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EUSeaMap

Final Report

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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 built upon the highly successful INTERREG MESH[1] and BALANCE[2] projects, by harmonising and improving methods used to produce the MESH EUNIS[3] 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 were improved upon and refined, and their coverage seamlessly extended in the specified Marine Regions.

This Final Report of EUSeaMap summarises the work of the project. 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 projects[4]. 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 end-users can explore and access the final seabed habitat maps, environmental variables and confidence maps will be available.

In the final phase of the project a series of assessments to demonstrate the applications of the maps were 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 has also been provided.

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[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] European Nature Information System classification (http://eunis.eea.europa.eu/habitats.jsp)

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

List of Acronyms

DEM/DTM - Digital Elevation Model/Digital Terrain Model

EEZ - Exclusive Economic Zone

EMODnet - European Marine Observation Data Network

EUNIS - European Nature Information System

GEBCO – General Bathymetric Chart of the Oceans

GES - Good Environmental Status

HELCOM - Helsinki Convention/Commission (Baltic marine environment protection)

IBCM – International Bathymetric Chart of the Mediterranean

MESH - Mapping European Seabed Habitats project

MSFD - Marine Strategy Framework Directive

OSPAR – Oslo-Paris Convention/Commission (North-east Atlantic marine environment protection)

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Note on figures: All maps are displayed in the ETRS89 LAEA projection, unless otherwise stated. Maps are orientated with north uppermost unless otherwise stated. Coastlien used in data processing for maps: Global Self-consistent Hierarchical High-resolution Shorelines version 2.0 July 15, 2009, distributed under the Gnu Public License. Coastline used for presentation of maps: World Vector Shoreline © US Defence Mapping Agency. Not to be used for navigation purposes.

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. CORINE[5] (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.

[5] 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 Palaearctic[6] 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*

[6] 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 HabMap[7] 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

[7] http://habmap.org

abiotic variables. Further analysis of these thresholds is often necessary to verify their appropriate 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).

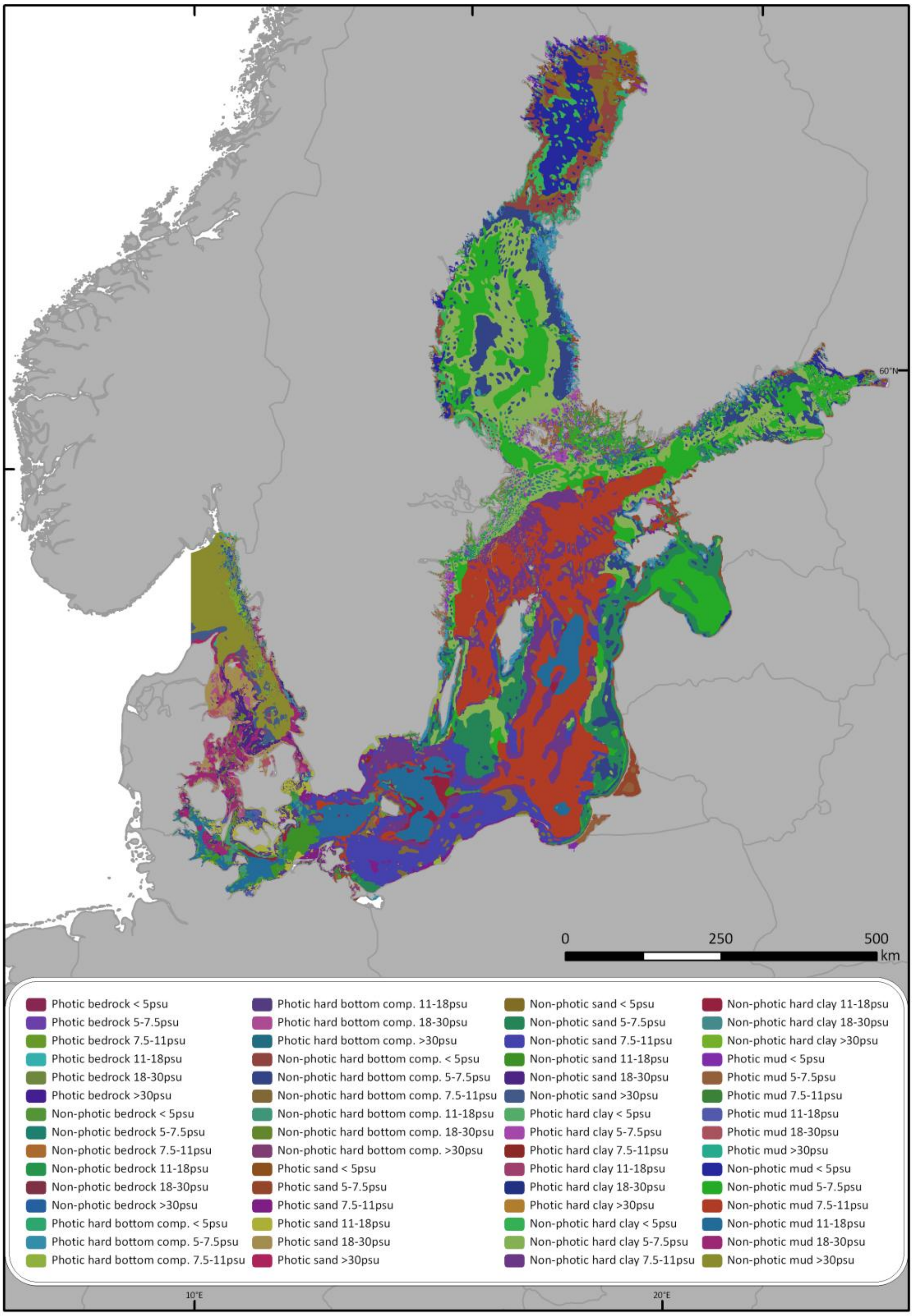

Figure 1 BALANCE seabed habitat map (Al-Hamdani & Reker 2007).

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.

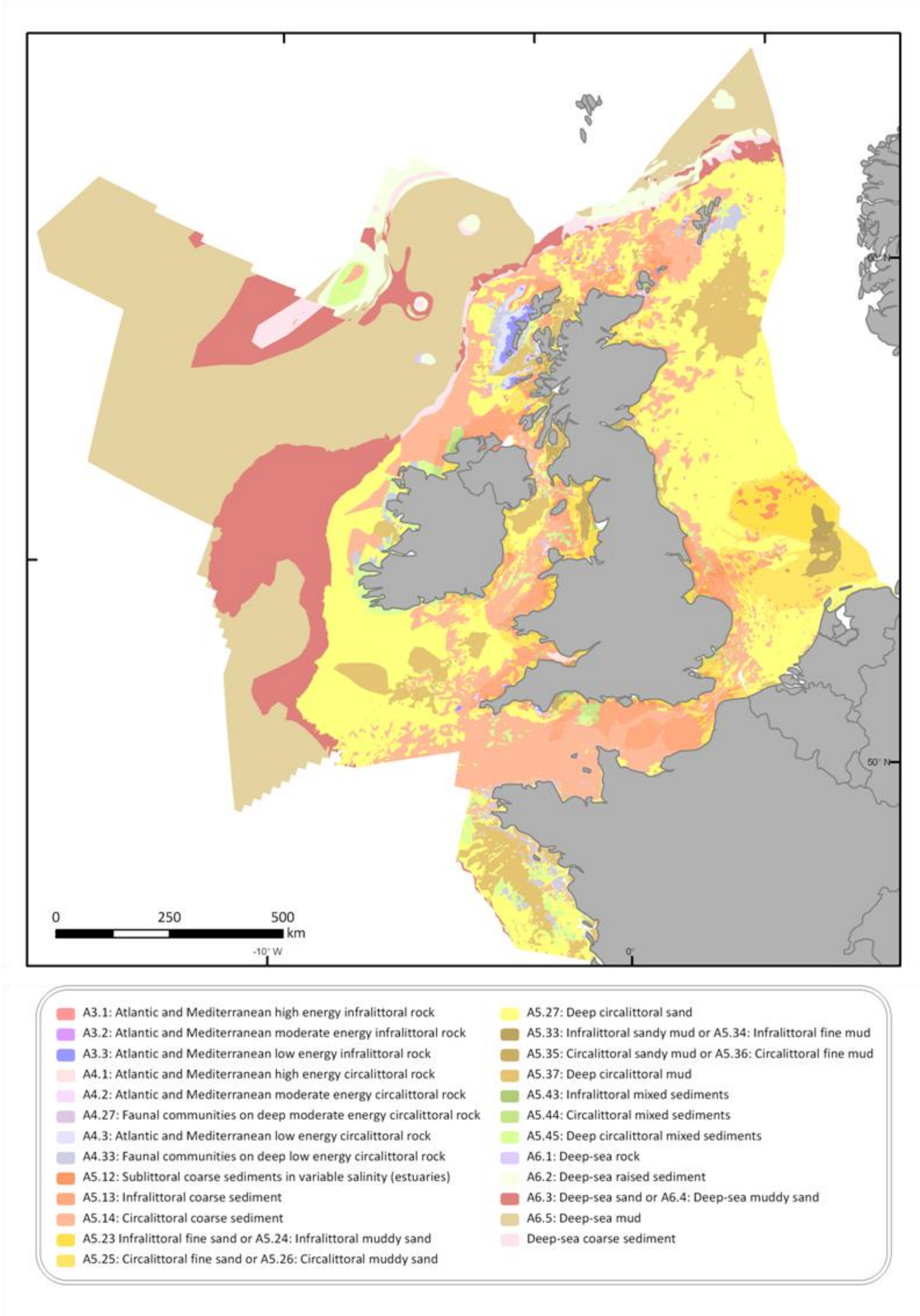

Figure 2 MESH predicted seabed habitat map. The map is a combination of EUNIS Level 3 and 4 habitats, showing the most detailed class available in each location (Coltman *et al*, 2008).

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 CHARM[8] and HERMES[9] 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 programme[10] 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.

[8] www.ifremer.fr/charm

[9] www.eu-hermes.net

[10] http://data.nbn.org.uk/hosted/ospar/ospar_text.html

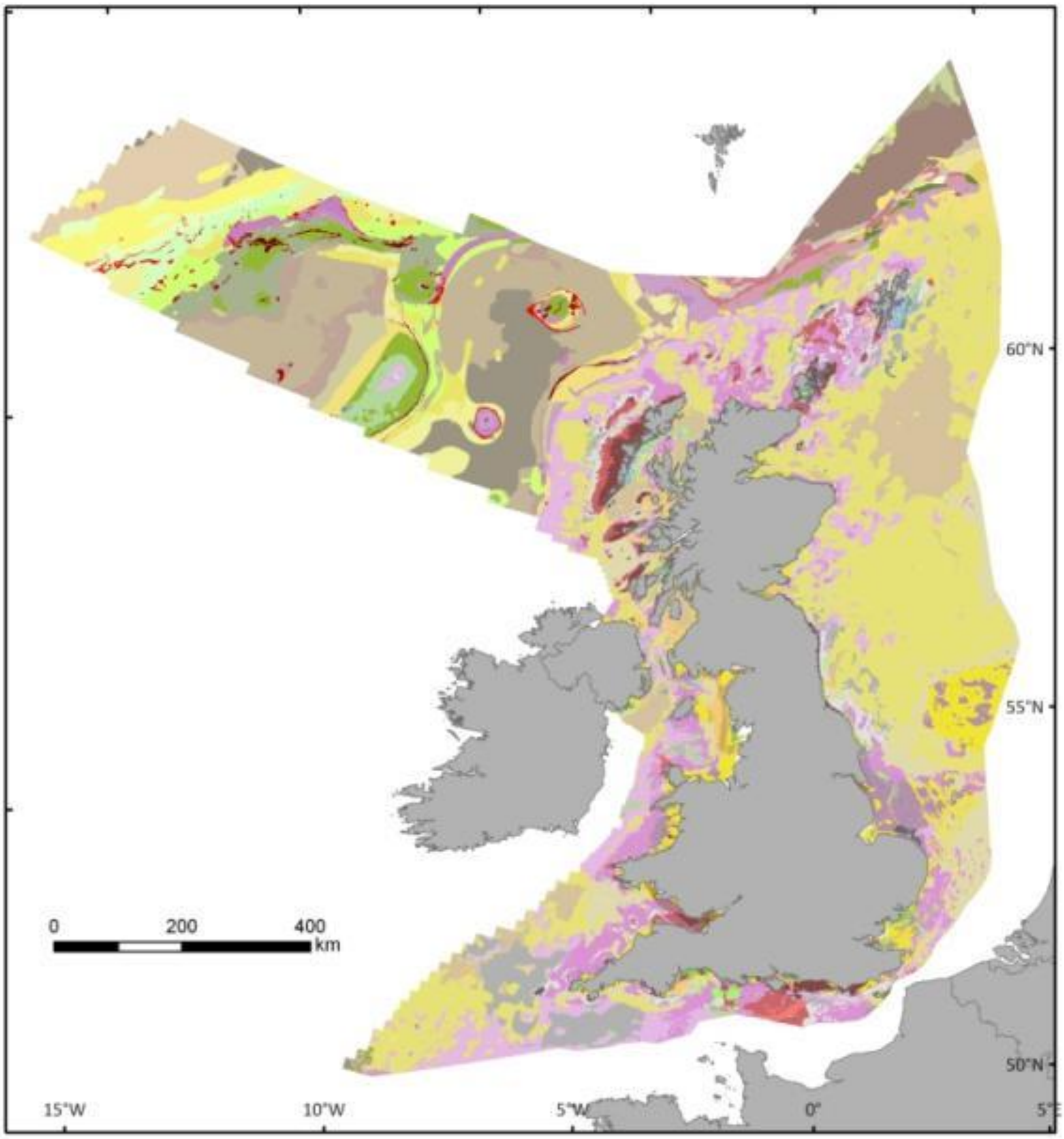

Figure 3 UKSeaMap 2010 predictive seabed habitat map (most detailed classes).

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: • 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	• 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 • 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	• Collated, harmonized and provided access to large amount of data at international level	• 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	• Standard and comparable predicted habitat units • Collated, harmonized and provided access to large amount of data at international level	Variable resolution offshore
Limitations	• No standard classification scheme • Thresholds largely based on expert judgement rather than derived from biological data	• No standard classification scheme • Requires large amount of biological community data	• No standard classification scheme • Coarse resolution	• Thresholds largely based on expert judgement rather than derived from biological data	• 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 Shelf[11] 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 FINMARINET[12]. 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 new areas. Testing these predicted seabed habitats with ground-truthing is planned in future cruises.

[11] www.emepc.pt

[12] Inventories and planning for the marine Natura 2000 network in Finland

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 CARG[13] (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 over large areas at high intensity is not cost-effective for producing habitat maps. This is because it is possible to distinguish many habitat types at broad scales by manipulation of data on the abiotic factors which determine these habitat types, at much lower costs than the collection of biological sampling data would require. However, where it is necessary to identify and map communities which develop at fine-scales, biological sampling will be required. Broad scale mapping efforts provide important tools to maximise efficiency by pinpointing areas where sampling for 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 that the approach to the mapping of seabed habitats under the EUSeaMap project is appropriate, especially because of common classification and data availability.

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[13] http://www.apat.gov.it/site/it-IT/Progetti/Progetto_CARG_-_Cartografia_geologica_e_geotematica

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 oceanica*) 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 of plants such as kelp and seagrass. The lower limit of the infralittoral zone is set to the depth limit of kelp in the Atlantic and to the depth limit of *Posidonia oceanica* and photophilic algae[14] in the Mediterranean. A value close to 1% of the surface light has been acknowledged by various authors as the boundary value for both these habitats. In the Baltic Sea, we suggest that a comparable level is the depth limit of macroalgal-dominated communities.

Light attenuation can also be used to define the upper circalittoral zone where the light reaching the bottom is estimated to range between 1% - 0.01% of the surface light thereby allowing the photosynthesis of sciaphilic[15] algae such as the Fucales (deep water Cystoseira and Sargassum spp.), Laminariales, Desmarestiales and Sporochnales as well as red algal (Rhodophycean) species. In the Mediterranean some characteristic communities such as coralligenous assemblages consisting of more or less massive bioconstructions formed by coralline algae, as well as Rhodolith (Maerl beds) thrive in this zone. Conversely, the lower circalittoral 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.

3.1.2 Other factors defining depth zones

Instead of light attenuation, the wave base can be used to define the limit between the upper and deep circalittoral zones, thus defining the deep circalittoral as the zone unaffected by waves. In the Baltic Sea, we suggest that the deep circalittoral is defined by the depth of the deep halocline (40-80 m depth). The choice of a different factor to define the deep circalittoral of the Baltic Sea is motivated by the special conditions in this basin, with a strong stratification driven by salinity. Areas below the halocline have a comparably constant temperature and salinity, more frequent anoxic or hypoxic conditions and is characterised by unique zoobenthic communities.

Bathyal and Abyssal zones

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.

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[14] Receptive to, or thriving in light conditions

[15] Receptive to, or thriving in low light conditions

Table 3 Limits of subtidal zones for EUSeaMap regions.

Biological zone	North & Celtic Seas[16]		Baltic Sea		W Mediterranean Sea	
	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit
Infralittoral	Lowest Astronomical Tide	Intersection of seabed and 1% surface light depth	Annual maximum low water[17]	2.5 ratio of depth/Secchi depth for mesohaline zones 1.6 ratio of depth/Secchi depth for oligohaline zones	Lowest Astronomical Tide	Intersection of seabed and 1% surface light depth
Upper Circalittoral	Intersection of seabed and 1% surface light depth	Maximum depth at which seabed is affected by waves	2.5 ratio of depth/Secchi depth for mesohaline zones 1.6 ratio of depth/Secchi depth for oligohaline zones	Position of deep halocline	Intersection of seabed and 1% surface light depth	Intersection of seabed and average 0.01% incident light fraction
Deep Circalittoral	Maximum depth at which seabed is affected by waves	Shelf edge delimited by the slope angle change of the continental platform, or proxy (200m)	Position of deep halocline	n/a (seabed)	Intersection of seabed and average 0.01% incident light fraction	Shelf edge delimited by the slope angle change of the continental platform, or proxy
Upper slope	Shelf edge delimited by the slope angle	Top of the permanent thermocline, or proxy	n/a	n/a	n/a	n/a

[16] Including the Skagerrak and Kattegat

[17] The limit is different compared to the other seas considered due to the lack of regular tides in the Baltic Sea. Since water level flutctuations are typically on a timescale of days rather than hours, the annual maximum low water sets the limit for perennial species without strong draught resistance and is used to delimit the "subtidal", permanently submerged sea floor. This follows the convention from Baltic Sea scientists (and the HELCOM habitats).

	change of the continental platform, or proxy (200m)	(750m)				
Bathyal	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)			Shelf edge delimited by the slope angle change of the continental platform, or proxy	Shelf slope break delimited by the slope angle change occurring at the base of the continental margin
Abyssal	Shelf slope break delimited by the slope angle change of the continental platform, or proxy (2,700m for Atlantic)	n/a (seabed)	n/a	n/a	Shelf slope break delimited by the slope angle change occurring at the base of the continental margin	n/a (seabed)

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 macrotidal[18] 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.

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

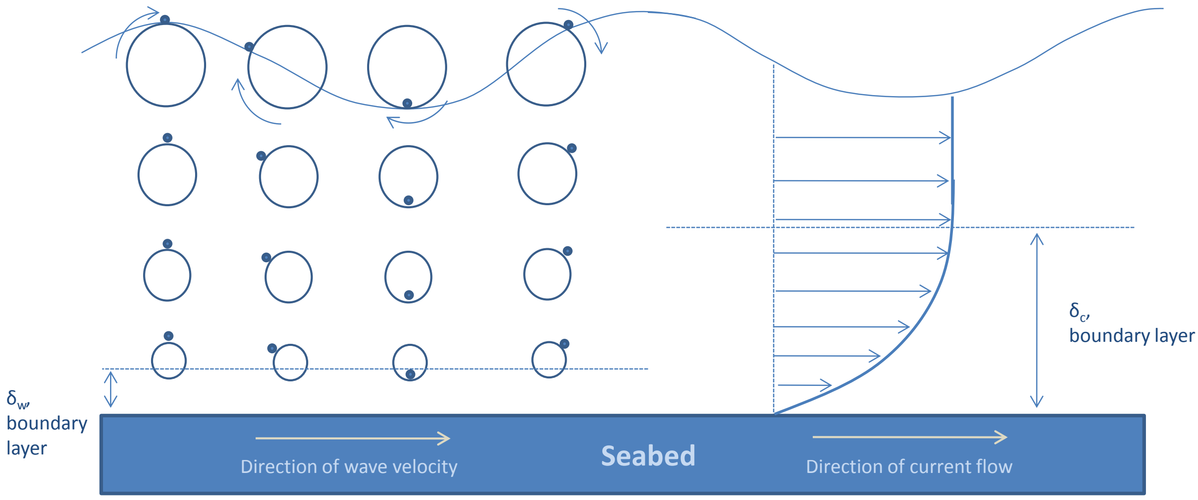


Figure 4 Overview of energy effects from water movement over the seabed due to waves (l) and currents (r) (adapted from Souslby, 1997).

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 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 (fucoids). 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 and stratification of water masses. 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 and a strong stratification due to the vertical gradient in salinity (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 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]) provides a proxy (which also relates to salinity regimes). Temperature variation in EUNIS is also considered 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 (2010) 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 several environmental variables.

3.7. Other abiotic variables

There are many other abiotic variables that affect community type. For example, 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. In addition, fixed categories have historically been applied by convention when presenting ice cover in the Baltic Sea (e.g. used by the BALANCE project based on data from Metria/Sweden and Leppäranta *et al.*, 1988) and it is difficult to obtain sufficient raw data for new analysis. For these reasons ice cover was notconsidered further for the EUSeaMap models.

The majority of other abiotic variables 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 ecoregions[19] 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.

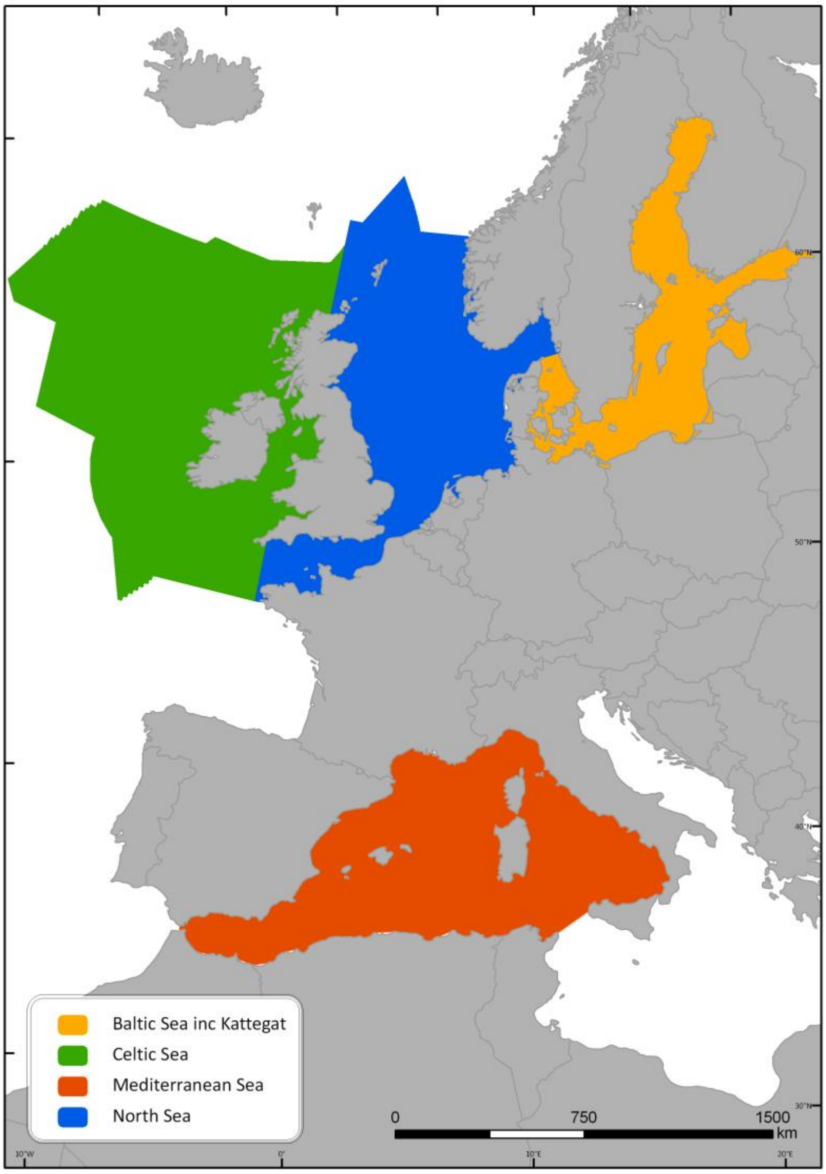


Figure 5 Geographic extent of the EUSeaMap project. In order to be compatible with future applications within the Marine Strategy Framework Directive, regional basins were defined by ICES ecoregions with additional areas where EEZs extend beyond these.

[19] http://www.ices.dk/aboutus/icesareas.asp

4.1. Application of EUNIS

As the only system to classify European seabed habitats consistently across a number of European sea basins, 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 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 eight broad 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 genuine 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.

Since the first levels of the EUNIS habitat classification scheme are defined on the basis of abiotic variables (level 2 and 3 depth zone and generic substrate categories; level 4 finer detail substrate type, biological zone, energy and salinity etc.) one would expect that most modeled habitats would consist in level 3 habitat types. However, in several cases modeled habitat types can consist of level 4 and in some exceptional situations, level 5.

In the Mediterranean Sea, the circalittoral rock modeled habitats lie at a level 4 classification because these assemblages (i.e. coralligenous bottoms and shelf edge rock) have a EUNIS position within a broader level 3 category which defines moderate energy rocky assemblages. This is because rocky assemblages of the Mediterranean circalittoral are mostly exposed to moderate energy conditions as opposed to the diversity of energy conditions that are observed in other circalittoral European seas. Therefore the modeling output of these specific level 4 modeled habitats is not the result of an actual energy layer used in the modeling process of the map, but rather to the intrinsic nature of where these 2 Mediterranean assemblages are located in EUNIS. On the other hand, most of the soft bottom habitats of the infralittoral and circalittoral present in the map consist of level 4 habitats. This is due to the fact that in EUNIS all sublittoral sediment habitats are grouped into a category (A5) and then introduces the next level differentiation (3rd level) in terms of substrate type (see Figure 6). It is only at the subsequent level 4 that habitats are differentiated according to biological zone. In the EUSeaMap the biological zone is a strong determining variable which distinguishes between the modeled habitats which therefore contributes to distinct level 4 habitat types.

In the North and Celtic seas, circalittoral rock habitats are divided into 2 categories of level 3 habitats based on energy levels (high and low) and subsequently into level 4 habitats based on upper and lower circalittoral zones. The differentiation between upper and lower circalittoral rock in the North and Celtic Seas and the application of an energy layer therefore allows modelling rocky assemblages of the upper and lower circalittoral zone exposed to different levels of energy, all of which are represented according to level 4 codes.

4.2. Modelling

This project has developed 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, across all basins, are seabed substrate and biological zones (also referred to as depth zones). Energy conditions at the seabed will be used in the Atlantic and Baltic models, with Salinity an additional layer in the Baltic. 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 though 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 (e.g. 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.

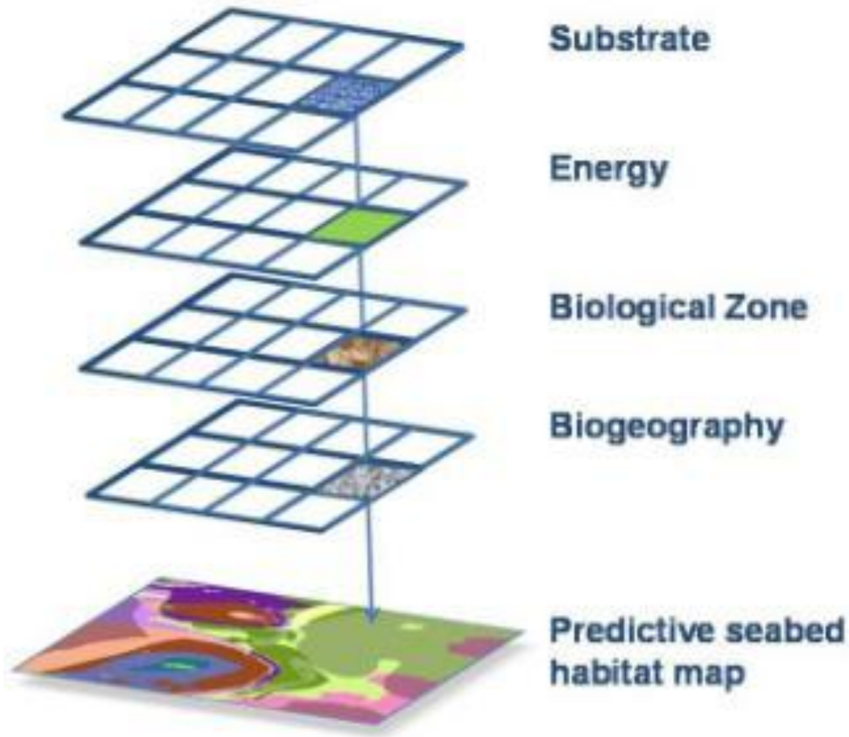


Figure 7 Illustration of raster based multicriteria evaluation.

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
Circalittoral	A4.1	A4.2	A4.3	A5.14	A5.25 or A5.26	A5.35 or A5.36	A5.44
Deep circalittoral	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

Datasets 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 (see Section 4.4).

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 datasets 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

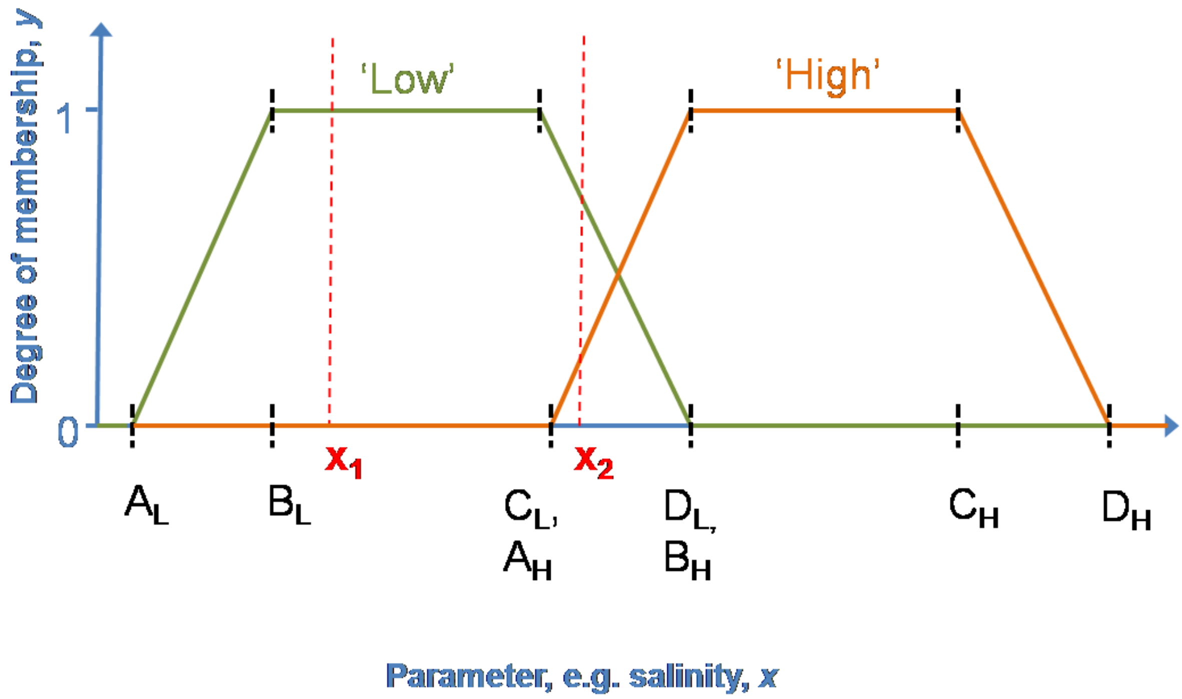
Crucial to the EUSeaMap seabed habitat modelling process is the structure of EUNIS, which informs the application of ecologically-relevant thresholds to environmental variables. These thresholds must classify the variables in a way that can be translated to the predictive units, in this case the level 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 were examined and the thresholds used previously (in the MESH and BALANCE projects) reviewed. Since this was a potentially large task, the project focused on the thresholds for those variables considered most critical in each Region. Fine-scale biological data (community types or biocenoses) was used in selected areas where possible 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 that divide the input variables into classes, and it is these hard boundaries are reproduced exactly 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.



Point with salinity value x_1: Membership of 'Low' class = 1
Membership of 'High' class = 0

Point with salinity value x_2: Membership of 'Low' class = 0.7
Membership of 'High' class = 0.3

Figure 8 Example of fuzzy thresholds, 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 purpose[20]. 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 of data collection methods
- Supporting maps showing underlying evidence used to interpret the final map
- Evaluation of all contributing data
- Independent validation by *in situ* mapping data
- 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 contributing factors according to agreed rules. The approach received positive feedback in international fora, including from the ICES Working Group on Marine Habitat Mapping (WGMHM)[21] and OSPAR Marine Protected Areas, Species and Habitats (MASH)[22] 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 using the degree of membership from the implementation of the fuzzy classifiers in the model. At each given location (each grid cell) these scores are a measure of the confidence in the grid cells predicted habitat type based on the conditions at that location in relation to the habitat thresholds.

Further consideration of these approaches and their development in the course of the project is given in section 8.

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[20] MESH definition

[21] http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=104

[22] www.ospar.org

5. Data layers and Thresholds

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. Results are summarised in the following section, with detailed descriptions of the methods used to produce the data layers and derive associated thresholds in the Technical Appendices accompanying this report. A full list of datasets 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 Convention[23] 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 Intergovernmental Oceanographic Commission (IOC) (of UNESCO) and the International Hydrographic	Coastal Digital Elevation Model GEBCO[24]	30m 30 arcsecond

[23] http://www.unepmap.org/

[24] 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[25] 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

[25] 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 ICES, SYKE[26]	In Kattegat & Skagerrak: MERIS on ENVISAT platform In Baltic Proper: Secchi depth data	1km 200m
Substrate	EMODnet Geology partners	EMODnet Geology substrate map (version 20100830)	1:1,000,000
Salinity & halocline	DHI	MIKE3 Classic 3D Hydrodynamic	3nm

[26] Finnish Environment Institute

		Model	
Waves	Aquabiota DHI	Simplified Wave Model MIKE21 Spectral Wave Model	25m 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 of these biological zone maps, and present the maps.

5.1.1. Light attenuation

Computing light levels in the water column

In the project two methods of determining light levels in the water column were used. Ocean colour satellite imagery is an effective way of providing large coverage light attenuation data at relatively high spatial and temporal resolution. Several models are commonly used to derive Kd_{PAR} (diffuse attenuation coefficient of down-welling photosynthetically available radiation) maps from satellite imagery. For EUSeaMap, an improved Kd_{PAR} layer has been estimated from radiance measured by MERIS, the Medium Resolution Imaging Spectrometer Instrument aboard the European Envisat satellite (Saulquin *et al.,* in prep.).

Depth zones can then be determined by intersecting the depth data layer with these light attenuation values and using a pre-defined threshold. This fraction (Fr) of surface light which reaches a given depth is computed using the formula:

$$Fr = e^{-h/D_m} \quad (1)$$

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

High resolution MERIS imagery (250m pixel size) was processed from 2003 to 2008 for the area shown in Figure 9. These 250m products are particularly relevant for the steeper shores found in the Mediterranean as well as for complex rocky shores like those found in some North East Atlantic shores. Within the work for EUSeaMap, the algorithm to predict Kd_{PAR}

from the MERIS satellite data has been improved for coastal waters by statistical analysis against *in situ* data collected across the regions as described below on the various basins.

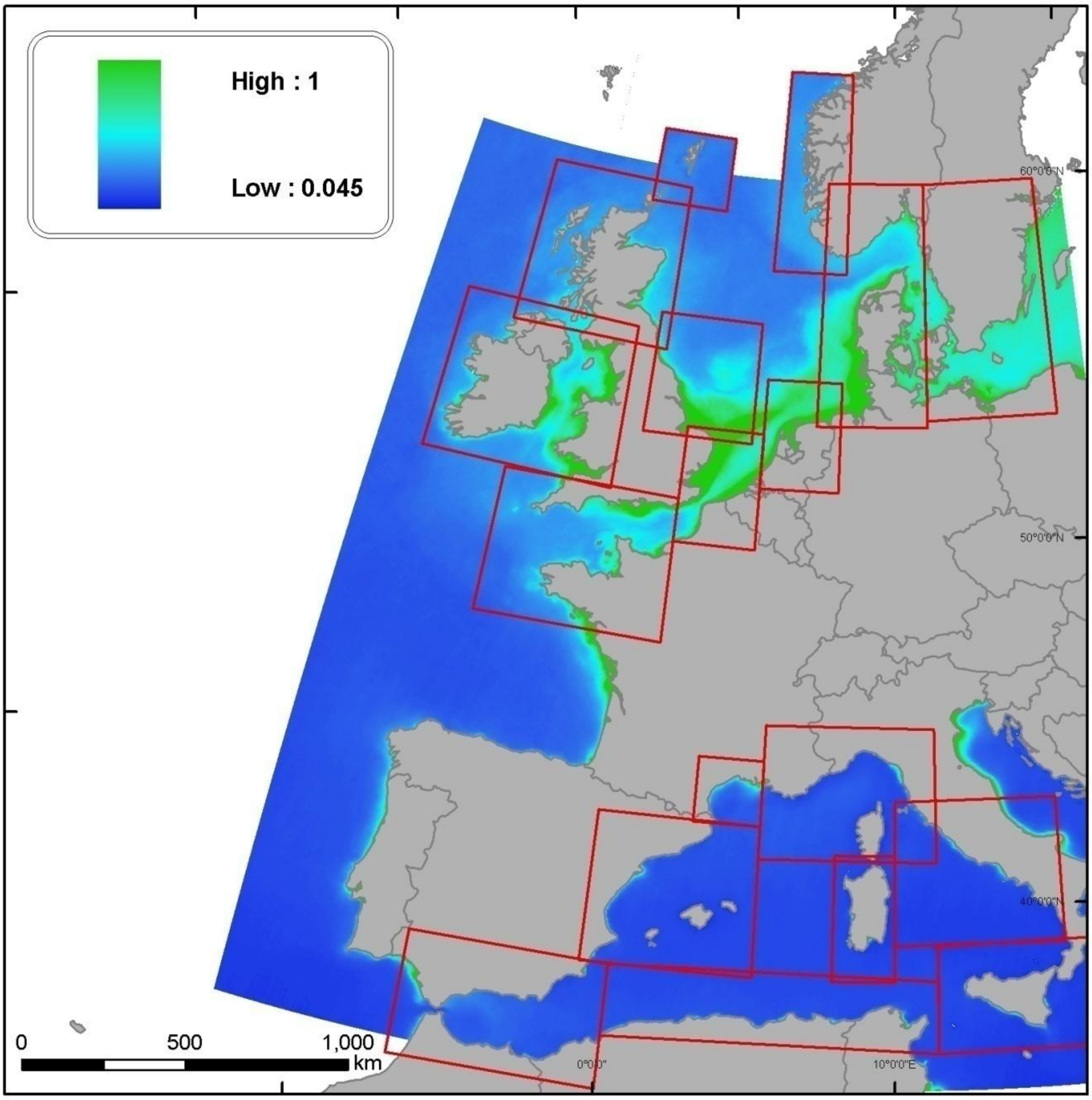

Figure 9 Overview of Kd_{PAR} as computed for the MERIS swath zone (limited by 13W, 18E, 36N, 60N). Red boxes show where high resolution (250m) was computed for the coastal areas within EUSeaMap.

High concentrations of detritic matter in the Baltic Sea make it difficult to develop satellite imagery, and as such, the simple "Secchi disc" method is a valuable alternative. Figure 10 shows the light layer derived from secchi data used in the Baltic model. Full details of the preparation of the light layers and threshold testing for all basins are described in the Technical Appendix for light.

Validating light thresholds

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 macroalgal-dominated communities 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 a lower light threshold relevant to define the lower limit of the upper circalittoral zone in some regions.

In order to check the validity of the light thresholds to define the lower limit of the infralittoral (and upper circalittoral in the W. Mediterranean) against the satellite imagery, comparisons were carried out with ground-truth data for each basin. In the North/Celtic Seas, acoustic measurements of kelp forests from 2006 and 2007 surveys in Brittany at a number of sites were plotted against the photic zone as derived from the Kd_{PAR}. In the Mediterranean the light layer from satellite imagery (250m MERIS data) was tested against the known distribution of *Posidonia oceanica* meadows with a good health status and whose lower limit is known to be determined by decreasing light rather than anthropogenic pressures. The approach was carried out on 40 selected meadows sites in Spain, France and Italy by identifying the largest homogenous polygons and ensuring that fragmented areas were excluded from the process. The bathymetry used to intersect with the Kd_{PAR} file to yield the photic zone was from the best available DTMs (resolution of approximately 100m). The lowest value of the percentage of surface light reaching the seabed was selected in each of the 40 polygons and the statistics were computed. In view of the log-normal distribution the median value of 0.82% was therefore considered a valid threshold value for the hard limit of the infralittoral / circalittoral boundary and the lower quartile (0.34%) and upper quartile (1.6%) were selected as fuzzy values to be used in the creation of a confidence map for this limit.

The lower limit of the upper circalittoral zone, reported to occur at 0.01% surface light in the Mediterranean, is defined by the limit of the deepest extent of sciaphilic algal. However, the distribution of these algae is not only poorly known and mapped but also limited in spatial extent and is far too fine-scale with respect to the broad scale 250m pixel resolution of the best-available satellite light data. A comparison of light data against distribution of sciaphilica algae was therefore not possible for determination of this threshold, and instead the value of 0.01% was taken as the limit of the upper circalittoral zone. In an attempt to express its uncertainty and give proper warning to users, it was decided to apply fuzzy limits of 0.005% and 0015% to this boundary.

A similar method was used for the polyhaline and fully marine areas of the Kattegat and Skagerrak (the transitional area between the North and Baltic Seas) and the 1% threshold was confirmed by checking against 198 diving transects.

In the oligo- and mesohaline parts of the Baltic Sea proper, the ratio between Secchi depth and depth was instead used to map the infralittoral/circalittoral boundary. The maximum depth/Secchi depth ratio recorded (1.2 and 1.8 for respectively oligo- and mesohaline areas) was used as the lower limit of the fuzzy threshold. The 75 percentile (2 and 3.2 for respectively oligo- and mesohaline areas) 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 that is likely to show the deepest occurrence of macroalgae and the resulting threshold values were examined and judged to give a reasonable result.

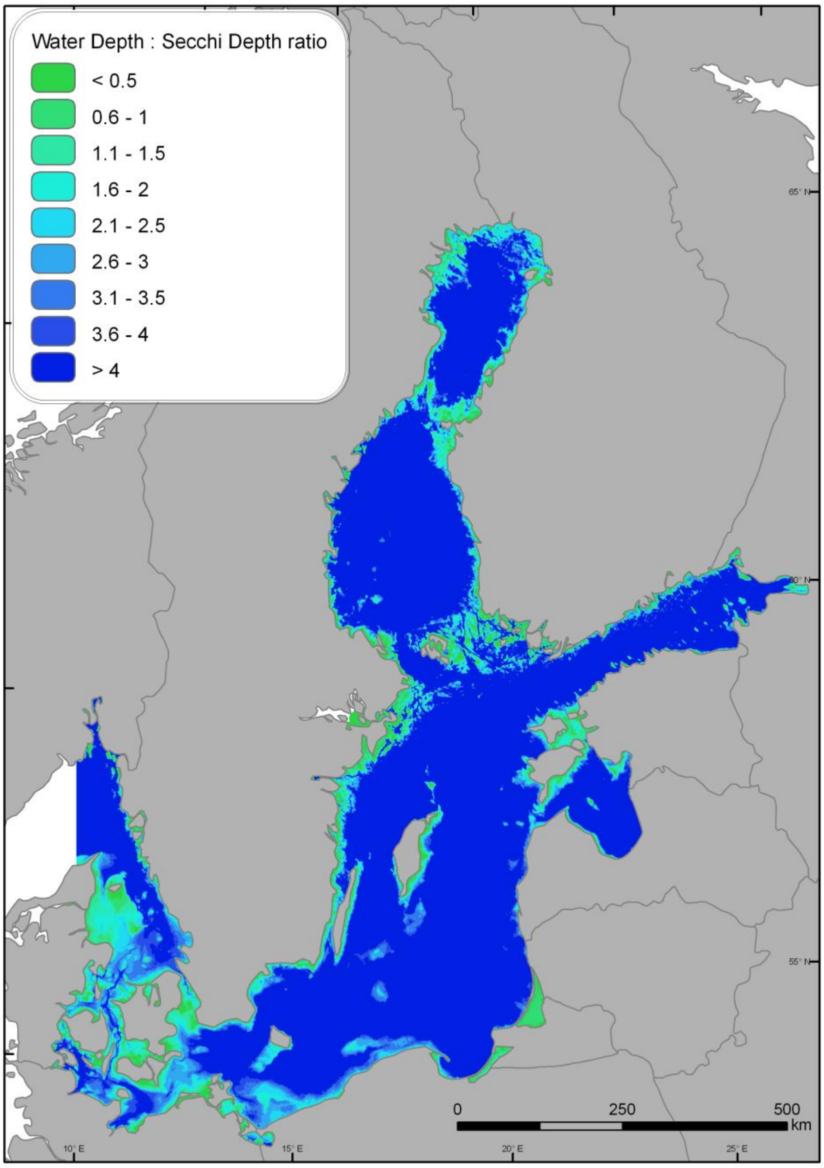

Figure 10 Ratio of water depth to Secchi depth in the Baltic, used in the model to delineate the infralittoral/circalittoral boundary for oligohaline and mesohaline areas.

5.1.2. Bathymetry

Bathymetry is one of the key deliverables for EUSeaMap from the EMODnet hydrography project. The DEM being developed by the EMODnet Hydrography consortium is of a minimum 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 13). The preparation of this North Sea and Celtic Seas DEM is described in more detail in the Hydrography project Interim Report. Due to difficulties encountered by EMODnet Hydrography group in obtaining data from the UK Hydrographic Office (UKHO), the EUSeaMap group used licensed SeaZone data for much of the UK shelf waters. EMODnet has since obtained data from the UKHO and is in the process of incorporating it into an update of the DEM, due in March 2011.

In the Western Mediterranean, EUSeaMap partners are also partners in the EMODnet Hydrography project. The projects have elaborated a Mediterranean global DEM with a resolution of 0.0027 decimal degrees (Figure 11). This DEM has been elaborated from twelve partial DTMs. One DEM was used for the French margin and one for the Italian margin. Ten DEMs 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
- CIESM – IFREMER-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.

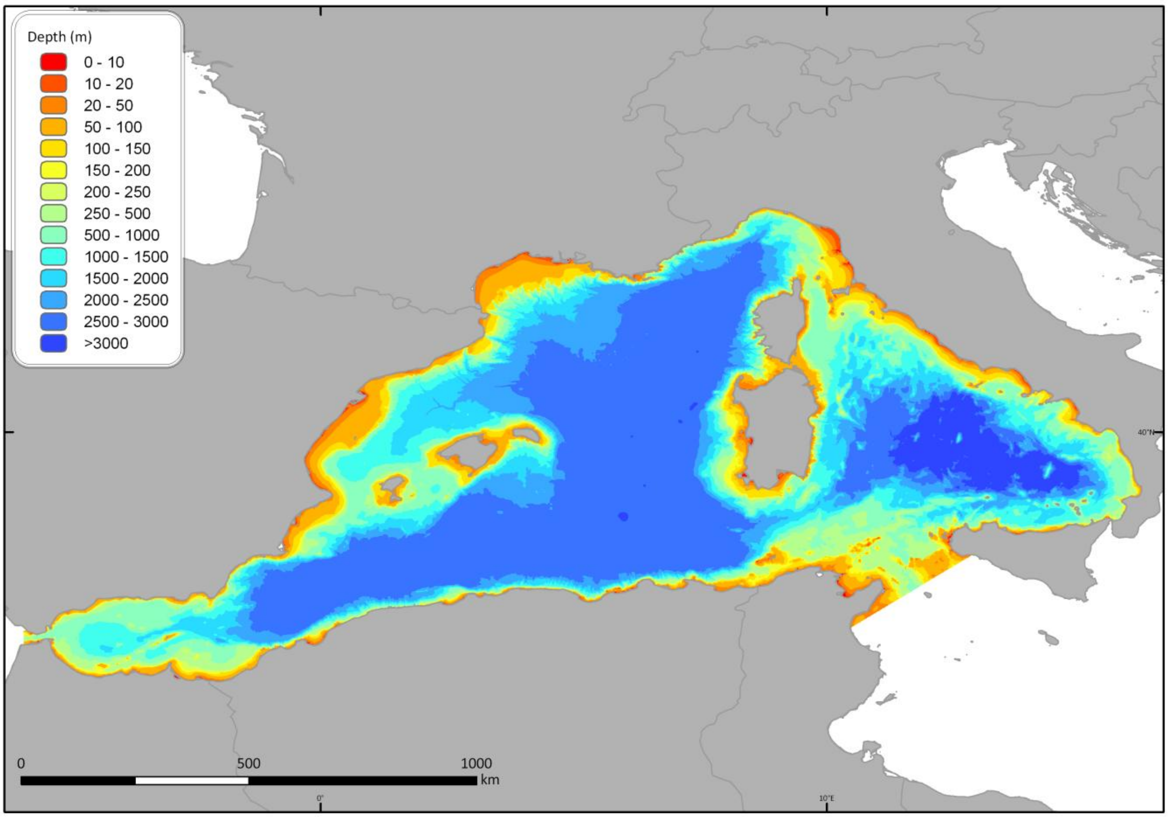

Figure 11 Bathymetry of the Western Mediterranean.

In the Western Mediterranean, bathymetry is the abiotic variable that was used to identify the threshold value to delimit the boundary between the deep 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 that actually contributes to different environmental conditions influencing the formation of discreet 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 seabed slope angle revealed more than one feature needing consideration for the definition of the deep circalittoral/bathyal and bathyal/abyssal boundaries. In particular, a first change in slope (shelf break) was observed at shallower depths than expected, and prior to the continental shelf edge. It was possible to manually delineate a boundary showing the shelf edge for the majority of the basin but in some instances no shelf edge was identifiable due to the absence of a strong change in seabed slope angle. The bathyal basin limit was identified as the point where the deepest and flat area of the basin begins, again based on change in slope. An alternative bathyal basin limit was identified as a noticeable change in seabed slope angle, but occurring at shallower depths than expected for the bathyal basin limit (often because of geological processes). The cartographic information on the different identified slope angle changes and topographic features is displayed in Figure 12 below. The lines showing slope changes around canyons and seamounts are presented here for information, but were not used in the predictive model.

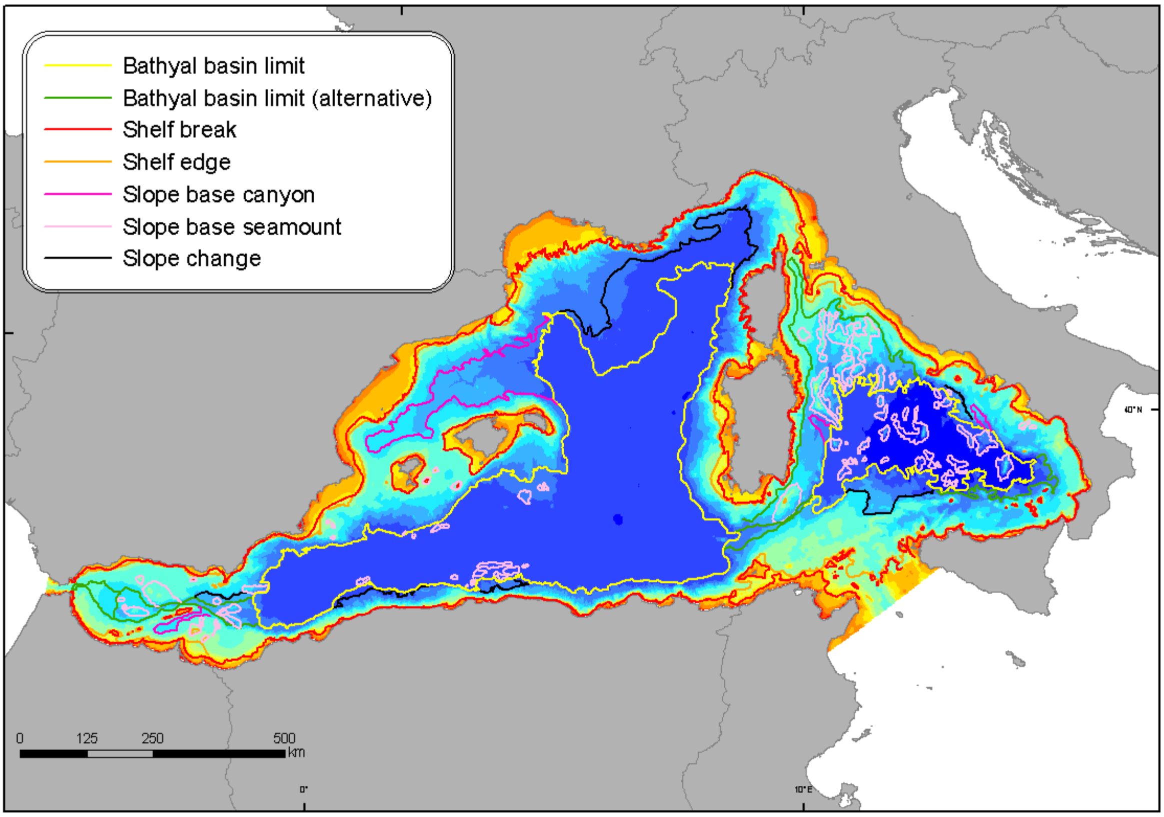

Figure 12 Sea bottom slope angle change observed in the western Mediterranean.

