convention de recherche Seagrass 2000 & O.E.C., Seagrass 2000 édit., Corte : 1-54 + annexes	1:10 000	Equipe Ecosystèmes Littoraux - Université de Corse, Office de l'Environnement de la Corse
Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : baie de Campomoro, Est de l'étang d'Arje, Porticcio, golfe de Roccapina, anse de Sciumara,	2005	PERGENT G., CLABAUT P., MIMAUULT B., PASQUALINI V., PERGENT-MARTINI C., 2005. Mise en oeuvre d'un Réseau de Surveillance Posidonies le long du littoral de la Corse. Deuxième phase : Porto-Vecchio / Ajaccio. Contrat Office de l'Environnement de la Corse et GIS Posidonie Centre de Corse, GIS Posidonie Publ., Corte : 1-133	1:5 000	Office de l'Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse
Substrate	Posodonia and Cymodocea	Cartes des herbiers à Posidonies en Corse : Les Agriates, baie de Calvi, Sud du port de Centuri, baie de Girolata, golfe de Saint Florent	2006 and 2008	PERGENT G., LEONARDINI R., MIMAUULT B., 2008. Mise en oeuvre d'un Réseau de Surveillance Posidonies le long du littoral de la Corse – Troisième phase : Ajaccio / Cap Corse. Contrat Office de l'Environnement de la Corse et GIS Posidonie Centre de Corse, GIS Posidonie Publ., Corte : 1 – 141	1:5 000	Office de l'Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse

Version 1

Energy	Wave energy at seabed	WaveWatch III model	june 2007 to april 2009	Previmer/SHOM and Ifremer	0.1° x 0.1° NetCDF	Previmer/SHOM and Ifremer
Energy	Tidal energy at seabed	MFS model	june 2007 to april 2009	INGV	0.625° x 0.625° NetCDF	INGV
Energy	Tidal energy at seabed	Previmer model	june 2007 to april 2009	Previmer/Ifremer	0.014° x 0.01° NetCDF	Previmer/Ifremer
Energy	Tidal and wave energy at seabed	Ifremer model	june 2007 to april 2009	Previmer/Ifremer	0.625° x 0.625° NetCDF	Previmer/Ifremer
Energy	Tidal and wave energy at seabed	Ifremer model	june 2007 to april 2009	Previmer/Ifremer	0.014° x 0.01° NetCDF	Previmer/Ifremer