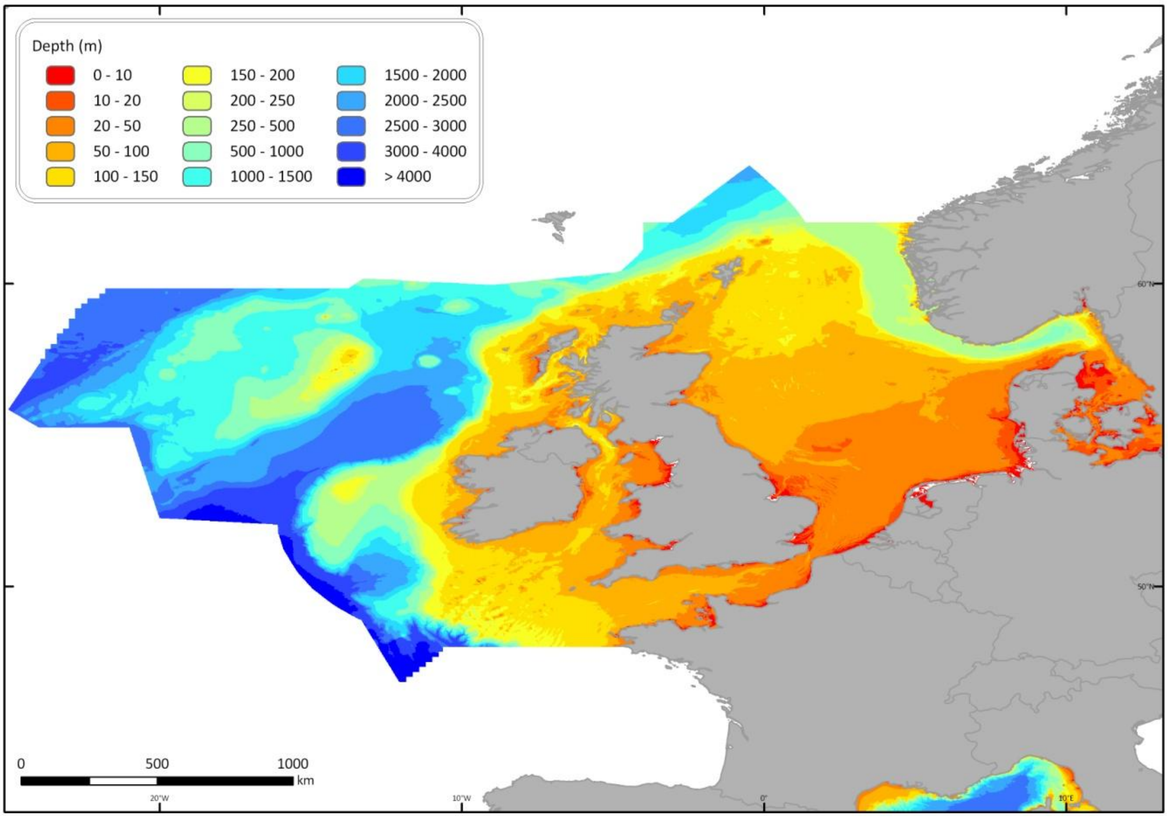

Figure 13 Bathymetry of the North Sea and Celtic Seas. Data are from EMODnet DEM (incorporating GEBCO where gaps exist).

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 four regional bathymetry maps (Figure 14), 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

A scale of about 1:3,000,000 being the minimum one can reasonably compare to a quarter minute resolution, such as the EMODnet bathymetry, these maps are then more than adequate to construct a bathymetry data set for the EUSeaMap working resolution. However, 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 arises from joining 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. The final Baltic bathymetry map used in EUSeaMap is shown in Figure 15.

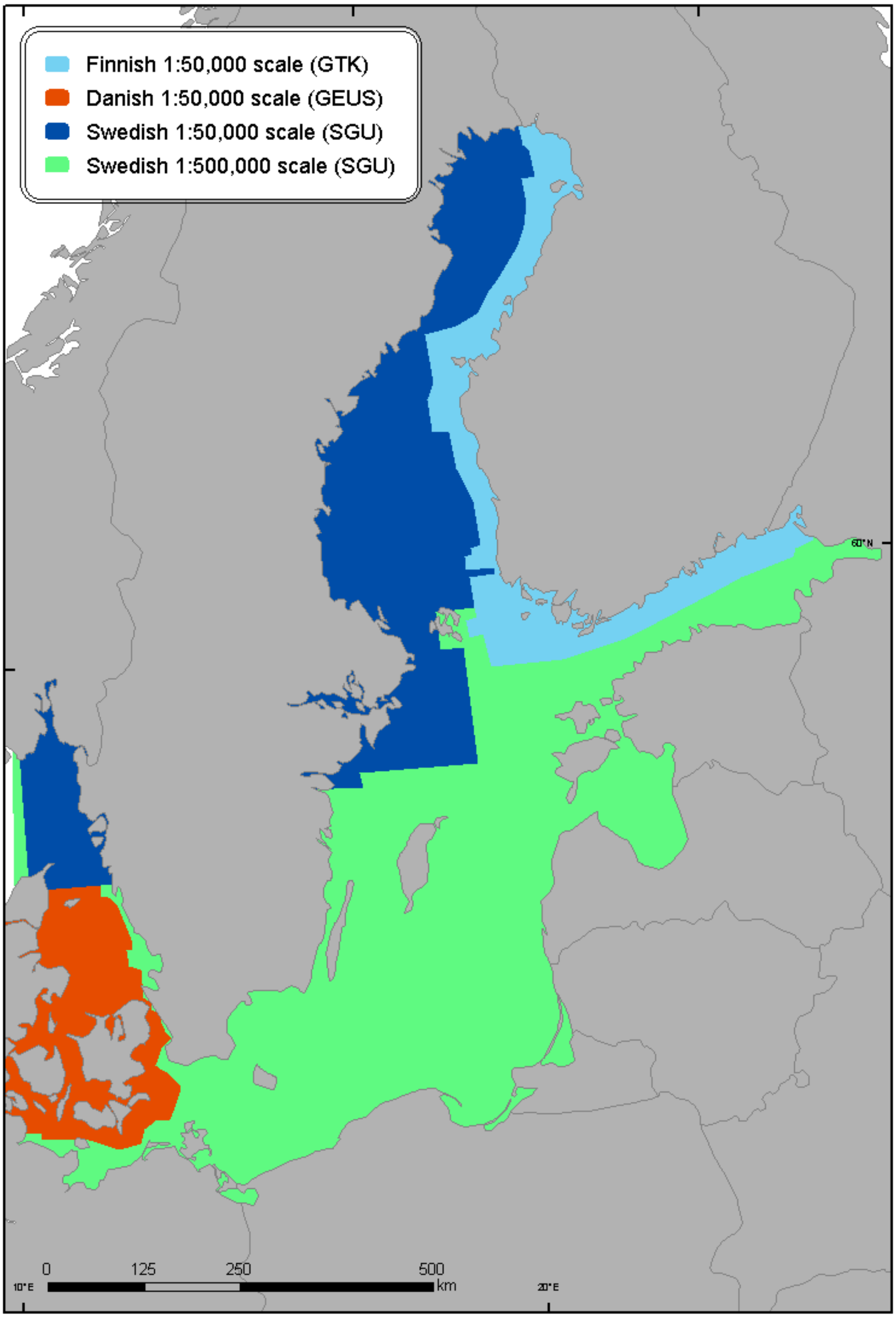

Figure 14 Coverages of four bathymetry maps used to make the BALANCE bathymetry map for the Baltic Sea map.

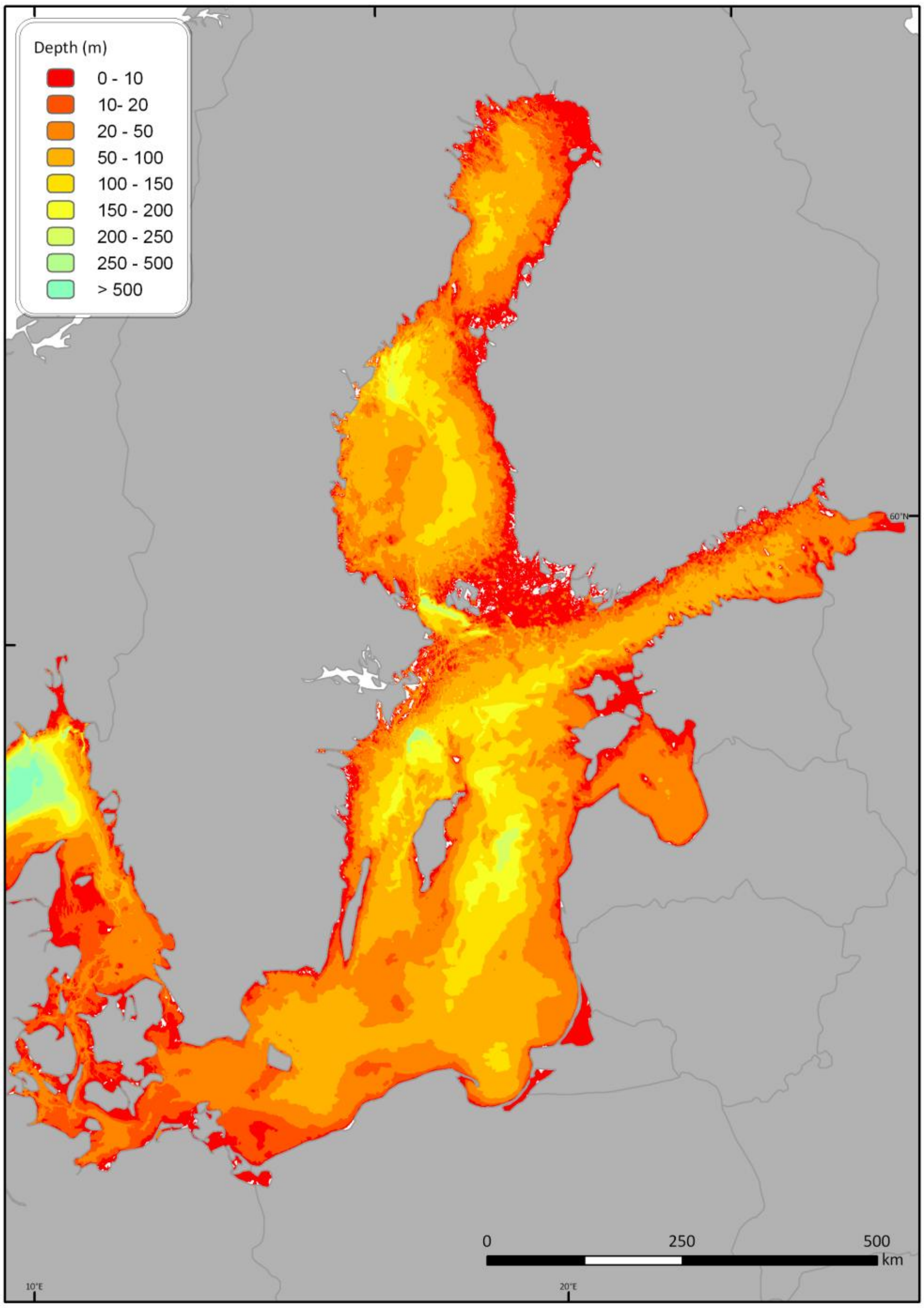

Figure 15 The BALANCE bathymetry map used in EUSeaMap.

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 16 and Figure 17 show the resulting maps.

Table 8 Biological zones used for mapping in the Baltic Sea.

Biological Zones of the Baltic Sea	Upper limit	Lower limit
Infralittoral	0m	1.6 ratio of depth/Secchi depth for oligohaline 2.5 ratio of depth/Secchi depth for mesohaline
Upper circalittoral	1.6 ratio of depth/Secchi depth for oligohaline 2.5 ratio of depth/Secchi depth for mesohaline	Seabed for oligohaline (deepest zone) Position of deep halocline for mesohaline
Deep circalittoral	Position of deep halocline for mesohaline	Seabed for mesohaline (deepest zone)

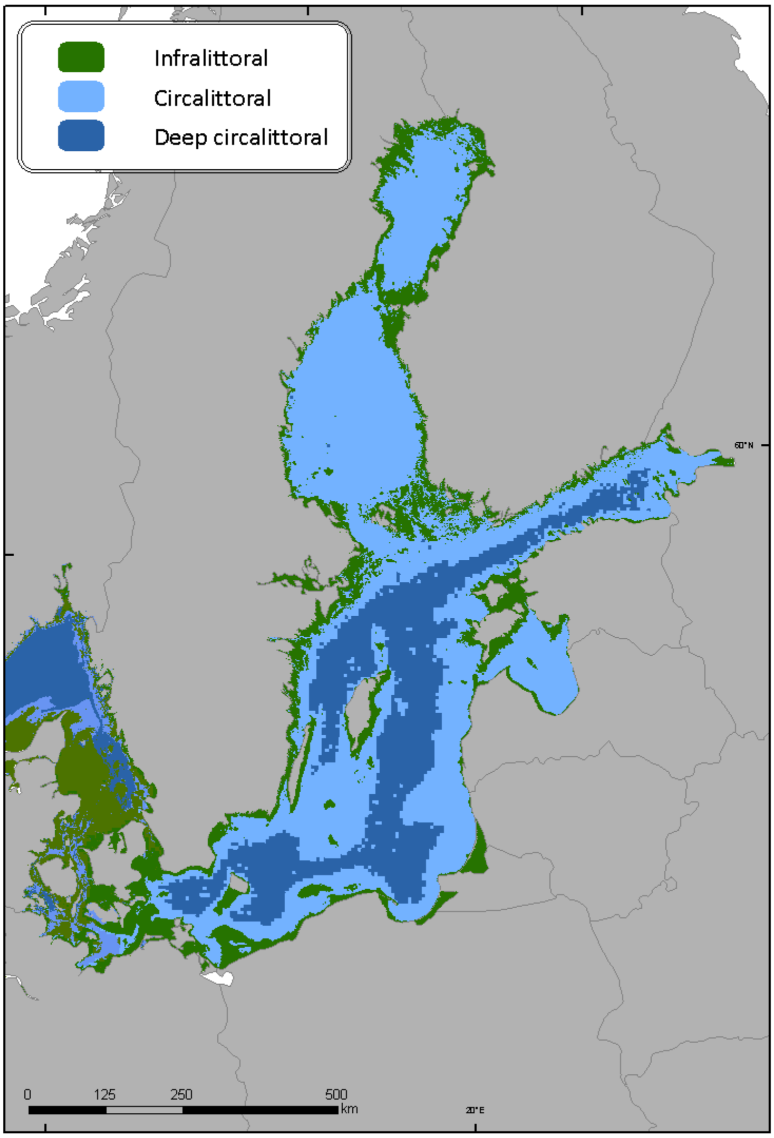

Figure 16 Biological zones of the Baltic Sea.

Table 9 Biological zones used for mapping in the North and Celtic Seas (including Kattegat/Skagerrak).

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	

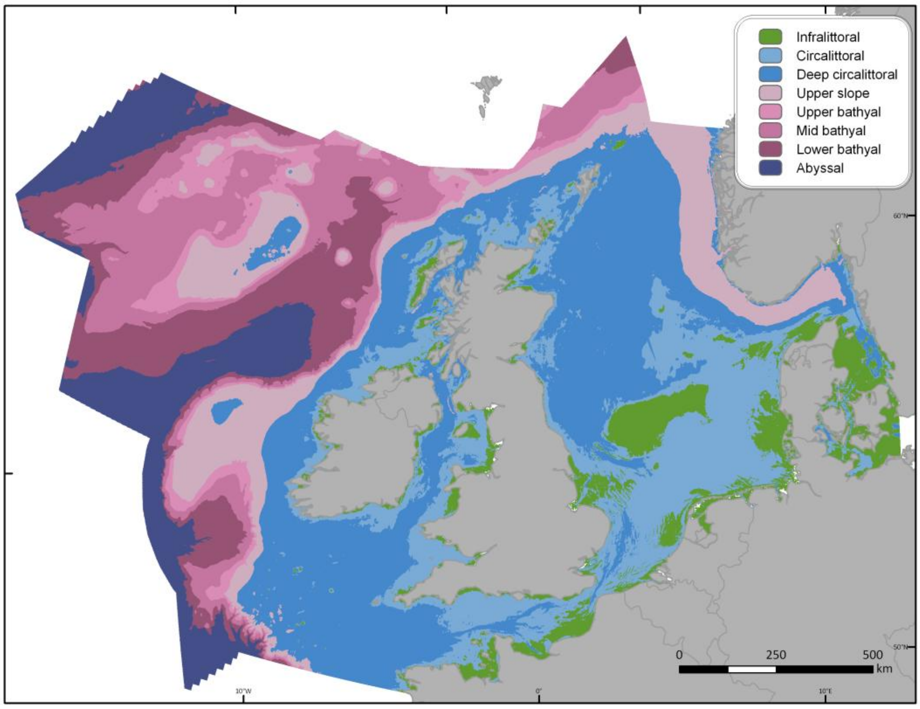

Figure 17 Biological zones of the North Sea and Celtic Seas (including Kattegat and Skagerrak).

Table 10 Biological zones used for mapping in the Western Mediterranean.

Biological Zones of the Western Mediterranean	Upper limit	Lower limit
Infralittoral	0m	0.8% light reaches the seabed
Upper circalittoral	0.8% 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

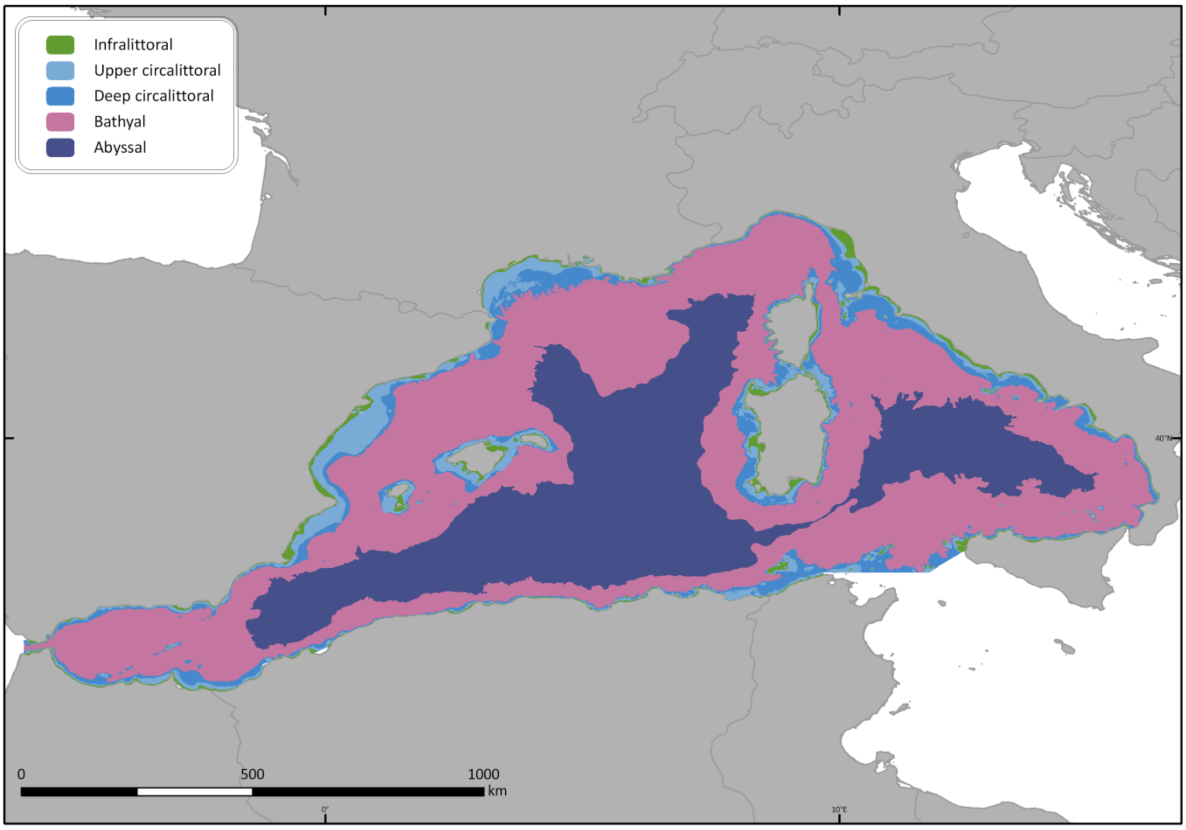

Figure 18 Biological zones of the Western Mediterranean.

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 datasets 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 19) 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 till[27] 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.

[27] Unsorted glacial deposits with no stratification.

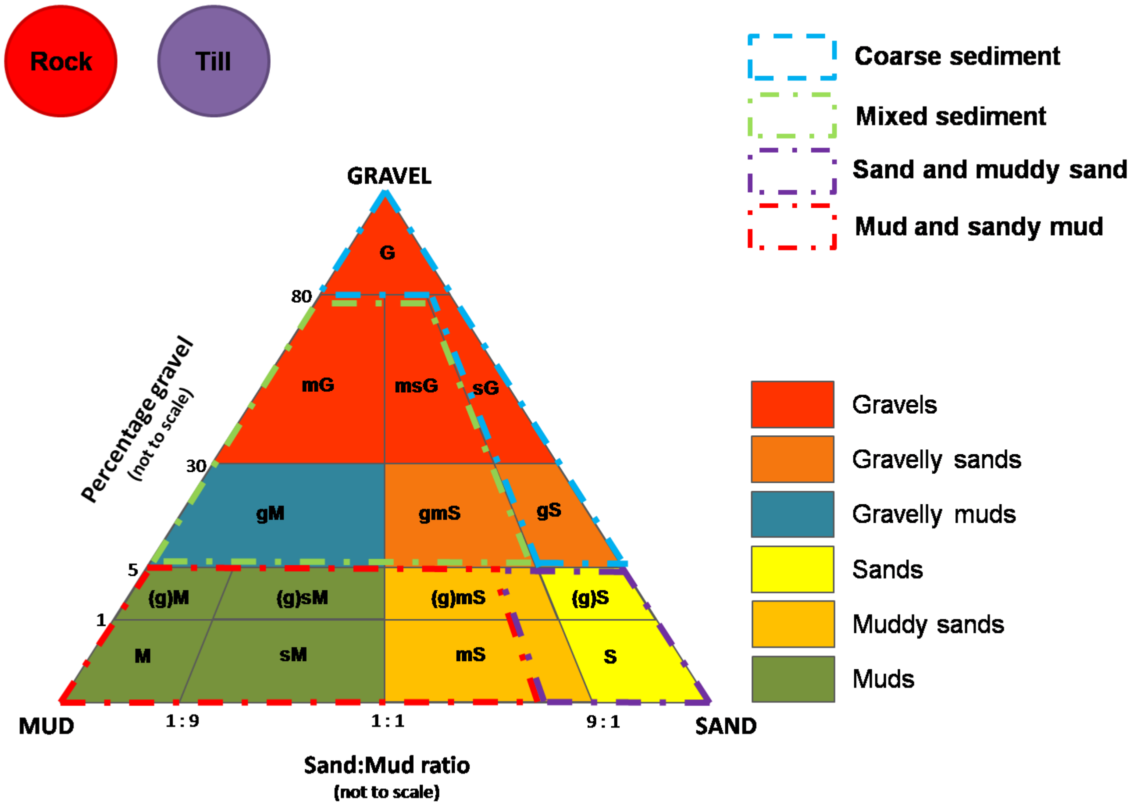

Figure 19 Folk classification of sediment types, with aggregated groups used by the EMODnet Geology group for the EUSeaMap project (North, Celtic and Baltic). Note the modified ratio threshold for the category Sand and muddy sand, and that boulders are included with rock.

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 20). Each partner submitted a substrate map of their national waters including the EEZ. The submitted shapefile contains attribute table containing information about the metadata.

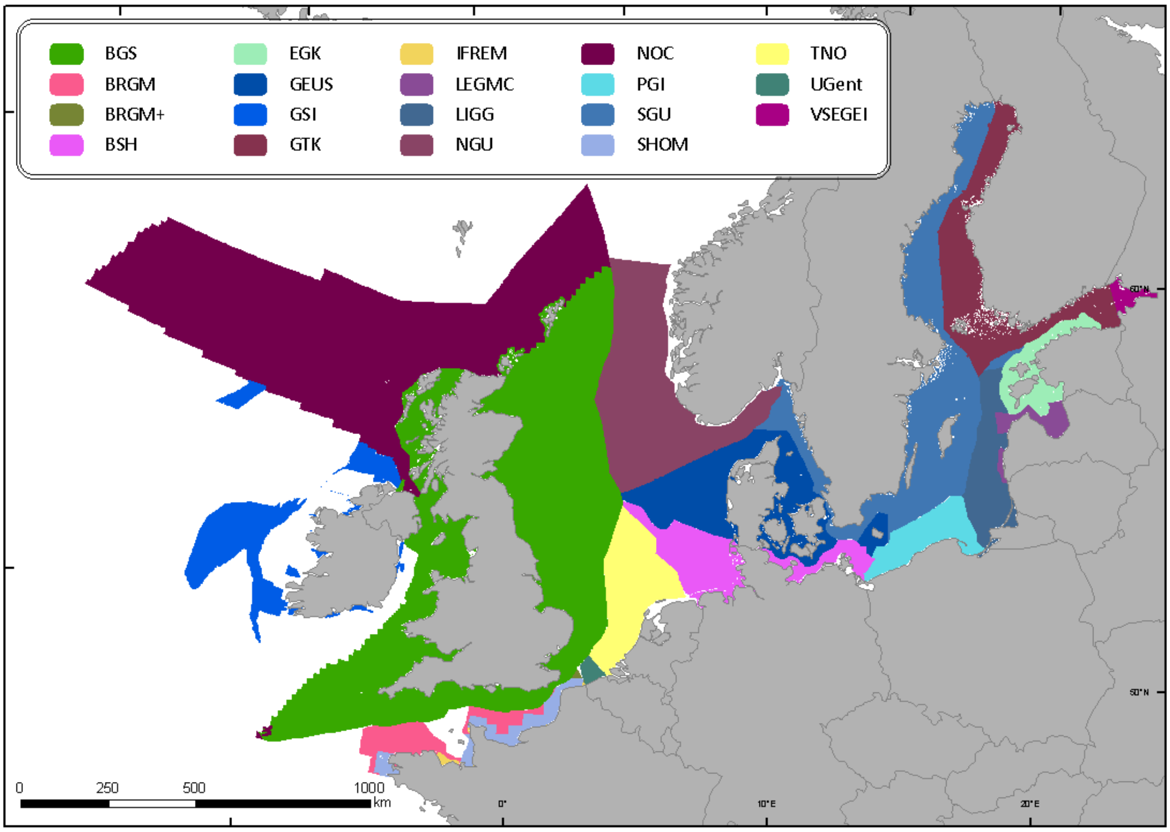

Figure 20 EMODnet substrate index map, showing sources of substrate maps used to create harmonised substrate map.

In the EMODnet Geology project more than 200 maps were harmonised to 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 four 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 three additional classes (boulder, till/diamicton, bedrock) (Figure 19). 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 project[28]. Accordingly the smallest cartographic unit (polygon) on a map of the scale 1:1 million is about 4km^2. Thus all sediment polygons less than 4km^2 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.

[28] http://www.searchmesh.net/default.aspx?page=1635

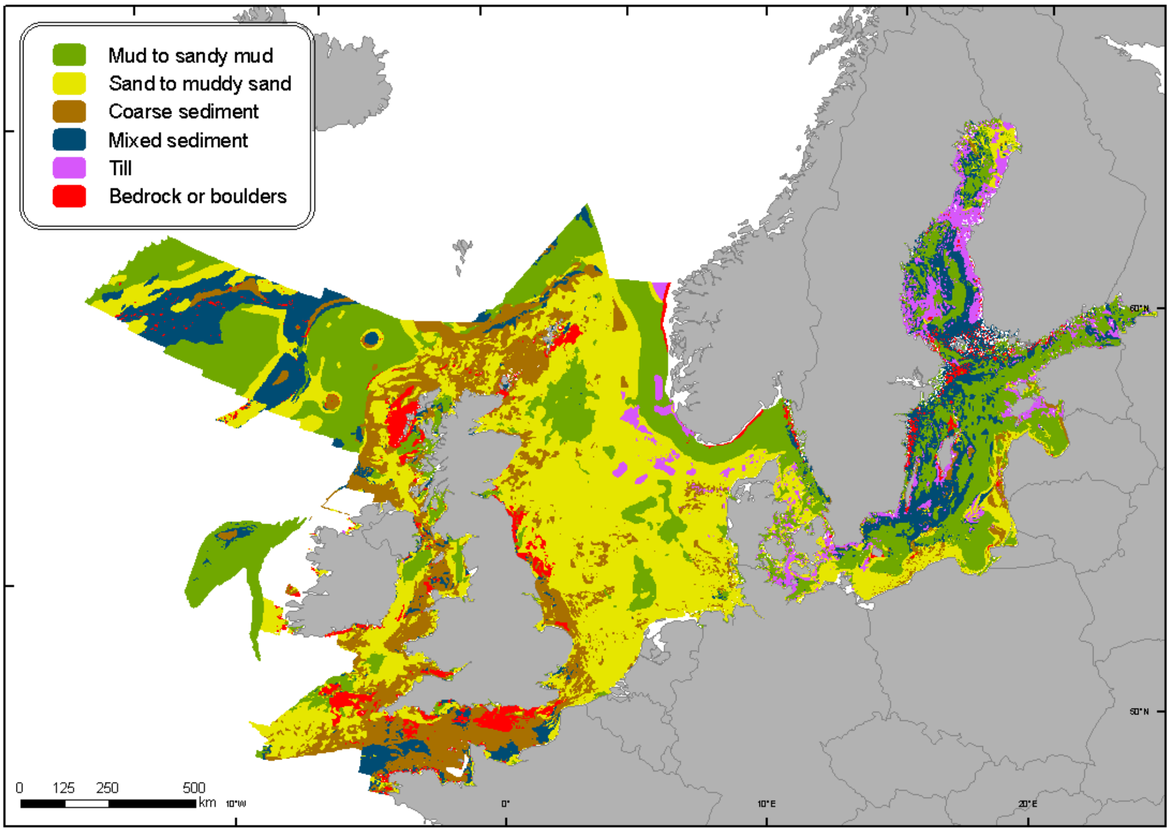

Figure 21 Seabed substrate map of the EMODnet geology study area (August 2010 release).

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 24). 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.

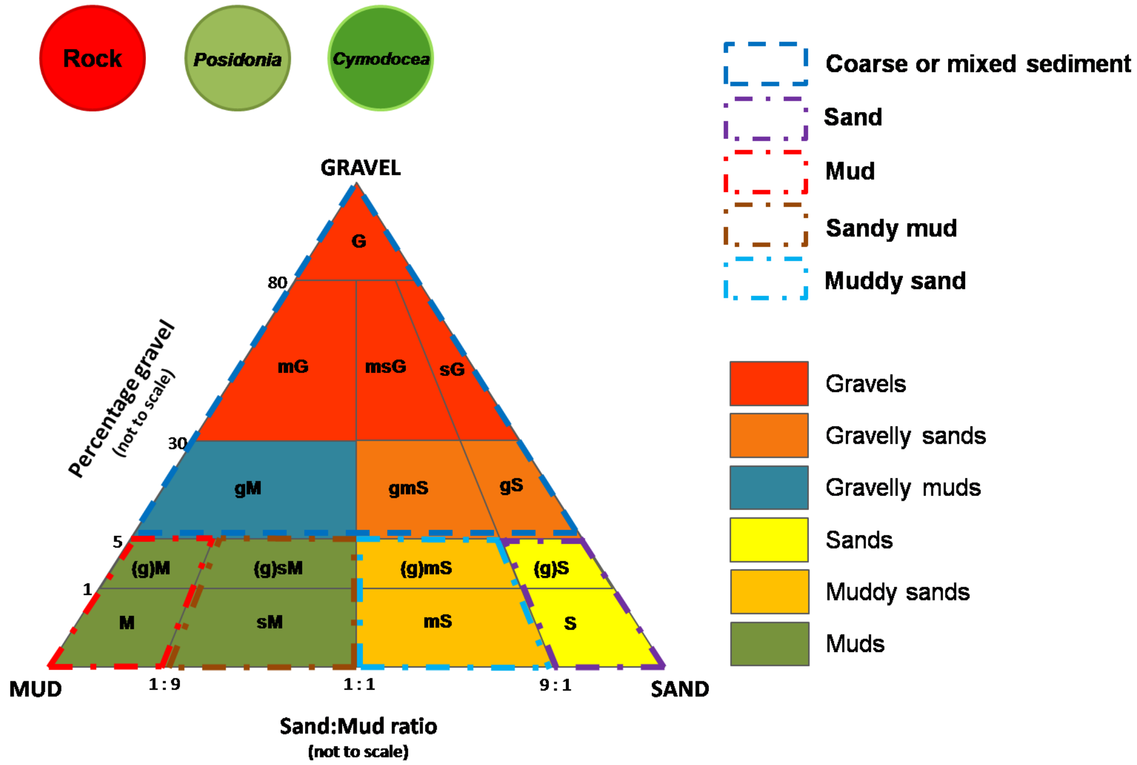

Figure 22 Aggregated groups of the Folk classification used in the western Mediterranean. As it was not possible to modify the ratio thresholds for sand and mud categories as for the northern regions, the project retained more classes for these sediment types.

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
- Il Mare del Lazio
- CARG

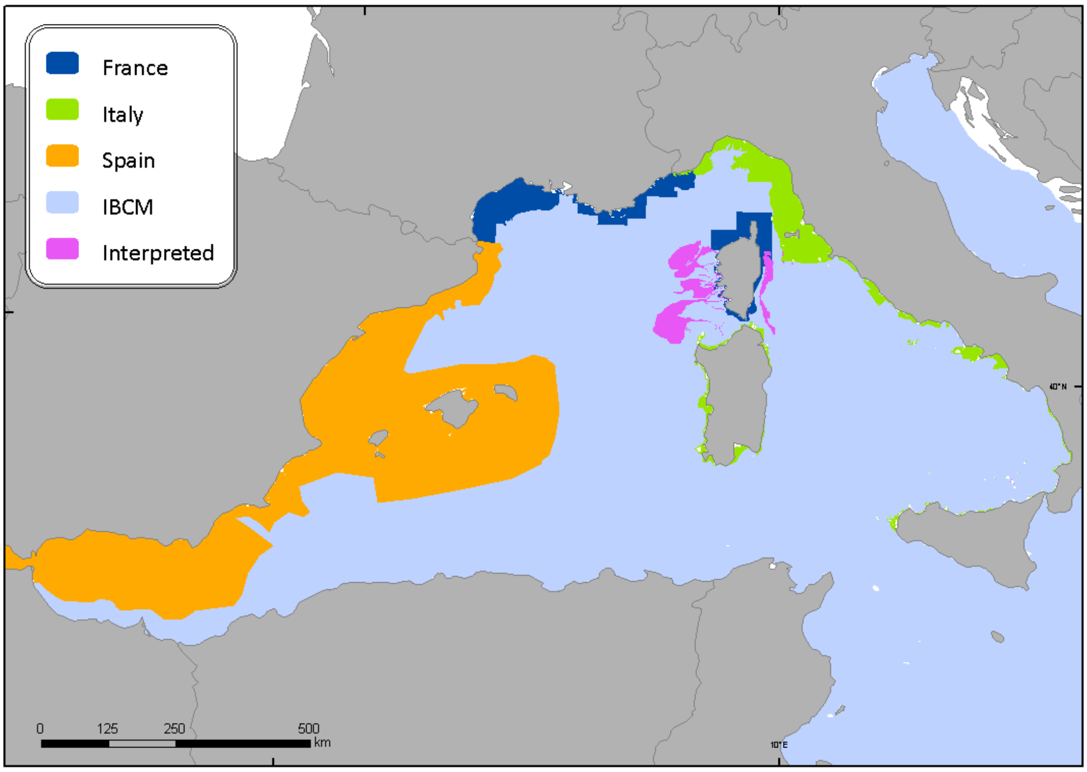

Figure 23 Western Mediterranean substrate index map, showing sources of substrate maps used to create harmonised substrate map. For details on those areas marked as interpreted see the Technical appendix for Substrate data layer preparation.

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. 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 six agreed Folk categories for the Mediterranean (Rock, Sand, Coarse Sand or Gravel, Muddy Sand, Sandy Mud, Mud).

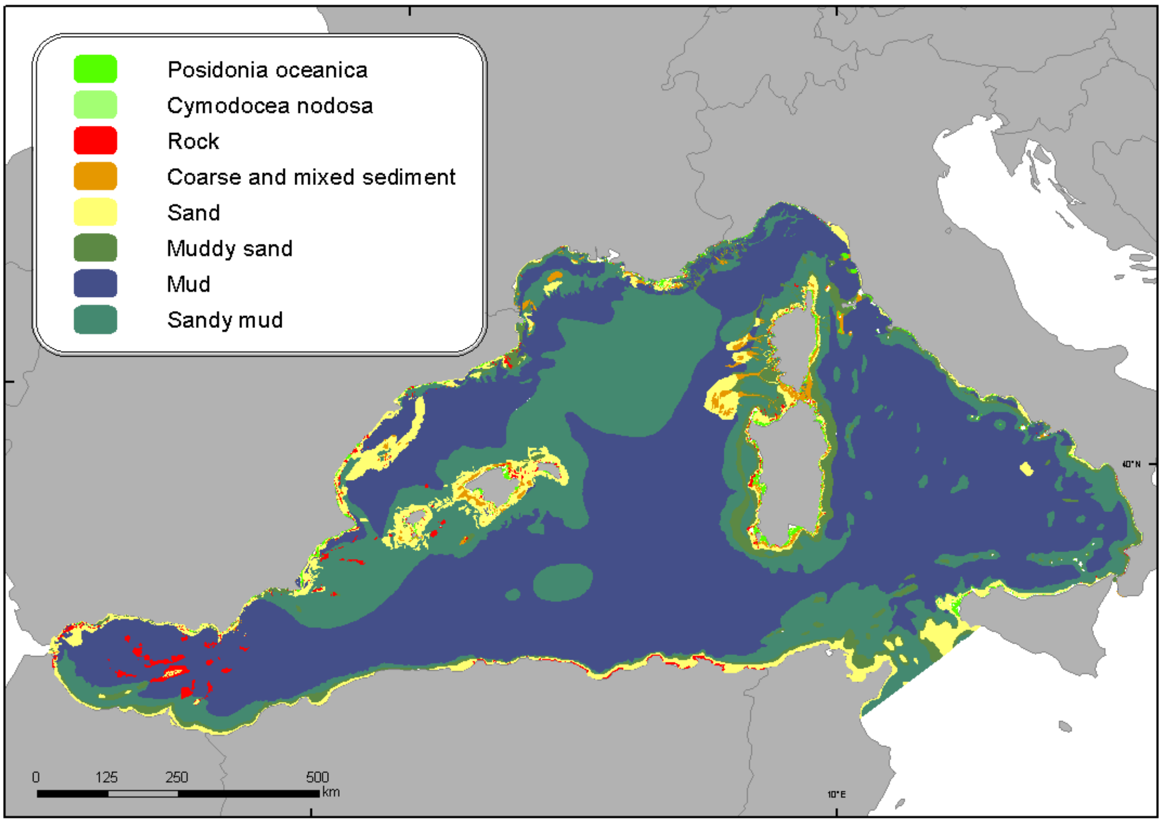

Figure 24 Western Mediterranean substrate map compiled by the EUSeaMap project.

5.2.1. Priority seabed habitats

Some seabed habitats are recognised as remarkable or priority habitats. This is the case of some OSPAR priority habitats[29], such as seagrass or maerl beds, or other seabed habitats 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

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

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 hectares. 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 addition 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 NOC[30] 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 PREVIMER[31] wave and current models (WAVEWATCH III at resolution of 10km and MENOR model at 1km

[30] National Oceanography Centre (formerly Proudman Oceanographic Laboratories, Liverpool and National Oceanography Centre Southampton).

[31] PREVIMer Coastal observations and forecasts www.previmer.org

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 fro 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.

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 data[32] 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. Regressional analysis was used to recalculate wave

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

height statistics from the oceanographic model as equivalent to SWM outputs and the two layers merged in GIS (Figure 25).

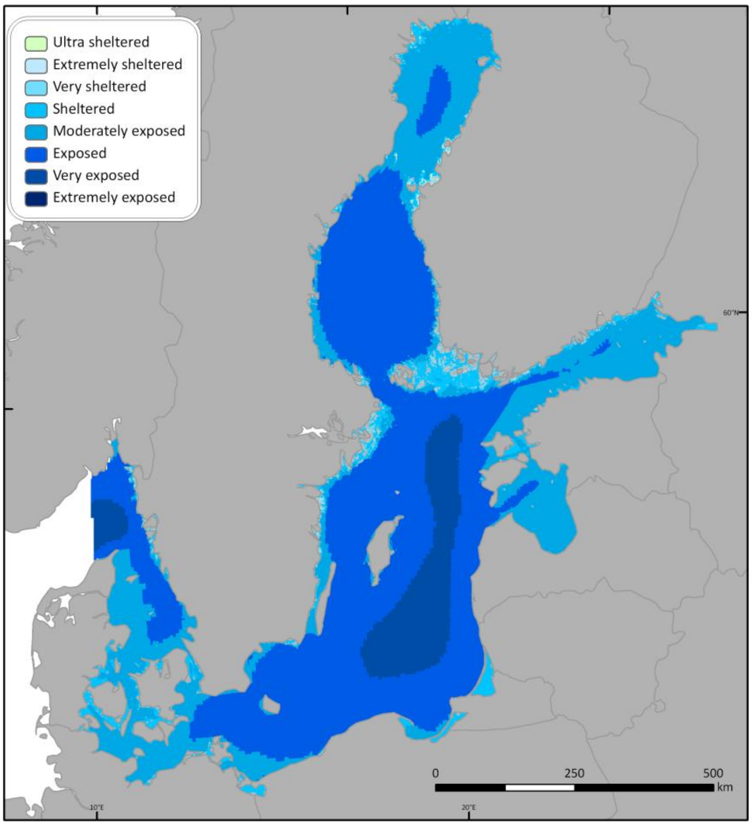

Figure 25 Simplified Wave Model layer for the Baltic Sea. SWM values for open sea areas are derived from recalculated significant wave height.

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.

Whilst the salinity data layer developed for the Baltic is adequate to divide the Baltic Sea into broad salinity classes, it was hoped to also delineate estuarine areas of reduced salinity in the North and Celtic Seas. Unfortunately it was not possible to obtain salinity data of sufficient resolution (the MyOcean MRCS model, whilst providing continuous coverage over the project area, has a resolution of ~6km, of a similar order to the DHI models), More fine-scale data does exist, but it was beyond the scope of the project to develop such data into continuous coverage layers that could be used for the model's needs.

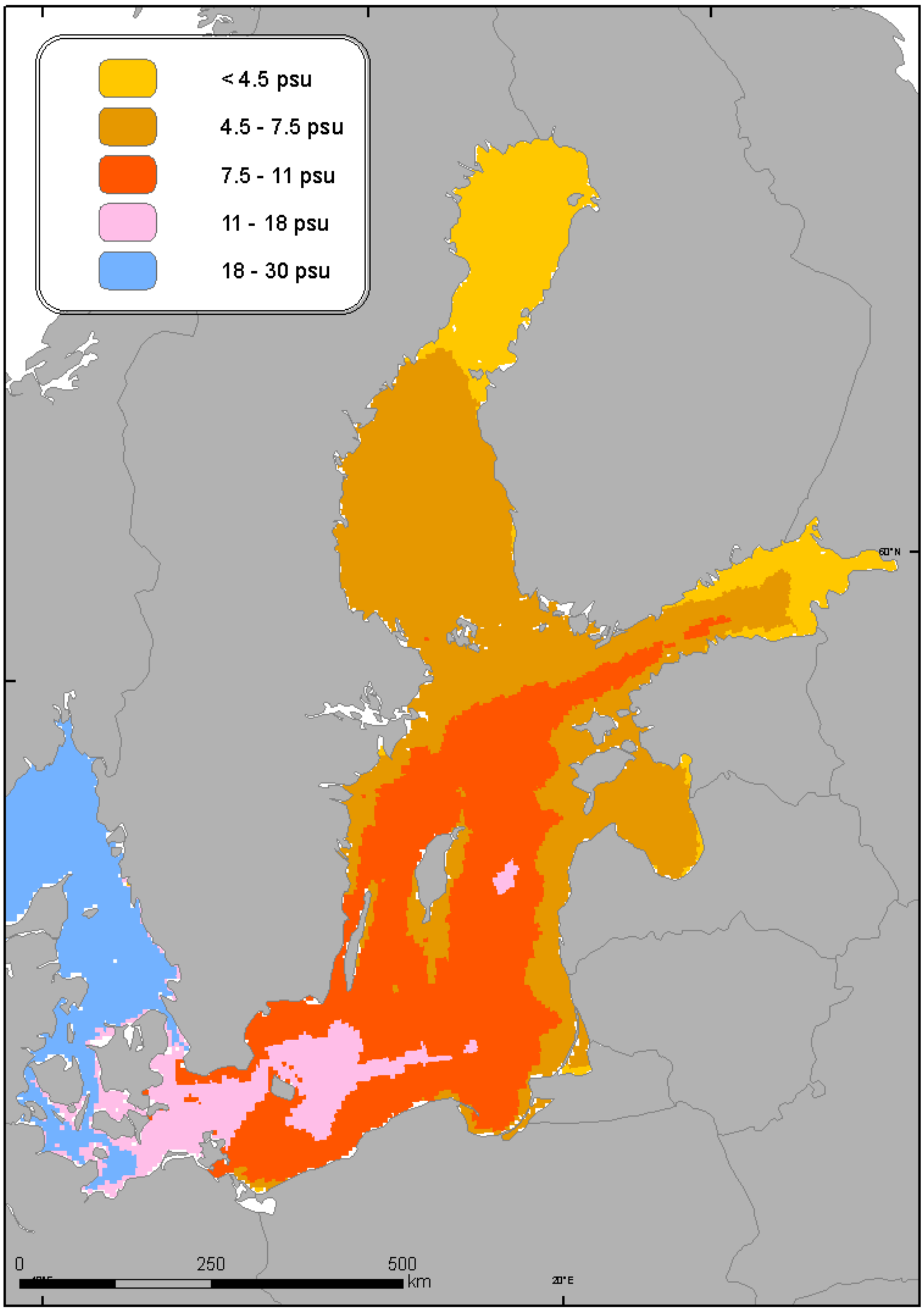

Figure 26 Baltic Sea salinity classes using mean salinity from nine years.

6. Modelling

6.1. General principles

Models were built using ModelBuilder in ESRI™ ArcGIS 9.2/9.3 with Spatial Analyst. 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 27). The models output a seabed habitat map ESRI™ shapefile which is then joined to a 'Translation Table', an MS Excel spreadsheet containing the EUNIS habitat attributes associated with each gridcode value. This post-processing step is done outside of the model. Figure 28 and Figure 29 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.

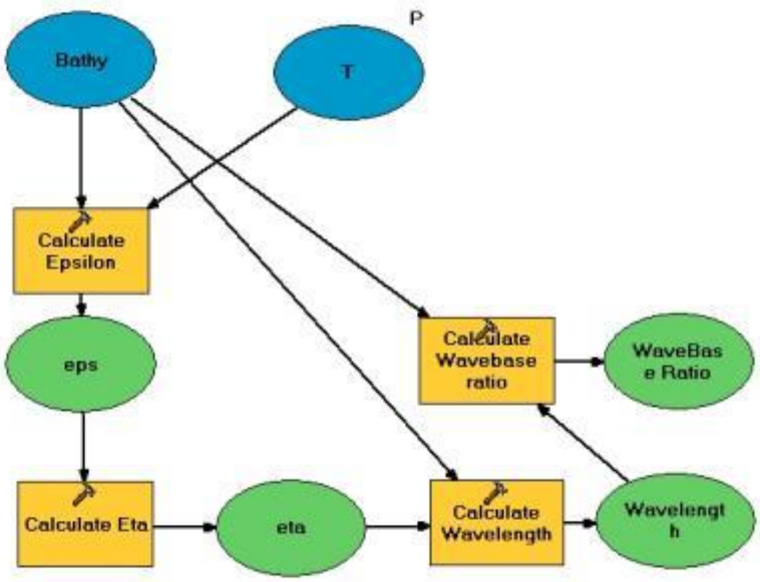

Figure 27 Module generating wave base ratio using peak wave period, Tp, as an input for the Baltic and Celtic/North Sea models.

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.

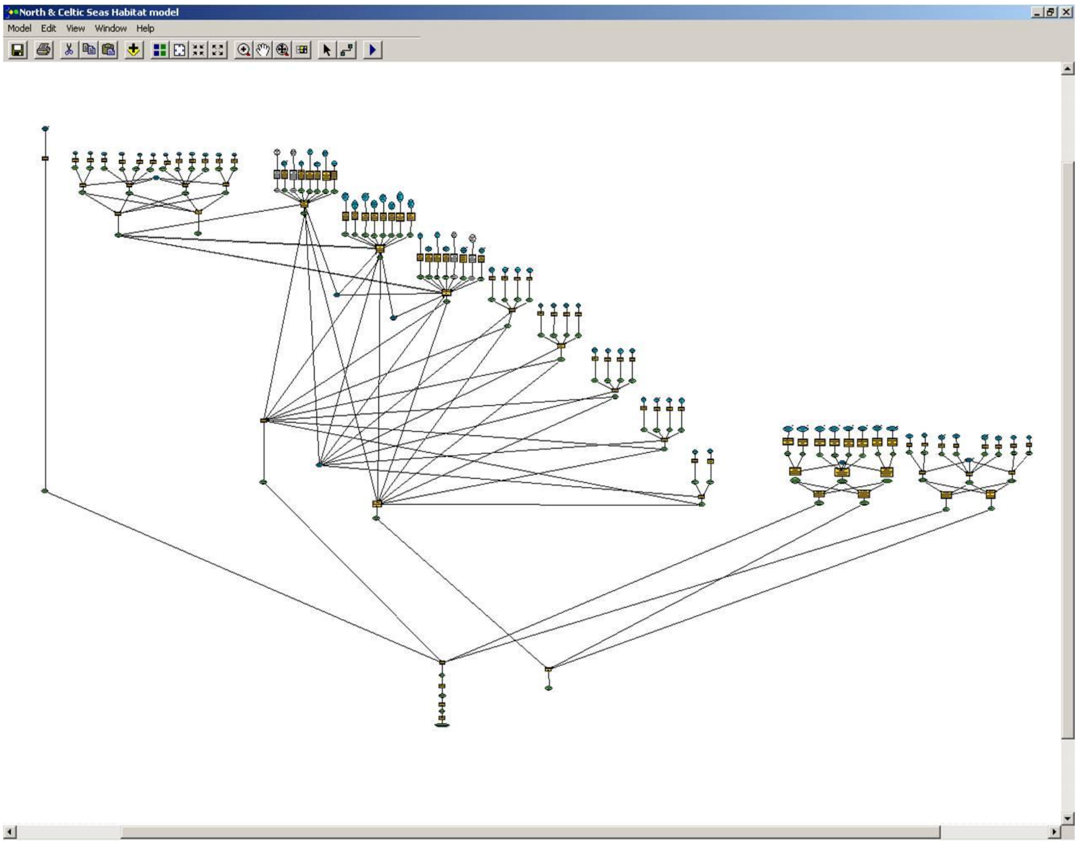

Figure 28 Visualisation of the North and Celtic Seas seabed habitat model in ArcGIS model builder interface.

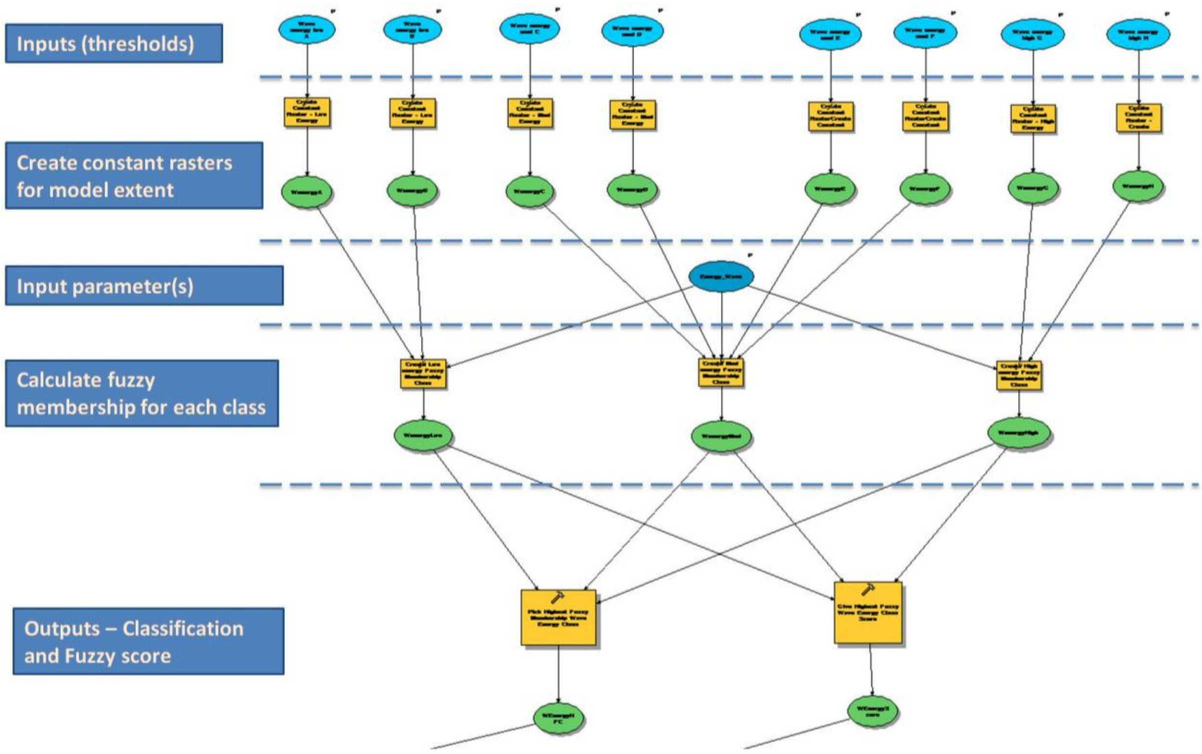

Figure 29 Detailed view of a subsection of the North and Celtic Seas model, illustrating the inputs and processes that produce the energy classifications.

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 ~69,000m^2 or 230x300m) and in the Celtic, North and Baltic seas, 0.0030 decimal degrees (which equates to a cell area of ~55,611m^2 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 extension 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 30), 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.

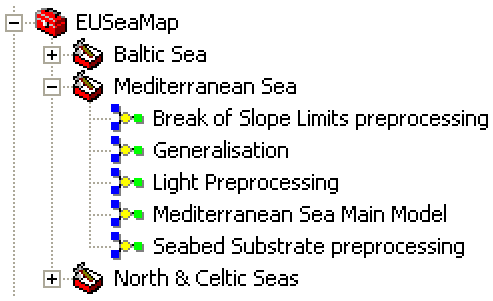

Figure 30 EUSeaMap Toolbox. It contains three toolsets (one per region), and each toolset contains at least one model, the main one. Here Mediterranean Sea toolset is opened. The main model is "Mediterranean Sea Main Model". The other models are not stand-alone, but are loaded by the main one.

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.

7. Seabed habitat maps

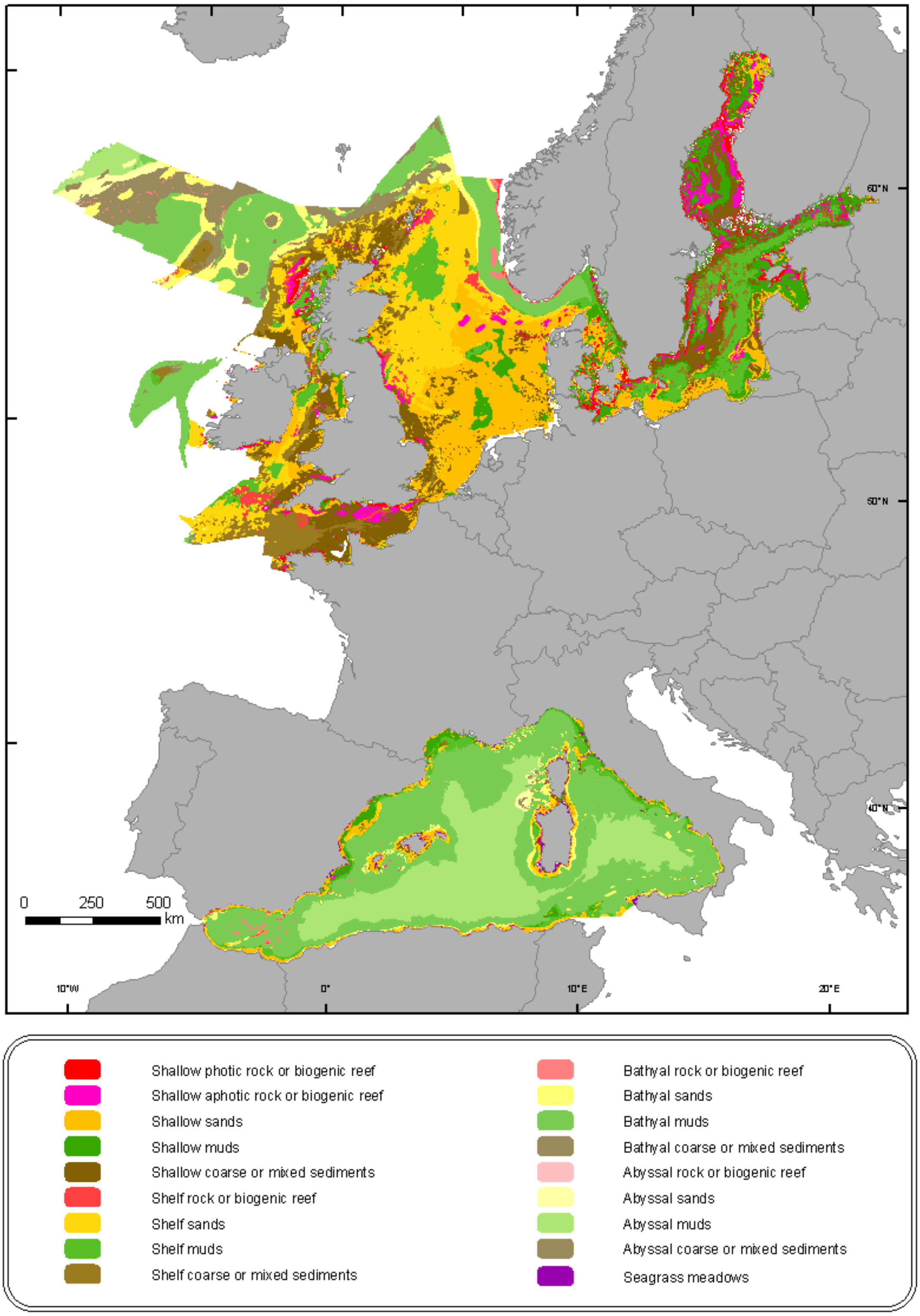

Figure 31 Aggregated version of the modelled maps from all basins. This presentation of the maps, based on substrata and biological zone information, shows how consistent maps might be achieved for very high level visualisation of habitats across Europe. Areas without substrata data have been omitted from this representation

7.1. Consistent maps across Europe

Aggregating habitats

A requirement of this project was to produce a harmonised map across the European regions. Due to differences in the characters of the Baltic, Celtic, North and western Mediterrean Seas already discussed, the models are capable of producing more detailed maps than those shown in Figure 31. The full detail maps (shown below in figures 32 - 39) are useful to many end-users, particularly if their interest lies within one basin, which is the general expectation. Within basins, due to the hierarchical nature of the EUNIS scheme, it is possible to aggregate up to display all habitats at a common level, which may also be useful for some end-users. However, with differences in both the numbers of habitats per basin (69 in total for the North and Celtic, compared with 54 for the Baltic and 20 for the western Mediterrean) and the abiotic variables and threshold used as explained, it is clear that alternative aggregations might be desirable when viewing the maps across basins over the whole project area in the context of each other. Therefore Figure 31 is a suggested representation which displays the modelled habitats according to the properties common to all basins, those of substrata and biological zone. These aggregations were made by manipulation of the translation table used to convert the model codes to EUNIS.

Full detail habitat maps

The final maps for each basin presented in Section 0 are shown to their full level of detail. That is, the furthest extent in the EUNIS classification that we were able to map within the constraints of the project. In the North and Celtic Seas, the project was able to predict some EUNIS level 4 habitat types (e.g. A5.15 Deep circalittoral coarse sediment), but for the most part, habitats are given to EUNIS level 3. For the areas of Irish waters where substrate data were not available from the EMODnet geology layers, habitats have been predicted in terms of their biological zone and energy classification, but without the critical substrate data these cannot be comparable with or presented in terms of the EUNIS classification scheme. In the western Mediterranean, since energy could not be incorporated into the model within the scope of this project, the range of habitats predicted are restricted to those that can be achieved by knowledge of substrate type and the modelling of the biological zone alone. Therefore the Mediterranean map achieves a small number of habitats, mostly to EUNIS level 4 (with level 5 coming from the direct mapping of *Posidonia* and *Cymodocea* seagrasses). The Baltic on the other hand is displayed at a level consistent with EUNIS level 3, though the scheme is that which is proposed by the project to be adopted, as discussed earlier in Section 4.1.

7.1.1. Recommendation of colour scheme for habitat mapping

In preparing the habitat maps for presentation, it was considered important by the project group that certain principles be applied aspiring to consistent and effective display for end users. In the western Mediterranean because there are a relatively low number of habitats in the final map (21 EUNIS habitat classes at our working resolution of ~250m; these are recalled in Table 11), it was possible to follow a systematic approach to establish a colour scheme.

Table 11 Modelled habitats for the western Mediterranean.

	Infralittoral	Circalittoral Upper	Circalittoral Deep	Deep Sea Bathyal	Deep Sea Abyssal
Rock (or other hard substrata)	A3	A4.26	A4.27	A6.1	A6.1
Coarse sediments	A5.13				
Detritic		A5.46	A5.47	A6.2	A6.2
Muddy detritic			A5.38		
Sand	A5.23			A6.3	
Muddy sand				A6.4	A6.4
Sandy mud	A5.33			A6.511	
Mud	A5.34	A5.39		A6.51	A6.52
Posidonia	A5.535				
Cymodocea	A5.531				

The presentation constraints were as follows:

- Simple colour symbology that can be used with raster format (excludes hatches or other symbology options)
- Approximate scale of 1:1M
- Good colour separability both on screen for webGIS users and on paper prints

Several tests were run taking into account the following principles:

- as far as possible, to respect some rules generally applied in sediment mapping:
  - sandy sediment: yellow to orange variations
  - muddy sediment: shades of brown
  - rock: conspicuous colour such as red or black
- to enhance patchy or small habitats by giving them a bright saturated colour (as opposed to pastel ones) to make them more visible
- to desaturate colours of similar habitats when going from the shore to the high sea across biological zones. Generally, habitat extent increases accordingly and this

results more pastel colours being more aesthetic over vast areas (e.g. for the Mediterranean's huge bathyal and abyssal zones A6.51 and A6.52)

- to check colour stability between screen and paper (based on HP Designjet 5500ps 42 A0 plotter on which maps are to be produced)
- to produce aesthetically pleasing maps

A first test was made using these principles including assigning shades of brown to mud, leaving a choice of bright blue and green for seagrass beds. Unfortunately the constraint of large extent habitats was too severe (Figure 32). While the zoomed area is "warm", when viewed at the level of the whole area, this scheme resulted in a rather dull map.

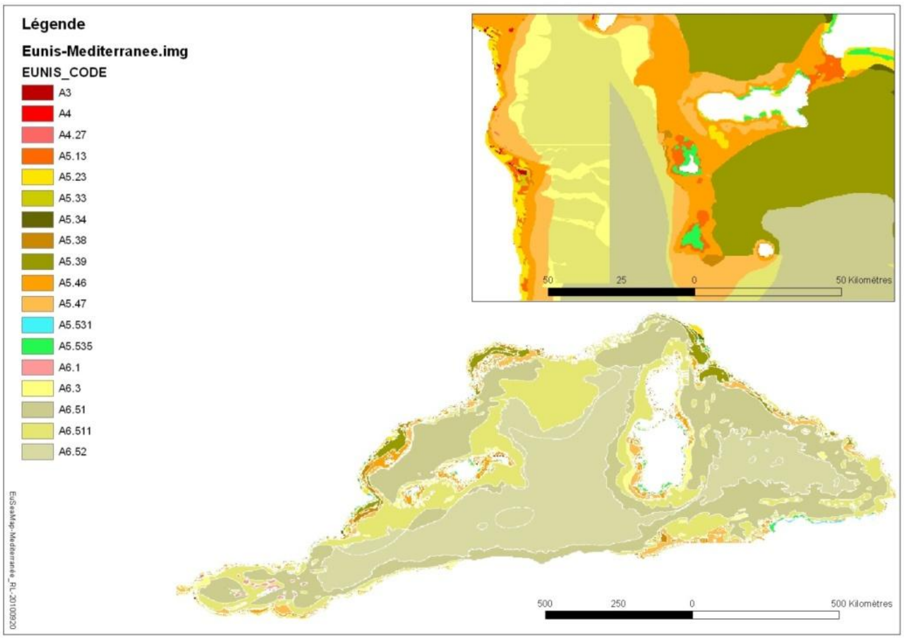

Figure 32 Habitat map resulting from the initial appliance of the colour scheme under the cartographic principles.

A way around this was to use shades of green to represent mud across the biological zones, from a very dark green for infralittoral mud (A5.34) to a very pale green for abyssal mud (A6.52). Likewise coarse sediment goes from dark orange in infralittoral to paler orange in deep circalittoral (Table 13) and sand and sandy mud go from bright yellow to paler yellow in deeper waters.

Seagrass beds have a particular status because being a protected habitat they need to be very conspicuous on a map, a tricky issue at a scale of 1:1M where most seagrass patches are quite small. Seagrass are usually displayed in green on biocenosis maps but as green was already used for mud, an alternative was proposed to assign variations of turquoise blue to them. Shades of red are reserved for hard substrate, from very bright red in infralittoral to salmon in deep waters.

With these modifications the colour scheme was eventually stabilised to reach that shown in Table 12. The range of colours was broadened in a non-conventional way. "Strong" colours were reserved fro the infralittoral zone and a progressive desaturation was applied seaward. Warm colours were assigned to hard and coarser substrate while in contrast colder colours were kept for finer sediments. A fine tuning was applied after a draft map was produced on the A0 plotter by using the HSV (hue, saturation, intensity value) coding system to adjust optimum contrast.

Table 12 Final colour scheme for habitat map in the Western Mediterranean. Colour codes are listed in ArcGIS HSV (%) and RGB values for each unique habitat type.

	Infralittoral	**Circalittoral** Upper circalittoral	**Circalittoral** Deep circalittoral	**Deep Sea** Bathyal	**Deep Sea** Abyssal
Rock (and other hard substrata)	**A3** *360,100,100* *255,0,0*	**A4.26** *320,100,100* *255,0,170*	**A4.27** *360,60,100* *255,100,100*	**A6.1** *360,40,100* *255,150,150*	
Coarse sediments	**A5.13** *25,100,50* *130,55,0*				
Detritic		**A5.46** *35,100,90* *230,135,0*	**A5.47** *35,70,100* *255,180,75*	**A6.2** *35,50,100* *255,200,130*	
Detritic mud			**A5.38** *50,100,75* *190,160,0*		
Sand	**A5.23** *45,100,100* *255,190,0*			**A6.3** *45,40,100* *255,230,155*	
Muddy Sand				**A6.4** *60,60,100* *255,255,100*	
Sandy mud	**A5.33** *70,100,70* *150,180,0*			**A6.511** *70,70,90* *200,230,70*	
Mud	**A5.34** *85,100,40* *60,100,0*	**A5.39** *85,100,60* *90,150,0*		**A6.51** *85,100,75* *110,190,0*	**A6.52** *85,25,90* *205,230,170*
Posidonia	**A5.535** *160,60,100* *100,255,205*				
Cymodocea	**A5.531** *160,100,70* *0,180,120*				

The final maps are shown in Figure 33 below. The bottom map features the nominal scale of 1:1M scale. The expected "salt and pepper" effect of small patches of habitats occupying a few pixels seems limited, but will be inherent to a map that has not been generalised. In web display, these tiny habitats have more relevance since they can be zoomed to a certain extent within reasonable limits.

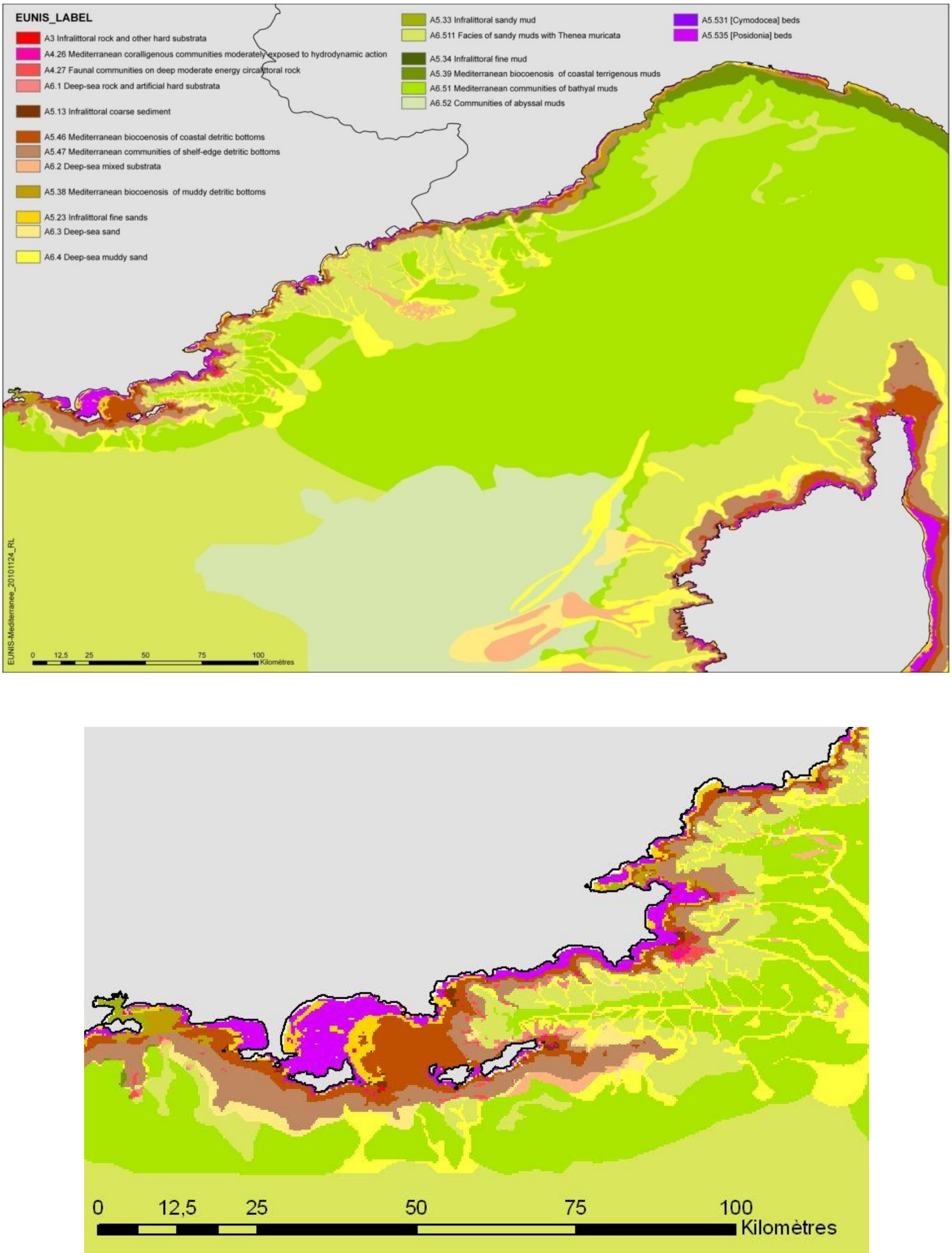

Figure 33 The modelled map with final colour scheme at scale 1:2.5M (top), and a sub area at approximate scale 1:1M (bottom).

For the North, Celtic and Baltic regions, these principles are impossible to apply as rigorously with the much greater number of different habitats (102 in the North and Celtic Seas and 31/52 in the Baltic, by salinity and energy respectively). This is principally because cartographic rules dictate one cannot utilise much greater than 30 different colours in a single map that the eye can distinguish between sufficiently. For this reason, every effort was made to follow the same general principles as for the Mediterranean (using the colours assigned to the EUNIS classes in Table 12), but accepting that in any printed hard copy of the map has this limitation. Through the webGIS however, as described later in Section 9, users can query the map to give the exact habitat code and description for any polygon, in addition to having the zoom functionality, which remove this problem.

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7.2. Full detail seabed habitat maps produced by the models

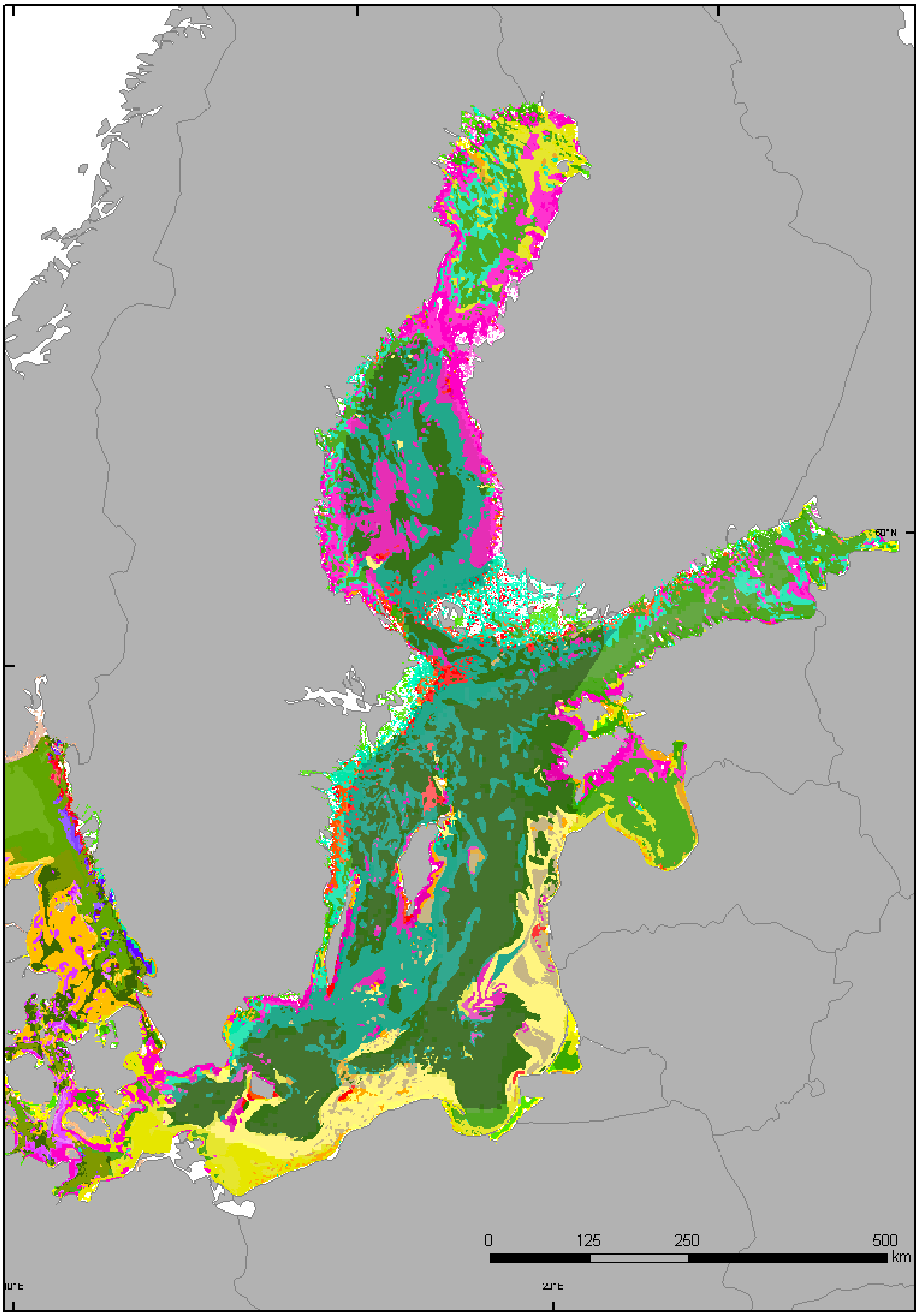

Figure 34 Full detail Modelled seabed habitats for the Baltic Sea, with top level classification structure using energy classes. This is the proposed top level structure for EUNIS in the Baltic (Wikström *et al*., 2010), which reflects the top level structuring used for the rest of EUNIS.

Figure 35 Legend for the modelled seabed habitats for the Baltic region, with top level structure using energy classes.

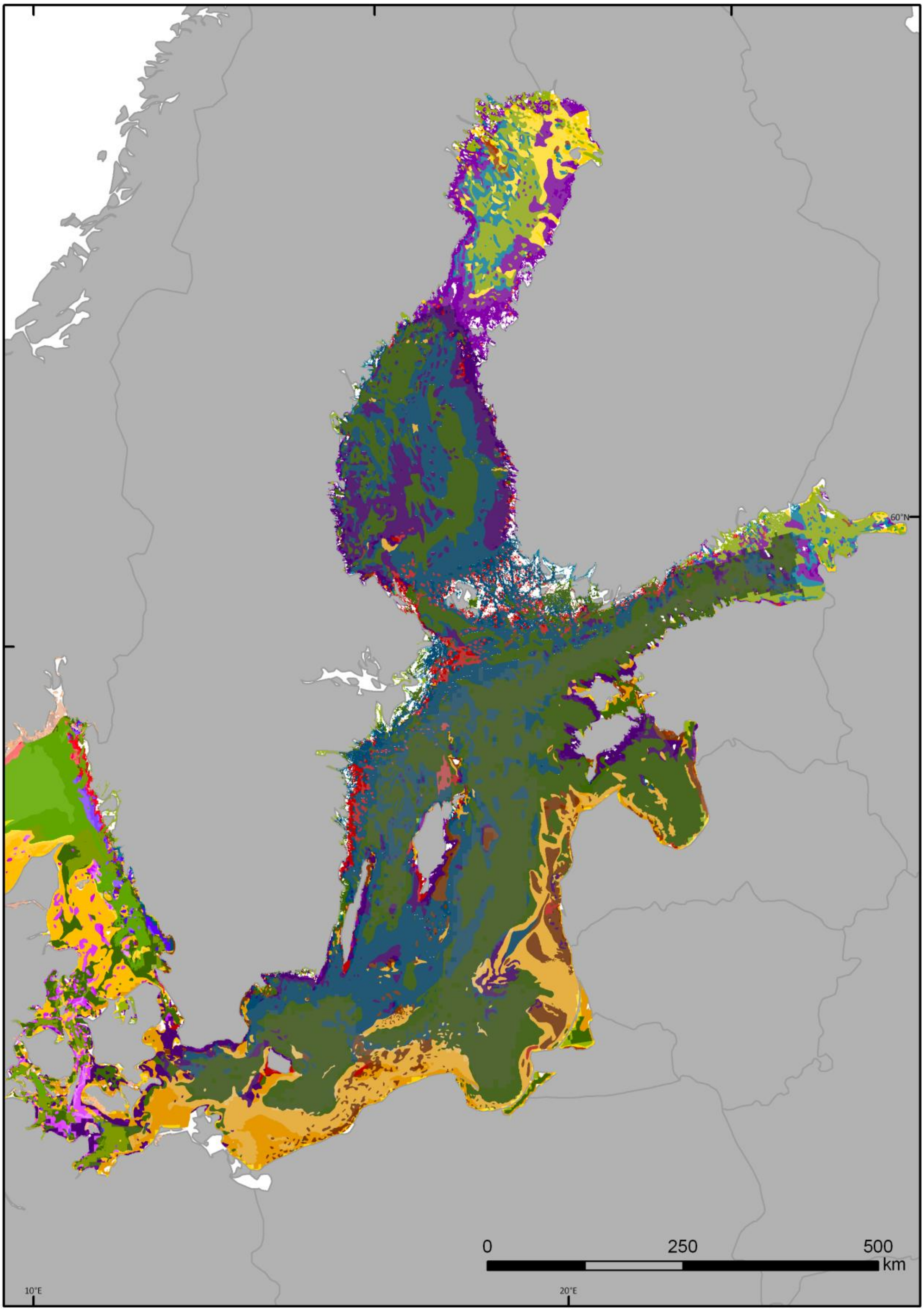

Figure 36 Alternative full detail modelled seabed habitats for the Baltic Sea, with top level classification structure using salinity classes instead of energy.

Figure 37 Legend for the full detail modelled seabed habitats for the Baltic region, with top level structure using four major salinity classes.

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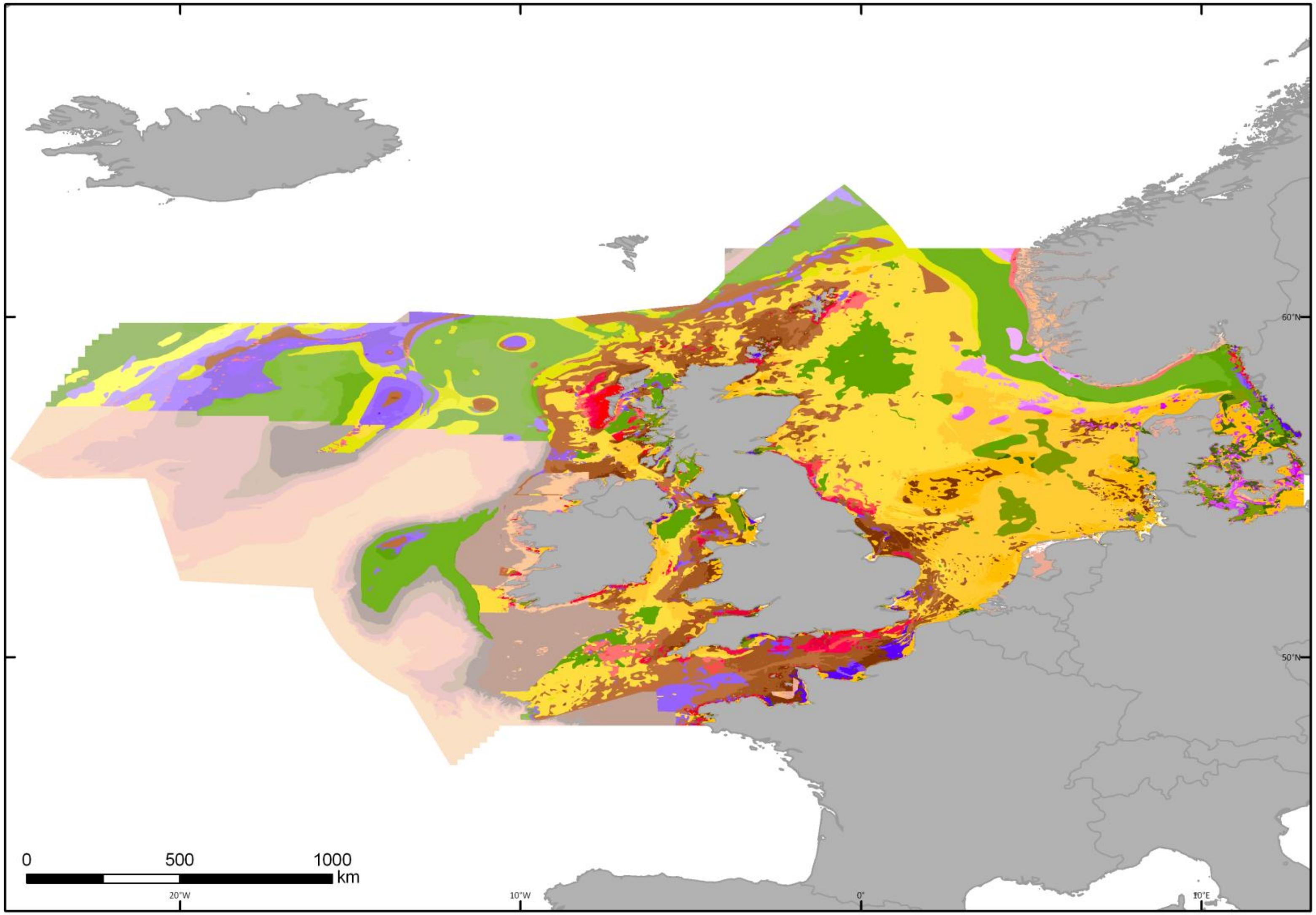

Figure 38 Full detail modelled seabed habitats for the North and Celtic seas. In areas without substrata data available from the current (August 2010 version) EMODnet data layer, such as for much of the Irish EEZ, biological zone and energy information from the model are still shown, but under a different colour scheme.

Figure 39 Legend for the full detail modelled seabed habitats for the North and Celtic regions. Areas without substrata data were modelled according to biological zone and energy class; since they cannot be fitted to the EUNIS classification without substrata data these have been labelled simply as seabed. In addition, the more detailed classification for the Atlantic deep sea as proposed by Howell (2010) has been shown here, rather than the broader EUNIS A6 classes.

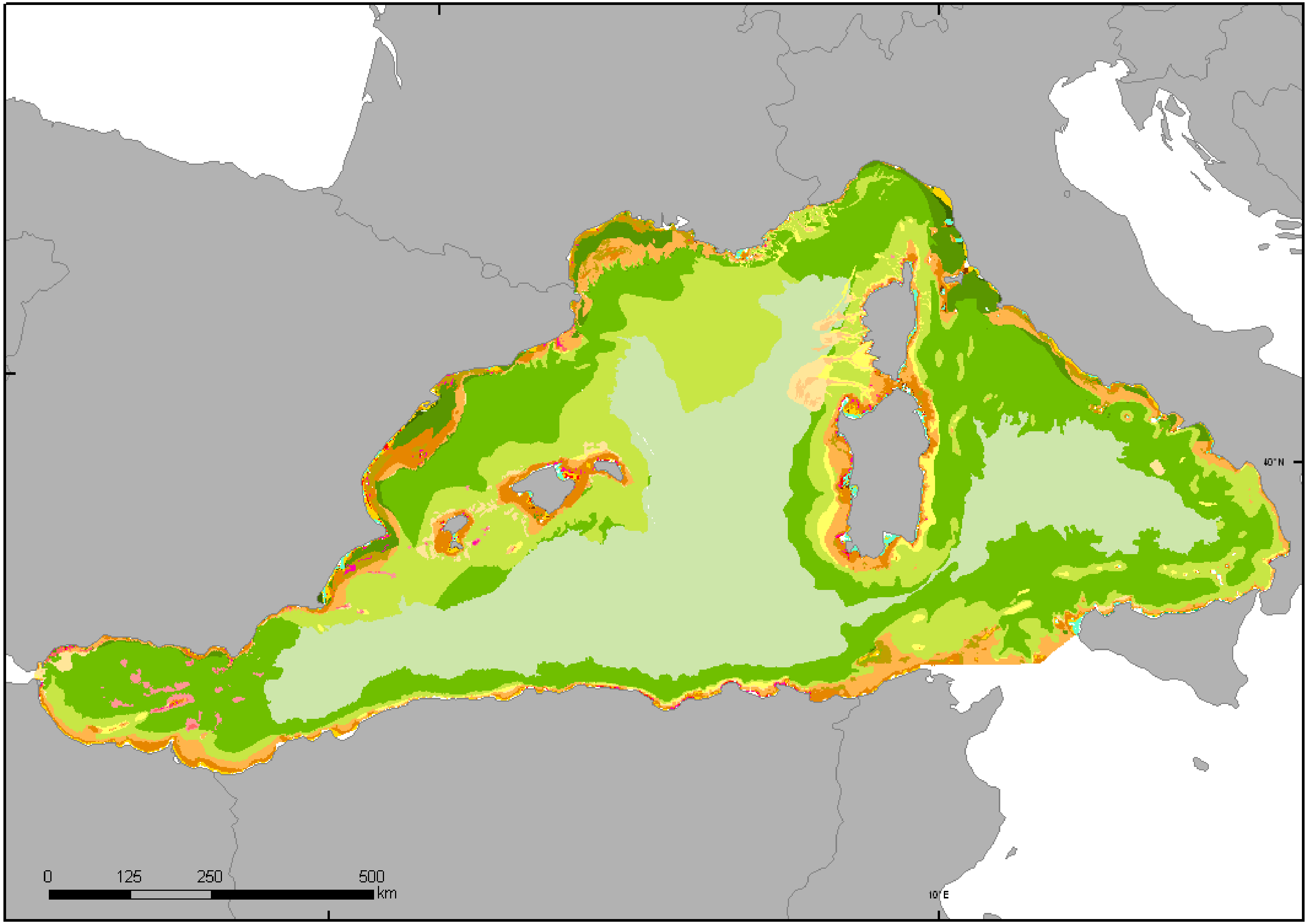

Figure 40 Full detail modelled seabed habitat map produced by the model for the western Mediterranean.

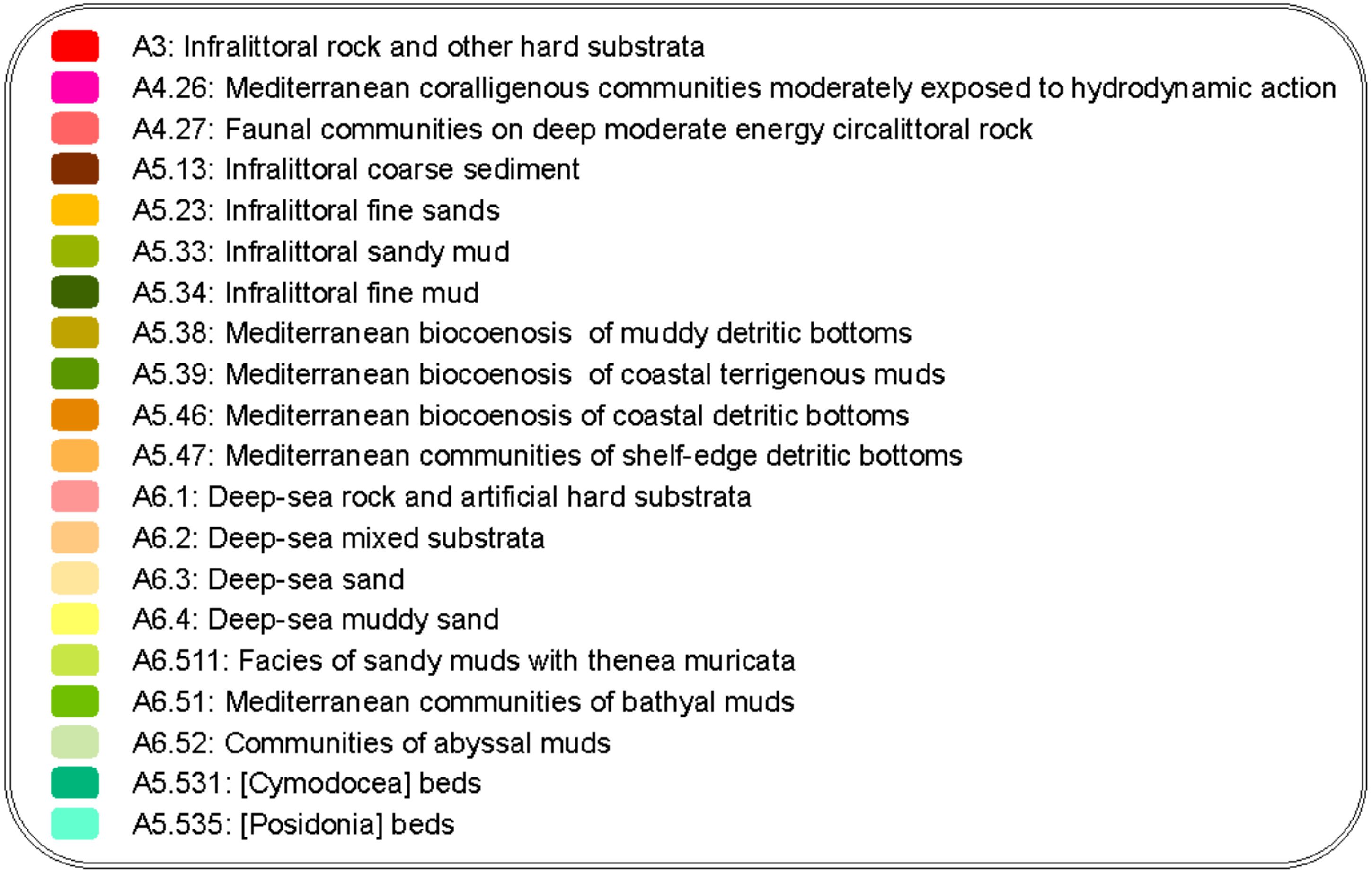

Figure 41 Legend for the full detail modelled seabed habitats for the Western Mediterranean.

7.3. Discussion of maps

In contrast to the North, Celtic and western Mediterranean Seas, the Baltic representation in EUNIS classification system is not well developed in the present version. The Baltic habitats are not comparable with the rest of the EUNIS classes at the same hierarchical level and also between the Baltic habitats there are several inconsistencies. For most habitats, there is a lack of description of the biological compartment. Furthermore, the habitats have been incorporated without any testing of the biological relevance of the environmental factors included at a high hierarchical level or the thresholds for these factors. An important step in the Baltic part of EUSeaMap project has therefore been to work on a more consistent Baltic EUNIS classification. The work has been done in collaboration with the HELCOM Biotopes Experts of the Project for Completing the HELCOM Red List of Species and Habitats/Biotopes, including experts from Sweden, Finland, Russia, Estonia, Lithuania and Poland.

The proposed Baltic EUNIS is presented in Wikström et al (2010). In short, it was decided to use substrate, biological depth zone and energy as upper-level factors, as in the Atlantic/Mediterranean EUNIS. However, an important difference is that in the Baltic, energy is used also applied to sediment. This was strongly advocated by the biotope experts, motivated by the facts that (1) mixed hard/sediment substratum of glacial origin (till) is a very characteristic feature of the Baltic Sea seabed across energy levels and (2) also sediment types such as sand are found in a range of energy levels, housing different biological communities. Hence seabed substrata alone are not an adequate proxy for energy conditions as in other regions (McBreen, Askew & Ellwood, in prep.). Another Baltic-specific feature is the presence of a strong halocline at 40-80 m depth, which separates specific deep zoobenthic communities from the more shallow communities. Therefore, the halocline was used to delimit the deep circalittoral in the Baltic proper.

The resulting map is shown in Figure 34. This represents a level corresponding to level 4 in the Atlantic/Mediterranean EUNIS system and gives 52 unique habitat classes for the Baltic Sea.

Salinity is known to be an important structuring factor in the Baltic Sea. Whilst salinity is perceived as a difficult factor to include properly, large-scale salinity can, however, be used to delimit biogeoraphic zones and has been used for management purposes within HELCOM. As such it is provided here as a possible alternative to energy for the high level structuring in the proposed Baltic EUNIS system. We therefore present a map of the substrate and depth zones (corresponding to EUNIS level 3) together with the salinity classes (Figure 36). This map may be more appropriate for certain applications, when it is important to consider the salinity regions. Including salinity and energy together with the habitats at level 4 is difficult, since it gives a very large number of unique combinations (~240), but could be done for smaller regions.

For most of the area covered by the North and Celtic Seas model, it was not necessary to give the same consideration to potential 'new' seabed habitat classes yielded by the model as it was in the other basins. The EUNIS classification system is generally well developed for the region, and a similar modelling exercise had been done in both the UKSeaMap and MESH projects. However, the use of improved datasets developed by the EUSeaMap project, extending the process to a greater area and much refined modelling techniques meant there were considerable challenges.

The development of the North and Celtic Seas model was done in close collaboration with the Baltic model, to minimise difficulties in the transitional area of the Skagerrak and Kattegat Seas between the North and Baltic regions. The models were developed to cover an area of overlap for two reasons. Firstly for technical reasons: to help to reduce run times, especially for debugging as the model was developed. Secondly, it allowed careful consideration and greater ease of testing how best to deal with the switch from the EUNIS system (for the Atlantic and Mediterranean) to the proposed EUNIS structure for the Baltic. The difficulty of this transition was compounded by the use of different datasets (for instance the use of satellite light data in the North and Celtic Seas, and Secchi depth data in the Baltic), and the varying influence of abiotic variables across the regions (e.g. salinity a critical data layer in the Baltic, or the relative lack of tidal currents when compared with the North and Celtic Seas). The models were eventually reconciled by using salinity as the data layer which determines the switch in the model rules. The North and Celtic rules were applied across the Skaggerak and Kattegat regions where the mean salinity was deemed polyhaline or euhaline (greater than 18 psu as applied to the DHI salinity layer). The salinity regime effectively becomes the dividing line; the switch between the North and Celtic Seas model and the Baltic model, and the respective classification schemes.

There are known issues that are related to or caused by the various input data used. In Irish waters EUNIS habitats were not possible to predict as the EMODnet geology project is in the process of incorporating ongoing work to reclassify Irish substrate data using backscatter data from recent multibeam surveys. As the other key data layers were available however, it was felt the area should be mapped as far as possible. Broad habitat descriptions are therefore given for these areas, based on biological zone and energy at the seabed, with these areas displayed in very pale colours only in the full detail maps (Figure 38). Figure 42 shows two particular issues; one relating to the difference in infralittoral/circalittoral thresholds applied to areas classed as polyhaline and euhaline. This is due to the switch in model rules and classification schemes between the Baltic and North Sea, which is dependent on the salinity regime. Refinements in the salinity layer, which is a relatively coarse resolution, could lessen the effect, as could future analysis of thresholds, specifically focusing on reduced or variable salinity habitats from this area. The second image shows errata in the bathymetry dataset that have been carried though from GEBCO. The project has made GEBCO aware of these and the EMODnet Hydrography group are incorporating more data in the next planned update to correct these areas.

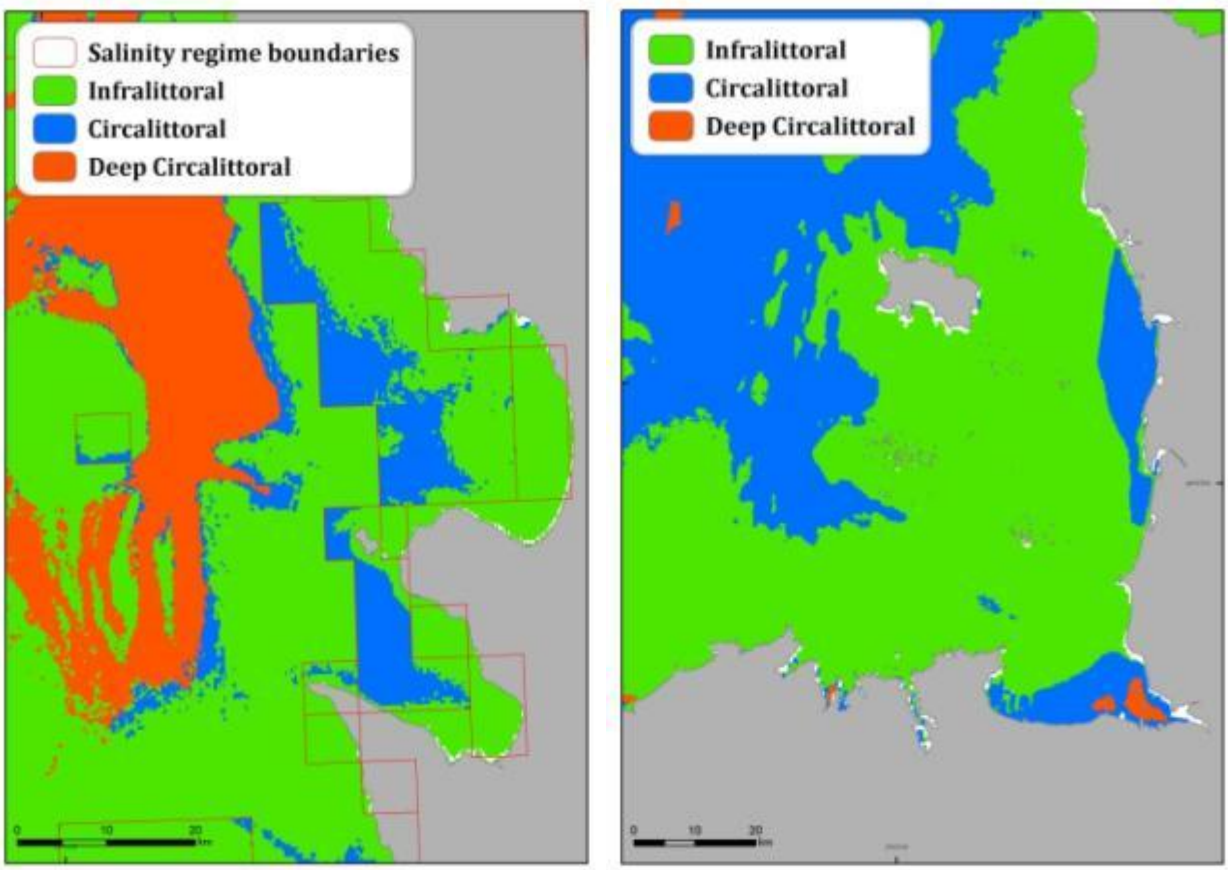

Figure 42 Errata in the EUSeaMap North and Celtic Seas. In the Kattegat (left), there are problems to be resolved with the light thresholds associated with the transition between the polyhaline and euhaline salinity regimes. In the Baie de Mont Saint-Michel, at the mouth of the Coueson river, and the Baie de Lancieux, depth errata from the EMODnet DEM, themselves residuals from GEBCO errata, are carried through into the misclassification of the biological zone in these shallow areas.

The Mediterranean modelled output consists of 21 habitat types (pertaining to 18 distinct EUNIS habitats) with the additional two seagrass habitats also inserted as additional substrata layers into the map. It must be remembered that the biggest challenge in choosing the modelled habitats for the Mediterranean consisted in identifying those biocoenoses which could be modelled first of all because of the their spatial extension with respect to the nature of a broad-scale map and secondly based on the intersection of the two principal abiotic variables at play: biological zone and substrate type. Trials to run the modelled map also utilising an energy layer proved unsuccessful because the energy layer resolution was not sufficient to differentiate the habitats at stake.

Six unexpected modelled habitat types (identified in red text in the table inAppendix II) are observed in the final map. These entail: two infralittoral soft bottom habitats (A5.33- infralittoral sandy mud and A5.34 - infralittoral mud), deep sea mixed substrata (A6.2) and deep-sea muddy sand (A6.4) found in both the bathyal and abyssal zones, and deep sea sand (A6.3) in the abyssal zone. All of these habitats do not have any interlinkage with the biocoenoses known to exist in the Mediterranean Sea.

A closer look at these novelty modelled habitats indicates that the infralittoral ones are the result of mud and sandy mud bottoms that are found in relatively shallow waters,areas that are modelled as infralittoral on the basis of the light layer. It must be remembered here that the study of benthic bionomy in the Mediterranean during the course of the last century has thoroughly described the existence of specific mud and muddy sand infaunal assemblages, properly known as occurring in the circalittoral zone, that can also be found in relatively shallower waters than usual when specific oceanographic conditions (currents) and fine particle sediment apposition (due to riverine inputs) are locally at stake. The likelihood of such a circumstance has already been mentioned in section 3.1. Analysis of the spatial positioning of these two habitat types in the modelled map (Figure 43) reveals that the larger areas are proximate to important river inputs (i.e. Tuscany: Magra and Arno rivers, southern Catalunya: Ebro river, Murcia/southern Valenciana: Segura river). In these cases, though the substrate would ordinarily attribute these areas as a likely circalittoral habitat in the western Mediterranean, the light layer used in the model to identify the biological zone overides and pushes the areas into the shallower infralittoral zone. This experience demonstrates that the EUSeaMap modelling approach could be improved by allowing specific substrate typologies (mud and sandy mud), when they are found in low depths, to actually override the light threshold limit (used to differentiate the infra and circalittoral zones) when in proximity to conspicuous river mouths. On the other hand analysis of the spatial positioning of these habitats where they occur on relatively smaller areas (Gulf of Lyon and Ligurian Sea) suggests that the error in biological zone attribution could be justified through the interpretation of the fuzzy confidence limit.

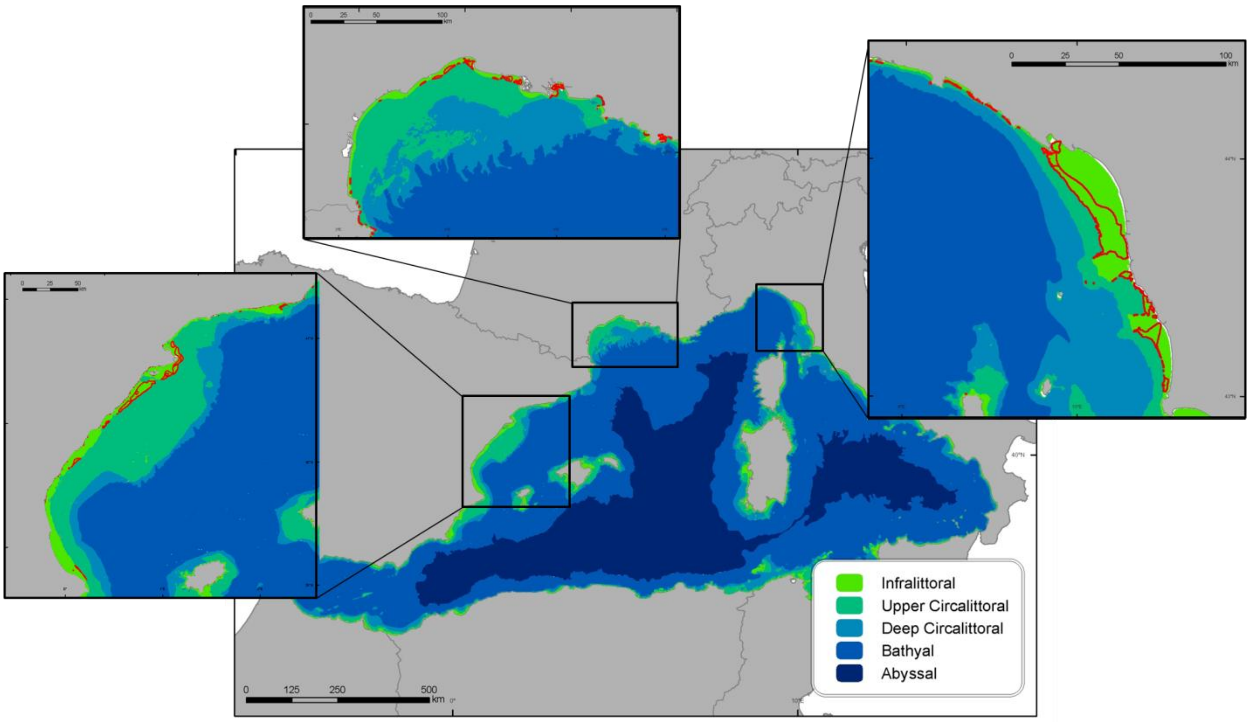

Figure 43 Infralittoral muddy habitats modelled in the western Mediterranean's infralittoral zone, which are thought to be a consequence of riverine influences. The areas highlighted are all near the mouths of major rivers: the Ebro and Segura in Spain, the Gulf of Lyon in France and the Arno and Magra in Italy.

The new modelled habitats identified in the bathyal and abyssal zones represent a very different situation to the infralittoral ones above. Such habitats emerge from the identification of specific areas, mostly located in the sea west of Corsica (Figure 44), for which recent investigative studies have demonstrated the presence of sand, muddy sand and mixed sediments at deep depths. Though there is no bibliographical knowledge for the Mediterranean on the biological communities that may be present on such substrate categories at these depths, nor how they may be different to those of other known deep sea communities, the emerging novelty of the EUSeaMap modelled map describes the presence of such habitats at least from a sediment category point of view.

Finally, it must be remembered that the current version of the EUNIS classification differentiates most of the deep sea (A6) categories only by substrate type, making no distinction between those of the Bathyal and Abyssal zones. In the North and Celtic models these deep-sea habitats have been shown according to a more detailed zonation of the bathyal and abyssal zones, as proposed by Howell (2010). The A6 habitat classes according to the current EUNIS system are only included as attributes to the cell outputs of the North and Celtic to allow for consistent presentation if required by the user. As no work has yet been done for the Mediterranean, the deep sea areas have only been presented under the current EUNIS classification scheme, regardless of their respective bathyal or abyssal positioning.

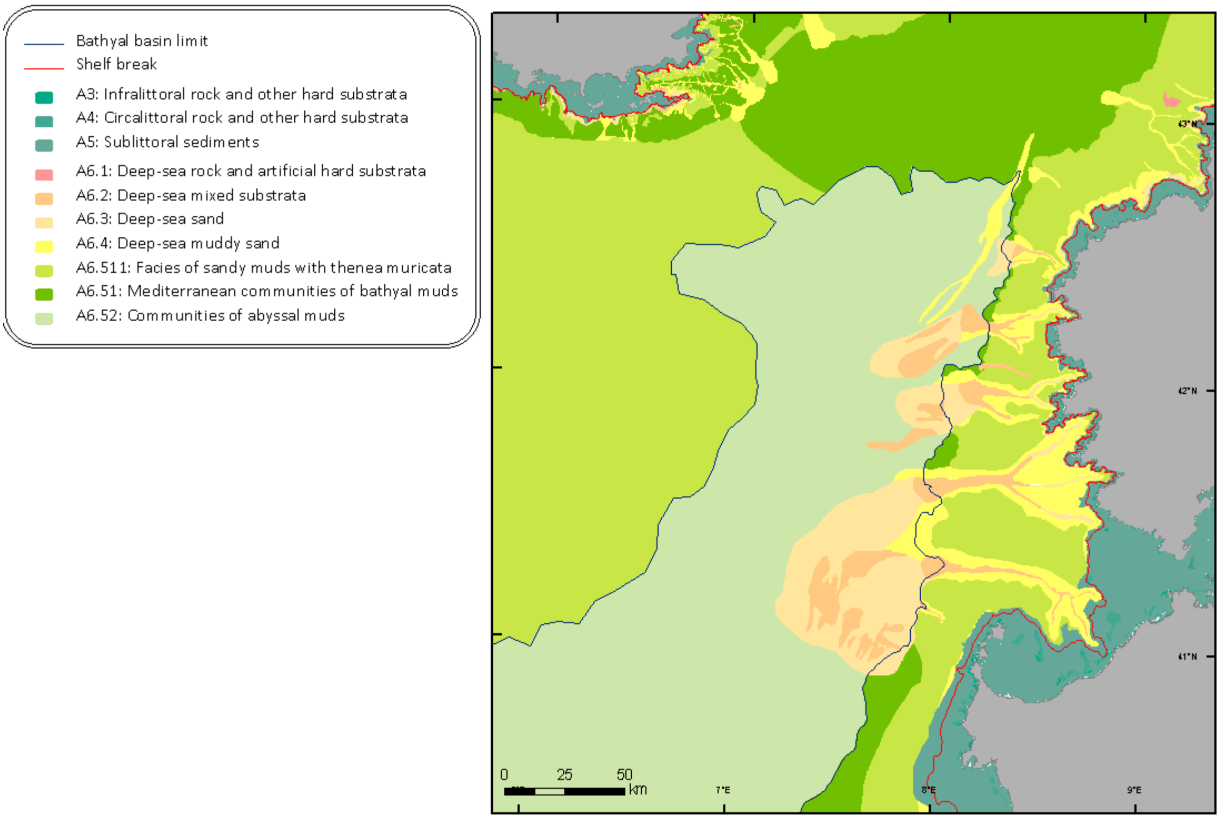

Figure 44 Close up of some of the deep-sea habitats in the western Mediterranean. The shelf break and bathyal basin limits illustrate the strating point of the bathyal and abyssal zones. Sublittoral habitats are only shown at EUNIS level 2 for the purposes of illustration.

8. 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

8.1. 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 used across the EUSeaMap basins, it was felt that computing probabilities of occurrence in each class for 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 datasets 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 45 and Figure 47 show the application of this index to the substrata maps, with scores varying from 30 in the central Mediterranean (IBCM substrata 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. The results can be seen in Figure 46 andFigure 48.

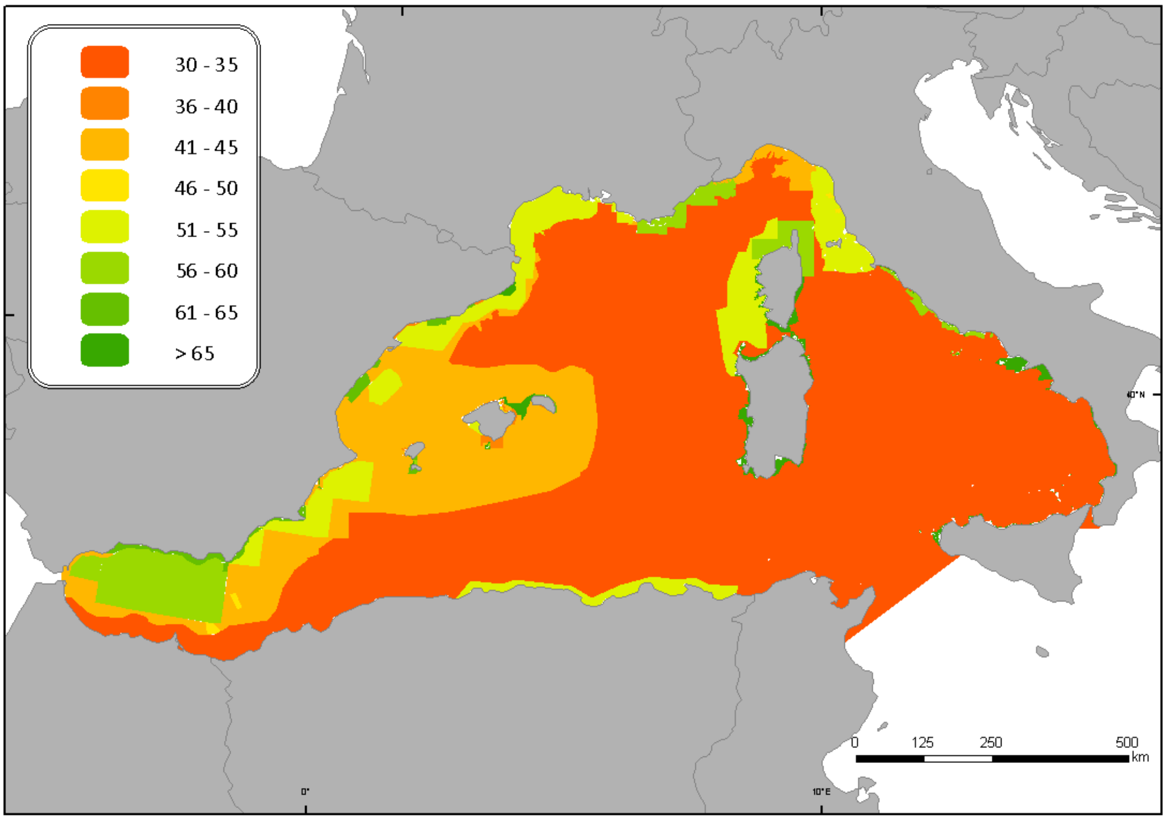

Figure 45 Scores of sediment maps for western Mediterranean.

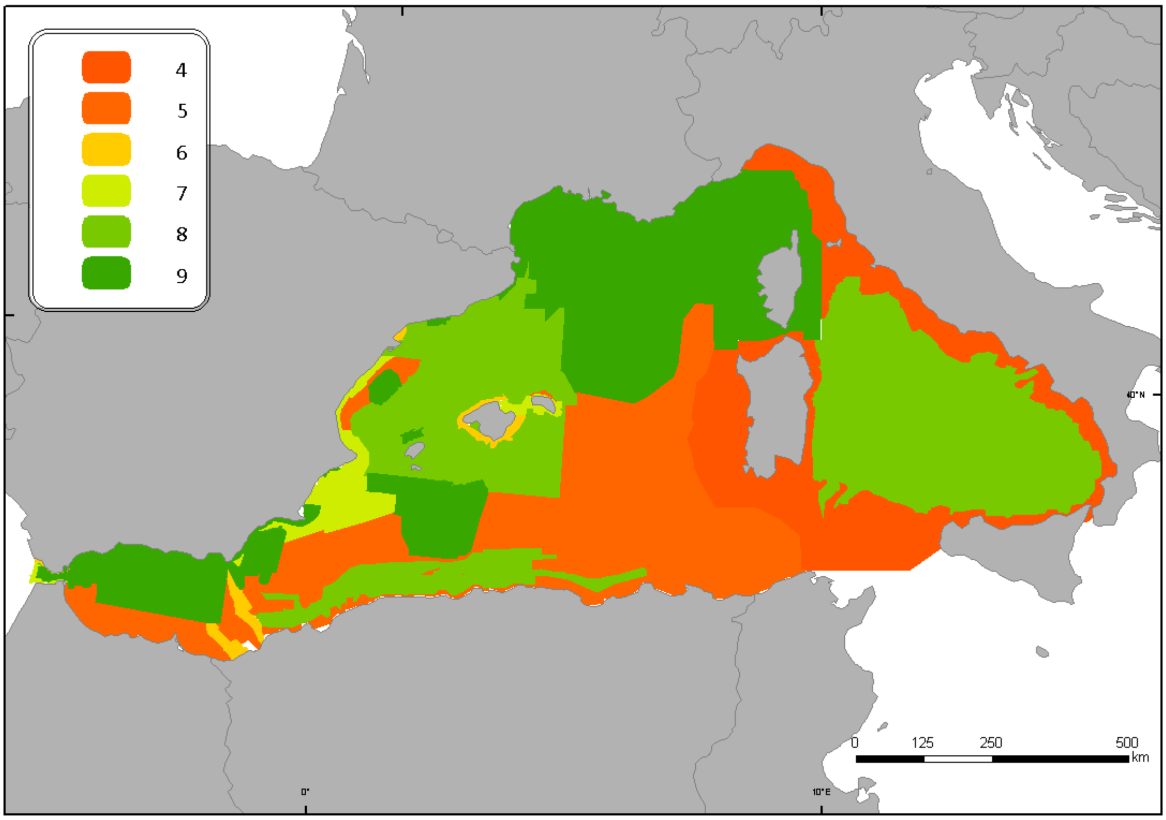

Figure 46 Scores of bathymetry maps for western Mediterranean. A maximum score is 9, from scoring 3 for each of resolution, vintage and data origin.

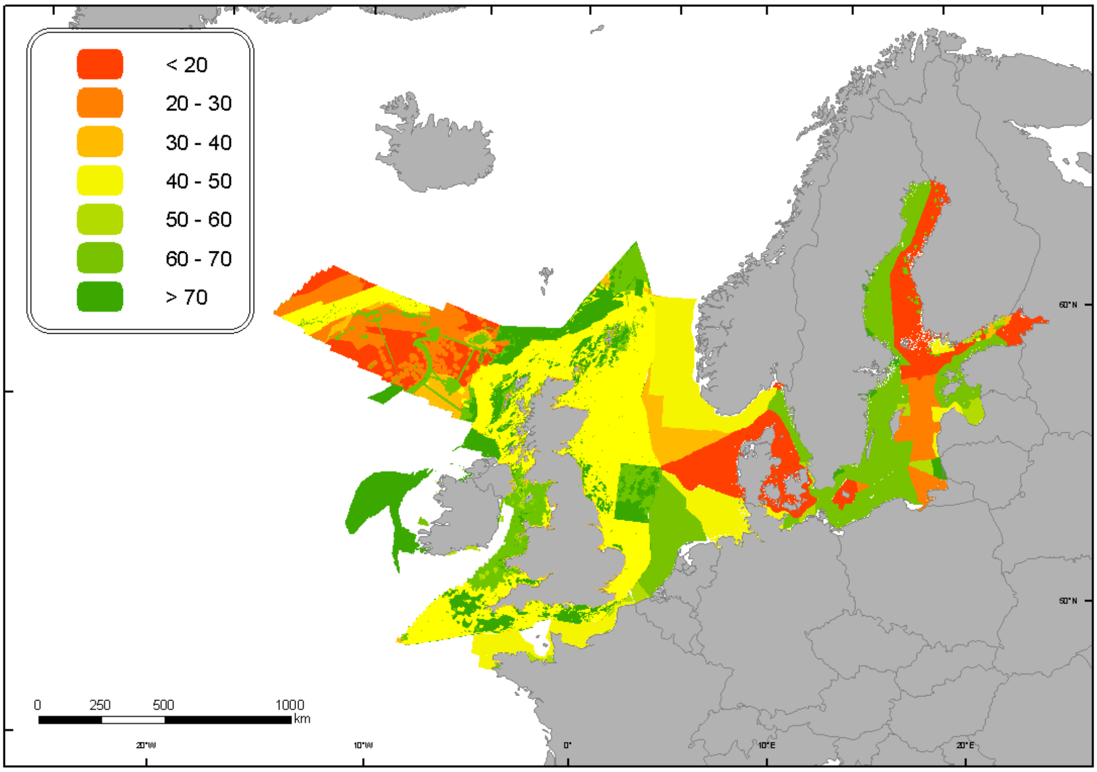

Figure 47 Preliminary scores of EMODnet sediment maps for Celtic, North and Baltic Seas. Note no score is given for areas of the Irish EEZ where data are not yet incorporated into the EMODnet geology substrate map. The EMODnet Geology project is working on a more detailed confidence assessment.

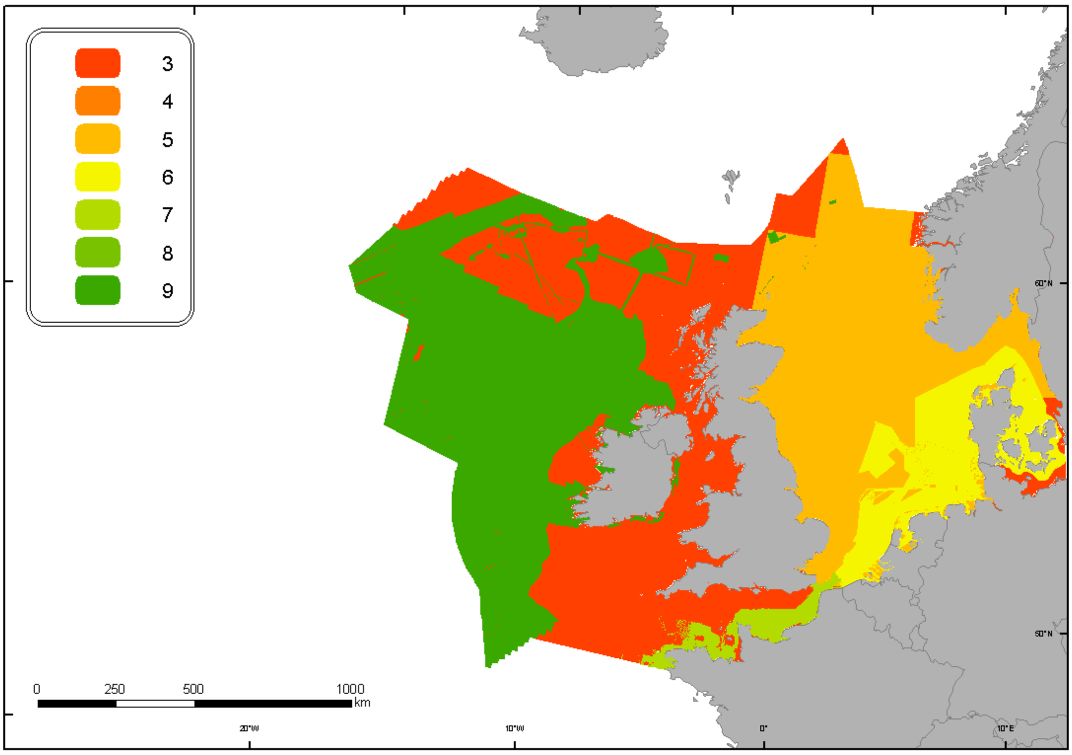

Figure 48 Source confidence assessment scores for bathymetry, North and Celtic Seas. Sources are those used for EMODnet Hydrography DEM. Though its was used for habitat modelling in UK waters, scoring for SeaZone hydrospatial is omitted here to illustrate better the EMODnet hydrography DEM, and the problems that arise from difficulties accessing UKHO data.

8.2. Confidence by validation against surveyed habitats

Tests were run in the Mediterranean using both the final modelled map and ground truth data available to the project. Among the 20 modelled classes, 13 classes were represented in ground truth data.

The following considerations centres on the analysis of the modelled habitats compared against known distribution of selected Spanish and Italian data (ground truth point sample data and polygon centroids from biocenotic maps) of biological communities pertinent to some of the modelled habitat categories. Table 13 and Table 14 report the degree of accordance or discordance, expressed in terms of number of point data, between the set of ground truth data considered for each habitat type with respect to its actual physical habitat allocation in the modelled habitat map for the western Mediterranean.

There is a general lack of sufficient quantities of biocenotic data useful for the validation of all the modelled EuSeaMap habitat types, hence not all modelled habitat categories could be validated against known habitat distributions.

Table 13 Validation results from Italian data on known biological community distribution

	Modelled habitat category in which point data fall (expressed as number of point data records)														
Category of known habitat point data used for the validation	**Italy**	A3	A5.13	A5.23	A5.33	A5.34	A5.535	A4.26	A5.46	A5.38	A5.39	A4.27	A5.47	A6.51	Total
	A3	4		10			1	2	5				2		24
	A5.13		2	2									5		9
	A5.23			39	1		2		5	1		1			49
	A5.33														0
	A5.34														0
	A5.535														0
	A4.26									1					1
	A5.46		3	5				1	15				2		26
	A5.38			3		1			7	5			1		17
	A5.39								2	13	21		6		42
	A4.27														0
	A5.47										6		3		9
	A6.51												1	3	4

	Modelled habitat category in which point data fall (expressed in percentage)													
Category of known habitat point data used for the validation	**Italy**	A3	A5.13	A5.23	A5.33	A5.34	A5.535	A4.26	A5.46	A5.38	A5.39	A4.27	A5.47	A6.51
	A3	16,7		41,7			4,2	8,3	20,8				8,3	
	A5.13		22,2	22,2									55,6	
	A5.23			79,6	2,0		4,1		10,2	2,0		2,0		
	A5.33													
	A5.34													
	A5.535													
	A4.26									100,0				
	A5.46		11,5	19,2				3,8	57,7				7,7	
	A5.38			17,6		5,9			41,2	29,4			5,9	
	A5.39								4,8	31,0	50,0		14,3	
	A4.27													
	A5.47										66,7		33,3	
	A6.51												25,0	75,0

In Italy a total of 172 data points were available covering ten of the more coastal habitats. Habitats for which no biological community/habitat data were available were: *facies* of sandy muds with *Thenea muricata*, deep-sea sand. Furthermore, for some habitats for which validation was possible, the number of pixel centroids that could be used in the validation process was extremely low (<10) thereby producing weak validation results due to low sample size. The validation process for such habitats (infralittoral coarse sands, faunal communities on deep moderate energy circalittoral rock, shelf edge detritic bottoms, bathyal muds) was therefore not considered because any conclusions on the accordance/discordance would likely lead to biased interpretations. For some habitats instead, a higher number of habitat data records (range 17-56 datapoints for each habitat validation trial) were available and the validation of the modelled habitat map for such habitat types can therefore considered sturdier. A closer look at the discordance values obtained for these validation trials illustrates some limits and drawbacks of the modelling process.

In Spain, 99 centroids were extracted from biocenosis maps in the Balearic Islands (Figure 49). They mostly fall into either A4.26 or A5.46, which improves the Italian dataset in terms of number of occurrences for these two habitats.

Table 14 Validation results from Spanish data on known biological community distribution

	Modelled habitat category in which point data fall (expressed as number of point data records)										
Category of known habitat point data used for the validation	**Spain**	A3	A5.23	A5.535	A5.531	A4.26	A5.46	A5.38	A4.27	A5.47	Total
	A3		1								1
	A5.23						1				1
	A5.535										0
	A5.531										0
	A4.26	2				33			2		37
	A5.46	1	5			4	45			1	56
	A5.38						3				3
	A4.27										0
	A5.47										0

	Modelled habitat category in which point data fall (expressed in percentage)									
Category of known habitat point data used for the validation	**Spain**	A3	A5.23	A5.535	A5.531	A4.26	A5.46	A5.38	A4.27	A5.47
	A3		100,0							
	A5.23						100,0			
	A5.535									
	A5.531									
	A4.26	5,4				89,2			5,4	
	A5.46	1,8	8,9			7,1	80,4			1,8
	A5.38						100,0			
	A4.27									
	A5.47									

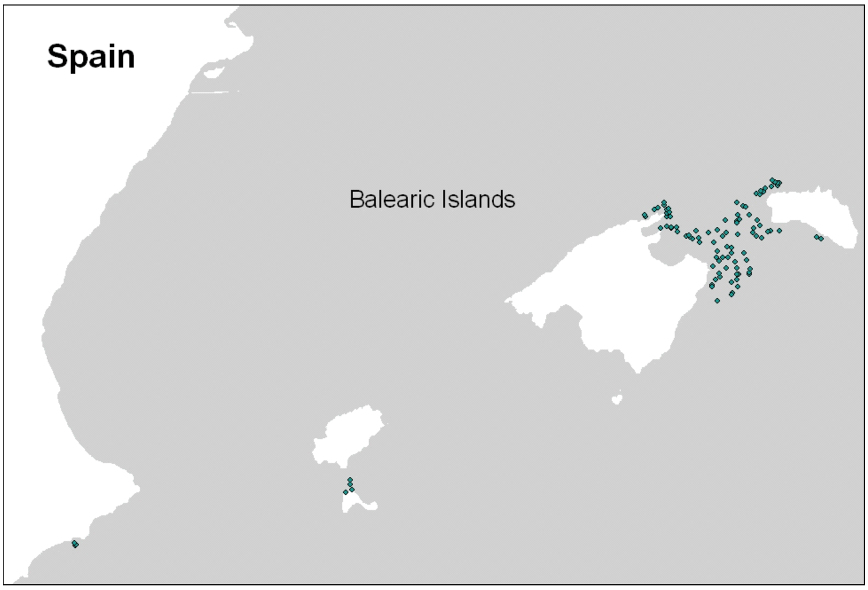

Figure 49 Location of point samples taken from Spanish biocenosis maps in the Balearic Islands.

The first observation is that the overall fit between the modelled map and ground truth data reaches 61%, an improvement with respect to preliminary results. According to the considerations above and from results given in similar exercises by the MESH project (MESH, 2008) it is acceptable that there is about a 50% chance that the habitat assigned by the model is correct.

Considerations on the specific habitat types for which validation entailed more than 17 data records are given below.

8.2.1. Infralittoral habitats

A3 – Infralittoral rock

Only 15% of this habitat's known occurrence in Italian data records was correctly attributed to this habitat category in the EuSeaMap. A high amount (37% in Italy) of data records for this habitat were incorrectly modelled as A5.23 - infralittoral fine sand. This is likely driven by the fact that infralittoral rock distribution in the Mediterranean has a spatial extension smaller than the 250 metre pixel size and as such, areas in which the rock is present are wrongly attributed to the substrate category of the surrounding soft bottoms which in most cases are naturally composed of infralittoral sands. 34% of known infralittoral rock data records (Italian seas) were instead attributed to habitats of the circalittoral (7.4% coralligenous rocky bottoms, 18.5% coastal detritic and 7.4% shelf edge detritic). This second category of discordance is largely driven by ground truth data involving rocky infralittoral habitats occurring on rather steep bottoms. Because of the steepness of the sea bottom the cartographic interpolation driven by the 250m pixel size can lead to the pixels being allocated to the beginning of the nearby circalittoral zone, and can also lead to the pixel involving the substrate layer, to be allocated to a wrong substrate category such as that of a mixture of sandy bottoms. The discordance values observed in the validation process therefore seem to highlight that infralittoral rock is a habitat type whose small spatial extension makes it not fully adequate for a broad scale habitat map, thereby easily leading this habitat distribution to its allocation into nearby soft bottom areas or, in the case of steep bottoms, to nearby circalittoral habitats.

A5.23 -Infralittoral fine sand

72% of Italian ground truth data for this habitat were correctly attributed to this modelled habitat category. On the overall, the modelled map seems to provide a good capacity to model infralittoral fine sand. A small minor amount (5.6%) fall within other infralittoral soft bottom habitats due to errors in pixel extrapolation. Another 13.2% of the data records fall in circalittoral habitats. This error is due in some cases to the fact that the steep incline of the sea bottom (i.e. the promontories of Campania) brings a rapid passage from an infralittoral zone to a deeper circalittoral one within a small horizontal distance.

8.2.2. Circalittoral habitats

A4.26 – Mediterranean coralligenous communities moderately exposed to hydrodynamic action

The coralligenous communities ground truth data, mostly identified by Spanish data, have an 89% concordance with the actual modelled habitat thereby validating the capacity of the modelled map to model this habitat type.

A5.46 - Mediterranean biocenosis of coastal detritic bottoms

The point data used for Italian and Spanish validation respectively display 57.7% and 80% correct attribution into this specific modelled habitat type. The gross amount of discordance in the Italian data involves infralittoral habitats of coarse sands and fine sands accounting for respectively 11.5 % and 19%. This discordance is mostly derived from the fact that the ground truth data used for the validation stem, in some cases, by coarse scale habitat maps (1:250,000) which tend to overestimate the extension of this circalittoral habitat with its likely real distribution.

A5. 38 – Mediterranean biocenosis of muddy detritic bottoms

Italian ground truth data show 26.3% modelling into the right category while 37% of the ground truth data instead erroneously falls into the A5.46 (coastal detritic bottoms) modelled category. This discordance is largely generated by the fact that the ground truth data used are extremely fine scale while the substrate cartography used to build the substrate layer in these specific points was derived from a broad scale map which is likely to have introduced an error bias in terms of substrate typology, thereby attributing muddy sand to areas which should have been classified as sandy mud. The transition between these two biocenoses could in most cases be determined by very fine scale substrate maps. However, since these maps are often not available, modelling of these two habitats (muddy detritic versus coastal detritic) could benefit from a further modelling input involving a third abiotic variable, specifically that of the energy at the seabed. In fact the presence of more or less mud in the upper circalittoral zone is very much influenced by the effect of bottom currents.

A5.39 – Coastal terrigenous muds

50% of ground truth data from Italian waters correctly falls within the modelled habitat for coastal terrigenous mud. The remaining coastal terrigenous data that discord with the model fall within other circalittoral soft bottoms, a large extent of which (31%) are allocated to the muddy detritic habitat. The explanation behind this discordance seems to lie in areas for which fine scale substrate data were not available and in which only gross scale data could be used (i.e. IBCM) or due to a harmonisation process involving transposition of sediment descriptions classified according to Nota (1958) and subsequently translated into Folk simplified classification. This is likely to have introduced a substrate allocation error thereby contributing to the translation of muddy substrate polygons into sandy mud ones.

Conclusions

In general, the accordance and discordance values observed in the validation process indicate that errors in the modelling process can only be defined using these methods if there is a large number of ground truth data available. The exercise showed that significant data records were only available for six of the modelled habitat types thereby indicating that more accurate ground truth data sampling needs to be envisaged when one approaches the validation process of a modelled habitat map. Very little ground truth data was available for habitats of the deep circalittoral and bathyal zones so validation on the correctness of fit of the boundary between upper and lower circalittoral was not achievable. The lack of ground truth data availability emphasizes the notion, already stated cited in the scientific benthic manuals, that deep water biological communities are still not completely well known. Future efforts will have to be geared to collecting sufficient validation data in a stratified way with respect to habitat classes.

Habitat types that have a limited spatial extension with respect to the 250m pixel resolution have a higher risk of being incorrectly modelled. This seems to be clearly the case for infralittoral rocky bottoms which not only run the risk of being erroneously modelled as a soft bottom habitat of the infralittoral but also as falling into the nearby circalittoral. In the Mediterranean where rocky infralittoral areas are characterised by steep bottom inclines this risk is heightened with small areas of infralittoral potentially being modelled as circalittoral.

Errors in modelling soft bottom habitat types having substrate characteristics that are the result of close transition in grain size (i.e. sandy mud versus muddy sand) can be grossly accentuated when the substrate layer is constructed with broad scale substrate maps (i.e. IBCM), or with old and less accurate maps, or that have an original grain size classification scheme different from the one used in the project. This implies that more attention needs to be put into collecting high quality sediment maps for geographic areas where such maps are missing. Fine modelling of some soft bottom habitat types requires a fine scale energy model to differentiate habitat types apart from sediment typology. This seems to be the case for coastal terrigenous and muddy detritic and coastal detritic habitats.

8.3. 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 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 50).

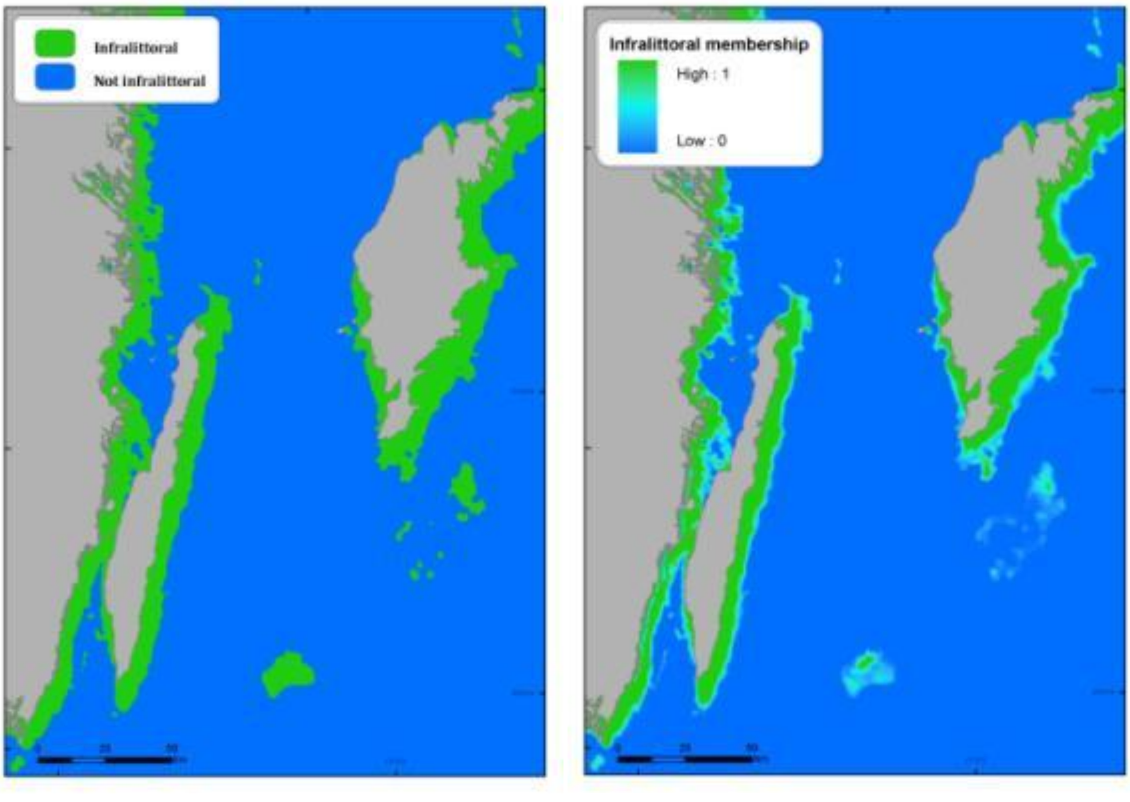

Figure 50 Example of a hard (left panel) and soft classification (right panel) of the infralittoral zone around Gotland and Öland in the Baltic Sea using depth : secchi depth quotient. The differences can be observed in the boundary zones of the habitat, where the soft classification results in a gradient of membership to the biological zone, itself a measure of confidence related to the threshold used.

In the EUSeaMap project, fuzzy classifiers were implemented in the models for all input variables except substrate, which as a discreet variable, since only a preclassified map was 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 were not available, arbitrary ranges were used around ‘hard’ classifier values to illustrate uncertainty around the thresholds between classes. A summary of the methods used to define the fuzzy range for each threshold is listed in Table 15 and the derivation of the thresholds used in the model are outlined in detail in the technical appendices associated with each input variable.

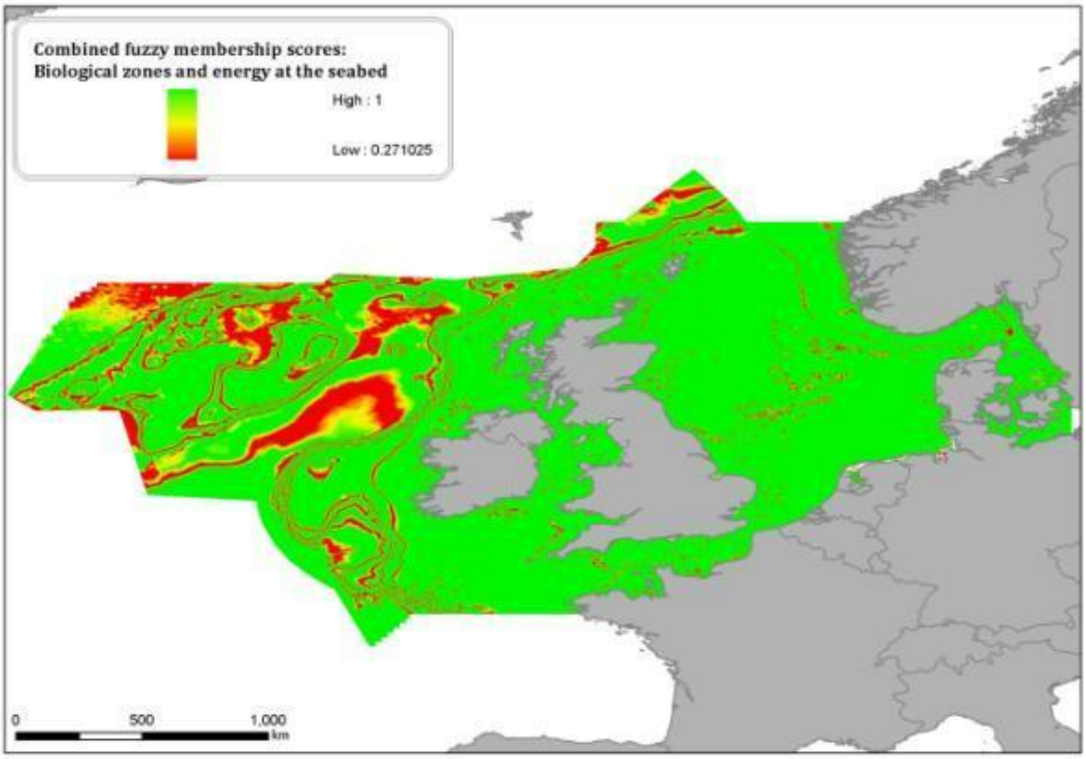

Figure 51 Combined fuzzy membership scores from biological zonation and energy regime produced by the seabed habitat model for the North and Celtic Seas.

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 (illustrated in Figure 52). A cell with a score of near one 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 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 51 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 (red areas) that subdivide the substrate map to produce the final seabed habitat map. Locations that are near average conditions for a particular biological zone and energy class, i.e. fall well within the fuzzy boundaries of a habitat with respect to light, depth, wave base and energy will appear green. In the example shown in Figure 51 the boundaries of the underlying biological zones can be seen clearly as a gradation from high to low membership (near the threshold range). In particular, the deep sea zonation can be seen as these thresholds were based purely on depth, with energy classed as low (and hence contributing a consistent high membership) for this area. Large areas of this red here therefore indicate an area of relatively slight change in depth (the gradual change from lower bathyal to abyssal). This could be reduced by reducing the fuzzy range around this threshold, however ideally this would be by means of access to more deep sea biological data to allow a statistical approach.

These maps produced using fuzzy logic provide the user with a sense of certainty in the classification of each grid cell. They are an indication of the certainty around boundaries, and hence a very different measure of confidence than that shown in the source data confidence assessments in section 8.1. The user can use both in conjunction to inform him better about the confidence associated with a habitat at a particular location, but they cannot be combined as they are derived in two very different ways and operate at different spatial scales.

Table 15 Summary of thresholds and the associated method used to define their fuzzy range.

Region	Layer	Variable	Threshold (lower limit)	Fuzzy
All	Biological zone	Light % at seabed	Infralittoral	Based on biological threshold analysis data
Mediterranean	Biological zone	Shelf break	Deep Circalittoral	Not possible, hard classifier
Mediterranean	Biological zone	Bathyal break	Bathyal	Not possible, hard classifier
North/Celtic	Biological zone	Bathymetry	Deep Sea zones (upper slope to abyssal)	Arbitrary (10%)
North/Celtic	Biological zone	Wave base	Upper circalittoral	Arbitrary (10%)
North/Celtic	Energy due to currents	Kinetic energy at seabed	High, Moderate and Low classes	Arbitrary (10%)
Baltic	Energy due to waves	Kinetic energy at seabed	High, Moderate and Low classes	Based on biological threshold analysis data
North/Celtic	Energy due to waves	Kinetic energy at seabed	High, Moderate and Low classes	Based on biological threshold analysis data
Baltic	Halocline	Probability of seabed below the halocline	Deep Circalittoral (in Mesohaline)	Expert judgement
Baltic	Salinity	Salinity (mean)	Oligohaline class	Based on biological threshold analysis data
Baltic	Salinity	Salinity (mean)	Mesohaline, Polyhaline and Euhaline classes	Expert judgement

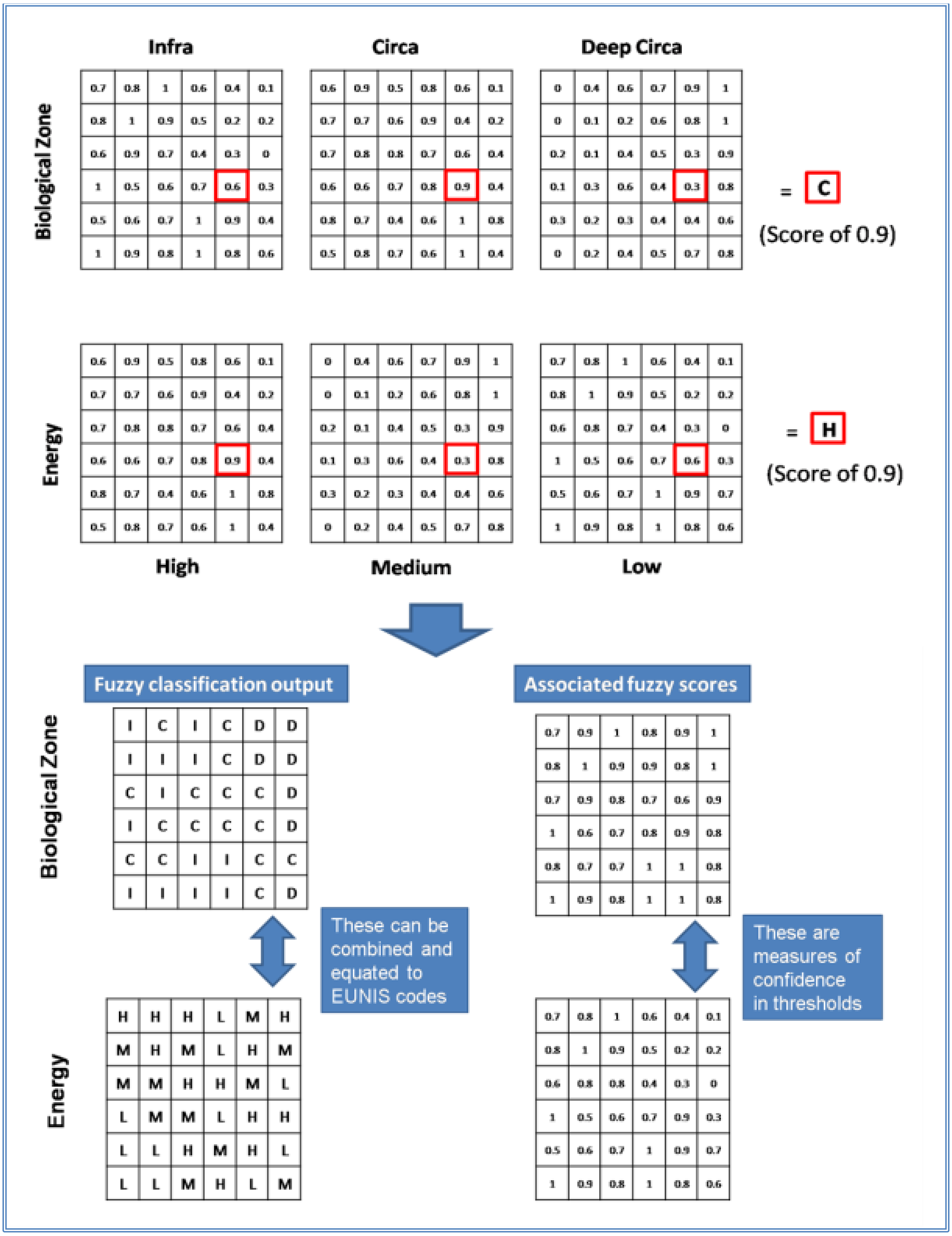

Figure 52 Illustration of the cell by cell process that uses fuzzy membership values to a) classify each grid cell using input data layers and b) retain the membership score for the output classification that gives a measure of associated certainty.

9. Making data available

www.jncc.gov.uk/EUSeaMap[33]

The modelled seabed habitat map is available free of charge to users. An interactive web mapping portal (a webGIS) allows 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 is 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 are 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 EUSeaMap webGIS uses 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, confidence maps, input data layers and raw data layers are loaded onto the webGIS.

The webGIS 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
- 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)
- Online instructions, to allow users to use the webGIS efficiently as well as to understand the EUSeaMap aims and methods

The input data layers used to model the seabed habitats are 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 are 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 conform to Open GIS Consortium[34] standards for exchange of geographical information. This is necessary for Web Mapping Services to function; the system is

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[33] username: emodnetpartner / password: euseamapportal

[34] www.opengeospatial.org

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 during the maintenance phase by entering metadata in the CAMIOON catalogue which is not yet available to EUSeaMap.

A login system for users to access restricted datasets has been developed, though not enabled, in case it should be required in future. 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 remain 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 a central WMS 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: Febr uary 2011-March 2011.

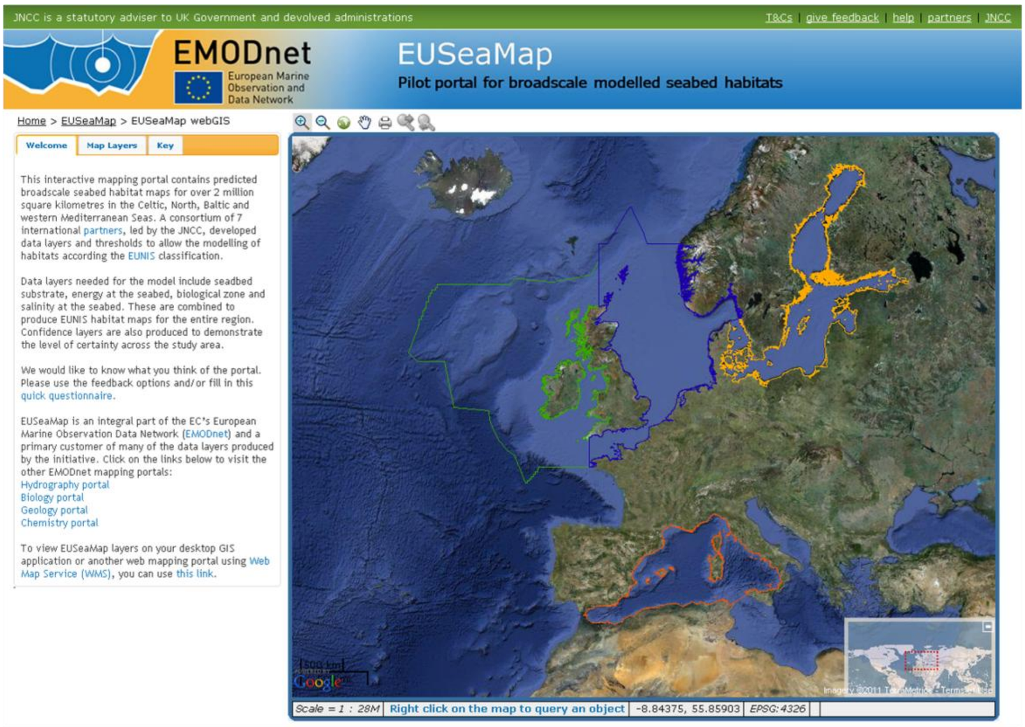

Figure 53 The EUSeaMap webGIS, showing the EUSeaMap project regions and Welcome tab.

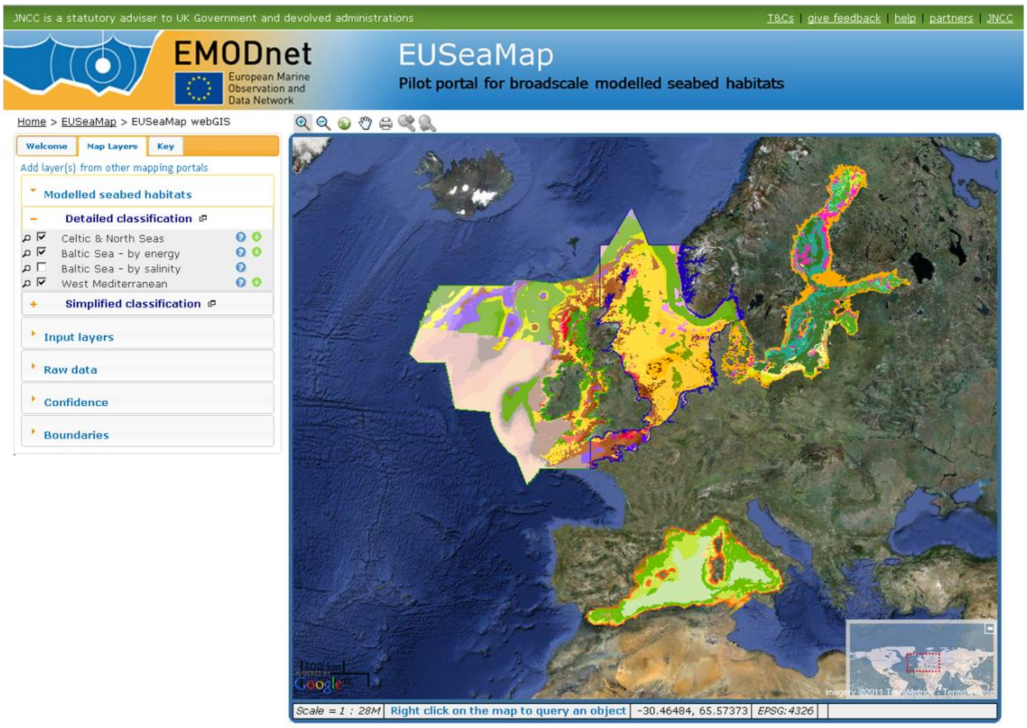

Figure 54 Seabed habitat maps for all basins, from the 'Model outputs' group. Map Layers tab is shown. Note the green download button and blue help button next to the layer name, and location window in lower right corner.

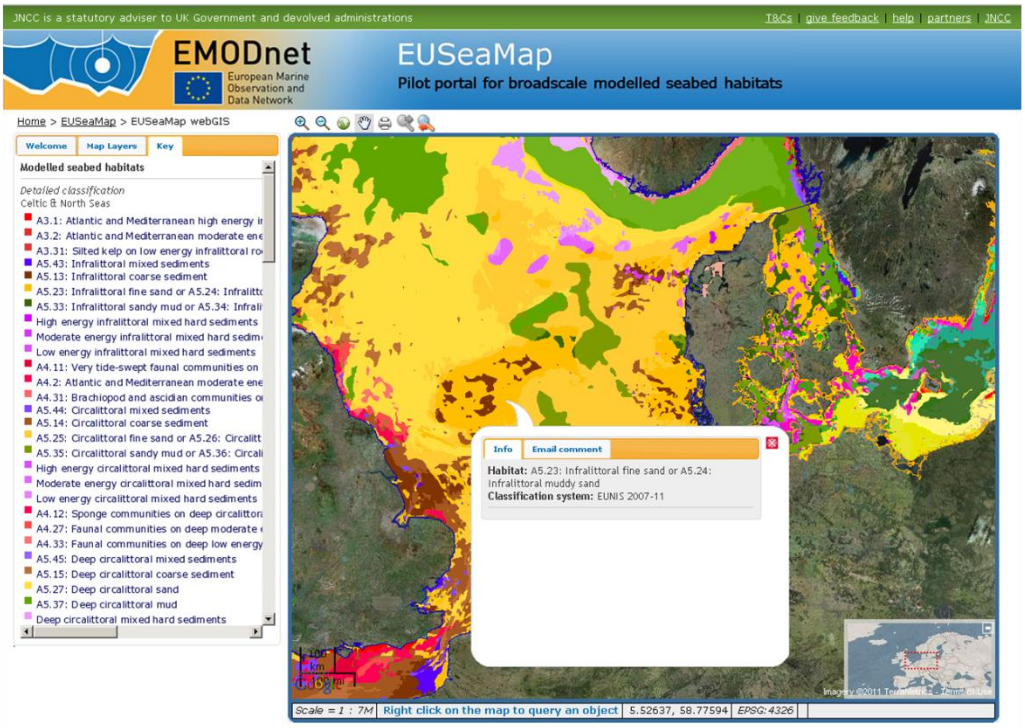

Figure 55 A zoom to part of the North Sea seabed habitat map, showing the Key tab. The Info pop-up is reached by right-clicking on the map and has a facility to comment on the layer via email.

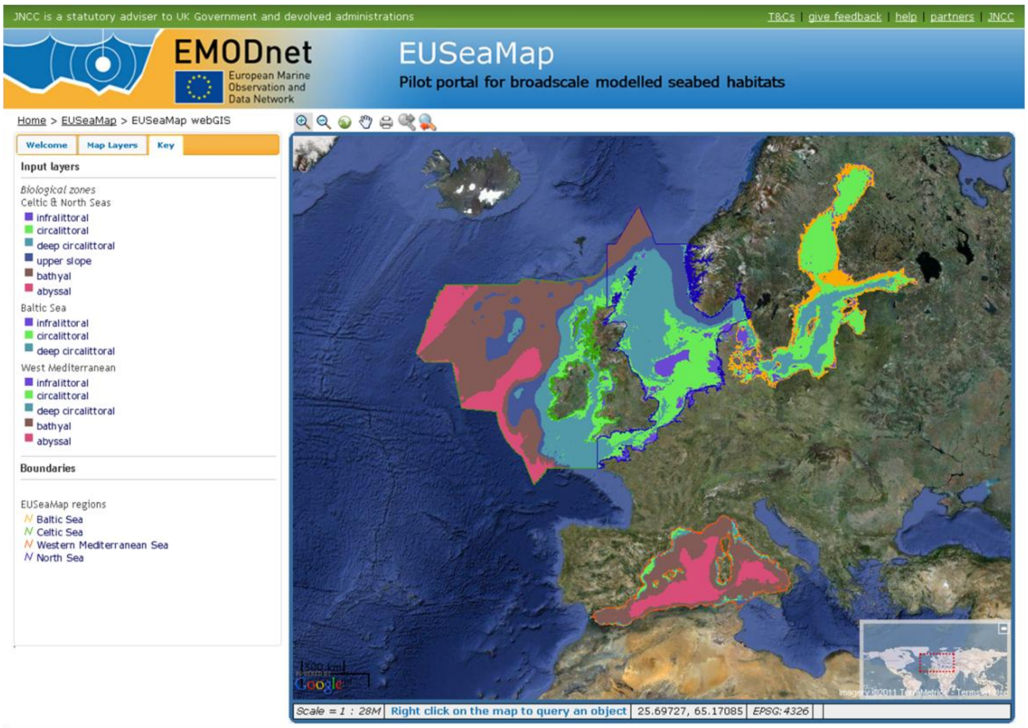

Figure 56 Biological zone maps for all basins, from the 'Input layers' group. Map Layers tab is shown.

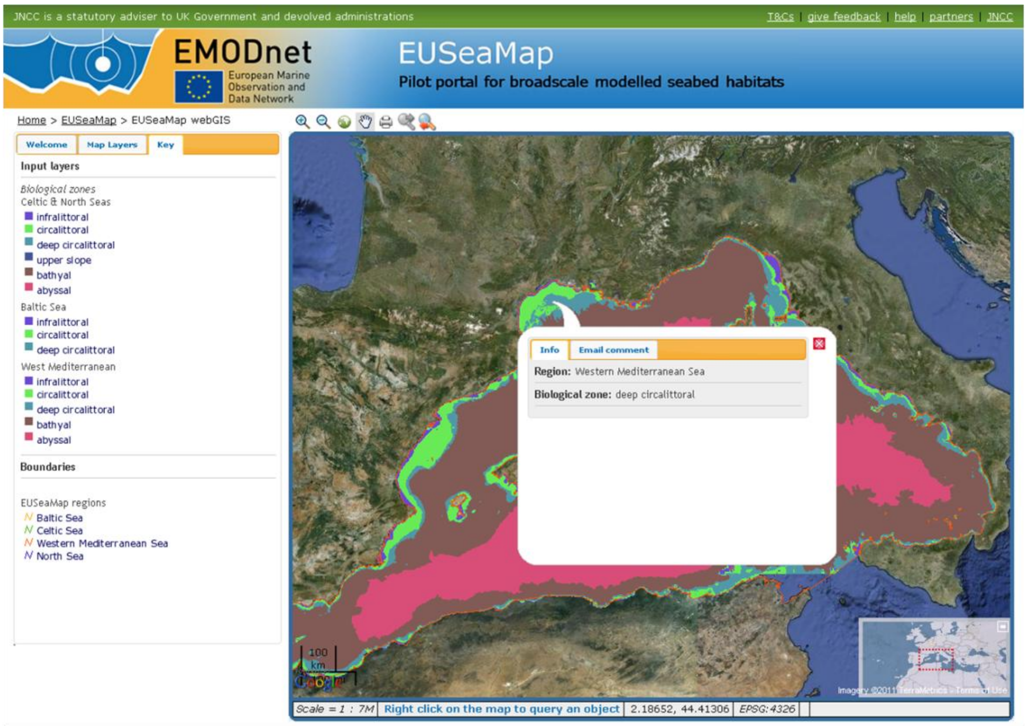

Figure 57 A zoom to part of the Western Mediterranean biological zones map, with Info pop-up.

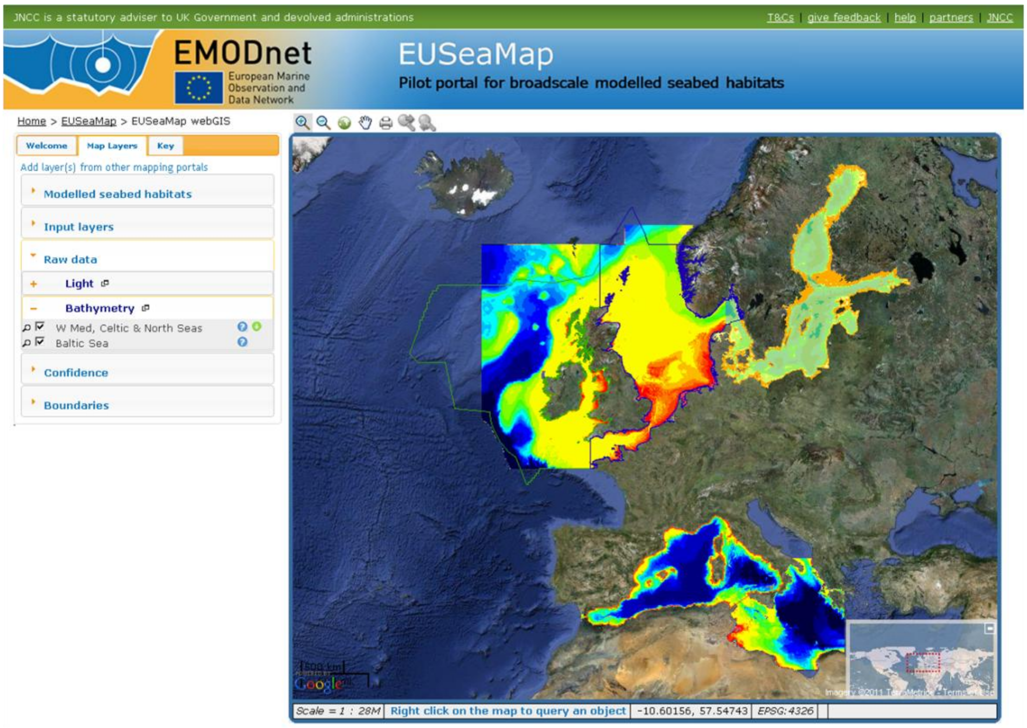

Figure 58 Bathymetry data for the all basins. The bathymetry shown for the North and Celtic Seas uses WMS links to the EMODnet Hydrography portal.

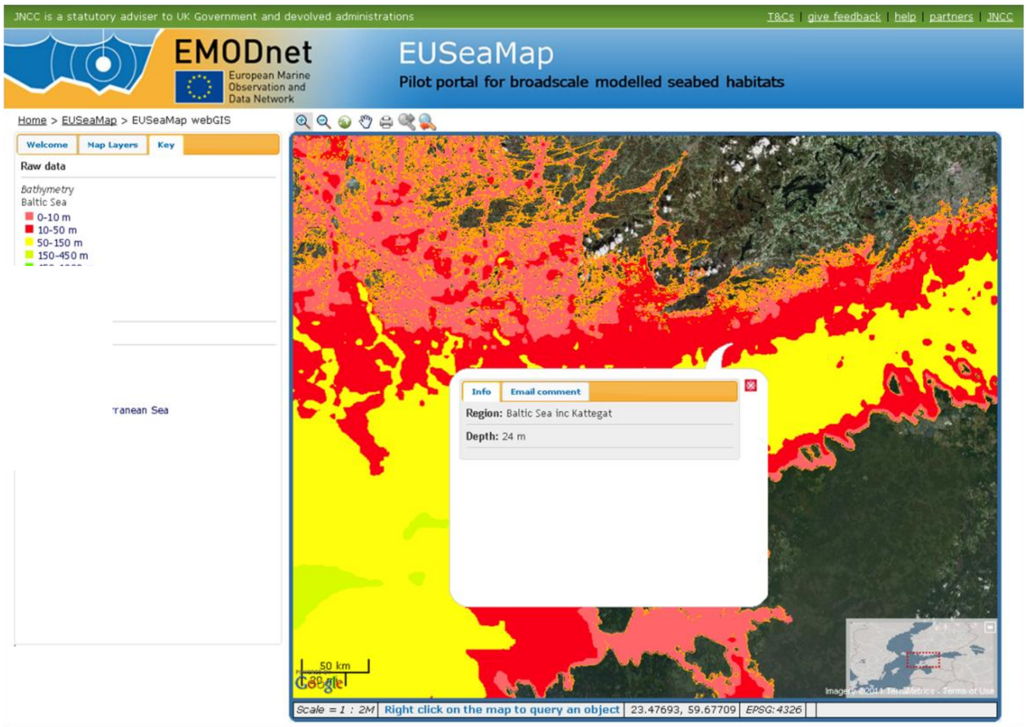

Figure 59 A zoom to the bathymetry data in the Baltic Sea, showing the Key tab and Info pop-up.

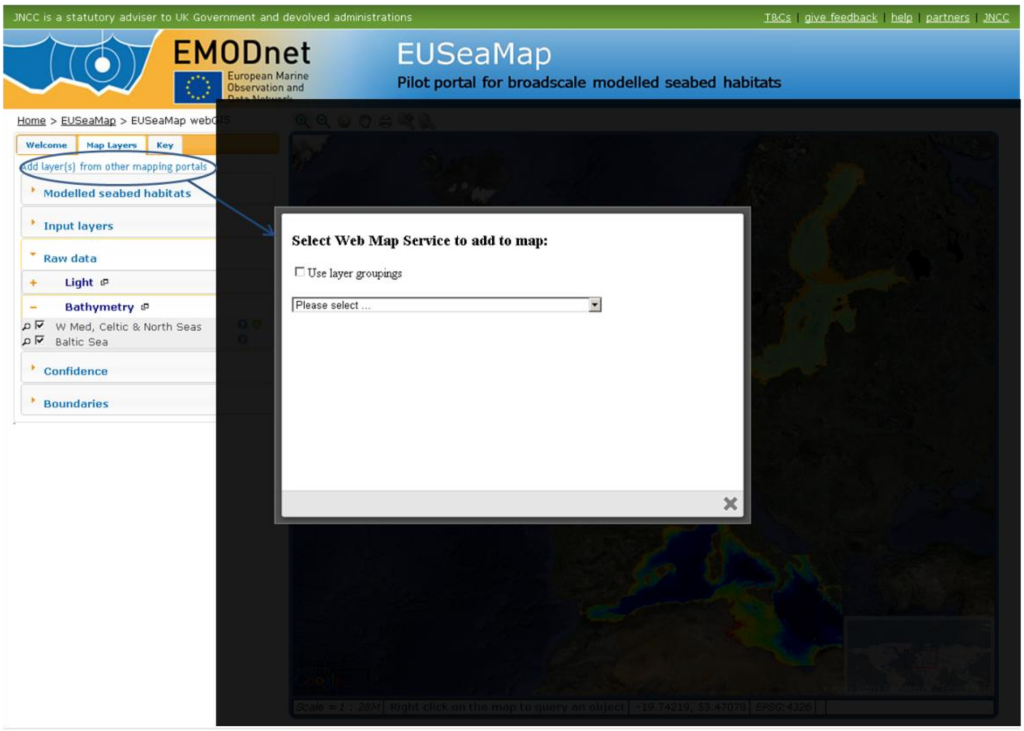

Figure 60 Users have the ability to add from EMODnet WMS layers or to add their own layer by pasting in a URL of a WMS ('Custom…' option).

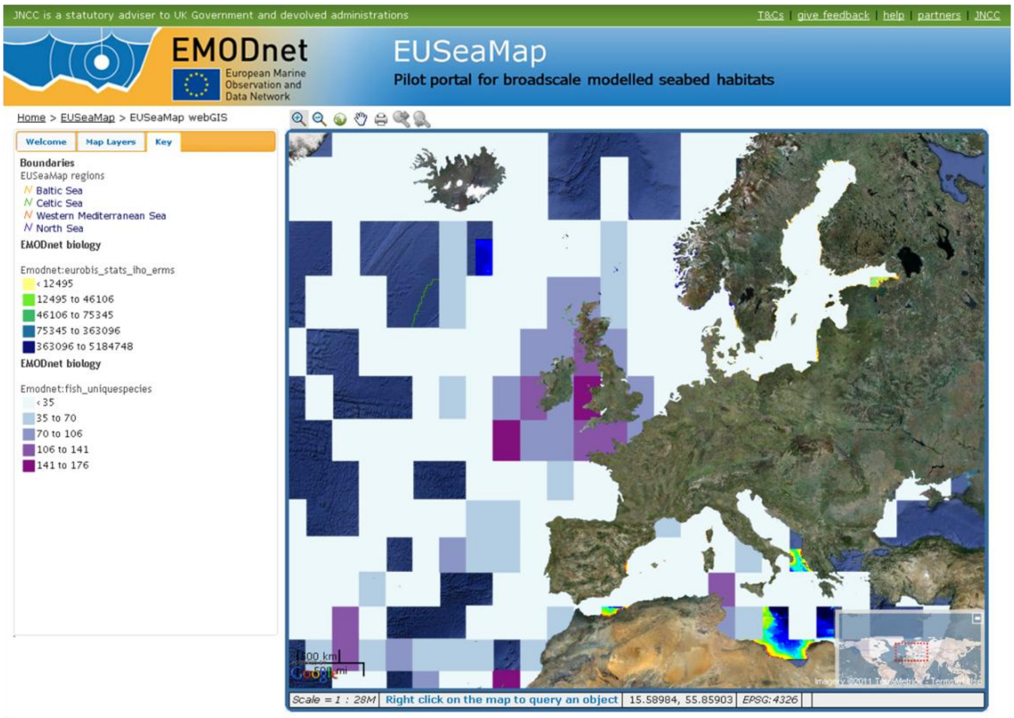

Figure 61 Having selected a WMS layer (in Figure 60), such as the EMODnet biological data, the user can select available layers from the Map Layers tab and they will be rendered in the same way as they are on the source portal.

10. Assessing the potential benefits of broad-scale habitat maps

Throughout the European regions we have made significant progress in rising to the significant challenges facing our shared seas. However, we must still do more to handle the threats that remain if we are to preserve and restore our marine regions for future generations.

Threats that are all too real. Fish stocks are overexploited, with notable species such as the European eel disappearing, while iconic species such as the Northern blue fin tuna and the Baltic sturgeon are already hovering on the brink of extinction. Meanwhile eutrophication still causes large areas to be depleted of oxygen leaving them unsuitable for higher life. Hazardous substances continue to find their way into the food web. Invasive species such as the Comb jelly Mnemiopsis *are being introduced. Natural marine habitats and their associated communities are under pressure from physical destruction and damage as well as the effects of climate change. At the same time, our use of sea space continues to increase whether for shipping, energy or leisure activities. Activities which require more and more space are adding to the cumulative pressure and potential irreversible impact on our unique and vulnerable European Seas.*

There is an immediate need for a transnational, coherent and integrated cross-sectoral approach to combat these threats. A need reflected by community initiatives such as the EU Integrated Maritime Policy, the Marine Strategy Framework Directive, regional initiatives such as the HELCOM Baltic Sea Action Plan or national actions such as the UK Marine and Coastal Access Act. Here the EUSeaMap partnership provides new ideas, concepts, practical tools and demonstrates how parts of these initiatives can be enhanced through the application of broad scale habitat maps and integrated maritime spatial planning. Maritime spatial planning has the potential to be a key tool for linking our uses of the sea with the long-term protection of the environment in a coherent and sustainable way. The EUSeaMap partnership also demonstrates how we, the countries sharing the marine regions, together can bridge the gap between science and informed planning and management of human activities in the marine environment, while continuing on our path toward a long-term sustainable development. Climatic change might cover the headlines today, but ecosystem degradation will cover the headlines of tomorrow.

The work done by the independent international partnership provides one small step along the path to achieving the policy visions of healthy European Seas which are sustainably used. This path will be filled with challenges that only can be overcome through committed and persistent international cooperation.

10.1. Introduction

Most human activities and pressures are already to some extent regulated through existing national law and international agreements resulting in significant efforts to handle specific pressures or uses. The obvious question is: why does the ecosystem degradation continue despite current management efforts? The logical answer is that our current approaches to governance of our European seas are to some extent a failure. The problem arises from the current fragmented approach to management, set up for handling individual sectoral use of marine resources, together with mismatches between policy visions, actual political actions, management tools and overall ecosystem capacity. Recognition of this has caused many scientists and politicians to advocate the use of a more holistic, ecosystem-based approach to management of human activities /[1]/.

A key to facing this challenge is to realize that maritime activities are all occurring somewhere within the marine ecosystem – hence they require or influence marine space already inhabited by one organism or another, be that the surface, water column, seafloor or underground. Competition for space is thus the only aspect by which it is possible to link multiple human uses and interests together with the myriad of life inhabiting our seas.

Acknowledging these challenges, the EU Commission launched the EU Integrated Maritime Policy in 2008 with the aim of enhancing Europe's capacity to face challenges of globalization and competitiveness, climate change, degradation of the marine environment, maritime safety, energy security and long-term sustainability /[2]/. An overarching principle of the Integrated Maritime Policy is to apply an ecosystem-based approach for management of human activities in the marine environment. The policy identifies several initiatives as well as concrete legislation deemed of special importance for which at least two would have added benefit of applying broad scale habitat maps – maritime spatial planning (MSP) and implementation of the EU Marine Strategy Framework Directive. These will form the policy framework for this demonstration of the application of broad scale habitat maps, though other international agreements might also be able to apply broad scale habitat maps for achieving their visions.

Directive 2008/56/EC on marine strategies entered into force. It establishes a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive or MSFD) and is the environmental pillar of the EU Integrated Maritime Policy /[3]/. It aims to establish a set of marine strategies in order to achieve Good Environmental Status within the European marine regions. A core principle in the marine strategies will be to apply an ecosystem-based approach to the management of human activities enabling a sustainable use of marine goods and services while preserving and protecting the marine environment and the organisms depending on a healthy sea.

Also in 2008 the EU Commission published a roadmap for maritime spatial planning (MSP). The roadmap identifies 10 principles for maritime spatial planning – principles which during 2009 were discussed and fine-tuned through a series of four workshops. A key prerequisite identified within the roadmap was that sustainable management of the marine regions depends upon marine ecosystems being in good condition. Hence, maritime spatial planning should be a tool that supports the overarching principle of implementing an ecosystem-based approach and delivering the MSFD rather than being a goal in itself.

This poses the Member States with the not insignificant challenge of identifying, describing and implementing the novel and somewhat loosely defined concept of "*ecosystem-based approach to management of human activities*" as well as determining "*Good Environmental Status*". Some initial guidance can be found in the annexes I and III of the MSFD, where physio-chemical as well as other ecological characteristics are listed. EUSeaMap has applied some of these characteristics e.g. salinity, sediments, available light etc. in the development of the broad scale habitat maps making otherwise ecologically-irrelevant information ecologically-relevant. Broad scale habitat maps can make a significant contribution to environmental assessment and maritime spatial planning.

The major strength of these ecologically relevant broad scale habitat maps is that they for the first time cover the entire seafloor of the marine regions mapped, and provide the units within which all the biodiversity depending on the seafloor can be included. A coherent description of the distribution and extent of ecosystem components such as marine habitats is a prerequisite for implementing an ecosystem-based approach to management of human activities in the marine environment. Without knowing the extent and amount of a resource or just what lives where, it will be difficult to protect, preserve or exploit it sustainably.

While there are many potential uses and applications of broad scale habitat maps, the most important benefit is that they can be used to provide coherent, ecologically-relevant information about our marine regions. The broad scale habitat maps provide a spatial overview of the differences, extent and distribution of marine habitats, revealing the complexity of the marine ecosystem often forgotten in the traditional "planning" view of a "uniform volume of water", where the seabed is hidden from sight. Such a coherent overview makes the maps an ideal tool for illustrating and thus assessing the cumulative environmental impact of human activities on the environment in a spatial context, they can help inform us of the potential resources available, provide valuable information for strategic planning of large-scale infrastructures, provide evidence for the representivity of networks of marine protected areas and most importantly, guide multiple interests in the context of maritime spatial planning.

In order to illustrate and hopefully inspire future national and European marine management and maritime planning efforts, examples of the potential use of broad scale habitat maps as well as some of their limitations are given below within the framework outlined above. It should be kept in mind that these examples are based on broad scale habitat modeling applying the best available knowledge for large expanses of sea where often little or no detailed habitat information exists. Though the confidence may vary, these examples demonstrate that broad scale habitat maps could be a valuable, if not an essential, tool for achieving a long-term sustainable use of the European marine ecosystems and their resources.

So far, EUSeaMap efforts have focused mainly on the technical aspects of habitat modeling in order to develop a harmonized approach across the European Seas. The next challenge is to turn broad scale habitat maps from being a scientific exercise into a viable, practical management tool. A tool which is based on science and capable of meeting political priorities and sectoral interests, while ensuring our use of the sea happens within long-term ecologically-safe thresholds.

The examples will demonstrate how broad scale habitat maps can be applied to support an ecosystem-based approach to management of human activities within the European Seas. Special focus will be upon how broad scale habitat maps can support the implementation of the MSFD. The second part of the report illustrates how the various applications fit within the EU Integrated Maritime Policy through direct linkage to a holistic, cyclic framework for maritime spatial planning.

10.2. Application I for the implementation of the MSFD – a harmonised broad scale habitat map

The Marine Strategy Framework Directive is the environmental pillar of the EU Integrated Maritime Policy. Since its entry into force in 2008 it has been the focus for an intense process leading up towards the Initial Assessment of the state of the marine waters, their pressures and impacts and the socio-economic uses in July 2012. A key principle within the MSFD (art. 6) is that it requires the Member States sharing a marine region to cooperate and coordinate in regard to the various elements of the marine strategies which are needed to achieve the objective of the Directive.

As part of the MSFD initial assessment Member States have to perform an analysis of the essential features and characteristics covering physical and chemical features, habitat types, biological features and hydro-morphology (art. 8). What this entails is further developed in an indicative list in annex III, table 1 of the Directive – what exactly is covered by the word “indicative” is still uncertain except that it entails some flexibility for selection and handling of the elements on the list. However, this list includes physical and chemical features such topography, bathymetry of the seabed, salinity, various energy elements, temperature, substrata of the seafloor etc. It also includes predominant seabed habitats. Keeping to the ambition of implementing an ecosystem-based approach this means that i) the physical and chemical features somehow have to be made ecologically-relevant, and ii) a coherent map of the distribution and extent of seafloor habitats would be extremely useful for the initial assessment.

EUSeaMap has through the development of broad scale habitat maps for several marine regions and sub-regions demonstrated several elements relevant for the implementation of the MSFD. EUSeaMap has shown that it is possible to develop a joint methodology for harmonisation of physical and chemical data layers mentioned in annex III, table 1 of the Directive. In the Baltic Sea alone the sediment map was originally composed from 16 different classification schemes existing in 9 languages /[4]/. EUSeaMap has also shown that by merging physical, abiotic characteristics it is possible to develop a harmonised ecologically-relevant broad scale habitat map showing the extent and distribution of the predominant habitat types within an entire marine region. At the same time it has been demonstrated that it is possible to apply the same mapping and classification approach across European marine regions spanning the Baltic Sea Region, the Greater North Sea sub-region, the Celtic Seas and the Western Mediterranean sub-regions and for fairly low costs and efforts. A harmonisation approach that cover territorial waters of 17 EU Member States and five non-EU Member States with methodologies being expanded even further by MESH Atlantic.

All in all, the efforts made by EUSeaMap contribute directly to coordination and harmonisation efforts required by article 6 of the MSFD within and between marine regions, thus directly supporting the efforts under the MSFD Common Implementation Strategy as well as efforts done by Member States and Regional Sea Conventions as part of the initial assessment.

10.3. Application II for the implementation of the MSFD – initial assessment and GES

Having overcome the not insignificant technical challenges of gaining access to data, harmonisation and development of mapping methodologies (even though building on previous experiences), the next challenge is to demonstrate other applications of the broad habitat scale maps in a MSFD context.

According to MSFD (art. 9) Member States shall for each marine region or sub-region determine a set of characteristics of Good Environmental Status based on the descriptors in annex I and the list of characteristics defined in annex III, table 1. However, the descriptors do not provide much guidance and have consequently been further developed by a process chaired by the EU Commission. This has resulted in a Commission Decision from 1 September 2010 on criteria and methodological standards on good environmental status of marine waters /[5]/. This decision develops 29 main criteria and 55 indicators describing the 11 descriptors in further details. The Member States are obliged to use all the criteria unless good reasons exist for not applying a criterion. It is up to the Member States to develop concrete indicators for the individual criteria.

Some of these criteria depend on the availability of broad scale habitat maps. One of the most obvious is found within Descriptor 1 on Biodiversity. This descriptor has seven criteria related to habitats, of which broad scale habitats can be used to inform criterion 1.4.1 on distributional range, criterion 1.4.2 on distributional pattern and criterion 1.5.1 on habitat area of marine habitats. Hence, such information has to be available for each marine region or sub-region.

As illustrated by Figure 62 and Figure 63 the broad scale habitat maps show the distributional range and distributional pattern of the marine habitats present in the Baltic Sea and the North Sea. Similarly, Table 16 shows the area covered by each habitat present within the (potential) Kattegat sub-division /[6]/. It is possible to derive such information for all marine regions for which a broad scale habitat map is available. For simplicity, the legend for the habitats in Table 16 follows the four-digit model code, but habitats which are specifically referred to in the text are described with their full habitat names.

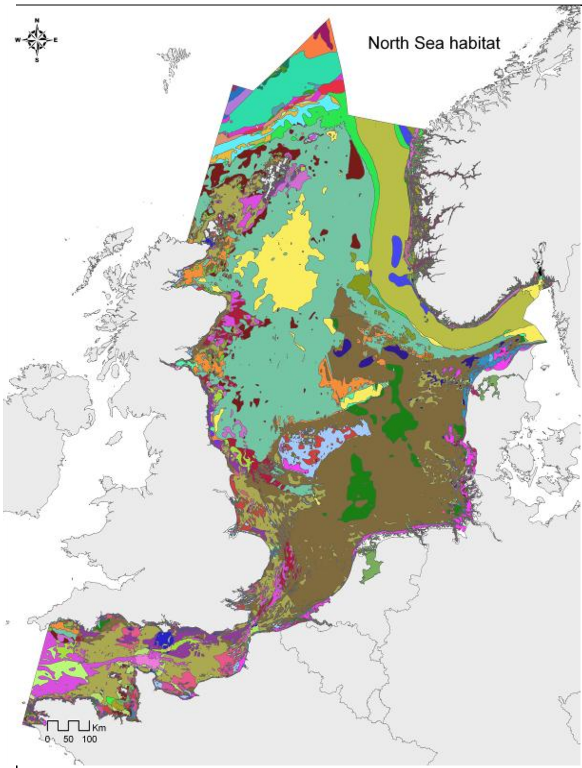

Figure 62 *Broad scale habitat map of the North Sea sub-region (excluding Kattegat) showing the distributional range and pattern of marine habitats in the North Sea.*

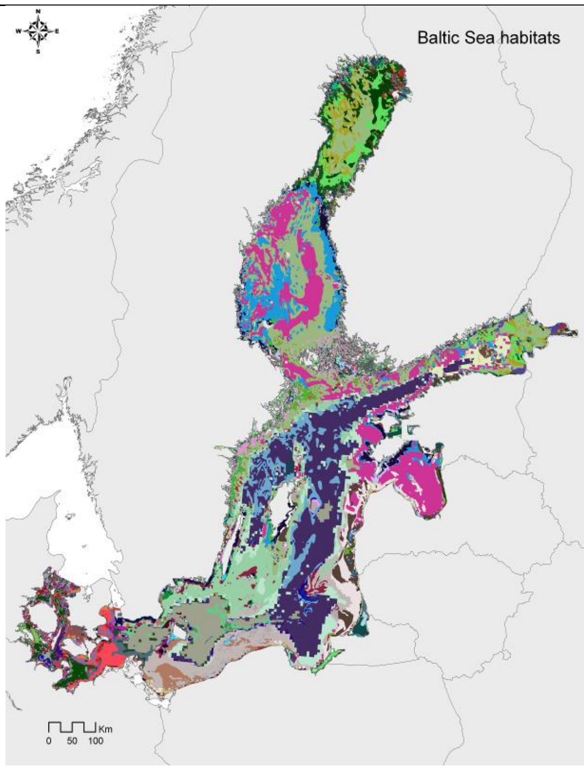

Figure 63 *Broad scale habitat map of the Baltic Sea Region showing the distributional range and pattern of marine habitats in the Baltic Sea.*

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[1] McLeod, K. L., J. Lubchenco, S. Palumbi & AA Rosenberg, 2005: Scientific Consensus Statement on Marine ecosystem-based management. Communication partnership for Science and the Sea (COMPASS).
[2] Anon, 2008. An Integrated Maritime Policy for the European Union.
[3] Anon, 2008. Directive 2008/56/EC establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)
[4] Al-hamdani, Z. and J. Reker. (eds.) 2007. Towards marine landscapes of the Baltic Sea. Balance Interim Report no. 10. Available at www.balance-eu.org/publications
[5] Anon 2010. Commission Decision of 1.9.2010 on criteria and methodological standards on good environmental status of marine waters.
[6] Andersen, J., Dørge, J. Skov, H., Stock, A., Uhrenholdt, Carstensen, J. Dahl, K., Hjorth, M., Josefson, A., Larsen, M., Strand, J. Andersson, P., Axe, P., Korpinen, S., and J. Reker 2010. Kattegat in a sub-regional marine perspective: delineation, data availability and management tools (KARMA). Research and development project done by DHI and SMHI for the Agency for Spatial and Environmental Planning, Denmark and the Swedish Environmental Protection Agency.

Table 16 *Area covered by the predominant broad scale habitats and area influenced by human activities (aggregate extraction, wind farms, are protection) and pressures (oxygen depletion) in the Kattegat – a potential sub-division of the North Sea sub-region. (Note that a comma is used here as a decimal separator, but a full-stop in the text)*

Habitat code	Habitat Area Km^2	Oxygen depletion Area Km^2	Aggregate sites Area Km^2	Wind farms Area Km	Natura 2000 Area Km^2	% of habitat influenced by oxygen depletion	% inside Natura 200
1110	765,74	408,91	0,22	0,06	5,90	53,40	0,77
1111	403,25	11,90				2,95	0,00
1114	6,80	0,06					
1120	895,77	548,39	0,35	14,06	14,27	61,22	1,59
1121	101,47	0,75			8,12	0,74	8,00
1124	7,68				0,19		2,47
1130	7,25	6,02		6,03	6,03		83,22
1131	4,30	1,62			0,29	37,66	6,76
1134	4,91	0,53				10,88	
1140	2,56	0,89			0,69	34,71	27,07
1141	43,11	12,37			1,02	28,70	2,37
1144	24,40	1,15				4,73	
1150	187,85	134,03	0,02		1,50	71,35	0,80
1151	44,43	1,03			20,03	2,32	45,09
1154	13,11				3,16		24,07
1160	5,60	1,38			3,67	24,59	65,41
1161	7,81	0,10			1,79		22,98
1210	1312,28	643,78		2,31	59,68	49,06	4,55
1211	23,56	3,13			4,31	13,28	18,30
1220	459,22	295,33	0,17	13,07	27,23	64,31	5,93
1230	4,33	2,45		2,87	2,63	56,60	60,67
1240	121,42	8,92			8,68	7,34	7,15
1250	113,45	22,85	0,02		4,36	20,14	3,85
1260	119,92	2,33			46,20	1,94	38,53
1310	5292,83	1351,21	0,38	5,83	121,46	25,53	2,29
1320	479,31	253,51		1,40	22,88	52,89	4,77
1330	3,29	3,23		2,64	3,23	98,16	98,10
1340	512,61	28,27			17,65	5,52	3,44
1350	253,35	74,42			8,99	29,37	3,55
1360	11,80	0,85			6,06	7,20	51,37
1410	1765,58				4,57		0,26
2110	1256,48	435,31	0,81		95,27	34,65	7,58
2111	92,71	0,70			0,54	0,76	0,58
2114	102,43	43,90				42,86	
2120	4946,03	1641,04	19,94	115,97	635,42	33,18	12,85
2121	70,29	6,29	0,00		20,73	8,95	29,49
2124	93,52	19,19	2,13		3,91	20,52	4,18
2130	46,82	23,90		16,31	30,01	51,04	64,11
2131	23,42	5,03			1,31	21,46	5,59
2134	46,54	11,72				25,18	
2140	372,86	273,97		4,57	37,66	73,48	10,10
2141	24,61	12,60			2,56	51,21	10,40
2144	2,22						
2150	989,49	342,16	0,29	28,30	126,75	34,58	12,81
2151	56,04	2,60	0,45		15,42	4,64	27,52
2154	152,94	22,29	3,29		20,69	14,58	13,53
2160	39,42	12,13			23,07	30,78	58,52
2161	10,81	0,74			1,29	6,86	11,95
2164	51,07	0,31			5,09	0,61	9,97
2200	2,30				1,09		47,51
2210	2775,53	1398,17	0,03	0,15	36,62	50,37	1,32
2220	165,74	99,44	0,27	7,30	44,91	60,00	27,09
2230	8,76	4,63		0,25	2,17	52,83	24,76
2240	402,93	105,75			15,30	26,25	3,80
2250	82,63	7,69			17,40	9,30	21,05
2260	171,42	21,12			59,72	12,32	34,84
2310	384,21	221,92			27,56	57,76	7,17
2320	15,79	8,79			5,33	55,68	33,78
2330	1,89	1,32			0,57	70,03	29,97
2340	62,12	10,43			3,14	16,80	5,05
2350	6,71	1,18			1,83	17,59	27,35
2360	21,61	9,59			2,52	44,36	11,67
2410	4,52				4,52		100,00
3110	325,20	57,18		1,98	41,64	17,58	12,80
3111	48,07	10,18			0,58	21,17	1,20
3114	55,80	8,28				14,85	
3120	1260,41	67,40		3,89	702,17	5,35	55,71
3121	191,80	29,01			50,84	15,12	26,51
3124	165,32	3,97			14,56	2,40	8,81
3125	11,58	3,59			1,10	31,00	9,50
3126	1,87	0,64	0,98			33,96	
3130	41,53	11,09		0,08	14,33	26,71	34,50
3131	45,97	6,45				14,03	
3134	75,76	4,62				6,10	
3140	159,60	37,36		0,64	44,39	23,41	27,81
3141	43,44	4,53				10,43	
3144	169,52	41,55				24,51	
3150	269,02	29,75	1,98		105,79	11,06	39,32
3151	33,19	5,66			3,07	17,04	9,24
3154	22,11				0,74		3,33
3155	1,69	1,28				75,88	
3160	233,16	71,75			106,04	30,77	45,48
3161	18,16	7,24			1,39	39,86	7,65
3164	2,28	1,15				50,77	
3165	2,37						
3210	221,80	118,94	0,03		39,22	53,62	17,68
3211	32,89	26,12				79,42	
3214	26,94	14,43				53,55	
3220	20,43	9,18	0,06		6,50	44,93	31,82
3224	11,84	7,84				66,22	
3230	7,58	0,76			0,56	10,02	7,34
3231	1,74						
3240	119,05	22,56			16,28	18,95	13,67
3241	3,77	0,54			0,94	14,27	25,06
3250	1,66	1,09			0,41	65,99	24,63
3254	1,18						
3260	157,50	40,90			53,26	25,97	33,82
3261	6,35	0,06			2,95	0,98	46,50
3264	5,15	0,56				10,90	
3310	63,82	12,37			25,83	19,39	40,47
3320	31,69	0,06			21,83	0,19	68,90
3340	30,29	0,58			0,28	1,91	0,91
3350	0,81	0,55			0,31	68,28	38,50
3360	39,90	5,58			6,97	14,00	17,47
Total	**29453,06**	**9228,12**	**31,43**	**227,73**	**2908,98**	**31,33**	**9,88**

Being able to present coherent information of broad scale habitats for a marine region as well as for being able to do so at an inter-regional scale is a major and timely achievement of EUSeaMap. More importantly, EUSeaMap has shown that its products inform criteria on predominant habitats defined for Descriptor 1 on Biodiversity on a marine regional/sub-regional level representing a major element of the marine ecosystems. It enables a clear description of the predominant broad scale habitats present within a marine region as well as the percentage present in national waters. If each Member State had applied their own habitat classification it would be impossible to compare across national boundaries and achieve the consistency called for by the Directive. If Member States wish to apply a more detailed habitat description this is still possible as long as it fits within the EUNIS habitat classification scheme. Such an approach to mapping and classification will enable national, regional and Pan-European assessments.

While the broad scale habitat maps are useful for an overview of ecosystem components it might in some instances be necessary to obtain more detailed information of special habitat types (*sensu* MSFD annex III, table 1) not picked up by the broad scale habitat map. Such an example could be biogenic reefs as described under the Habitats Directive (1170) *Reefs* (Figure 64) or (1180) Submarine structures made by leaking gases (Figure 65). It is also important to keep in mind, that the broad scale habitat maps *do not* take account of spawning, breeding and feeding areas of highly mobile species. This is partly because it is impossible to map the life-history requirements of every single species, and partly because no formal decision has been made as part of the MSFD Common Implementation Strategy (CIS) in regard to which life-history requirements of which species should be mapped. However, as the maps developed by EUSeaMap cover the entire marine seafloor, and thus the range of species living or depending on the benthic habitats, a precautionary approach of establishing representative networks of marine protected areas would likely cover important spawning, breeding and feeding areas.

Figure 64 Modiolus modiolus *biogenic reef in the Kattegat. Biogenic reefs are covered by the EU Habitats Directive under (1170) Reef.*	***Figure 65*** *Habitat (1180) Submarine structures made by leaking gases are a priority habitat protected by the EC Habitats Directive. These features are too fine-scale to be picked up by the broad scale habitat maps.*

This still leaves the question of what to do with information on the distribution and extent of marine habitats and how it can contribute to assessing Good Environmental Status. Some possible answers to these questions will be demonstrated in the following examples, but ultimately it will be up to the Member States, the CIS process and the Regional Sea Conventions to develop the full use of broad scale habitat maps further.

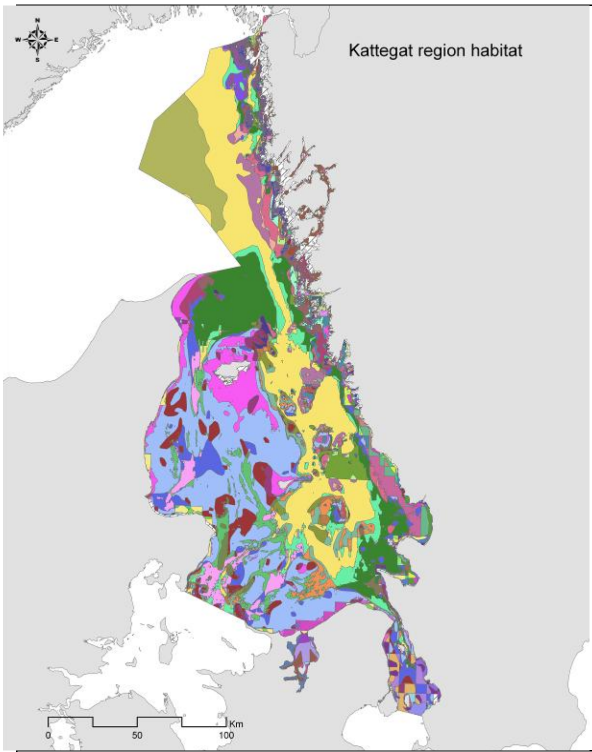
10.4. Application III for the implementation of the MSFD – GES, oxygen depletion and habitats

In order to answer the question we have to look towards the MSFD (art. 1, 8 and 9), which requires an analysis of the collective and predominant pressures and impacts from human activities. These are further described in annex III, table 2 of the MSFD, which identifies 18 pressure and impact groups.

Furthermore, the Commission Decision on criteria and methodological standards includes for Descriptor 6 on Seafloor integrity a criterion (6.1.2) on the extent of the seabed significantly affected by human activities for different substrate types /[7]/. Assuming that the intention is, as mentioned in the preamble of the descriptor, to assess impact upon seafloor substrates structuring benthic habitats and thus in reality the habitats, then this is where a broad scale habitat map comes really comes into play.

The following examples are based within the Kattegat area shared by Sweden and Denmark. The delineation of Kattegat follows one of boundary scenarios discussed informally by Sweden and Denmark on the potential designation of the Kattegat as a sub-division *sensu* art. 4 of the MSFD (Figure 66) /[8]/. The area is part of the Greater North Sea sub-region according to the MSFD and part of the marine waters covered by two Regional Sea Conventions, OSPAR and HELCOM. EUSeaMap has identified 104 broad scale habitats (each >1km^2) illustrating the dynamic area of this shallow sea situated between the saline North Sea and the oligohaline Baltic Sea.

The extent and distribution of the 104 marine broad scale habitats present within the 29,450 km^2 Kattegat area varies from the predominant types such as *deep circalittoral mud* (model code 1310) and *infralittoral fine/muddy sand infralittoral muddy sand* (model code 2120) each covering approximately 5,000 km^2 to more rare habitats such as *mesohaline infralittoral mixed hard sediment in high energy* (model code 3164; no EUNIS code) covering slightly more than 1 km^2 (Figure 66, Table 16). Such information can form the basis for an ecosystem-based approach to management, as demonstrated in the following example(s).



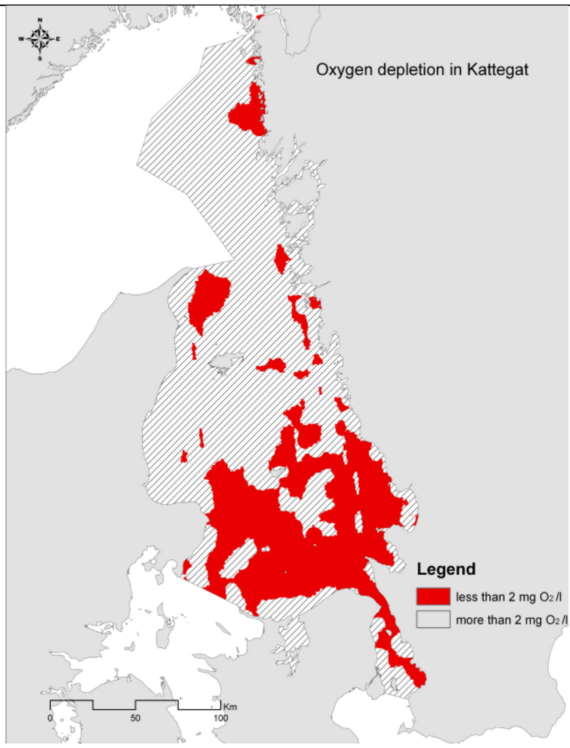


Figure 66 *Broad scale habitat map of the Kattegat area.*

Figure 67 *Area where the oxygen concentration falls below 2mgO_2/l at least once in a 9-year period.*

The marine habitats in Kattegat are under impact from a range of different pressures and activities. One of the major environmental challenges faced in the Baltic Sea, Kattegat and even the North Sea eutrophication. One of the main effects of eutrophication is the occurrence of low oxygen concentrations (<2mgO_2/l) covering often large areas of the seafloor (Figure 67). Of the 104 benthic marine habitats only ten were not influenced by oxygen depletion during a nine-year period (2000-2009), while 21 habitats were only influenced to a minor degree (1-10% of total area, Table 16). Most of these are found within the photic zone. A 9-year period was chosen for demonstration purposes as large variations in the area covered by oxygen depletion exists from year to year depending on predominant weather conditions. In regard to implementation of the MSFD it would make sense to apply a 6-year cycle.

Large proportions of especially non-photic soft substrate habitats are under significant threat from oxygen depletion e.g. the non-photic *oligohaline circalittoral mud and sandy mud in high energy* (model code 3211) with 79% influenced by oxygen depletion. The most severe event of oxygen depletion in Kattegat occurred during the autumn of 2002 /[9]/. When such large proportion of a habitat is influenced by oxygen depletion, the consequences upon the organisms living within the habitat are most likely to be severe as it influences both the abundance of the species and quality of the habitat. During the event in 2002 it was estimated that 371,000 tons of marine invertebrates died in the Kattegat and the Danish Straits /[10]/. No figures are available for fish.

Besides influencing the biomass, changes in species richness will also occur following a series of repeated events of oxygen depletion. Time series faunal data from the Danish Belts and Kattegat show that the communities undergo temporal changes in the entire area over a time scale of a few years. A 50% reduction in the species richness over the past 13 years has been observed in the soft bottom communities at certain localities /[11]/.

Spatial information such as broad scale habitat maps can provide additional, valuable information on the proportion of a habitat impacted by a pressure. In this example such information can help inform about which habitats or areas are under urgent need for additional management measures.

This relatively simple overlay analysis can be done not only for at marine region, but also for national territorial waters in order to help inform concrete programmes of measures i.e. as required by the Water Framework Directive and by the MSFD.

The oxygen information layer can inform criteria 5.3.2 in regard to the area influenced by low oxygen concentrations. If combined with the broad scale habitat map it can help inform which parts of the marine ecosystem are most severely influenced. This could cause actions to protect and preserve the remaining proportion of the habitat not influenced oxygen depletion from other impacts until more permanent measures are established through the Programme of Measures (MSFD art. 13). The knowledge could also be used to inform a discussion on the development of targets e.g. what proportion of a specific habitat can be influenced by an impact(s) for the habitat to be in Good Environmental Status, or what proportion of a habitat in an area can be influenced by oxygen depletion for the area to achieve Good Environmental Status. Comparing trends over several years can help show the progress towards Good Environmental Status.

Similarly, the hydrodynamic models providing the oxygen information can also be used to provide input on hydrological and chemical conditions related to criteria 1.6.3. If nutrient information is included, then the same modelling exercise can be used to inform criteria 5.1.1 on nutrient concentrations in the water column. Such information has also been included in the development of the benthic broad scale habitat map. In summary, the knowledge can inform the criteria mentioned, and it could also lead to a development of indicators based upon areal extent of individual habitats allowed to be impacted by a pressure. Exactly how much of a habitat can by under impact could be further developed in the context of the Regional Sea Conventions and, in the end, turned into concrete management measures by the Member States.

10.5. Application IV of broad scale habitat maps for the strategic planning of offshore industries exemplified by marine aggregate extraction

Besides informing the implementation of EU Directives broad scale habitat maps can also inform marine industries. One such industry is the marine aggregate industry. Extraction of marine sand and gravel makes a significant contribution to the supply of aggregates to the European construction industry. Marine aggregates are also very important for beach nourishment and flood and coastal defence schemes. While it is essential that an adequate and steady supply of aggregates remains available to the communities (Figure 68), it is recognised that extraction efforts cause damage to the marine environment. Such activities, including licensing, must therefore take appropriate measures in order to minimise the impacts on the marine environment, fisheries and the potential effects on the coastline.

This section will demonstrate that habitat maps can be used for strategic planning including assessment of potential sites by the industry, by the licensing authorities and for assessing impacts at a broad scale from the marine aggregate extraction activities. It will also show that for informing specific extraction activities a higher resolution map is necessary. The examples will be based upon information from the English Channel, the eastern North Sea and the Kattegat.

Figure 68 *An industry at work. As land-based sources are being depleted marine aggregates become more attractive. (Courtesy of BMAPA, UK)*

The marine areas investigated for aggregate extraction are often quite large. In France, after a preparatory survey focussed within two regions – the Channel and in the Bay of Biscay – the French government recently ordered the extension of the study to the whole wider coastal zone, an area of almost 150,000 km². Similarly, in 2010 Denmark has initiated preparatory surveys of Danish territorial waters covering potentially almost 100,000 km² beginning in the North Sea (Figure 69). The Danish initiative will potentially run for the next 10 years depending on funding and results. In the UK, the Marine Aggregate Levy Sustainability Fund has commissioned four Regional Environmental Characterisations, each covering between 1,000 and 3,000 km^2. All of these national initiatives will collect acoustic data and ground-truthing data (e.g. seabed samples, video and photographs), and sometimes sub-surface information.

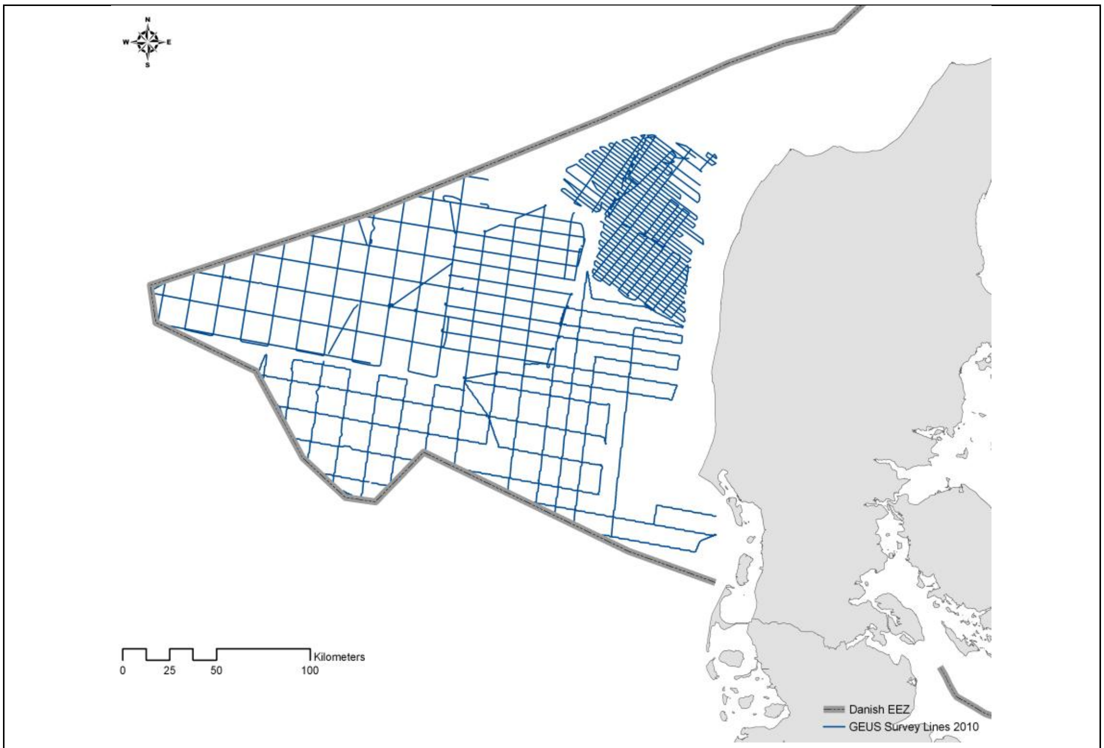


Figure 69 *Survey lines from a combined broad scale habitat mapping and marine aggregate resource exploitation survey in the Danish part of the North Sea in 2010.*

Such preparatory surveys can inform a wide range of topics, though focus is upon getting the appropriate information on sediment grain size and geology as well as biological information. The data from the Danish survey will also be combined with information from fisheries efforts (after the deadline for EUSeaMap). This provides sound information for a) assessing the potential aggregate resources, b) assessing potential impact, and c) updating and improving habitat maps.

The French Ministry for Industry survey plan focussed on two marine areas – the Channel and the Bay of Biscay. The plan was divided into three consecutive mapping phases. Phase one was focussed on mapping the aggregate resource. It drew on the knowledge of surface sediment as portrayed in medium scale heritage marine sediment maps available for the French shelf area and was supplemented to a large extent by seismic and core sampling surveys to get insight into sediment thickness. The second phase dealt with the impact on fisheries, specifically on the abundance of fish species and on the fisheries activities. The third phase aimed to provide an overview of the benthic communities' distribution and assess their vulnerability to extraction activities.

The application of the knowledge obtained from such three phases can be illustrated by the Danish example. The Danish preparatory survey identified a 3km long sandbank at 25-45m of depth with a sand thickness of 8.5m to 14m situated 39km from the coast (**Error! eference source not found.**a, 72b and Figure 72). It provides a potential ideal resource for marine aggregate extraction though slightly deep compared to the current fleet of the Danish extractors. The broad scale habitat map delivered by EUSeaMap identifies this area are being *sublittoral sand* (A5.2), but does not clearly distinguish the sandbank from the surrounding area. At EUNIS level 4, the model predicts this habitat as *infralittoral fine/muddy sand*: distinguishing these two types would require more detailed sediment information. However, even with this additional sediment information, it would still not be possible to distinguish the sandbank from the surrounding area. This is because the sandbank is a topographic feature, and would also require some slope analysis on detailed bathymetry data to delineate its boundaries. This shows the limitations of the EUSeaMap approach for delineating individual sandbanks. The EUNIS level selected for environmental impact assessment will to some extent determine the outcome of that assessment. For example, if local assessments is carried out only on a EUNIS level 3 maps (including several e.g. 8 different level 4 habitats) , this could cause a "dilution" of the effects and impact of the extraction activities. The extraction activities could in reality focus on one specific level 4 habitat in that area covering e.g. 10% of the level 3 habitat (e.g. infra littoral fine sand, fig. 73). Hence, an Environmental Impact Assessment applying only a level 3 map could end up concluding that the activity on targets a small amount (10%) of the level 3 habitat, while in fact it end up removing 100% of the EUNIS level 4 habitat present in the area.

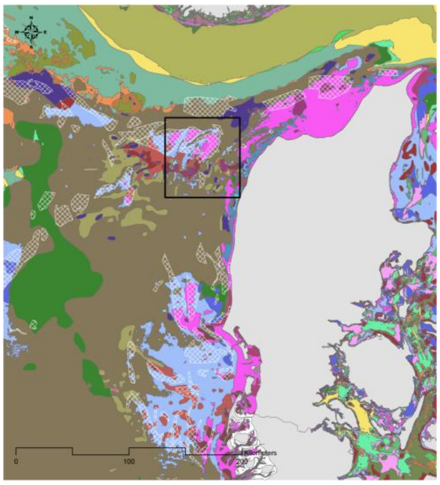


Figure 70a *Comparison of the broad scale habitat map with known areas for sand eel fisheries. Such information can be used for assessing value of and impact on specific habitats.*

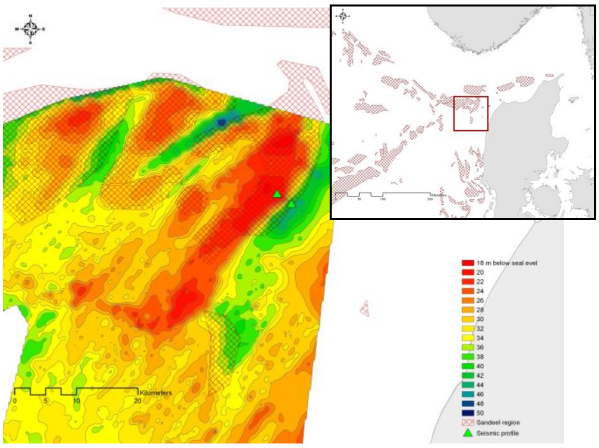


Figure 71b *Acoustic survey identified a 3km long sandbank in the Danish part – a potential valuable aggregate resource. The overlain areas indicate sand eel fisheries which are discussed in a later section (source: DTU Aqua).*

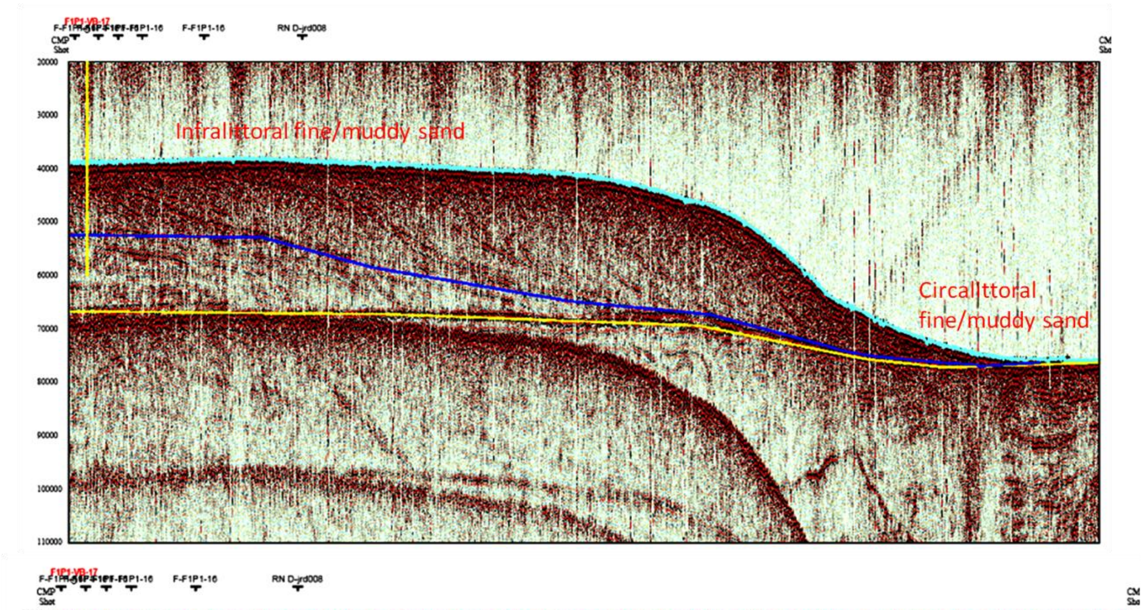
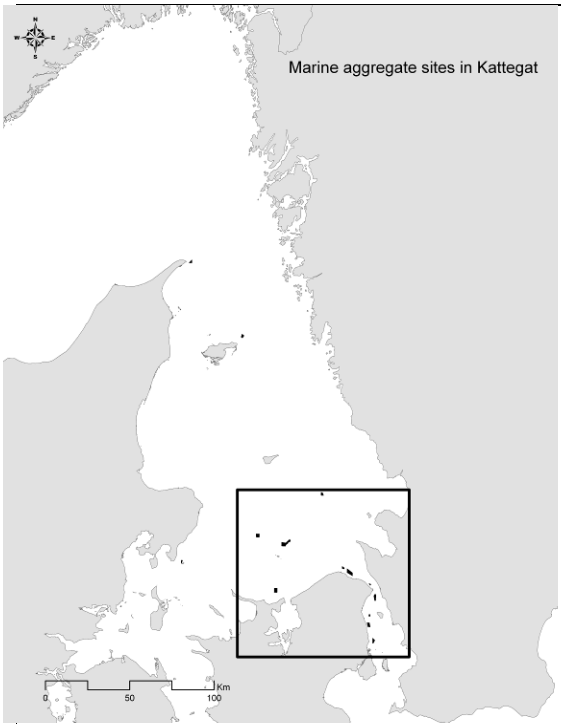


Figure 72 *Seismic profile of the sandbank identified. The section shown is 3km long, based at 25-45m of depth and the height of the sandbank is up to 14 m. (light blue = seafloor, dark blue = seabed on which the bank is moving, yellow = upper Holocene).*

The example with the variation in the thickness of the sandbank is also a good example showing that EUSeaMap EUNIS classes are based on information on the surface sediment layer and, as such, can not stand alone in regard to inform on seabed geology and potential aggregate resources (Figure 72).

However, in regard to the strategic planning of surveys for identifying potential sites for extraction of marine aggregates (or for other purposes) there is a benefit in applying broad scale habitat maps (EUNIS level 3) from the very start. They provide valuable information which can be used for prioritising and targeting survey efforts. By comparing this level of the habitat map with existing sites for marine aggregate extraction it is possible to identify a clear trend that some marine habitats are more attractive than others for the industry. This can be illustrated for the Kattegat.

All in all, 18 marine habitats are present within current marine aggregate sites in the Kattegat (Figure 73 and Figure 74). Looking at the information available in Table 16 for marine aggregates it becomes apparent that of the 31.34 km^2 designated as sites for marine aggregate extraction one habitat occupies 19.94 km^2 or a total 63% of the area currently covered by marine aggregate sites) to be of special interest for the industry. Three of the remaining 17 habitats constitute another 24% of the sites of interest (Table 16). Hence, there appears to be a linkage between a broad scale habitat map (EUNIS level 3) and the sites chosen for marine aggregate extraction.



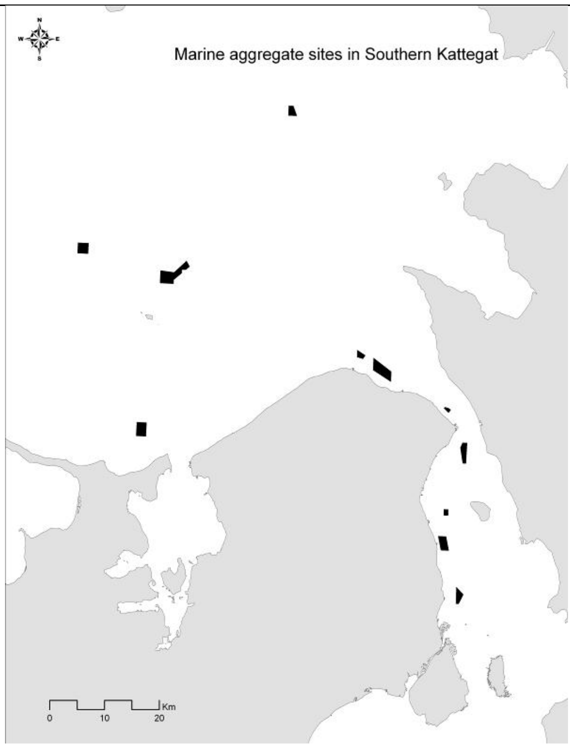


Figure 73 *Existing and potential sites for marine aggregate extraction in the Kattegat.*	***Figure 74*** *As land-based sources are being depleted marine aggregates become more attractive.*

In summary, for the aggregate industry the main use of broad scale habitat maps (EUNIS level 3) is to contribute to an initial assessment of the broad suitability for aggregate extraction of large expanses of marine seabed such as e.g. the shelf area of a whole basin and thus be of potential huge value for the offshore marine aggregate industry in regard to strategic planning of exploitation surveys. The maps would enable the industry to pin-point areas with the potential highest suitability for extraction efforts and thus save valuable time and efforts when designing preparatory surveys.

The broad scale habitat map can also contribute to Environmental Impact Assessments done by the marine aggregate industry by enabling an impact assessment taking account of the entire industry across a marine region, sub-region or sub-division *sensu* the MSFD. If done with the purpose of supporting an ecosystem-based approach to management, this would be supported best if the geographic scale applied were at a regional level (or rather ecologically-relevant level) e.g. not larger than Kattegat in order to avoid “dilution” effects (a few small sites in the big ocean). An ecosystem-based approach should result in healthy seas in your neighbourhood and not only somewhere else.

In regard to environmental impact assessment of individual activities or sites, the broad scale habitat maps have to be supplemented with ground truth data on abundance and biomass of the infauna inhabiting the seafloor in order to assess seabed sensitivity. If an ecosystem-based approach to management is desired, then a hierarchical habitat classification system should be applied (e.g. EUNIS) as this enable marine regional comparisons and assessments of the status across a marine region and across industrial efforts. As such this ought to be a requirement from the responsible authorities to any environmental impacts assessment saving time and efforts for both the industry as whole as well as individual Governments. If such requirement on hierarchical habitat classification was applied as part of all Environmental Impact Assessments across industries it would save Governments (and industries) a lot of effort and money when implementing an ecosystem-based approach to management – one could even challenge whether an ecosystem-based approach is possible without such harmonised approach to describing the marine environment?

However, besides these obvious conclusions on the importance of broad scale habitat maps for the marine aggregate industry similar benefits exists for other sectors. The following section will illustrate this for the offshore energy sector.

10.6. Application V of broad scale habitat maps for the strategic planning of offshore industries exemplified by offshore wind farms

Broad scale habitat maps can also be used for strategic planning of maritime infrastructure. As non-renewable energy sources are being depleted and the remaining resources becoming increasingly expensive, society has started to develop alternative resources for renewable energy. The part of the energy sector focussing on wind farming has experienced particularly sharp growth over the last 10 years, especially in the offshore environment where turbines are often seen as preferable because they are out of sight. As the turbines are getting larger, and due to public demand for moving them further offshore, the potential for offshore wind farms are under fast development throughout the world. This example shows that it is possible to draw some interesting and valuable conclusions supporting strategic planning within the maritime industries. Some of the conclusions illustrated for the marine aggregate sector are also valid for the offshore energy sector, but no repetition of the line of thought has been done.

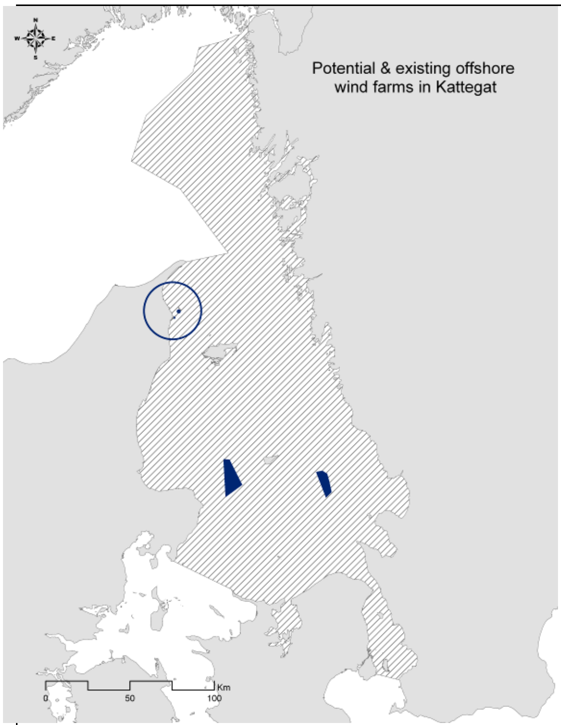


__Figure 75__ Existing and potential sites for offshore wind farms in the Kattegat area.

__Figure 76__ Wind farms are an up-coming space demanding offshore activity. Blyth offshore wind-farm (© AMEC Wind www.offshorewindfarms.co.uk)

In regard to the strategic planning of offshore wind farms in Kattegat there is a clear trend towards selecting areas for offshore wind farms dominated by relatively few marine habitats (Figure 75 and Figure 76). In the Kattegat a total area of 228 km2 has been designated as existing or potential sites for offshore wind-farms. All in all, 20 marine habitats out of the 104 marine habitats present in the area are included within these sites.

If Table 16 is studied more closely it becomes apparent that it is in reality very few habitats that are of (current) interest for the wind farm industry in the Kattegat region. Of the 228 km^2 selected for offshore wind farms, *infralittoral fine/muddy sand* (model code 2120) covers 115 km^2 or 50% of this area, with four other habitats covering another 31% (Table 16).

The strong relationship between the current sites chosen for offshore wind farms and a narrow range of habitat types indicates that a habitat map could be used for the identification of potential sites for establishment of new offshore wind farms. Such areas would have to be further surveyed for a more detailed assessment of the suitability of the area, particularly in terms of the wind resource available.

The habitat map could also be used to indicate the overall potential of a marine area for the establishment of new offshore wind farms. If industry determines some habitat types as suitable for establishment of wind farms, then this information can be used for evaluating the capacity potential in a marine region. In conclusion, information on broad scale habitats is valuable for the offshore energy sector in identifying potential sites appropriate for infrastructure. A broad scale habitat map can help identify the potential distribution and extent of ideal areas for infrastructure construction efforts and thus inform long-term planning and future investments of an industry, though such planning would become even more valuable if linked to other activities through maritime spatial planning.

10.7. Application VI for the implementation of the MSFD – assessing multiple pressures illustrated by oxygen depletion, marine aggregates and offshore wind-farming

The MSFD initial assessment (art. 8) requires an analysis of the predominant pressures and impacts based on the indicative list of elements set out in annex III, table 2 of the Directive. This includes an assessment of the main cumulative and synergetic effects. This is further developed by criteria 6.2.1 of the Commission Decision, which requires an analysis of the extent of the seabed significantly affected by human activities for different substrates or habitats.

The previous examples show that it is possible to spatially merge information on marine habitats, with information on pressures influencing the ecosystem. Likewise, broad scale habitat maps can be an important tool for illustrating the cumulative impact of the current activities and pressures influencing the marine environment.

The can be illustrated by looking at *infralittoral fine/muddy sand* which covers a total area of 4,946 km^2 in Kattegat. This habitat coincides with activities of the wind farm industry and the marine aggregate industry. In absolute terms, 116 km^2 has been identified for potential offshore wind farms and 20 km^2 designated for marine aggregates. This amounts to only 2.7% of the available habitat area.

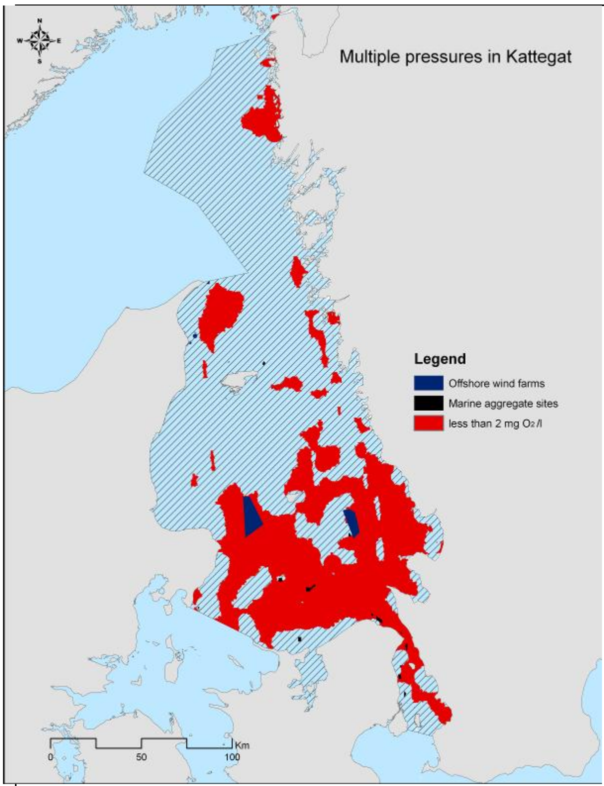


Figure 77 *Multiple pressures in Kattegat.*

Figure 78 *Impact will depend on habitat type.*

However, the illusion of a relatively low impact from these two activities on the habitat shatters if yet another pressure is added to the equation. The effects of eutrophication (e.g. oxygen depletion) impact 1,641 km^2 of the habitat, increasing the sum of cumulative pressures significantly, resulting in a total of 34.6% of the available habitat area being affected (Figure 77). The area impacted would increase further if more pressure was added e.g. the effects from bottom trawling. The EU Commission recently published a report concluding that the effects of bottom trawling has made the commercial stocks in Kattegat 100 times lower value than the stocks in the Sound (where trawling is banned) though the effects on biodiversity is not included in the report /[12]/. All in all, HELCOM HOLAS identified 52 pressures in the Baltic Sea region (the HELCOM region includes the Kattegat) and it ought to be the sum of impact from these activities upon our ecosystem that should be assessed rather than the few in our example. However, our example can be used for illustrating several points:

First of all, it is important to keep in mind that not all activities influence the marine environment equally and that addressing some of the major pressures might prove more cost-efficient than handling many small activities. It is also important to keep in mind that not all activities have the same ecological impact upon the habitats. The offshore wind farms are targeting large areas of specific habitats, though the actual ecological spatial foot-print upon the seafloor will be fairly small compared to the devastating, non-reversible impact from marine aggregate extraction. From an ecological point of view not all activities have the same impact, and impact will depend on habitat type (Figure 78). From a spatial planning point of view, one sector might have a small ecological impact, but still put huge demands on maritime space requiring integrated planning for comparing and meeting the demands from multiple users. Similarly, an activity might have small spatial demand, but have a potential high ecological impact.

If Figure 77 is studied closely it also becomes apparent that the area influenced by oxygen depletion is also the area targeted for offshore wind farms. As one pressure already has reduced the biodiversity in the area, the additional impact might be even less from placing a wind farm on the locality (compared to a pristine locality). It also opens up for exploring synergetic effects as required by the MSFD. It has been demonstrated that adding hard substrata in an oxygen depleted area (with available light at the seafloor) might improve oxygen concentrations locally and hinder exponentially development of oxygen depletion events /[13]/. Similarly, initial results from restoration of reef areas in the Kattegat show an increase of biodiversity in the area surrounding the restored reef /[14]/.

Secondly, in order for an Environmental Impact Assessment to support an ecosystem-based approach to management all the activities influencing a specific ecological component – here seabed habitats – ought to be taken into account. Our previous examples for marine aggregates and offshore wind farms clearly indicates that Environmental Impact Assessments applying a *site-by-site* approach will fail to support an ecosystem-based approach to management as it must include the cumulative impact of multiple pressures upon the ecological component which is being assessed. Our examples illustrates that when making Environmental Impact Assessments, broad scale habitat maps are invaluable for assessing multiple pressures upon specific ecological entities. The requirement is for the habitat maps to be relatively precise in qualitative terms as they otherwise could be used to "dilute" the effects or impacts from activities with a small spatial footprint, but which impact a particular habitat.

Thirdly, in regard to the MSFD initial assessment such spatial information and the ability to combine it are important in regard to assessing the overall achievement of Good

Environmental Status by 2020. It informs criteria 6.1.2 on the extent of the seabed significantly affected by human activities for different substrate types. As argued previously it ought to be broad scale benthic habitats significantly affected by human activities rather than ecologically-inert substrate types. However, such a comparative analysis is now possible for every region mapped by EUSeaMap.

In regard to criteria 6.1.2 the logical step would be to use spatial information to start a discussion of viable indicators as well as targets of such indicators. This could be in regard to the exploitation level of any given habitat as well as the protection level. For example, a "simple" indicator could be the maximum allowed percentage of area exploited for each predominant habitat i.e. X%. Such areal indicators could inform the initial assessment, the Programme of Measures as well as the development of the representative network of marine protected areas. Such discussion could be developed and informed by work done in the context of the Regional Sea Conventions.

In case of our demonstration *infralittoral fine/muddy sand* 34% was under impact in the Kattegat from only three pressures. It should be mentioned that 12.9% of this habitat type is found within Natura 2000 areas. With the present management practice in Denmark, both offshore wind farms and marine aggregate extraction can occur inside Natura 2000 if those activities pass an EIA it could be argued that current protection schemes could be improved. This is especially important if these spatial protection schemes are meant to counter-balance our exploitation of the marine environment. It is only rarely that an EIA results in refusal of permission to exploit an area of the seabed.

Fourthly, broad scale habitat maps provide the industry with valuable information about the limitations imposed by the lack of availability of suitable habitat for certain developments and that new approaches/technology might be needed in order to exploit other habitats. Such challenges could be guided by developing relevant targets under the MSFD e.g. for descriptor 6 on how much of a marine habitat can be safely exploited while maintaining a long-term sustainable development and functioning (sea-floor integrity). The result of any Programme of Measures trying to handle this challenge would most likely have to include some sort of integrated maritime spatial planning. In our example, it is clear that while offshore wind farms and marine aggregate extraction areas are not currently overlapping, they might be in the future and a conflict of interests could occur. If more varied stakeholder interests are added such as shipping and fisheries these conflicts would become even more apparent.

Lastly, when prioritising among activities it should be kept in mind that while both the wind farm and marine aggregate sectors are targeting the same habitat not all of the habitat area might be of interest to the aggregate sector. A site selected for marine aggregate extraction will depend on the volume of the resource rather than the surface layer (important for the habitat). Hence, some areas will be suitable for aggregate extraction, while other will not. Such concerns should be recognised when prioritising between demands to the same area.

As an added bonus, such information and targets would allow the industry and the Member States to associate economic value to targeted habitats i.e. the amount of aggregates available or wind farm capacity possible. This would inform the socio-economic assessment as well as long-term sectoral planning. Whatever the target decided upon (and these might vary according to habitat resilience, impact from an activity, community demands etc.) such information could guide and inform several steps of the maritime spatial planning cycle described later in order to balance different stakeholder interests and political ambition of having a healthy sea.

In conclusion broad scale habitat maps can be applied to show the amount or area of habitat available in any given marine region. Combined with human activities it the information can be used to gain insight into the level of exploitation or impacts upon individual ecosystem components.

The broad scale habitat maps now are available for large areas of the European Seas making these simple overlay analyses possible for any human activities for which spatial data are available in the European maritime areas mapped by EUSeaMap. It presents the European Community with a strong tool to truly achieve and implement an ecosystem-based approach to management in order to achieve a long-term sustainable development.

10.8. Application VII for the implementation of the MSFD – assessing cumulative pressures in the marine environment

The previous example indicate that while these simple overlay analysis can be used to inform many different aspects of the MSFD initial assessment as well as for strategic planning of maritime interests, they would very fast become extremely complicated to handle if more activities were to be added.

Hence, a different approach has to be implemented in order to assess the cumulative impact of multiple pressures in the marine ecosystem. This brings us back to the basic understanding presented in the introduction – maritime activities are all occurring somewhere within the ecosystem and require or influence marine space already inhabited by one organism or another be that the surface, water column, seafloor or sub-surface. The key in trying to solve this challenge will be to find a spatial framework in which compare very different entities.

The broad scale habitat map provides one part of the solution (based on MSFD annex III, table 1) and the MSFD annex III, table 2 provide important guidance for the second part of the solution. It identifies 8 major and 18 minor pressure and impact groups. The logical step would be to classify human activities according to these groups and use them to describe the cumulative pressures in a spatial context e.g. what is occurring on any given locality. The next step is to develop an approach enabling a direct comparison of pressures with coherent broad scale ecologically-relevant information e.g. broad scale habitat maps.

In 2008 an approach develop by Halpern *et al*. was introduced in *Science*, for assessing cumulative pressures /[15]/, which since has been tested for the Baltic Sea region by HELCOM. This resulted in the holistic assessment performed by HELCOM HOLAS for the Baltic Sea Region, which was published in 2010 /[16]/. The methodologies are currently under further development for the eastern part of the North Sea sub-region by the HARMONY project – a joint project initiated by authorities in Norway, Sweden, Germany and Denmark.

The methods for assessing cumulative pressures and impacts are straight forward to apply and aim to combine information about pressures and the ecological components of the marine ecosystems. The methodology is outlined in Figure 79 and described in detail by HELCOM /[17]/.

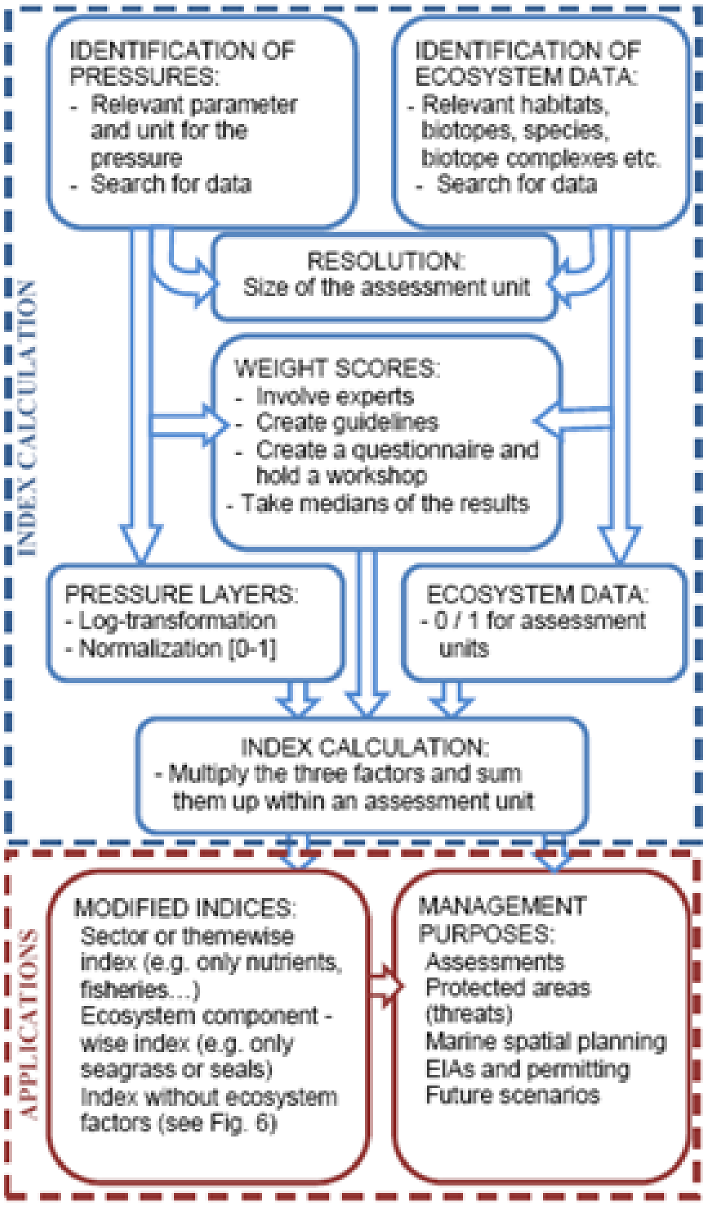


Figure 79 *Conceptual model of the steps in the calculation of cumulative pressures and impacts and their adaptations as well as indication of some potential management purposes (from Korpinen* et al.*, submitted).*

A key element for such a holistic assessment is to have a comprehensive and coherent description of the marine ecosystem in a spatial context as well of the pressures occurring in any given locality. If such coherent information is not available, then any assessment performed will be unbalanced. This will result in some areas is overrepresented, while other areas underrepresented in the analysis. Broad scale habitat maps thus provide a coherent and strong tool for any analysis claiming to support an ecosystem-based approach to management. Though many challenges still remains in regard to relating pressures with the impacts caused on ecological entities, such as broad scale habitats, the approach developed by HELCOM provide an important step towards assessing cumulative pressures in the marine ecosystems compared to handling separate pressures individually.

The combination between ecological information and pressures provide a range of important information. This includes an overview of the relative sum of pressures in any given area presented as a pressure index. Such index can be structured according to the 18 groups identified in annex III in the MSFD thus directly supporting the MSFD marine strategies.

If the information on pressures is combined with broad scale habitat maps (and by applying expert judgment) an index illustrating the impact upon the ecological entities and the marine ecosystem can be developed. This can be applied for illustrating which areas are under which amount of pressure. Assuming that the assessment of the impact is fairly correct then the potential use of pressure and impact indices include: i) overview of pressure and impacts from specific sectors in different areas, and ii) a ranking of pressures, e.g. per marine region, sub-region or sub-division or even at a smaller scale. Both the overview and ranking provides a prototype Decision Support Tool in regard to cumulative pressures and impacts and thus for prioritization of remedial actions (Figure 80 and Figure 81).

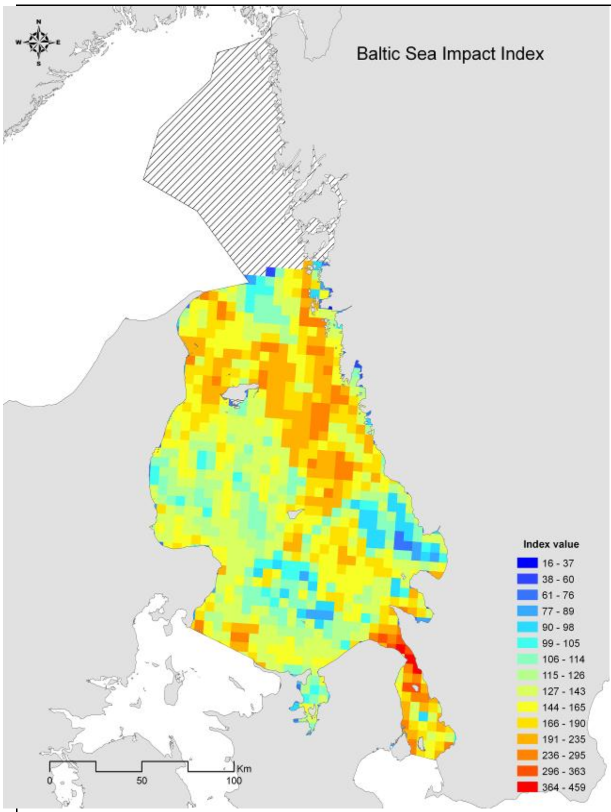


Figure 80 *The Baltic Sea Impact index is merging broad scale ecological information with the pressure index for the Kattegat area (including the northern parts of the Sound). Source: HELCOM HOLAS /[18]/.*

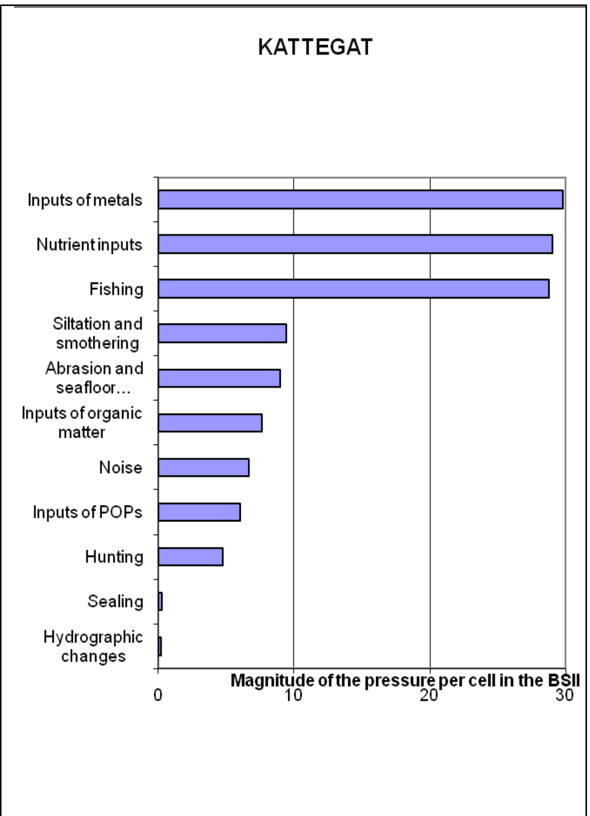


Figure 81 *The Baltic Sea Pressure index summarizing the cumulative pressures in the Kattegat. Source: HELCOM HOLAS, unpublished data*

On basis of Figure 80, it is clear that there is a large geographical variation in the magnitude of impacts within the wider Kattegat area where some parts are only slightly impacted whilst others, for example the northern parts of the Sound, is significantly impacted.

Raking a total of 52 pressures within the Kattegat (Figure 81) reveals that three pressures (inputs of metals and nutrients as well as fishing pressures) are dominant compared to all other pressures. Additionally six other pressures (1: Siltation and smothering, 2: abrasion and seafloor extraction, 3: inputs of organic matter, 4: noise, 5: inputs of POPs and 6: hunting) also seem to play a crucial role. Surprisingly, the remaining pressures could seem to be – at the Kattegat scale, not necessarily on a local scale – of limited importance for the overall environmental status of the Kattegat. In other words: the cumulative impact index provides a transparent tool for evidence-based prioritisation of actions and reduction of risks of implementing actions with limited effects on the overall environmental status.

Such information can form the basis for an informed programme of measures. Part of establishing the programme of measures would be to break down the information provided by the impact index by looking at the background information on individual pressures and e.g. broad scale habitat maps as illustrated in the previous examples. It should be part of the spatial planning process described in the next chapter as holistic solutions will require balancing between sectors as well as an understanding of the carrying capacity of the marine ecosystems.

In conclusion, broad scale habitat maps are essential for understanding cumulative pressures and their impacts upon the marine environment no matter which assessment tools are applied. Indices on pressures and impacts provide a simple tool to describe the effects of multiple pressures in the marine environment – a description which very fast would become impossible if each pressure and each ecological entity was handled individually. Such indices thus support the simple overlay analysis made previously, and when combined they can inform the MSFD initial assessment or the Programme of Measures.

10.9. Application VIII for the implementation of the MSFD – linking broad scale habitat maps with fisheries

The European Seas has for thousands of years provided the people living along our shores with fish be that the legendary herring fisheries of the Baltic Sea, the cod fisheries in the North Sea or the blue fin tuna in the Mediterranean. With the marine environment deteriorating and the continued increase in human use of its resources, services that until now have been taken for granted are endangered. The implications are profound and the coastal communities and economies are at the forefront of changes that will influence the daily life of the people depending on the sea to provide a living.

One of the industries which stand to gain the most from reversing these trends through the implementation of an ecosystem-based approach to management is commercial fisheries. Commercial fisheries can also reap the benefits of broad scale habitat maps, though the application of these maps to support fisheries would require close linkage to other management measures.

EUSeaMap mapping efforts has been focussed on providing a coherent and harmonised approach to habitat mapping reflecting broad scale patterns of the benthic communities in the European Seas. At the same time a different tradition has been applied for fisheries, which has had a tendency to focus on a single species. This approach is now being set aside as fisheries management has started to move towards a more holistic ecosystem-based approach. At the same time, the concept of essential fish habitats (EFH) and their relation to fish stock are now a common consideration in fisheries science. EFH are defined as "*those waters and substrates necessary for fish spawning, breeding or growth to maturity*".

Fish habitats are usually split into seabed habitats and water column habitats. In addition to demersal fish closely depending on the seabed, pelagic fish – at least in certain of their life stages – also show dependency of seabed habitats. The BALANCE project summarised the many ways fish use the seabed /[19]/:

- Spawning areas
- Nursery areas (for larvae and juveniles)
- Adult feeding areas
- Migratory corridors

However, in order to bridge a gap between these two rather different mapping approaches (one providing a coherent mapping approach and one focussing on single species) an obvious question is whether the habitat classification and mapping provided by EUSeaMap also reflect the distributional patterns of individual species. If such linkage could be established between broad scale habitat maps and a commercial targeted species, then the broad scale habitat map could provide valuable information for the fishing industry.

This would not be in regard to help the commercial fleet to find the fish as a broad scale habitat maps can not compete with the knowledge passed from generation to generation of fishermen. Rather it could help to identify the total habitat area available for a commercial targeted species and identify the pressures impacting upon the habitat. The BALANCE project has shown that the recruitment or cohort of Cod (*Gadus morhua*) in the Baltic Sea is directly linked with the habitat volume available for spawning /[20]/. Similar, patterns can be seen with the local populations of sea trout in Danish streams and rivers. If there is an increase in potential spawning habitat, then there is also an increase in the population. Of course, many factors influence the size of a population, but it is not unreasonable to propose the hypothesis that a linkage exist between the habitat available for a species and the potential size of a stock or population.

Unfortunately, it is often very difficult to obtain any useable information on where different species are caught at a sufficient high resolution to inform a comparative analysis. Information presented at the level of ICES squares is useless for informing such analysis as no linkage can be made between the broad scale habitats and the information gained from fisheries. However, it has been possible to identify one useful information layer for commercial fisheries of Sand eels (*Ammodytes* sp.) in the Greater North Sea sub-region provided by DTU Aqua in Denmark /[21]/.

In order to make a comparison a few facts on the Sandeels have to be presented. Sandeels bury in the sediment during the periods when they are not feeding on zooplankton the water column. They do not feed when the light is low or when the food is scarce e.g. during winter. Furthermore, the distribution of settled Sandeels is highly patchy and appears to be related to the composition of suitable substrate and energy conditions. A typical habitat for Sandeels in the Greater North Sea would be on sandbanks located at 20-70 m where the content of silt and clay are less than 10% /[22]/. Hence, it appears that a broad scale habitat map could be able to pick up suitable habitats for sandeel provided that a sufficient detailed sediment map was available.

In the above study the sandeel fishing grounds were mapped and presented as a proxy for the foraging habitat of sandeels. The fishing grounds are identical to the foraging areas of the sandeel often located at or nearby areas where the benthic habitat for sandeels are located (Figure 82). A combination of the knowledge of fisheries and the ecological requirements of sandeels was thus used to present a GIS map of the fishing ground. The methodology is described in details in /[23]/.

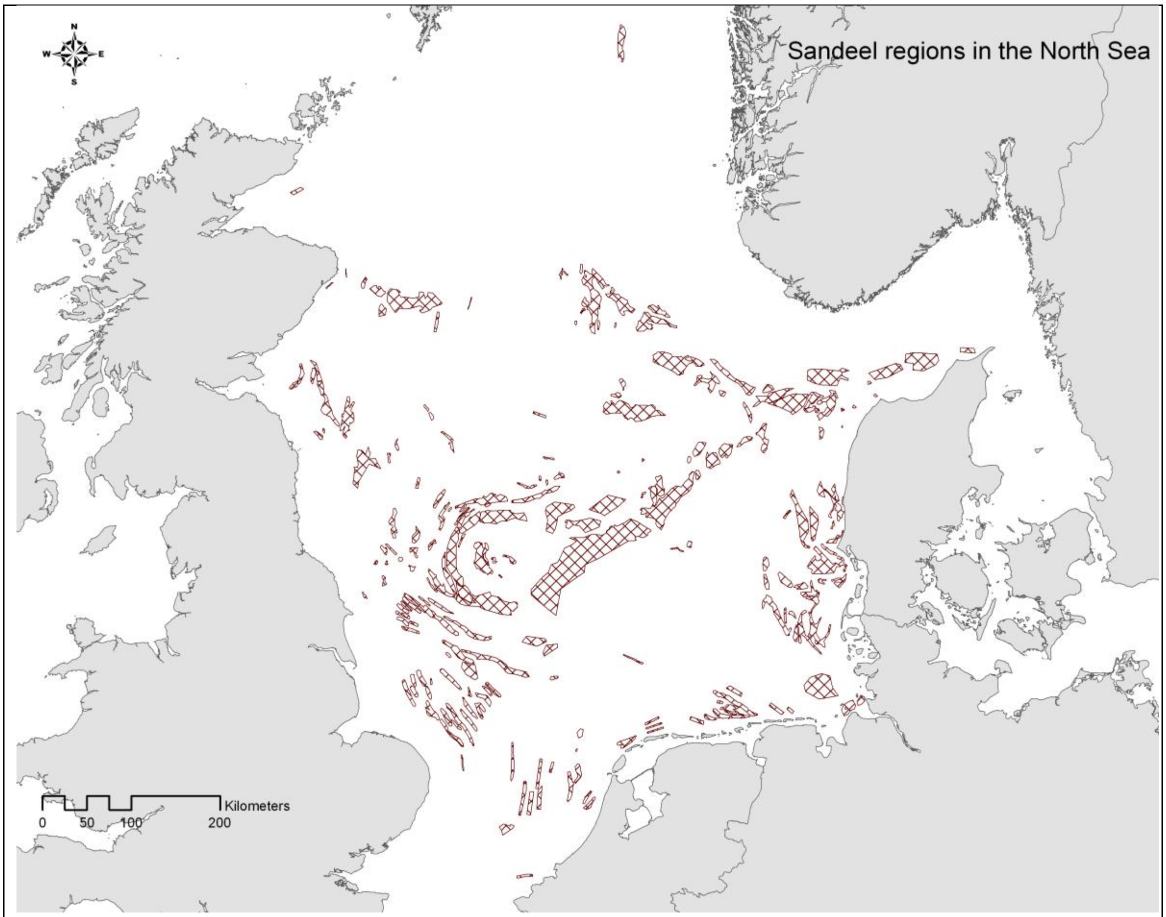


Figure 82 *Broad scale map showing the fishing ground for foraging sandeels in the Greater North sea sub-region.*

Respecting the conditions of the map it is possible to compare such extensive knowledge from fishermen and fishery scientist with the broad scale habitat map for the Greater North Sea sub-region developed by EUSeaMap (Figure 62). From a habitat-mapping point of view such knowledge can help to provide valuable advice in regard to the classification of individual layers i.e. the sediment map and thus help improve the overall confidence in the map. Based on a simple overlay analysis it becomes apparent that while sandeels can be found on fishing grounds covering a total area of 33,500 km^2 and 31 different habitats, five habitats make up 87% of the area targeted by fisheries efforts. It indicates that there is a linkage between the broad scale habitat map and fisheries efforts for sandeels.

Should other benthic fish species be included in the future development of broad scale habitat maps it will be possible to further strengthen the linkage between the broad scale habitat maps and species targeted by commercial fisheries. The benefits are potentially many. A broad scale habitat map could help the identification of potential new fishing grounds or at least less exploited fishing grounds. It could also help inform fisheries of how large a percentage of an available habitat they target with their efforts and thus aid considerations on an environmental impact assessment. It could help identifying areas or habitats, which might be overexploited and in need of either a temporal or permanent closure of some of the areas. This could either be specific grounds or parts of the larger grounds to ensure improved recruitment. Such spatial management initiatives could supplement existing management through quotas as well as supporting the fisheries industry in their promoting of sustainable fisheries. As an added benefit the effects on the benthic biodiversity would probably be very positive, especially if some areas was not to be affected by fisheries and hence could be used to strengthen the green image of the industry by showing they are not only concerned about healthy stock, but also the broader biodiversity.

More importantly, and by assuming the hypothesis proposed above on the linkage between available habitat and size of the stock / population of a species is valid, such sharing of knowledge can help to inform an ecosystem-based approach to management. If the fisheries efforts for sandeels are compared with the broad scale habitat map, it becomes apparent that it is not only offshore wind farms and marine aggregates that compete for the same habitats. Commercial fisheries are also competing for the same area and habitats. Figure 83 shows the sandbank identified in the Danish part of the North Sea as a potential large and valuable resource for marine aggregate extraction.

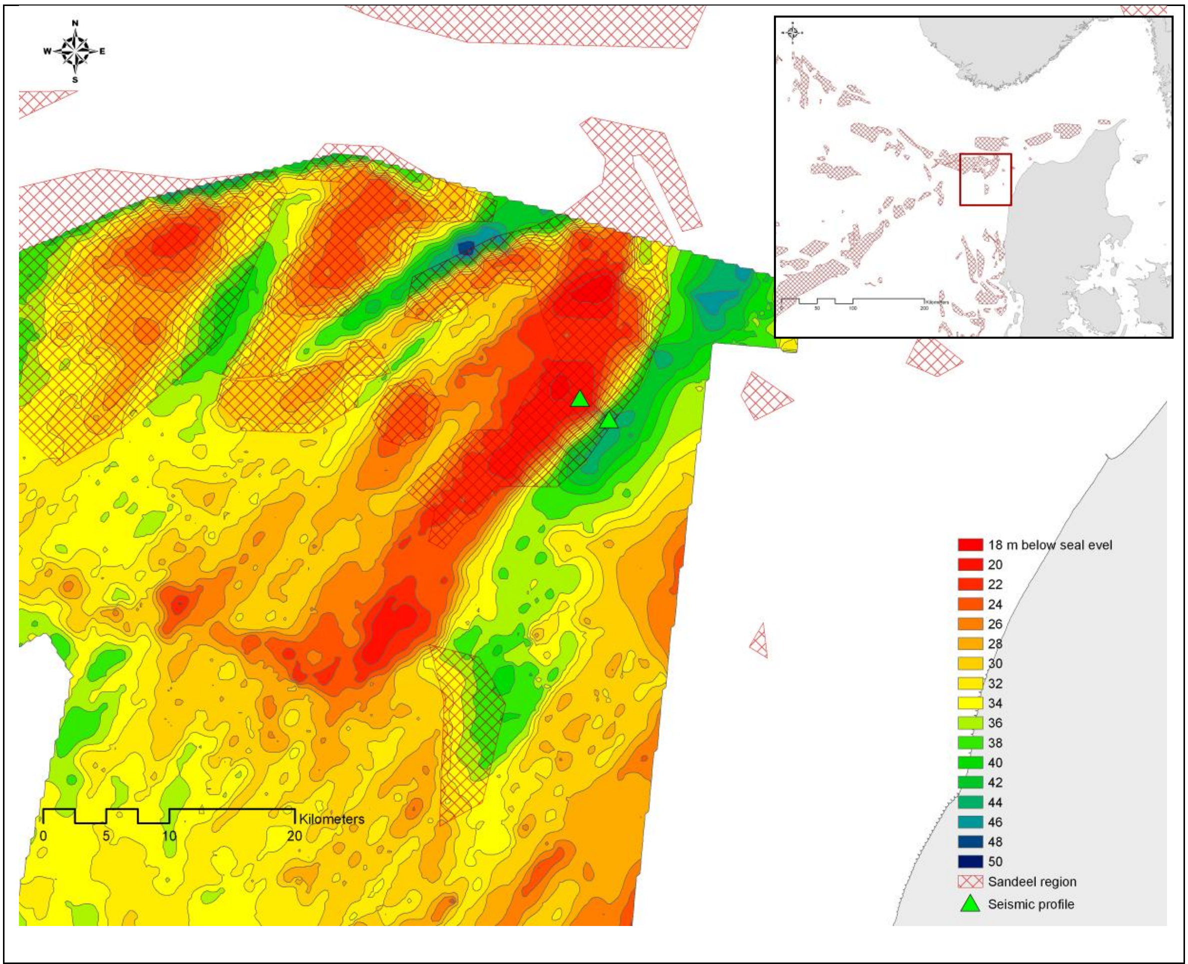


Figure 83 *Acoustic survey identified a 20 km long sandbank in the Danish part – a potential valuable aggregate resource. The overlain areas indicate sand eel fisheries (source: GEUS and DTU Aqua).*

By adding the current efforts of fisheries it becomes apparent that fisheries also have in invested interest in the sandbank. This can result in several conflicts of interests. For example, if the sandbank is designated as a site for marine aggregate extraction, then it might influence the suitability of the area as a suitable habitat for sandeels both in the short term and long-term. Removing e.g. 8 meters of the height of the sandbank will change the local environment and most likely the combination of grain size and energy favoured by the sandeels. Thus it marine aggregate extraction could influence the area of suitable habitat for sandeels at least in the local area. The point here is not so much the effect of a single marine aggregate extraction site as these sites normally are of a fairly small spatial extent, but rather to illustrate that other activities than fisheries might influence the potential size the commercial targeted stocks. If small parts of a habitat is removed by a range of different pressures, then the carrying capacity or here potential stocks size will be smaller (assuming the hypothesis on linkage between available habitat and stock size mentioned above is correct).

In summary, broad scale habitat maps can help identify potential new fishing grounds. They can inform assessments of total habitat available for commercial fisheries targeting species depending on specific benthic habitats and thus provide a spatial input to management measures. The broad scale habitat maps can also be used to asses the impact of multiple pressures upon the habitats suitable for specific species, thus providing food for thoughts on which activities influence the health of populations targeted by commercial fisheries.

10.10. Application IX for the implementation of the MSFD – informing monitoring programmes

The MSFD art. 11 requires the Member States to establish and implement coordinated monitoring programmes for the ongoing assessment of the environmental status of their marine waters. This should be based upon annex III, table 1 and annex V of the MSFD.

As the broad scale habitat maps are based upon several parameters from annex III, table 1 and acting as a proxy for many of the other elements mentioned, it is logical to use the broad scale habitat maps where possible. This could be in regard to designing a comprehensive net of monitoring stations (few intensive and more extensive surveyed stations) throughout a marine region covering all habitats or, more realistic, major groupings of broad scale habitats e.g. abyssal muddy habitats or photic rocky areas. Such design would enable both a good representation of ecosystem components and provide reliable information for a description of the communities dominating each broad scale habitat. This information could be further developed into strong indicators for assessing Good Environmental Status informing several criteria and sub-criteria. For example, quantitative information on infauna from a survey designed to cover muddy habitats could inform criteria 1.1, 1.2 and 1.3.1 on species. These could then be linked to criterion 1.4 on habitats to make an overall, general assessment of the extent and status of infauna communities within a marine region, sub-region or sub-division even if every single habitat was not surveyed and species identified. This would be a cost-efficient solution and while it is neither possible nor viable to monitoring every single species in the European Seas, then some species information linked to habitat maps (and the status of these habitats) could provide a good proxy for all the species living or depending on these habitats. Of course, it has not been possible to develop this as part of EUSeaMap, but it could be further developed through the MSFD Common Implementation Strategy or by the work done in the Regional Sea Conventions e.g. OSPAR ICG-COBAM.

Similarly, the infauna information could inform on criteria 2.1 and 2.2 in regard to invasive species. If merged with the broad scale habitat maps and information on dominating currents likely vectors for spreading of invasive species (depending on a specific type of habitat/substrata) from one site to the next could be identified. Broad scale habitat maps could also form the basis for a detailed survey aiming to inform criterion 4.3 on e.g. habitat forming species (EUNIS level 4 or 5) by providing information on the most likely occurrence of such habitats. Of course the broad scale habitat maps have to be further improved (in regard to associated communities) in order to fully support such needs.

Lastly, as demonstrated previously, broad scale habitats are essential for informing criteria 6.1.1 and 6.1.2 in regard to impact on the seafloor. The broad scale habitat map should be combined with information on pressures (pressure and impact indices as described previously) and a stratified monitoring programme could be developed based on the amount of pressure and sensitivity of the habitats influenced.

Broad scale benthic and pelagic habitat maps could together inform monitoring programmes. Though EUSeaMap has not developed pelagic habitat maps and hence, can not demonstrate the use of these, similar and synergetic benefits could be derived from having pelagic habitat maps. This could result in the question of whether monitoring done for the Nature directives and especially the Water Framework and MSFD directives could or should be combined with the monitoring efforts done for informing fisheries. Combining such efforts would be cost-effective and reflect an ecosystem-based approach. This holistic approach is underway in the UK, under the Marine Biodiversity Surveillance and Monitoring Programme. At least the MSFD monitoring programme could learn from the approach for monitoring stocks rather than just national territorial waters. Covering a marine region in a joint monitoring programme using the exact same methodologies, joint survey planning and a shared database (in the context of the Regional Sea Conventions or the European Environment Agency) would result in making better use of the information gathered. It would result in a more coherent basis for advising policy decisions.

10.11. Application X for the implementation of the MSFD – representative networks of MPAs

According to the MSFD art. 13.5, Member States shall within their programmes of measures include spatial protection measures. These shall contribute to coherent and representative networks of marine protected areas and adequately covering the diversity of the constituent ecosystems. The spatial protection measures should include existing spatial protection schemes such as areas designated by the Natura 2000 directives. This representative and ecological network has to be reported to the EU Commission by 2013.

10.11.1. Case study: Kattegat

First of all, the habitat maps can be applied for making a simple analysis of the complexity of different marine areas identifying areas with low and high habitat complexity (Figure 84). This figure shows that not all areas are equally diverse. Such information is important if multiple stakeholders are competing for space as it identifies areas where a MPA could encompass several different habitats, thus limiting the amount of space needed to be set aside for MPAs.

The western part of Kattegat contains fewer broad scale habitats compared to the eastern side and only a few habitats dominate the seafloor of Skagerrak. The map only shows the numbers of habitats present within a 10 km grid and does not distinguish between grids. Hence, a dark blue grid cell might contain one broad scale habitat, while the neighbouring blue grid cell is equally diverse but contains a different single broad habitat.

The complexity map can also be used to inform maritime activities. For example, in regard to designation of maritime assistance sites it might be desirable to have these in less complex areas in order to simplify any assistance efforts, including cleaning efforts after oil spills. This has been further developed in the section on maritime zoning.

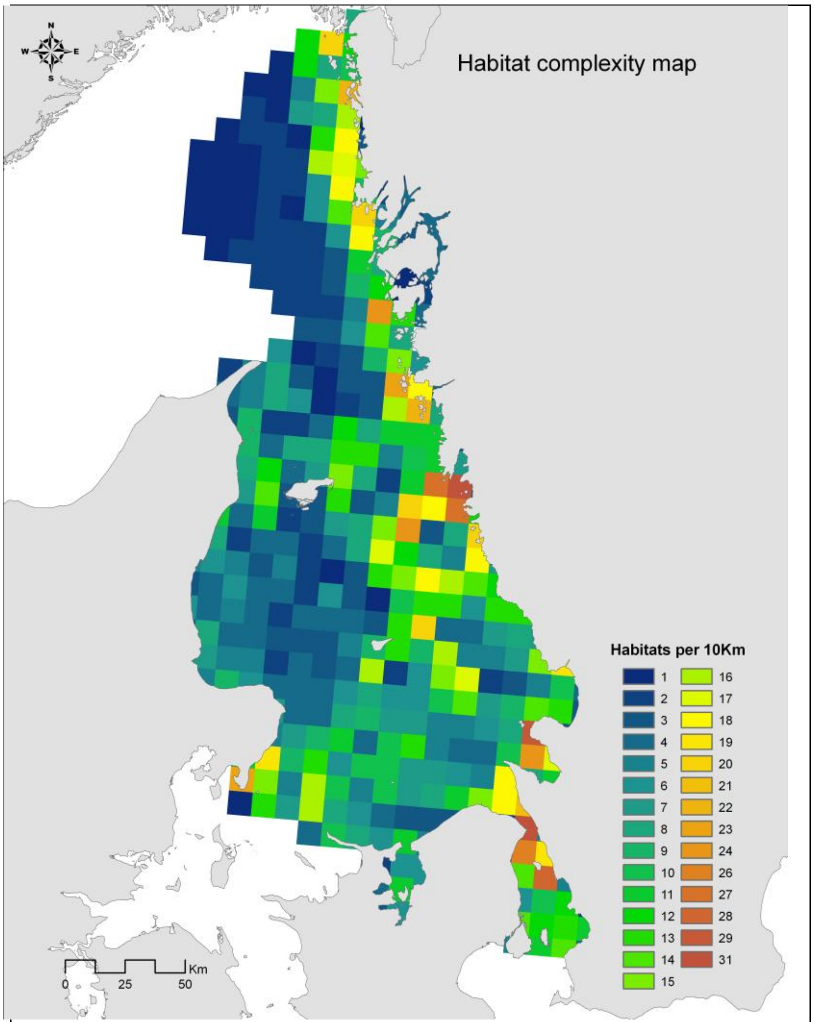


Figure 84 *Number of habitats present in a 10-km grid indicating highly diverse areas.*

Returning the designation of a representative and ecological coherent network of MPAs, then broad scale habitat maps can provide essential information for assessing current spatial protection schemes such as on the representativity of the existing Natura 2000 network of marine protected areas /[24],[25]/.

First of all, ecological coherence should be defined. The INTERREG IIIB project BALANCE defined ecological coherence within a network of MPAs as: *i) Interacts and supports the wider environment, ii) Maintains the processes, functions and structures of the intended protected features across their natural range, iii) Functions synergistically as a whole, such that the individual protected sites benefit from each other in order to achieve the two other objectives, and iv) be designed to be resilient to changing conditions.*

In summary, a MPA network should be designed to ensure resilience and ecological functioning of an ecosystem, i.e. the aim should be to keep the natural state or "balance" of the ecosystem as a whole /[26]/.

A logical solution to progress further towards the requirements of MSFD art 13.5 would be to nominate the existing Natura 2000 network and state that it meets the MSFD requirements. However, broad scale habitat maps can be applied as a safeguard to assess whether this is in fact the case (Table 16). Before illustrating how to conduct a simple overlay analysis based on examples from the Kattegat and the Western Mediterranean it is important to be aware of certain conditions:

- The existing Natura 2000 network has been designated based on the requirements of the Natura 2000 directives, which *per se* do not require a representative protection of the marine ecosystem. Hence, the MSFD goes beyond the Natura 2000 directives.
- The Natura 2000 network has been designated based upon a few, poorly defined marine habitats.
- Our knowledge of marine habitat mapping and classification has improved significantly since the entry into force of the Habitats Directive.
- Our methodology for designation of sites has improved significantly since the entry into force of the Habitats Directive.
- The Birds Directive does not require protection of the benthic habitats unless they are of importance for the birds for which the site has been designated. Hence, these sites are not part of the analysis as no protection exists for the majority of the habitats inside these areas.
- If a habitat is not listed within the annexes of the Habitats Directive then the habitat is not automatically protected even if it is found inside a Natura 2000 site. This can be exemplified with the current management practice of allowing marine aggregate sites, offshore wind farms and fisheries inside Natura 2000 areas if they pass an EIA. Hence, by applying a direct spatial comparison between the MPA network and the habitat map, the protection level will be overrepresented compared to the actual level of protection. This lack of actual protection might be central for understanding some of the current pressure on the marine biodiversity.
- Our assessment is based solely upon the broad scale habitat map and does not take any other considerations into account for which a site might have been designated.
- Sites set aside for other purposes, e.g. temporal fisheries closures, have not been included because they are a fisheries management tool rather than a biodiversity protection tool.
- The existing Natura 2000 network has been formally approved for the biogeographic area(s) in question; this example should not be perceived as a criticism of the current implementation of the marine Natura 2000 network.
- Part of the text below and similar conclusions were also published by the BALANCE INTERREG IIIB project /[27]/.

Keeping these conditions for the assessment in mind, broad scale habitat maps can be applied to improve the coherency and representativity of current spatial protection schemes.

A total of 2,909 km^2 or 9.8% of the Kattegat has been designated under the Habitats Directive as a marine protected area (Figure 85). Of the 104 broad scale habitats present in the Kattegat 22 were not present at all inside the current network of protected areas (Table 16), while the remaining 82 habitats are represented from 100% to less 1% of their total area. Of these, 37 occur inside a designated site with more than 20% of their total area. In general, broad scale habitats within the photic zone have a higher representation than broad scale habitats from the non-photic zone.

Table 16 shows that broad scale marine habitats, which to some extent can be related to habitats mentioned in annex I of the Habitats Directive, are well represented within Natura 2000. This is especially true for e.g. sand in the photic zone or hard bottom in which the reefs can be found. There is no doubt that while the current Natura 2000 network in Kattegat fulfils the requirements of the Habitats Directive (approved at the biogeographic seminar), the current implementation of the Habitats Directive appears to be less than adequate for protecting a representative part of the marine environment as required by the MSFD. For example, though mud habitats have an area of 14,963 km^2, only 469 km^2 or 3.1% is found inside a protected area. The explanation is that there is no habitat identified in the Habitats Directive annex I for non-photic mud. A similar pattern is found for habitats dominated by sand and coarse sediments, where a total of 9,088 km^2 is found within the Kattegat. Of this area 1,596 km^2 or 17.6% is found inside protected areas. Only 8.8% of the non-photic habitats dominated by sandy/coarse sediments are inside protected sites, while 18.7% of the photic habitats are inside. The explanation is partly the limitation in the definition of sandbanks, which states that it only includes sandbanks slightly covered by water (down to 20m) and that not all parts of a sandy seabed form sandbanks. Hence, some of these habitats are not protected under the Habitats Directive.

If this information is compared to the oxygen information in Table 16 it is apparent that the broad scale habitats most likely to be influenced by the effects from eutrophication are also the habitats outside current spatial protection schemes. For example, *infralittoral sandy/fine mud* (model code 1110) has a total area of 765 km^2, of which 408 km^2 (53.4%) is influenced by oxygen depletion and only 0.8% is found inside the Natura 2000 network. Similarly, *circalittoral sandy/fine mud* (model code 2210) has a total area 2,775 km^2 of which 1398 km^2 (50%) is influenced by oxygen depletion and only 36 km^2 (1.3%) is inside a protected area (and even so, not formally protected in this protected area). All in all, of the 104 habitats identified 11 habitats have more than 60% of their area influenced by oxygen depletion. Of these 11 habitats 6 are not inside Natura 2000 at all and only two are inside a Natura 2000 site with more than 30%.

As mentioned previously, it was estimated that 371,000 tons of marine invertebrates died during the oxygen depletion event in the Kattegat and the Danish Straits, while a 50% reduction in species richness has occurred in the infauna communities /[28]/. The argument that a representative and ecologically-coherent network of marine protected areas as required by the MSFD ought to include the small part of a marine habitat not adversely affected by e.g. oxygen depletion from any other negative impacts appears strong. Such protection will be necessary to maintain sanctuaries for healthy donor populations communities acting as a safeguard for ecological catastrophes such as extensive oxygen depletion or intense bottom trawling /[29]/. Based upon this analysis, the example of multiple pressures and impacts occurring in Kattegat and e.g. the Commission analysis of fisheries in the Kattegat and the Sound/[30]/, it could be argued that such sanctuaries do not occur in sufficient numbers or sufficiently extensive areas to fulfil the requirements to a representative and ecologically-coherent network of MPAs, capable of supporting the achievement of Good Environmental Status.

The aim for designating a representative and ecologically-coherent network of marine protected areas designated under the MSFD is to support the achievement of Good Environmental Status, while keeping the overall visions of halting the loss of biodiversity and the achievement of a long-term sustainable development in mind. Finding strong, viable solutions will pose some interesting challenges in the coming years.

The positive side is that, as demonstrated, a simple representativity analysis is now possible for all marine areas for which a broad scale habitat map is available and which is encompassed by the MSFD (as the initial assessment requires an assessment of all significant pressures and impacts by 2012). As shown for the Kattegat such analysis will most likely result in the identification of some gaps in our current MPA network and management practices. Broad scale habitat maps could also be an essential part of any more advanced representativity analysis applying site selection tools such as MARXAN or assessments done by HELCOM /[31],[32]/.

However, keeping in mind that Natura 2000 forms the basis of our biodiversity protection, a logical step towards an representative network of MPAs could be to expand our current management schemes to include <u>all</u> habitats present inside a protected site. This could even include the protection of <u>all</u> habitats within sites designated under the Habitats Directive and the Birds Directive. If this solution was adopted it would increase the total area of benthic habitats protected in Kattegat from 2,909 km^2 to 5,694 km^2 or 19.3% of the total area ensuring that 99 out 104 habitats were represented inside a protected area compared to 82 habitats if only sites under the Habitats Directive were used (Figure 85 and Figure 86). In conclusion, for the Natura 2000 network to contribute support to art. 13.5 of the MSFD one option for the Kattegat might be to expand the current protection to include all benthic habitats inside the Natura 2000 sites.

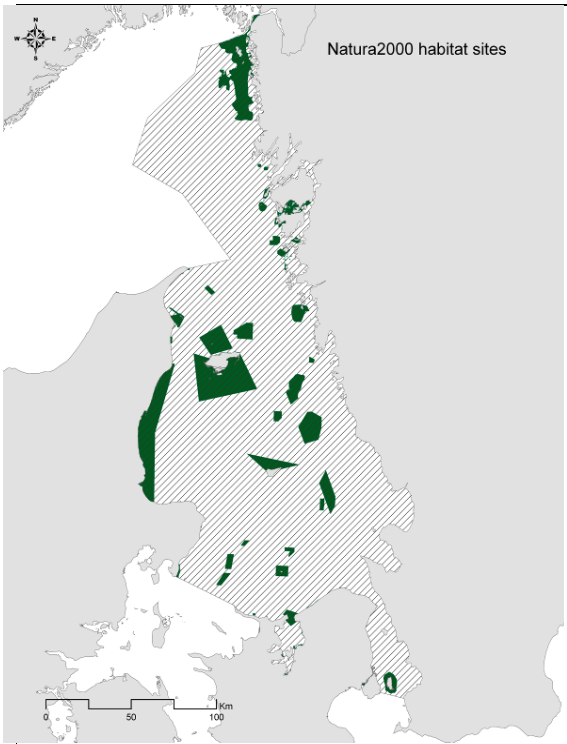


Figure 85 *The Natura 2000 habitat sites in the Kattegat. Areas protected under the Birds Directive are not included.*

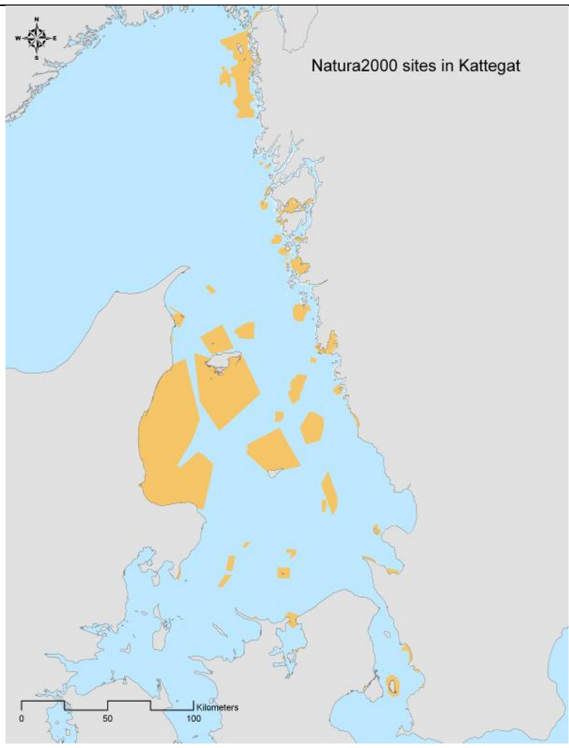


Figure 86 *The Natura 2000 habitat sites in the Kattegat. Areas protected under the Birds Directive are included.*

If such a management solution were adopted, then it would still leave questions of adequacy (are enough sites large enough?), representativity (what are the gaps in geographic distribution and percentage coverage of individual habitats?), replication (replication of sites e.g. if a habitat is only protected in one site it is very vulnerable to sudden impact from e.g. oil spills), and connectivity (not all sites contribute equally to the coherency of a network). All these concepts has been developed and explained by different initiatives /[33],[34]/ and regional sea conventions such as HELCOM /[35]/.

10.11.2. Case study: Western Mediterranean

For the Mediterranean, the Barcelona Convention Protocol on Specially Protected Areas and Biodiversity has produced guidelines for the establishment of MPAs based on a reference list of marine habitat types which deserve specific attention due to their vulnerability, economic, aesthetic, high heritage value or to the presence of protected and rare species[36]. The EC Habitats Directive and the EC Birds Directive and Barcelona convention indications differ from the ecosystem-based approach introduced by the MSFD.

This case study is centred on the evaluation of the usefulness of the modelled seabed habitat map with respect to evaluating the representativity of the existing network of MPAs in the EC countries of the Western Mediterranean Sea. The modelled habitat map will be used to first describe the representativity of the existing network of MPAs with respect to the modelled biological zones and habitat types and then subsequently evaluate the map's usefulness in identifying potential gaps.

Preparation of datasets showing the distribution of MPAs in the Western Mediterranean

The distribution of MPAs in the Western Mediterranean was mapped using data from the following cartographic datasets:

- 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.)[35]
- Natura 2000 network of protected areas database, set up for species and habitats according to the 1979 Birds Directive and the 1992 Habitats Directive[36]

The CDDA dataset was filtered so as to retain only the marine areas subject to protection regimes and also which include the conservation of marine benthic habitats in their objectives. This therefore excluded those marine areas protected under other legal frameworks whose protection objectives are exclusively limited to the management of commercial fish stocks and/or areas for the protection of pelagic resources (i.e. the International Mediterranean Sea Cetacean Sanctuary "Pelagos").

Moreover, the CDDA was updated to include marine protected areas established since the date of the last uploaded CDDA. This update includes cartographic information from the following official national sources and databases:

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[35] http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-3 ; uploaded version: 30 Oct 2008; CDDA boundaries_v8_ 2009

[36] http://www.eea.europa.eu/data-and-maps/data/natura-2000 ; uploaded version September 2010

- French Marine Protected Area Agency (Agence des Aires Marines Protégées): this source allowed addition of cartographic information on natural marine parks[37], national, regional and Corsican natural reserves[38], national parks[39].
- Spanish Ministry of the Environment: this source of information allowed addition of cartographic information on marine reserves of central government competence.
- Autonomous Region of Catalunya and the government of the Balearic Islands: this source allowed access to the establishment decrees and respective cartographic information of marine protected areas[40].
- Italian Ministry of the Environment: this source allowed access to the establishment decrees from which the cartographic information of national marine protected areas not present in the CDDA October 2008 dataset were acquired[41].

The Natura 2000 protected area database was considered only in terms of the marine Sites of Community Importance (SCIs) which were selected on the basis of the presence of at least one Habitat Directive marine habitat or species. The Special Protection Areas (SPAs) present in the database, and established under the framework of the Birds Directive, were not considered because their conservation objectives are not geared at benthic marine habitats.

Furthermore, for the purpose of this application, a territorial water shapefile of each country was defined by calculating a 12 nautical mile buffer from the baselines which were constructed as defined by the respective national legislations.

The cartographic datasets were used to produce two ESRI™ shapefiles: SCIs and other Marine Protected Areas (oMPAs). The latter contains 18 Spanish, 7 French and 20 Italian marine protected areas. These two shapefiles were analysed separately and together (hereafter referred to as ALL). It is important to note that there is a partial overlap between both datasets. This means that the values of the total coverage are not the sum of the coverage values for analysis of the two separate shapefiles. Figure 87 and Figure 88 indicate the distribution of the oMPAs and SCIs in the territorial waters of the western Mediterranean EC countries.

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[37] database version 02/2010

[38] database version 12/2009

[39] database version 08/2009

[40] Freus de Ibiza i Formentera, Badia de Palma, Isla del Toro, Migyorn de Mallorca, Islas Malgrats, Nord de Menorca, Parco Natural I reserve marina Cabo de Gata.

[41] Secche della Meloria, Santa Maria di Castellabate, Costa degli Infreschi e della Masseta, Isola di Bergeggi, Regno di Nettuno.

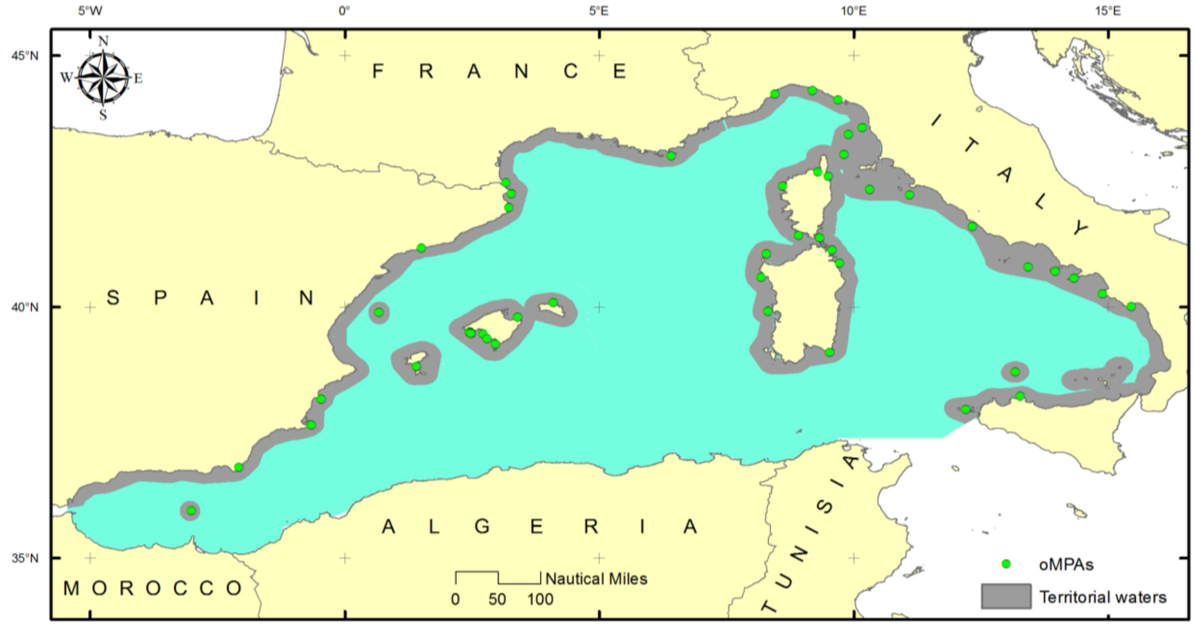

Figure 87 *Distribution of oMPAs in Italian, French and Spanish territorial waters.*

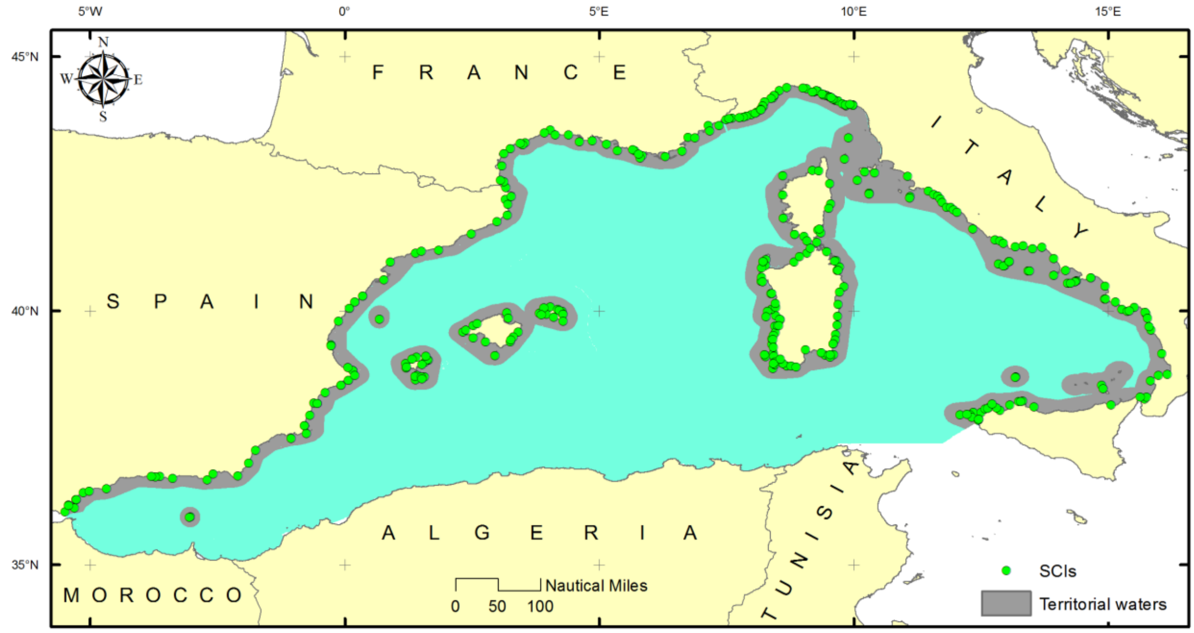

Figure 88 *Distribution of SCIs in Italian, French and Spanish territorial waters.*

The protected area shapefiles were analysed as follows:

- Spatial coverage of the two types of protected area separately (SCIs and oMPAs) and together (ALL) so as to describe the distribution of protected areas and how representative it is with respect to the modelled biological zones and marine habitats of the Western Mediterranean

- Spatial coverage of the protected areas so as to pinpoint the usefulness and limitations of the modelled habitat map by considering the conservation requirements/targets set out under different Directives and Conventions:
    - Examining representativity in the context of the MSFD (ALL)
    - Examining sufficiency in SCIs according to the EC Habitats Directive
    - Examining sufficiency according to the conservation targets set by the Barcelona Convention

Spatial coverage of the protected areas in the Western Mediterranean and EC territorial waters

Figure 89 shows that protected area coverage (ALL) represents almost 2.5% of the total surface area of the modelled map, of which 0.9% is oMPAs and 1.7% is obtained through SCIs. Figure 90 on the other hand shows that if the same analysis is carried out taking into account only the EC countries' territorial waters, the relative percentages increase, with the entire protected area coverage (ALL) amounting to 10.1% of are of the modelled map within territorial waters, of which 9.3% is obtained through SCIs and oMPAs cover 2.4%. Furthermore, each bar in the histogram is split to show how the percentage protected is distributed across the biological zones. It is interesting to notice that the IUCN and CBD 10% protection coverage target, is reached when the entire protected are network (ALL) is considered /[37], [38], [39]/.

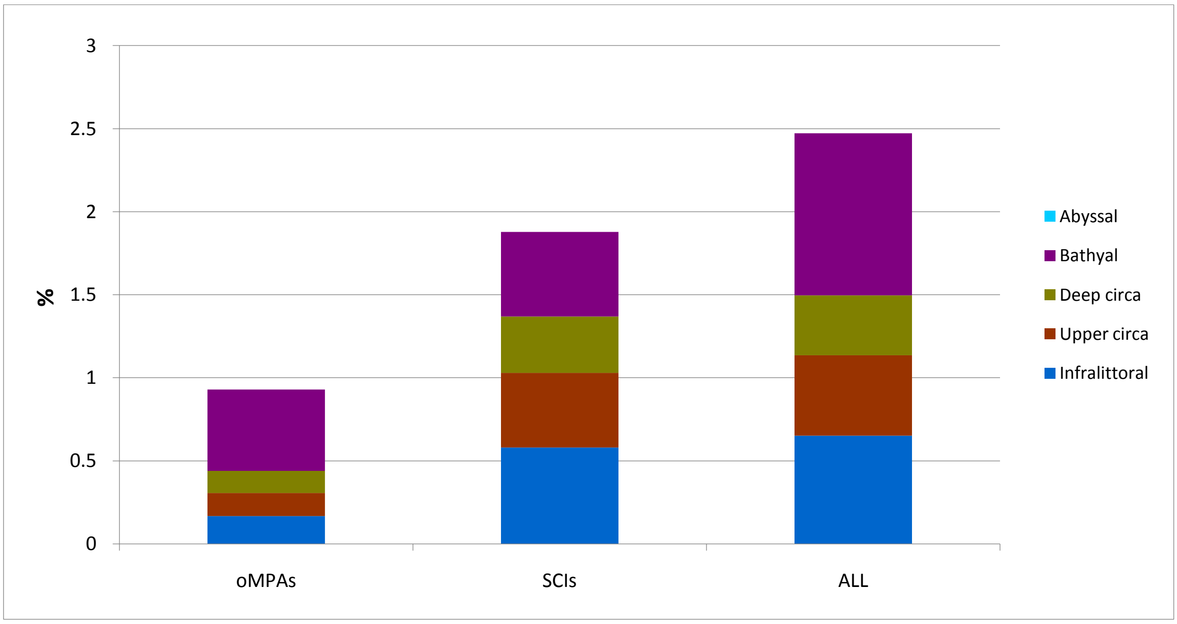

Figure 89 *Percentage of distribution of oMPAs, SCIs and ALL by biological zones in the whole Western Mediterranean.*

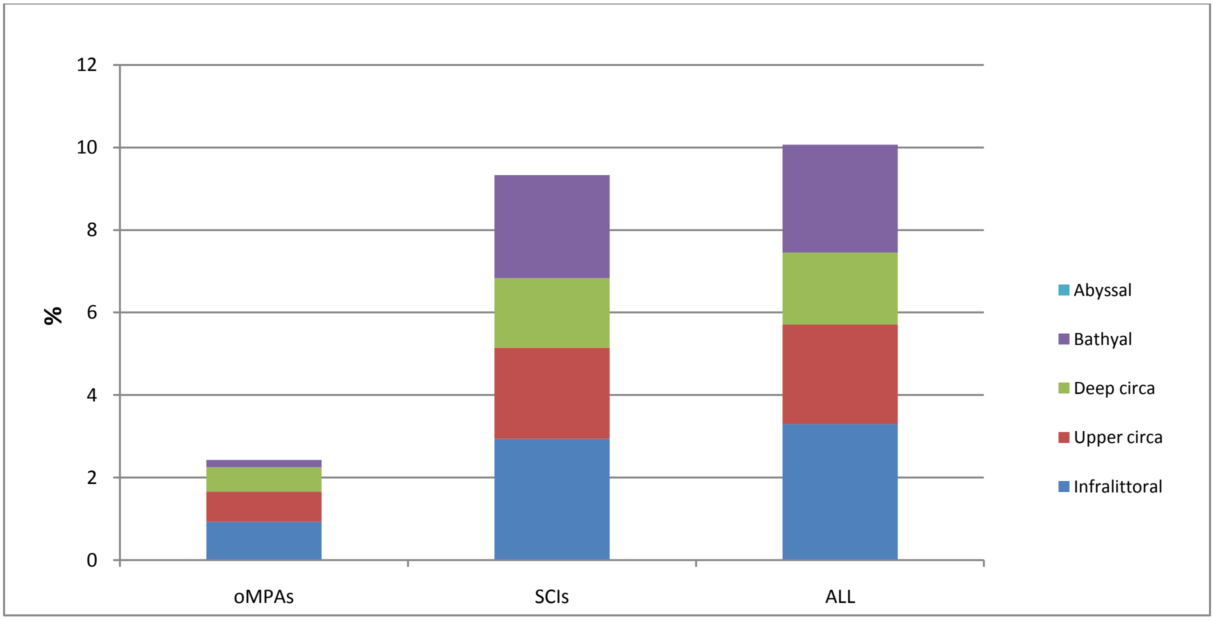

Figure 90 *Coverage different categories of MPAs (oMPAs, SCIs, ALL) as a percentage of the total area of territorial waters of EC countries in the Western Mediterranean. Within this percentage, proportions of the category of MPAs which fall in each of the five biological zones are given.*

An analysis carried out on the entire network of protection (ALL) with respect to the extent of each Member State's territorial waters (Figure 91) indicates the difference in protection percentage exerted by each country. In this case the modelled habitat map allows subdivision of entire protected network in each country's territorial waters with according to biological zones. In this case it must be remembered that the percentage territorial water protection identified is not indicative of the entire national waters as the case study only includes the Western Mediterranean.

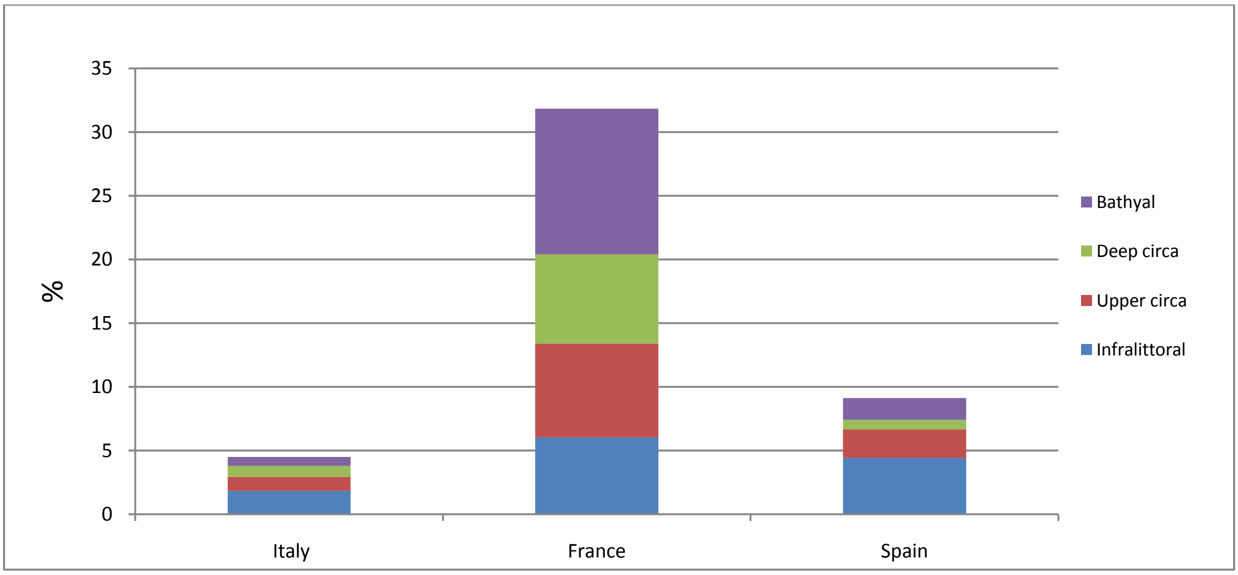

Figure 91 *Distribution of the oMPAs + SCIs (ALL) with respect to each country's territorial water extent (respective proportion of biological zones indicated in each histogram).*

The modelled habitat map can also be used to visualize the percentage covered by the different networks of protected areas (oMPAS and SCIs) with respect to their spatial extent in each biological zone in the EC countries' territorial waters. A way to represent this is shown in Figure 92.

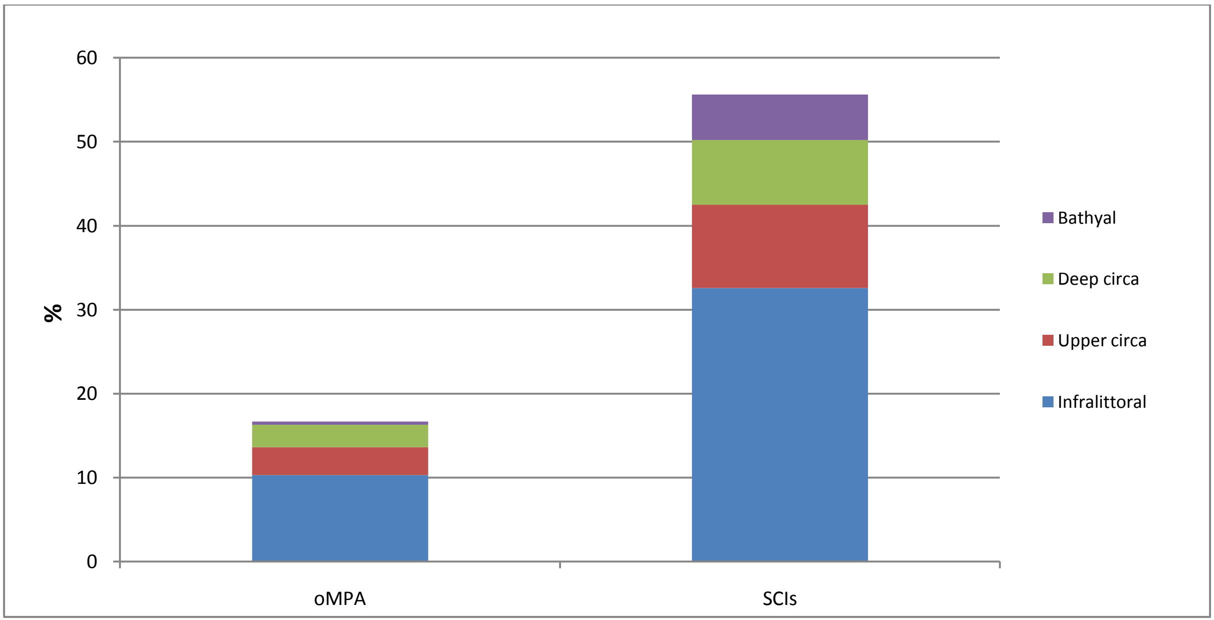

Figure 92 *Distribution of the two different classes of protection (oMPAs and SCIs) by biological zones in the EC countries' territorial waters.*

It is evident that the protection decreases with depth (from infralittoral to bathyal), a factor which is surely reflective of a coastal approach to protection but also likely to be influenced by the lack of knowledge about the spatial extent of the deeper habitats that are worthy of conservation attention.

Moreover, the map also allows identification of how, in each EC country, spatial protection coverage is distributed throughout each modelled biological zone. The percentage coverage in the territorial water of the total protection (MPAs and Natura 2000 networks) with respect to the spatial extent of each biological zone in Spain, France and Italy is reported in Figure 93. France is the exception in protecting more than >10% of the biological zones below the infralittoral (upper circalittoral, deep circalittoral, bathyal).

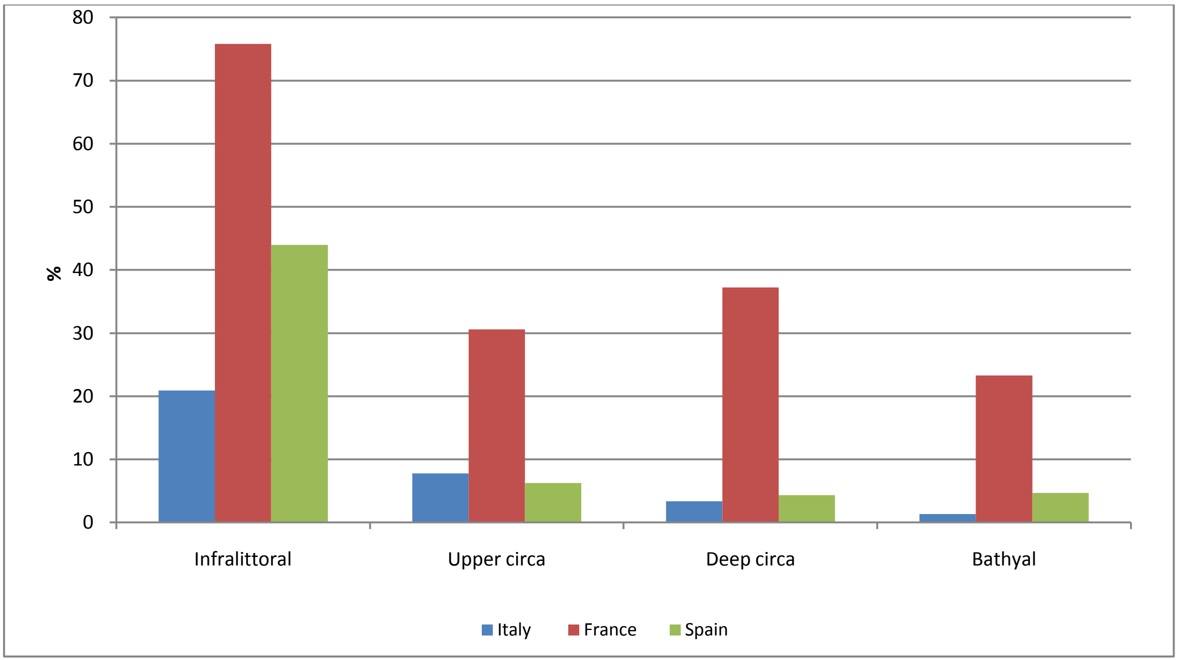

Figure 93 *Percentage of distribution of ALL with respect to each country's biological zone in its territorial waters.*

Using the broad-scale habitat map to evaluate characteristics of protected area networks against conservation requirements

The modelled habitat map, consisting in 21 modelled habitat types and 2 assembled habitats (*Posidonia* and *Cymodocea* meadows) can be a useful support in the evaluation on the distribution of existing marine protected areas with respect to the conservation targets established by the different legal/environmental frameworks. Seventeen out of 23 habitats occur within marine protected areas in the Western Mediterranean. The six habitat types which are not covered by any protected area networks are bathyal and abyssal habitats (A6.2 Bathyal and Abyssal – deep sea mixed substrata, A6.4 Bathyal and Abyssal – deep sea muddy sand, A6.52 Communities of abyssal muds, A6.3 Abyssal – deep sea sand). An analysis of the habitat types which are included within protected areas allows quantification of what percentage of each habitat type is contained in each network within the study area and at a national level (Table 17).

Table 17 For each country's territorial waters, the percentage of each habiatt type included in a protected area is given, for SCIs, oMPAs and in the overall network (ALL). 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's territorial waters								
	Italy			France			Spain		
	SCIs	oMPAS	ALL	SCIs	oMPAS	ALL	SCIs	oMPAS	ALL
A3	29.2	42.3	**59.2**	75.4	8.6	**75.4**	35.6	19.8	42.9
A5.13	13.2	22.0	27.5	75.7	13.7	**75.8**	38.1	13.0	40.9
A5.23	11.3	6.5	13.6	70.4	0.3	**70.4**	32.6	9.4	35.6
A5.33	12.5	2.9	13.1	53.3	0.7	**53.3**	69.4	2.4	**69.4**
A5.34	0.1	0.5	0.6	49.6	0.0	**49.6**	38.8	0.8	39.3
A5.535	23.4	19.3	33.2	85.0	11.3	**85.0**	63.6	9.4	**63.8**
A5.531	7.2	0.8	7.3	100.0	0.0	**100.0**	100.0	100.0	**100.0**
A4.26	4.6	4.7	7.8	64.6	2.1	**64.6**	10.1	2.1	10.2
A5.46	7.2	6.8	9.6	62.7	12.5	**62.8**	8.1	2.5	8.3
A5.38	4.6	2.3	6.1	23.2	0.7	23.2	2.1	0.4	2.0
A5.39	1.7	1.3	1.8	4.1	0.0	4.1	1.9	0.2	2.0
A4.27	6.1	0.6	6.3	49.9	0.3	**50.1**	8.9	0.0	8.9
A5.47	3.6	3.0	4.2	42.3	10.5	42.3	5.0	0.1	5.0
A6.1	39.0	2.4	41.5	70.2	0.0	**70.2**	11.0	0.0	11.0
A6.3	3.2	1.5	4.1	26.6	0.0	26.6	4.0	0.0	4.0
A6.51	0.2	0.2	0.2	8.7	0.0	8.7	1.0	0.0	1.0
A6.511	1.2	1.0	2.1	26.4	0.0	26.4	8.0	0.0	8.0

The Marine Strategy Framework Directive indicates that all marine habitats should be adequately protected in order to maintain good marine environmental status. This may imply their inclusion in marine protected areas. The percentage cover of each modelled EUSeaMap habitat in the total MPA and Natura 2000 network with respect to each country's national waters is listed in Table 17. Habitats which are present in each country with over 50% coverage in the total protected area network are highlighted in bold.

The EC 47/92 Habitats Directive marine habitats mostly consist of physiographic features (i.e. estuaries, coastal lagoons, partially submerged marine caves etc.) or habitat typologies (i.e. reefs) which can be interpreted as hosting different benthic communities or even hosting different Directive habitats (i.e. a coastal lagoon could contain a reef). The exception to this in the Western Mediterranean is *Posidonia* seagrass meadows which represent a marine benthic assemblage. To this effect, evaluation of the usefulness of the broad-scale habitat map with respect to the EC Habitats Directive conservation objectives is difficult as there is rarely a direct link between the classification of the Directive habitats and the hierarchical classification of broad scale benthic habitats present in EUSeaMap. This limit had already been evidenced in an analogous broad scale mapping exercise carried out in the Baltic Sea /[40]/. Nevertheless, two Habitats Directive marine habitat types can be related to the list of 23 EUSeaMap habitats predicted in the Western Mediterranean: *Posidonia* meadows (1120) and reefs (1170).

Posidonia meadows (1120)

The EUSeaMap did not model *Posidonia* meadows but compiled all the cartographic information available for this habitat type. The mapped distribution of *Posidonia* meadows (EUNIS habitat code A5.535) can therefore be used to evaluate SCI distribution nationally. Table 17 shows that EUSeaMap is a useful tool for the purpose of evaluating the protection level provided by the existing network in terms of percentage inclusion of this habitat. The total amount of *Posidonia oceanica* inclusion in all three countries is 46%. It must be remembered that this analysis only encompasses waters of the Western Mediterranean and that the percentage cover of this mapped habitat in the Natura2000 network indicated below is only partially representative of the habitat's distribution elsewhere.

Reefs *(1170)*

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 littoral 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 (Table 17) then relate this to the Directive habitat 1170 Reefs. Evaluation of the total percentage coverage throughout the entire study area indicates that the highest percentage of protection through inclusion is applied in the infralittoral zone (Table 18).

Table 18 Percentage inclusion of each hard bottom habitat in the total SCIs network of the study area.

EUNIS habitat code	EUNIS habitat name	Total % coverage in Natura 2000 network
A3	Infralittoral rock and other hard substrata	36.6
A4.26	Mediterranean coralligenous communities moderately exposed to hydrodynamic action (intended as coralligenous beds)	12.1
A4.27	Faunal communities on deep moderate energy circalittoral rock	12.4
A6.1	Deep sea rock and artificial hard substrata	14.8

The Barcelona Convention has identified the benthic communities of priority conservation interest for which Mediterranean protected areas should be established so as to guarantee their protection. Such habitats have been identified because of their vulnerability, as endemic, uniqueness, rarity, aesthetic and economic value (UNEP/MAP 2006). These priority habitats are usually composed of specific biocenosis and facies/associations so the identification of their distribution, for the purpose of ensuring their spatial protection, entails a fine-scale habitat map which in some cases could involve a finer pixel resolution. It is clear that most of these benthic assemblages are not described in the EUSeaMap because of its broad-scale nature. The EUSeaMap habitat types which can be completely ascribed (intending all its possible sub-community/assemblages) to a Barcelona Convention priority habitat are Posidonia meadows (A5.535) and coralligenous communities (A4.26). These two habitats are included in the total protected areas network (ALL) to different percentage inclusion throughout the three EC country's waters as highlighted in Table 17 above.

Limitations of the broad scale habitat map for assessing MPA networks

The 250m pixel size scale of EUSeaMap is able to give a far better potential habitat coverage estimate than the 10km grid cell reported by Member States under the Habitats Directive article 17 reporting obligations.[42] The usefulness of the map to this extent is crucial as a tool for Europe and can be considered an improvement with regard to existing cartographic tools.

Though purely indicative of a potential biological zone partitioning, the EUSeaMap is the only tool available to date which can identify protection efforts or gaps according to biological zone. This is particularly useful for the evaluation of Habitats Directive habitat typologies that scope across more than one biological zone (i.e. reefs) thereby allowing to evaluate their distribution across different zones.

The broad scale nature does not allow modelling of littoral habitats and the finer scale habitats (facies and associations) occurring within broad habitat categories. As such, evaluation of the distribution of the endemic, threatened and highly diverse benthic assemblages that occur in the coastal waters of the Mediterranean is not always feasible with this tool.

Further considerations on other protection measures needed to guarantee good environmental status

It is important to keep in mind that information on fish and their breeding, spawning and feeding areas have not been included as background information for most designated marine Natura 2000 sites. Hence, a separate analysis of such areas (and mapping of these) is needed in order for European communities to reap the full benefits of spatial protection measures set aside for protecting biodiversity. A debate of no-take sites e.g. part of the Natura 2000 network or applying changes in fishing practice would no doubt help to improve local populations of commercial targeted fish and shell fish. This could include establishment of some very large no-take as done in for American waters. For example, former US president George W. Bush closed an area of 362,600 km^2 as part of the Papahânaumokuâkea Marine National Monument for fisheries coming into force in June 2011 /[41]/. Other large areas have been closed for fisheries in the North Atlantic with effect on stocks, biodiversity in general as well as increased catches in the immediate area next to the closures.

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[42] Assessment, monitoring and reporting under Article 17 of the Habitats Directive: Explanatory Notes & Guidelines FINAL DRAFT. October 2006.

http://circa.europa.eu/Public/irc/env/monnat/library?l=/habitats_reporting/reporting_2001-2007/guidlines_reporting/notesguidelines_2/_EN_1.0_&a=d

It should also be kept in mind that even highly restricted MPAs will not be able to achieve Good Environmental Status on their own – they rather represent a "blue breathing space" for nature (as well as humans). General measures in regard to minimising impacts on the marine environment as a whole are necessary if we are to achieve Good Environmental Status. This includes reducing overall nutrient loading, reducing inputs of hazardous substances, observing long-term sustainable quotas for fisheries and changes in fishing practices /[42]/. It also includes the continued development of synergetic measures such as those described for offshore wind farms.

This example should not be perceived as a criticism of the current implementation of the marine Natura 2000 network, except to point out the limitations in the number of the habitats mentioned in annex I of the Habitats Directive and the (potential) existence of several high impact activities and pressures inside the sites protected. It should rather provide food for thought for how to achieve an ecosystem-based approach to designation and management of a representative and ecological coherent network of MPAs as our current protection and management schemes do not achieve an ecosystem-based approach on their own. The solutions proposed for Kattegat reflect more a change in management practice rather than significant new designations etc. The solution required might vary between marine regions.

10.12. Limited application of broad scale habitat maps for tourism industry

As demonstrated in the previous examples, broad scale habitat maps are useful for maritime planning and marine management at the scale of marine Region to sub-division. However, when it comes to tackling local planning challenges the broad scale habitat map is most likely of too coarse a spatial resolution. This example will show a planning challenge where application of the broad scale habitat map is too coarse to give any meaningful input to the planning process.

The Baltic Sea is in many ways a very special sea and one of the more scenic qualities is the huge amount of small and large archipelagos with more than 10,000 islands. The area around Finland is especially blessed with many small islands and it is common in Finland to have a retreat or summer cottage on one of these numerous islands. In many instances the only way to approach these islands is by boat and hence there is a need for harbours or mooring place on these islands. One example is the small island of Täikko near Kemi – an island of roughly 1km of length and 250m wide and home to a number of summer cottages (Figure 94).

When looking closer at the aerial photography it becomes apparent that dredging of harbours is very common on Täikko (Figure 95). More than 20 small harbours and mooring facilities have been dredged in the shore of Täikko in order for the locals to gain access to the island. According the broad scale habitat map the island is surrounded by 13 km^2 of *oligohaline infralittoral sand and muddy sand in high energy* (model code 3121) and 19 km^2 of *oligohaline infralittoral sand and muddy sand in medium energy* (model code 2121). Compared to this the area of the harbours does not influence the total area by much. However, if higher resolution habitats map (EUNIS level 4 or 5) were available, it would most likely be apparent that a high percentage of a specific habitat is influenced by a very local, though extremely destructive pressure e.g. permanent removal of a habitat.

Figure 94 *The small island of Täikko near Kemi in Finland with numerous small harbours or dredged inlets for mooring. The island is only 1 km long and 250m wide. (Google Earth)*

Figure 95 *A dredger at work in near Helsinki, Finland. (Photo: Metsahällitus)*

Should several habitats be present the impact of the dredging becomes even more severe as the area of the individual habitats become smaller. A broad scale habitat map such as those developed by EUSeaMap would not be applicable for assessing such local pressures. This does not mean that the pressures are not significant, but rather that our tools (habitat maps) and management and planning responses have to be *fit-for-purpose*. From an outside perspective it would in the case of Täikko appear that some of the pressure for dredging could have been avoided by having one or two shared harbours on the island.

These examples demonstrate the value of broad scale maps in regard to various management challenges under the implementation of the MSFD. If nothing else, they provide one clear conclusion: *Planning a single activity on a "blue background" is not good enough when implementing the ecosystem-based approach to management.*

However, the examples do not provide a coherent, pragmatic and cost-effective solution for tackling these challenges in the slightly wider context of the EU Integrated Maritime Policy. Such a solution will be presented below.

10.13. Maritime Spatial Planning – a flexible, cost-efficient tool to management

MSP appears to be a logical choice by which to balance interests while ensuring healthy ecosystems. MSP is a worldwide emerging tool for handling human activities, multiple pressures, minimizing potential conflicts as well as providing a secure investment framework for human activities. The most notable and successful example occurs in Queensland and Victoria in Australia, where human use is balanced according to ecosystem capacity as well as in regard to each other /[43], [44]/.

In Europe MSP is a new process though it has been implemented with more or less understanding of the complicated linkage between the ecosystem and impacts from multiple human uses *e.g.* the Irish Sea /[45]/, Norway /[46]/, Belgium /[47]/ or Germany /[48]/. Other legally binding plans are emerging through the UK Marine and Coastal Access Act /[49]/, the Marine Bill in Sweden /[50]/ as well as for Polish marine areas. Similarly, the EU Commission has with the launch of a Roadmap for Maritime Spatial Planning and the following process tried to identify and achieving common principles for the European Community /[51]/. Likewise, international fora such as HELCOM /[52]/, OSPAR /[53]/, UNESCO /[54]/, IUCN /[55]/ and VASAB /[56]/ have launched similar initiatives or guidance. Some European nations still lack an integrated approach to maritime planning and instead apply a sectoral approach to the use of marine resources leading to fragmented policies, an uncertain framework for economic investments and the continued degradation of the marine ecosystems.

Before we progress further a definition of maritime spatial planning is needed. Boyes defined it as "*plan-led framework, which enables integrated forward-looking consistent decision-making for the use of the sea*" /[57]/. Similar, the EU Commission defines MSP, as "MSP is a tool for improved decision-making *it provides a framework for arbitrating between competing human activities and managing their impact on the marine environment. Its objective is to balance sectoral interests and achieve sustainable use of marine resources…*" /[58]/.

A holistic framework for maritime spatial planning (MSP) was originally developed by the INTERREG IIIB project BALANCE. The template has incorporated both definitions with the addition to the Boyes definition "…*decision-making for the [sustainable] use of the sea*". The BALANCE template will be described below with a clear linkage to the examples described previously. It will be followed by an example elaborating a simple fit-for-all zoning approach using the information applied for the application examples above.

10.13.1. Basic elements for maritime spatial planning

When trying to implement an ecosystem-based approach to management building upon MSP two basic elements should be kept in mind: i) MSP should aim to support overall governance by promoting rational, cost-efficient use of marine space and improve decision-making, building upon the respect and understanding of the inherited carrying capacity of the ecosystem, and ii) MSP should fit and balance human interests into this framework through forward, integrated planning and adaptive management, while providing a secure environment for sectoral economic investments. A range of other principles as defined by the EU Roadmap for Maritime Spatial Planning also exist and how to incorporate these into on step-wise, coherent approach will be demonstrated below.

Our needs as a community will always change over time as new sectors emerge; new goals for existing sectors are set as our knowledge improves. Hence, in order to support existing and future needs MSP has to be forward looking and capable of adapting to ever-changing needs. The BALANCE project described the steps needed for implementing MSP as a tool for planning and managing human activities in the marine environment (Figure 95). They applied four key principles: i) Respecting and prioritization of ecological information, ii) the combination of ecological information with information of multiple human uses, pressures and impacts, ii) a spatial planning template describing the steps towards MSP linking spatial planning to the existing international legal framework, and iv) a simple, balanced zoning approach allowing space for most current and future human uses, while minimizing the impact on the marine environment.

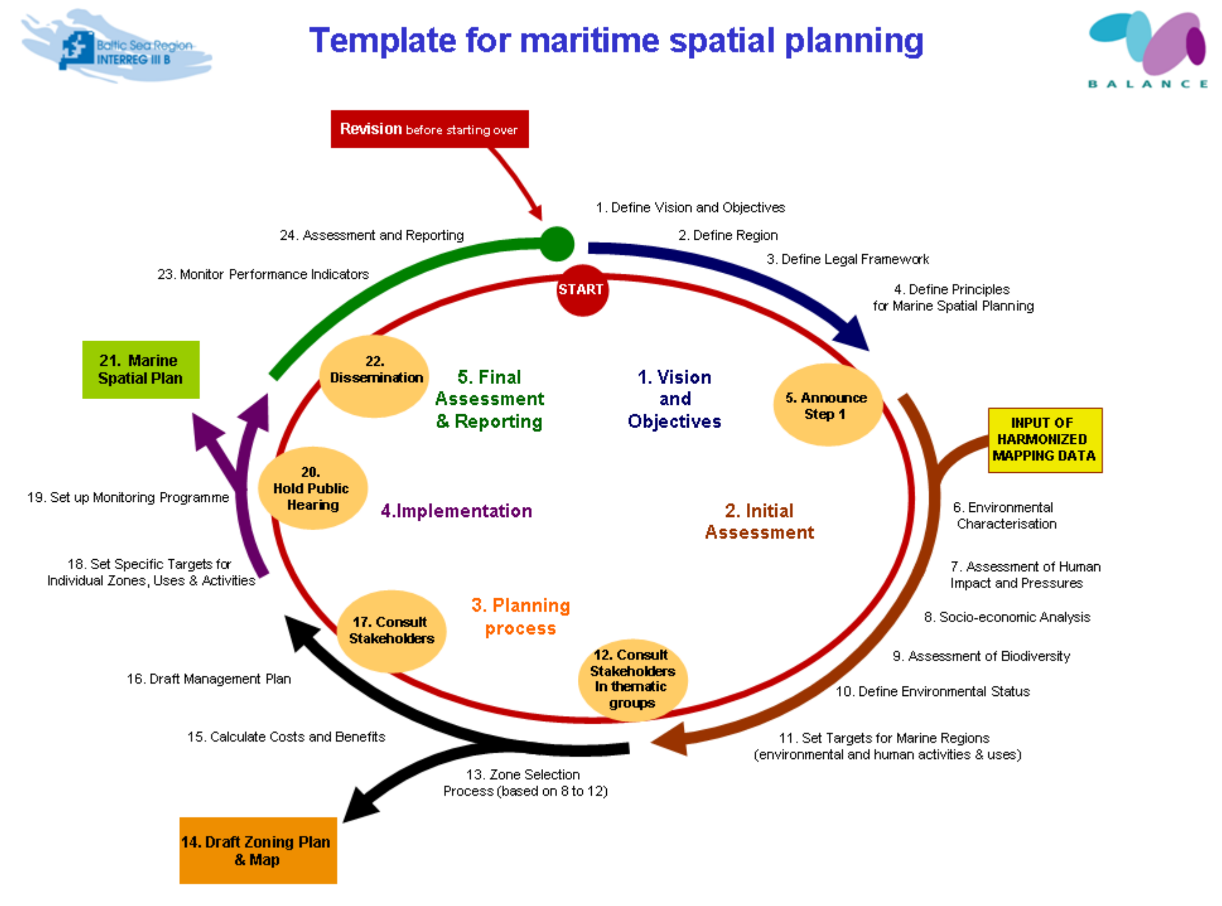

Figure 96 *A template for maritime spatial planning illustrating a cyclic step-wise approach. The concept was developed by the BSR INTERREG IIIB project BALANCE /[59]/.*

10.13.2. A template for maritime spatial planning

The template is cyclic in nature reflecting adaptive management consisting of six main elements (Figure 95): 1) Vision and objectives, 2) Initial assessment, 3) Planning process, 4) Implementation, 5) Final assessment and reporting, and 6) Stakeholder involvement. Each main element is split into several individual steps that can encompass rather large efforts.

Stakeholder involvement is ongoing throughout the entire process and it has been handled separately. Similarly, besides describing the template, focus will be on describing the novel zoning approach. The individual components are inspired by existing initiatives from *e.g.* the Great Barrier Reef /[60]/ and coast of South Australia /[61]/ zoning processes, the Irish Sea Pilot MSP process /[62], [63]/, and, to some extent, also the experiences from Belgium /[64]/. We have also looked closely at guidelines published by IUCN and WWF /[65]/, CBD /[66]/ and VASAB /[67]/.

The MSP template is nevertheless a novel product specially designed to suit some of the present needs or activities within the EU. The differences from other initiatives are in particular the general structure of the template, the applied principles, the way stakeholders are involved, the use of only four *fit-for-all* zones, the cost assessments and the acknowledgement of relevant EU directives.

10.13.3. The cyclic approach

The cyclic step-wise design is logical, easy to understand and it emphasizes the need to repeat the process based on the performance assessments, as an inherited requirement in adaptive management or simply – learning by doing. Our information will always be incomplete and we have to be able to adjust management efforts as our knowledge or needs change.

Having identified the need for MSP to be a cyclic, step-wise exercise in order to continuously, being able to adapt to emerging needs and new knowledge the question arises as to how to define the individual cycle? In the case of the EU Marine Regions, the answer is straightforward. It has to be linked to existing international legal obligations *e.g.* the 6- year reporting cycle of EU Directives. An added benefit is that such a planning cycle is long enough for most sectors to plan concrete investments, while short enough to enable adjustments to new market demands or according to new knowledge on environmental impacts.

However, in regard to be able to link and reflect on long-term issues such as climatic change or renewable energy goals an element stretching for 12-24 years should be included for long-term visions and objectives.

10.13.4. Vision and objectives (1)

At the start of the MSP process the vision and objectives is defined with the aim of achieving a balanced long-term sustainable use of resources according to the ecosystem based approach management of human activities. The components of a vision and objectives for a marine region are already defined for most European marine regions. The important aspect for including vision and objective in the MSP process is to link and harmonize, from the start, existing and new political ambitions for the communities and the environment with strategic goals for the individual sectors. Its five steps include an analysis of existing legal framework and a definition of the core principles for the MSP process. Some of the steps have been prepared by the preparatory actions by the EU Commission /[68]/ though some cross-cutting work on visions still needs to be done e.g. across EU Policies, visions of UN and Regional Sea Conventions and national ambitions. MSP as a tool could be the glue to link these visions and objectives together rather than being a goal in itself.

10.13.5. Initial assessment (2)

The purpose of the initial assessment is to provide the input to the overall planning process *e.g.* harmonization of data, information of the marine ecosystem, information on human uses and pressures, information on socio-economic interests, identification of interaction between different human uses as well as with the environment. Only by doing this will it be possible to find an informed basis on which to discuss and integrate individual interests. This includes considerations of overall Community priorities and definition of targets. This could compare sectoral and environmental targets. For example, if the sandbanks are limited, their importance as fish spawning grounds, marine aggregate sites, renewable energy sites or nature conservation, has to be prioritized jointly and a decision on how to exploit them should made through a transparent political process.

Another important element in the initial assessment is by recognizing the value of MSP through linkage to a socio-economic analysis. Such assessment should include information on the costs and benefits for the individual sectors and the community for implementing integrated MSP. It should also show the costs for the environment for not implementing it. Broad scale habitat maps can provide information about the extent of natural resources and act as a proxy for biodiversity, thus binding different concerns together.

Each sector has to harmonize and share information with everybody else in order to inform the MSP process. For the environmental sector such assessments is already done under *e.g.* the Habitats Directive, the EC Water Framework Directive and especially the EC Marine Strategy Framework Directive. As with the planning process itself, the initial assessment has to operate at three different geographic levels: i) *the Marine Region or sub-region*, ii) *the national level or sub-division (sensu MSFD)*, and iii) *the local leve*l. Most of this process is actually part of the initial assessment performed by EU Member States in their current effort of implementing the MSFD or by the preparatory actions of the EU Commission (e.g. EMODnet or EUSeaMap).

For example, EUSeaMap and EMODnet feed directly into step 5 in regard to harmonization of data as well as step 6 in regard to environmental characterization. Step 7 on assessing multiple pressures and impacts are informed by activities such as HELCOM HOLAS. This concept is further developed by some EU Member States and Norway as part of their MSFD initial assessment (the HARMONY project). In regard to step 8 most Member States and the EU Commission has on-going activities trying to come up with a comprehensive socio-economic analysis – work supported by the EU Commission in WG ESA. In regard to the biodiversity assessment in step 9 such an analysis has to be done by 2013 as part of the MSFD implementation (art. 13). Similarly, step 10 has moved a huge step forward with the Commission Decision from 1. September 2010. Lastly, the definition of environmental targets will be done within the next 2 years. A lot of important work and cooperation informing the individual steps is also going on in the Regional Sea Conventions.

The conclusion is that EU Member States have come quite far in regard to the preliminary steps of a maritime spatial planning process as described by the BALANCE template above.

The remaining part is the actual integrated spatial planning process. A key element when moving for the initial assessment towards the actual spatial planning process is to remember the ecosystem-based approach to management. If the initial assessment concludes that specific areas or ecological components are under pressure and that environmental targets are not met, then this will influence the planning and management until the targets for environmental status is achieved. On the other hand, if good status is achieved then an approach for maintaining it should be applied. This would allow for expanding current or new activities. In summary, just as step I guide step II, then step II should guide step III in order to ensure that our activities do not adversely effects the marine ecosystems. Step IV will ensure that all/most human activities can continue to exist in the marine environment in harmony with each other and the environment. The actual planning steps are described in step IV below.

10.13.6. Spatial planning process (3)

The purpose of this process is to develop the actual spatial plan. The element central in the MSP process is the application of marine zoning operating at the three geographical levels described in the zoning section below.

Zoning is a tool for planning the multiple uses of sea areas in a way that balances the various human activities with nature conservation goals. Zones, *i.e*. areas defining which human activity can take place where, should be based on existing legislation, sectoral strategic goals and environmental assessments.

Having defined the four principle zones (see zoning below) and the three geographical operational levels the next step is to try and apply them to already existing uses within a predefined geographical area, while taking both the priorities made in the initial assessment into account as well as any predicted future needs or goals.

This includes drafting an actual zoning plan and calculation of the cost and benefits of such a plan. The aim with these calculations is calculate the costs and benefits for alternative planning solutions, taking the cost to and value of ecosystem services into account. The focus should not only be on the economic value but also on the significance of alternative planning solutions at various spatial scales (local economy, national economy, regional economy) without forgetting that social, cultural as well as natural values that often cannot be transformed into Euros and cents. In order to illustrate how a local spatial plan could be done EUSeaMap made a simple zoning scenario (Figure 98) based on existing activities in the Kattegat area. A more holistic approach is of course needed if actual zoning plans where to be developed. Such efforts could apply the knowledge from the MSP and MSFD initial assessments and merge them through the application of a zoning tool.

One of the most central element is to develop clear guidance for the zoning process in order to ensure that as many stakeholder and environmental concerns are visible and can be addressed by the spatial plan from the start.

10.13.7. Implementation (4)

This step focus on the publication of the final spatial plan and the individual management plans for the agreed zones, *e.g.* setting up the management plan for a Natura 2000 site, the fish farm or the marine aggregate site, including specific targets and monitoring programmes. It also focuses on stakeholder engagement and dissemination of the plan. This could also be directly linked to art. 13 of the MSFD thus merging the EU Integrated Maritime Policy with the MSFD through a holistic Programme of Measures

10.13.8. Final assessment/reporting (5)

This step collates the experience and monitoring results in order to inform the next planning cycle in the best possible way.

10.13.9. Stakeholder involvement (6)

Stakeholder involvement is essential throughout the planning process in order to ensure the ownership and consequently successful implementation. The template describes an effective stakeholder involvement throughout the planning and management processes. Due to its importance, it has been discussed separately.

In summary, the on-going efforts of the MSFD implementation can be considered as the preliminary steps towards an integrated maritime spatial planning process. At least it is difficult to come up with an ecosystem-based approach to management that not involves spatial management measures. The added benefits and cost-efficiencies of implementing truly integrated MSP appear to outweigh fragmented sectoral policies and management approaches (some of these have been demonstrated in the applications previously).

10.14. Zoning – a pragmatic, flexible tool for harmonizing across different activities

Zoning of European marine areas has not been practiced in a comprehensive overarching manner as done on land in regional and land use plans. Instead various uses of sea areas has been established in areas most suitable for the activity at hand, without giving too much consideration about other interests to use these areas, the sustainability of the activity or whether or not the biodiversity is preserved.

Zoning is a way to divide the sea according to the type of activity allowed within a certain area (zone) and the regulations by which these zones are administrated. Day define zoning as "*a spatial planning tool that acts like a town planning scheme*" that "*allows certain activities to occur in specified areas but recognizes that other in-compatible activities should only occur in other specially designated areas and in this way zoning provides area-based controls and separates conflicting uses*"/[69]/.

10.14.1. Zoning prerequisites

It is important to be aware of a few prerequisites for understanding the zoning approach. Several different activities might be designated to the same zone (though not occur in the same area) *e.g.* a renewable energy park would be assigned as an Exclusive use zone. If synergetic elements such as closing the area for fisheries or including aquaculture between the wind turbines this could be allowed and handled through the management plan for that specific site. The area would still be an Exclusive use zone as it addresses the offshore wind farm first. A neighboring zone might be a fish farm also designated as an Exclusive use zone.

Similarly, some activities could be assigned to *e.g.* the Targeted Management zone in one area, while the Restrictive access in another. An example could be Natura 2000 sites where most would be zoned as Targeted management zones, while a site protected as a seal resting place or White-tailed eagle nesting site requires a higher level of protection /management. The use of individual zones would be apparent from the management plan associated with each zone and the master spatial plan. A zone could also be of a temporal character.

A word of caution - zoning is for integrated, coherent spatial planning of human uses within the available marine space ensuring space for all – it is not for specific activity management. Each activity is still regulated by relevant legislation operating for the individual sector and/or sea area. For example, the environmental targets for nutrient concentrations would still be operational within most zones *e.g.* within an Exclusive use zone set aside for an off-shore wind-farm. Only where a specific activity has a permit to deviate from overarching targets is such deviation allowed *e.g.* increased nutrient loading within a fish farm. How such regulations interact is solved through the (existing) management plan set up for the individual activity and/or zone.

10.14.2. The geographic area

Zoning has to operate at three different levels, i) *the Marine Region or sub-region*, ii) *the national level or sub-division (sensu MSFD)*, and iii) *the local level.*

The *Marine Regional level* is necessary because an ecosystem-based approach to management, many maritime activities and interests as well as pressures are inherently trans-boundary in nature. It also provides the forum for agreeing on a joint effort using the same principles, targets and overall strategic goals. For example, all nine Baltic countries are to some extend bound to the same goals through international agreements and conventions. The regional effort informs the national implementation process and *vice versa*. The *national level or sub-division* is necessary for meeting national political ambitions, sectoral planning and for obvious administrative reasons. The *local level* is necessary for implementation and for ensuring local ownership to the plan e.g. our sea, our heritage, our resource, our responsibility!

Ideally, the delineation of the specific sea areas to be zoned would take biogeographic sea regions into account in order to maximizing the effect of apply spatial conservation measures. These sub-divisions should be further subdivided by information based on catchments areas in order to link the planning units to land-based activities and pressures. Such subdivision would allow an overview of the extent of marine habitats and sum of resources within the area – habitats on which the local plants and animals depend upon. Only by taking such an approach will it be possible for MSP to support an ecosystem-based approach to management and more importantly, for achieving a long-term sustainable development within our (healthy) seas.

The strength of this zoning approach is that it fits all existing sea use occurring within a marine region, while allowing for new future activities. Hence, it can be applied at all three geographical levels and thus, in theory, be implemented by all nations sharing the European marine regions. It is in reality "only" a question about political will to adopt such an approach.

10.14.3. The four zones

The BALANCE project defined four zones: i) *the general use zone*, ii) the *targeted management zone*, iii) the *exclusive use zone,* and iv) the *restricted access zone*. These are only briefly described here. The definitions, objectives and restrictions of zones and description of the zoning process are available elsewhere /[70]/.

The *general use zone* is the least restrictive of the four zones and it allows all human activities or sea use to take place with exception of those specifically prohibited by law. Some activities may require permission and some also an Environmental Impact Assessment. It covers the major part of the sea.

The *targeted management zone* is applied for areas where the use is restricted further, *i.e*. where an authorization (permit, license) has been granted for one or several activities or where the area includes nature conservation targets that require that the use of the area to be regulated, either permanently or temporarily. Within this zone overlapping human activities or sea use may occur. Many Natura 2000 sites fit into the *targeted management zone*, as well as areas with restrictions of some activities (*e.g.* no bottom trawling allowed), while other fishing methods are allowed (*e.g.* pelagic trawling or standing fishing gear). Similarly, temporal fishing closures would be designated to this zone.

The *exclusive use zone* is the second most restrictive and it shows the extent of the marine area reserved exclusively for a single use, which prevents the sea area to be used by most other types of sea use. Some human activities such as recreational activities and research can occur within this zone without permission, as long as there is no conflict with the main purpose of the zone. The exclusive use zone is for *e.g.* renewable energy constructions, fish farms, pipelines and cables or marine aggregate extraction.

The purpose of the *restricted access zone* is similar to the exclusive use zone with the main difference of the very strictly regulated access to the zone. The objective is to ensure satisfactory protection of the area *e.g.* a vulnerable shipwreck, or to ensure the safety of potential visitors' e.g. military firing ranges. It has a very small spatial extent.

10.14.4. Developing a spatial plan through systematic zoning

Having identified the principles needed for implementing MSP, the next obvious challenge would be to draft a spatial plan. Such endeavor falls under national jurisdiction and real life engagement with stakeholders can only occur if a political decision has been made to make a spatial plan.

The cost-efficient and trustworthy approach would be to develop and apply a zone selection approach, similar to the regional, systematic site selection sometimes applied for nature conservation purposes. Such zone selection process would be able to provide several different planning scenarios of how to obtain the most efficient spatial plan minimizing restrictions, environmental impact and optimizing the use of space available. These scenarios would then form the basis for stakeholder engagement illustrating that all interests have been taken into consideration. An analysis at the Marine regional and national level would provide advice and input to the detailed local planning effort.

In order to maximize the benefits of such a systematic and objective zoning approach it is important that i) all existing information is made available and included, ii) existing sectoral goals and environmental targets are known, iii) local interest in specific areas are being included, and iv) international cooperation and coordination is operative. Based on these principles priorities for the analysis or scenario development can be defined in an open transparent way. The prioritization has to include aspects of environmental, social and economic character for each interest and compared to the sum of needs as well as the total amount of resource available. Different interests will vary in their costs and benefits.

Most importantly, a zoning process would help balancing between policy visions and actual political actions. It would show were visions for biodiversity might conflict with visions for growth or were ambitions for one sector might be hindered by visions for another sector. As these potential conflicting policies and goals are made visible through an integrated approach, it would enable politicians to make informed decisions through a transparent public process.

In the examples above, we have already demonstrated that several interests compete for the same resource e.g. habitat 2120. The energy sector have a target for offshore installations requiring a certain amount of space, fisheries might want to protect a certain amount of spawning grounds to secure commercial fish stocks, marine aggregates sector might need a certain amount of sand and gravel, and nature conservation might be legally required to protect 20-60% of existing sandbanks.

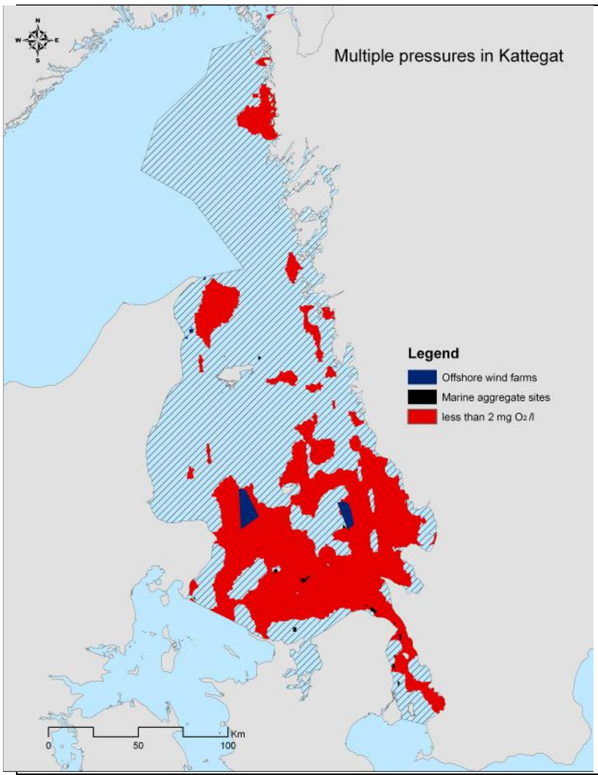

Figure 97 *The spatial extent of pressures in the Kattegat. Here oxygen depletion, offshore wind farm, marine aggregates and areas for maritime assistance.*

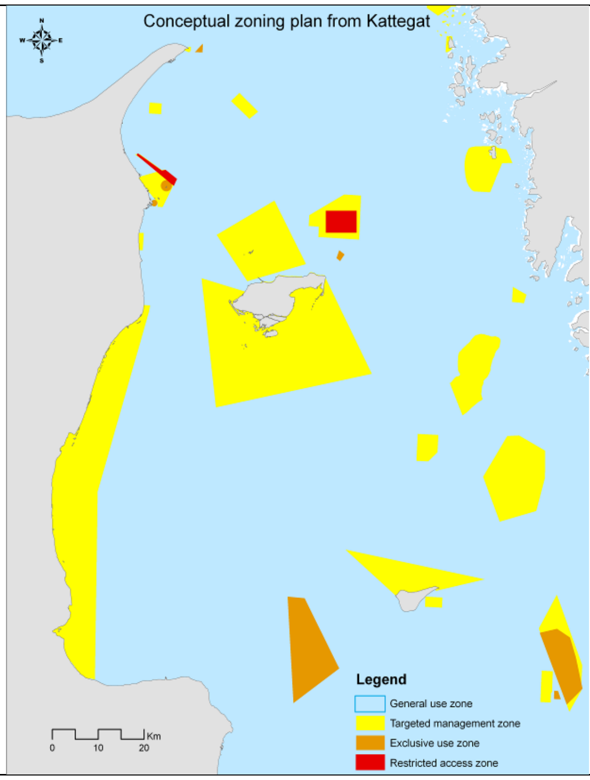

Figure 98 *A draft zone plan of demonstrated on existing use.*

All these needs has to be known, prioritized and to be feed into the zone selection process along with information of the total space or amount of the resource (here sandbanks in shallow waters), after which the specific zones can proposed and discussed. In some areas, some activities might not get what they want, while their wishes will be met in other areas. In the end, this will be an open, transparent process subject to a final accountable political adoption (similar as on land).

Based on our previous examples, it is obvious that broad scale habitat maps provide valuable ecological information for prioritizing efforts of human activities in the marine environment. Broad scale habitat maps are an essential part of the pressure and impact indices enabling identification and ranking of dominating pressures as well as areas (and habitats) under significant impact. Similarly, by making comparative analysis at the local level it is possible to identify the resource/space/habitat available and use it to designate specific activities to specific area. This makes it possible to link current pressures and impacts with future use, while doing so within an ecosystem-based context. Of course, that requires that the prioritizing efforts take due notice of and respecting ecosystem carrying capacity.

Another element in the prioritization efforts will be to identify and develop cost-effective and holistic approaches ensuring value for money (optimizing measures) that explore synergies. E.g. if the effects of eutrophication were minimized fewer limitations might exist for other sectors impacting upon the same habitat or if the synergetic effect of offshore wind farms where developed it might help lessen the restrictions imposed on agriculture for reducing nutrient output.

The benefit is that the plan will provide a long-term certainty for the individual sectors once decided upon, while providing the opportunity for short as well as long-term planning.

Another important point with the zoning example for Kattegat is that it is possible to show the zones based on real data. Most of the sea is designated as a General use zone (the blue area) only restricted by existing targets whether they are rules of maritime conduct, environmental targets or fisheries quotas. A lot of the Natura 2000 sites are designated as targeted management zones as special management plans exists for the areas. Such areas could also exist for fisheries e.g. in the Sound where trawling has been banned since 1934 due to shipping concerns. Similarly, the areas set aside for maritime assistance could also be considered Targeted management zones as the management only enter into force at special emergencies. Designation of such sites can also benefit from knowledge of broad scale habitats. For example, accidents or cleaning after oil leakages will be easier to handle in sandy areas or less complex areas compared to more complex habitat areas with reefs or submarine structures made by leaking gases. This makes information as presented in the complexity map (Figure 84) is highly useful and it can help to inform prioritization efforts when designation areas for different purposes.

A smaller part of the sea has been assigned to the Exclusive use zone including both marine aggregate sites and offshore wind farms. This zone could also be used for e.g. important fishing grounds excluding other activities or for aquaculture etc. A few of the Natura 2000 areas have been designated as Restricted access zone (which is already in place). One place is because of the Natura 2000 habitat (1180) *Submarine structures made by leaking gases* and the other one is because of a large scale restoration project of cave forming reefs (which dramatically changes the bathymetry). This shows that one zone can overlap with another and that the reasons for such difference can be handled within the management plan for that zone, which in turn is referred to in the Master spatial plan.

In regard to marine monitoring, then the zones would also support a layered approach with more intensely monitored areas e.g. Exclusive use zones and less intensely monitored areas as Targeted management or General use zones. Monitoring of these two zones would provide the background and cover large sea areas for the general health assessment and general programme of measures, while monitoring of the more restricted zones would inform on concrete permit or actions related to the specific activities in question.

In conclusion, broad scale habitat maps (and other ecologically-relevant information) and any associated targets could help inform and guide the zoning process especially if maritime spatial planning were to support an ecosystem-based approach to management. Marine zoning allows for a neutral graphic illustration of a spatial plan harmonizing across activities based on their spatial and management requirements rather than applying the traditional sectoral perspective. Marine zoning also enable a flexible planning approach that can easily be adopted to current and future uses. Lastly, it allows for an integrated approach to solving potential conflicts among stakeholders while being guided by the ecosystem-based approach to management keeping the vision of achieving a long-term sustainable development in mind.

One last issue on which everything depends, though the template for maritime spatial planning, the zoning approach and the broad scale habitat maps are strong tools supporting a holistic and integrated approach to management of the marine regions, they all depend on one thing to deliver optimally – political involvement, guidance and action. Almost each individual step of the planning template will result in tough political decisions if the policy visions of a long term sustainable development within thriving and healthy oceans are to be achieved. Not every stakeholder will be able to get what they want and not every decision will be popular. At the same time there will, for certain areas, be significant costs for the Member States involved if e.g. Good Environmental Status is to be achieved.

Secondly, administrative turf wars will most certainly start as integrated management will result in breaking down traditional areas of responsibility and result in transference of empowerment from one agency to another. Hence, in order to succeed a neutral agency with the sufficient empowerment to do integrated maritime planning with the necessary political backing from the entire Government (and ideally across the Parliaments) will most likely be required to facilitate the planning process and to ensure the adherence to the overall political visions – a long-term sustainable development within a healthy environment. Such an approach will depend upon a broad political agreement if it is to succeed, not only across parties, but also spanning European to regional levels as well as strong national support and local involvement.

Therefore to truly reap the benefits of broad scale habitat maps and maritime spatial planning, long-term sustainable development and the achievement of healthy seas will have to be high upon the political agenda and will depend upon political willingness to achieve these joint visions for the European Seas. As demonstrated we have the policies and the tools to continue the journey. The focus need to get the administrative framework with strong political backing in place if we truly are to achieve an ecosystem-based approach to management.

10.15. Conclusions – applications of broad scale habitat maps

We are currently experiencing an increasing public and political awareness of the need to take urgent action to combat climatic change. Research has made it clear that climatic change is a global threat against our prosperity and the quality of our life in general.

However, climate change is just one of many pressures contributing to the degradation of marine ecosystems, their habitats, species and services in general, with potentially dire consequences. Stavros Dimas, former European Commissioner for the environment, has stated, "*Scientists are not exaggerating when they refer to the 6th great planetary extinction*" /[71]/. The real danger is if we fail to recognize that it is not a single pressure that endangers our quality of life, but the sum of cumulative pressures on the ecosystems occurring from our current lifestyle. Of these pressures, only a few require true global action, compared to many which could be handled on a regional and local scale through decisive political actions embracing an ecosystem-based approach to management.

Keeping the goal of achieving sustainable development firmly in mind, any measures have to encompass its three pillars: conservation of biological diversity, sustainable use of ecosystem components and a fair and equitable sharing of benefits. Together these pillars can lead to environmental, economic and social sustainability /[72]/. Therefore, any practical solutions would have to consider several different aspects of coherence in order to deliver sustainable development rather than focusing solely on a single threat. The solutions also have to include spatial and temporal coherence reflecting both the dynamics of the marine environment and our future needs. Finally, scientific coherence for providing comprehensive advice for informed management as well as institutional coherence in order to break down the groupings within which our community traditionally organizes itself /[73]/.

The use of an ecosystem-based approach to management in the European marine regions is – until now – more strategic and conceptual than practical. However, the EU Maritime Policy and the Marine Strategy Framework Directive have just initiated the first tentative steps down a long and challenging road; steps which initiatives such as EUSeaMap can support through the provision of timely and science-based advice.

In summary, some lessons can be learnt from the examples here, which describe the application of broad scale habitat maps for supporting an ecosystem-based approach to management of human activities in the marine environment. These lessons reflect the opportunities presented by broad scale habitats, but the extent to which the lessons will be put into practice is to be decided by the individual Member States and the Regional Sea Conventions.

Implementation of the MSFD – characterisation, harmonisation and coordination

Broad scale habitat maps provide a strong management tool which can help achieve the policy visions for European Seas. They provide a concrete easily adaptable solution to help EU Member States fulfil international political agreements and legislative obligations. For example, in regard to requirements of the initial assessment under the Marine Strategy Framework Directive to characterise the marine ecosystems in a coordinated manner across marine regions, EUSeaMap has shown that it is possible to:

a) Develop a joint methodology for describing and harmonising physical and chemical data layers across a marine region (based on MSFD annex III, table 1).
b) Develop ecologically-inert characteristics into a harmonised ecologically-relevant approach for broad scale habitat mapping showing the extent and distribution of the “predominant habitat types” present within an entire marine region (MSFD annex III, table 1).
c) Apply the same mapping approach to habitat mapping across European marine regions spanning the Baltic Sea Region, the Greater North Sea sub-region, the Celtic

Seas sub-region and the Western Mediterranean sub-region. The harmonised approach covers territorial waters of 17 EU Member States and five non-EU Member States and thus directly supports the coordination and harmonisation efforts required across marine regions (MSFD art. 5 and 6). If each Member State applies their own habitat classification it will be impossible to compare across national boundaries, and therefore we will fail at achieving an ecosystem-based approach.

d) Apply a more detailed approach to habitat classification if any Member States should wish to do so, as long as it fits within the EUNIS habitat classification scheme.
e) Apply broad scale habitat maps for the determination of Good Environmental Status by informing several criteria under the Commission Decision (MSFD art. 9).
f) Inform criteria on "predominant habitats" defined for Descriptor 1 on Biodiversity on a marine regional level. It enables a no-nonsense description of the predominant broad scale habitats present within a marine region as well as the percentage present in national waters (COM DEC. 1.4.1; 1.4.2; 1.5.1; 1.6.2).
g) Apply a hierarchical mapping and classification approach that allows for inclusion of high resolution information allowing for identification and inclusion of "special habitat types" (MSFD annex III, table 1) when such is necessary. Such an example could be biogenic reefs as described under the Habitats Directive (1170) *Reefs* or (1180) *Submarine structures made by leaking gases*. Such a hierarchical approach is necessary to enable national, regional and Pan-European assessments as well as for comparisons across EU and national legislation.
h) The maps *do not cover* aspects in regard to spawning, breeding and feeding areas (mentioned in MSFD annex III, table 1). It is impossible to map the life requirements of every single species and no formal decision has been made in regard to which life requirements of which species should be mapped. The maps developed by EUSeaMap cover the entire marine seafloor and, by default, ought to cover the species living or depending on the benthic habitats.

Implementation of the MSFD – human activities and cumulative pressures

The broad scale habitat maps and associated hydrodynamic modelling can also support implementation of the MSFD by providing coherent layers of ecological information against which human activities and their impacts upon the marine environment can be assessed. Such assessment can help inform a description of the current environment status at different geographical levels. Specifically broad scale habitat maps can support on-going management efforts by:

a) Providing information about the area of the seafloor influenced by low oxygen concentrations (COM DEC. 5.3.2). If combined with the broad scale habitat map it can help inform which parts of the marine ecosystem is most severely influenced. This could cause urgent actions to protect and preserve the remaining proportion of the habitat not influenced oxygen depletion from other impacts.
b) Allowing for comparing spatial trends in oxygen depletion over several years and thus showing the progress towards achieving Good Environmental Status and the

effects of management measures established under the Programme of Measures (art. 13).

c) Applying the hydrodynamic models (applied for EUSeaMap development) for providing information on hydrological and chemical conditions (COM DEC. 1.6.3).
d) Applying the hydrodynamic models to inform on nutrient concentration (COM DEC. 5.1.1).
e) Informing a discussion on the development of targets e.g. what a proportion of specific habitats can be impacted by such pressure and the habitat still be considered to be in Good Environmental Status or how large a proportion of habitats can be impacted by a pressure(s) and the area still be in Good Environmental Status (MSFD art. 10). Discussions which could be continued as part of the MSFD CIS process and within the Regional Sea Conventions.
f) Allowing for an evaluation of the total amount or area of habitat available in any given marine region and a combined assessment of the scale, distribution and intensities of the pressure impacting upon them. As such broad scale habitat maps support an assessment of cumulative pressures (MSFD art. 8, COM DEC. 6.1.2, COM DEC. General condition no. 6).
g) Broad scale habitat maps can provide valuable information for developing concrete and measurable spatial indicators and targets operating at different ecologically-relevant levels taking into account the extent, vulnerability and resilience of different ecosystem components (COM DEC. General condition no. 5 and 6).
h) Broad scale habitat maps illustrate the diversity of environmental conditions existing between and within marine regions, sub-regions and sub-divisions supporting considerations of the applicability and ecological relevance of specific indicators, while ensuring consistency across European marine regions (COM DEC. General condition no. 7).
i) Coherent broad scale habitat maps are an essential part of any assessment of the predominant pressures and impacts in the marine environment. They can be combined through various assessment tools as demonstrated by HELCOM HOLAS.
j) Such assessment of cumulative pressures can be done for any of the geographic levels mentioned in the MSFD (art. 4) as well as for national territorial waters if coherent habitat maps are applied.
k) Broad scale habitat maps now are available for large areas of the European Seas making these analyses possible for the European maritime areas mapped by EUSeaMap. It presents the European Community with a strong tool to truly achieve and implement an ecosystem-based approach to management in order to achieve a long-term sustainable development (if such is truly desired).
l) New approaches are needed to implement an ecosystem-based approach to management. Broad scale habitat maps are essential for providing an ecosystem perspective to integrated spatial management measures, such as maritime spatial planning (COM DEC. 6).

Implementation of the MSFD – informing monitoring programmes and spatial protection measures

Broad scale habitat maps can also be applied for informing other elements than the MSFD initial assessment e.g. by informing the design of monitoring programmes under the MSFD (art. 11) or by provide valuable input to the up-coming discussions on spatial protection measures (MSFD art. 13):

a) Broad scale habitat maps can help ensure an adequate network of monitoring stations is established covering a representative part of the marine habitats.
b) Broad scale habitat maps can provide linkage between the species and communities chosen for monitoring efforts and all of those species that we are not able to monitor.
c) Pelagic broad scale habitat maps are not yet developed. These could, if developed, supplement benthic broad scale habitat maps, and thus the design of a comprehensive monitoring programme.
d) Broad scale habitat maps could inform potential efforts of linking monitoring efforts under Natura 2000 directives, WFD and MSFD with fisheries monitoring into a comprehensive monitoring programme supporting a true ecosystem-based approach to data collation.
e) Broad scale habitat maps can be applied for implementation of the MSFD art. 13.4 by contributing to an analysis of whether a network of MPAs is protecting a representative part of the benthic habitats present in a marine region, sub-region or sub-division as well as the identification of any gaps in current spatial protection schemes.
f) Broad scale habitat maps can contribute to an assessment of ecological coherence, adequacy and replication coverage of a network of marine protected areas.
g) A simple overlay analysis indicates that the current Natura 2000 implementation is insufficient to meet the MSFD requirement of a representative and ecological coherent network of marine protected areas.
h) Annex I of the Habitats Directive does not represent an adequate representation of the marine habitats present in the Kattegat or the rest of European marine regions.
i) The concept of broad scale habitat maps could help inform any process under the Habitats Directive discussing or developing protection measures for marine areas and habitats. Especially in regard to the approach of habitat description and classification.

Application of broad scale habitat maps for the strategic planning of maritime activities

Besides informing the current "narrow" efforts for implementing the Marine Strategy Framework Directive, broad scale habitat maps can also inform other elements under the EU Maritime Policy as well as provide a cost-effective and valuable tool for offshore industries and the authorities regulating them:

a) Broad scale habitat maps (EUNIS level 3) are of huge potential value for offshore industries in regard to strategic planning of exploitation surveys.
b) Broad scale habitat maps can help identify the distribution and extent potentially ideal areas for concrete construction or extraction efforts and thus inform long-term investment and planning activities.
c) Broad scale habitat maps can help identify potential areas or habitat of interest for individual as well as several industries.
d) By comparing the extent of areas used or licences for the offshore energy and other sectors for specific habitat types, the broad-scale maps can be used to strategically manage the balance between conservation of each habitat type and its sustainable use.
e) Broad scale habitat maps can support Environmental Impact Assessments by enabling an assessment of i) the cumulative impact of the entire industry, and ii) the cumulative impact from multiple pressures (different pressures) influencing or targeting the same ecological entity in order to support an ecosystem-based approach to management.
f) Broad scale habitat maps enable an impact assessment of the industry across a marine region, sub-region or sub-division supporting an ecosystem-based approach.
g) Broad scale habitat maps have to be supplemented with ground-truth data on abundance and biomass of the infauna inhabiting the seafloor in order to assess impact assessments for site specific activities.
h) A hierarchical habitat classification approach could be a requirement to presentation of spatial ecological information of all Environmental Impact Assessments. It would support ecosystem-based assessments operating a different scale and allow for comparison within and across human activities for both offshore industries and regulating authorities ultimately saving valuable time and efforts for all involved.
i) An ecosystem-based approach to management would be supported best if the geographic scale applied were at a fairly “regional” level e.g. not larger than Kattegat in order to avoid “dilution” effects (a few small sites in the big ocean).
j) Broad scale habitat maps are not suitable for informing local planning efforts as severer local impacts can be diluted by the lack of high-resolution information. This is exemplified for local, intense dredging efforts which would require more detailed information to assess the local impact.
k) Coherent broad scale habitat maps are essential for providing an ecological component to maritime spatial planning. As demonstrated nature is not only present inside marine protected areas.
l) Broad scale habitat maps can help inform on the extent, sensitivity and vulnerability of nature in any area targeted or influenced by (multiple) human interests and activities. They can provide an ecological basis on which possibilities for the use of any area can be assessed.
m) It should be kept in mind that broad scale habitat maps can not stand alone when doing environmental status assessments and other information is necessary for a comprehensive analysis.
n) The cyclic approach to integrated maritime spatial planning shows that EU Member States progressing towards an ecosystem-based approach to marine management though many obstacles remains. The demonstration of applications of broad scale

habitat maps shows that it is possible to apply ecological information when planning and managing human activities in the marine ecosystems.

o) Marine zoning allows for a neutral graphic illustration of a spatial plan harmonizing across activities based on their spatial and management requirements rather than applying the traditional sectoral perspective.
p) Marine zoning enables a flexible planning approach that can easily be adopted to current and future uses.
q) Marine zoning it allows for an integrated approach to solving potential conflicts among stakeholders while being guided by the ecosystem-based approach to management keeping the vision of achieving a long-term sustainable development in mind.
r) Strong political guidance and actions are necessary if we are to exploit the full potential of broad scale habitat maps and integrated approaches to maritime planning and management.

In summary, keeping the goal of achieving sustainable development firmly in mind, any management measures have to encompass its three pillars - conservation of biological diversity, sustainable use of ecosystem components and a fair and equitable sharing of benefits. The examples provided by EUSeaMap illustrate that any practical solutions would have to consider many different aspects of coherence in order to deliver sustainable development rather than focusing solely on a single threat. The solutions have to include spatial and temporal coherence reflecting the dynamics of the marine environment, while allowing for our future needs to be met. Hence, broad scale habitat maps are just one tool out of many which have to be applied and integrated if we are to halt the degradation occurring within our European Seas – one small step at a time.

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11. Assessment of next steps

11.1. Challenges and costs of extending the modelling process to other regions of Europe

In the Bay of Biscay and the Iberian coast, two projects are going to fill a gap in the EUSeaMap seabed habitats map. For the French part of the Bay of Biscay, modelling work has been commissioned by the Agency for Marine Protected Areas (AMP) and carried out over the same period as the EUSeaMap project. The modelled map is now readily available for dissemination under the aegis of the AMP Agency. For the Iberian coast, it is within the scope of work of the MESH-Atlantic Project to complete a similar map within the next two years. MESH-Atlantic is an INTERREG IVB Atlantic Area conducted by a partnership of institutions from four countries (Ireland, Spain, Portugal and France) under the leadership of Ifremer. The plans are to have the broad scale map ready in 2012, following the same rationale and methodology as defined by EUSeaMap. The partnership is currently gathering source data layers and making them homogeneous over the area. The anticipated budget is approximately 500K€. The risk of not completing this work is low given the prospects of data availability in the four countries; however some shortcomings may arise as regards access to suitable oceanographic data (currents and waves necessary for computation of the exposure at the seabed). In addition there is a high probability of seeing a bathymetry layer shortly delivered by EMODnet hydrography for this area.

In the eastern part of the Mediterranean there are no plans to replicate the work done so far in the western basin. Apart from some particular datasets such as the eastern part of the CIESM bathymetric map covering the Ionian, Aegean and Levantine Seas, the general lack of knowledge of data in existence in these basins (including the Black Sea) makes it difficult to anticipate the efforts needed to replicate the work there. Even though EUNIS was not the most recognised classification in the western basin, at least there was a cultural agreement between the three EU bordering countries resulting from decades of collaborative seabed studies and mapping that enabled immediate transnational understanding. This is not likely to be the case elsewhere because a) EUNIS is not well developed, b) there are far less historic data, c) a number of countries bordering these seas are not European and hence not concerned by EUSeaMap.

The total cost of the EUSeaMap Mediterranean segment can be estimated at approximately400K€. By applying a simple proportionality to the surfaces involved (which assumes a similar level of data availability) a rough estimate of the cost involved to expand mapping to the whole region would be about 1M€. If this extension was to be undertaken, it would probably be safer to start with a lower resolution (e.g. one kilometre instead of 250m), thereby providing a better chance for the enterprise to be comprehensive.

11.2. Improved input data layers to reduce uncertainty

11.2.1. Bathymetry

Filling gaps in bathymetry is a twofold issue. The lack of depth data results a) from data not being released by hydrographic offices as was the case in Italy (where depth data were picked from isobaths), or b) from data not existing at the required resolution, e.g. where only GEBCO is available. The former case is bound to be improved as EMODnet gains momentum and establishes agreements for high quality data delivery among the European hydrographic community. The cost of filling gaps where the nominal 250m resolution for depth data were not achieved is somewhat easy to assess since depth is a straightforward parameter. It is specifically in the remit of the EMODnet bathymetry projects to assess this figure and feed it back to EUSeaMap.

11.2.2. Seabed substrata

Substrate is a major issue since a sufficiently detailed substrate map is far more difficult to obtain than a depth map of sufficient resolution. A broad scale substrate map would need to provide the classes agreed on by EUSeaMap. Such requirements would likely be achieved by using the backscatter signal from multibeam surveys and interpreting it to provide these coarse classes of sediment. This is currently being undertaken by the INFOMAR programme in Ireland. Some ground-truth data in deeper waters would also be necessary; however, data mining would be necessary to check whether opportunistic data from the many surveys carried out by national and international projects (samples in shallower waters, video and ROVs data in deeper ones) would meet the requirements as validation data. It is in the remit of the EMODnet geology project to assess cost of these elements.

11.2.3. Oceanography

Progress in oceanography data, namely hydrodynamic models for waves and currents would stem from three components: a) reliable bathymetry at one kilometre resolution (assumed above), b) human resources to work on improving models, c) collection of validation data. As a first approximation it is anticipated that a task force of three people for two years with available ground-truth data would make it possible to reach a resolution of 1km over the whole European marine area. Except in extremely steep shores (e.g. the Côte d'Azur and west Corsica), this resolution would give a reasonably good picture of exposure at the seabed in the whole basin. Ground-truth data are going to be made available by the EMODnet physical oceanography lot, however it is difficult at this point to estimate if these are going to be sufficient to validate the models. Whether more calibration/validation data remain to be acquired by bespoke surveys (e.g. current meter moorings, offshore wave buoys) is a pending question out of the scope of EUSeaMap.

11.3. Additional biological data

The collation of EUNIS biological data either from samples or from recent detailed habitat maps is a prerequisite to adequate assessment of modelled outputs. It has been shown by EUSeaMap that we dramatically lack biological data to carry out assessment of the model, especially in offshore areas. Ideally these data should be in sufficient numbers to allow a regional assessment (per basin or even sub-basin, e.g. the Gulf of Lions). Even within an institution it has proved difficult to collate validation data in the right form. Either these data were species description data not been expressed in a habitat classification scheme, making translation a challenge, or they had not been stored properly in an accessible way. With a lack of adequate sample data, the project resorted to biocenosis map data (i.e. polygon centroids from recent maps) which may prove a low quality surrogate.

The EMODnet biology project could provide a solution in future and indeed this strand of work has been mentioned at the last EMODnet meeting as a potential test for them in the coming months; the two projects will be in touch on this topic. EUSeaMap partners are also encouraged to provide more ground-truth data from their institutions so that perhaps the assessment can be re-run during the maintenance phase. Detailing costs involved is impossible and the only recommendation the project can make is that teams strive to properly keep track and record metadata for their biological ground-truth data.

11.4. Updating the model with higher resolution layers

For the regional and sub-regional application of broad-scale habitat maps for MSFD, a resolution of 250m is a very promising start and in most areas is more than sufficient. However, provided relevant data layers were made available, it could be a case of increasing the resolution of the model, especially in areas featuring small size habitats which the current 250m resolution model was not able to cope with. To get an insight into the consequence of improving the resolution, Figure 99 shows a subset of the French coast around Saint-Tropez modelled at 100m. The degree of detail is clearly much higher and the enhanced resolution makes it possible to keep from the initial habitat list four more infralittoral habitats the size of which was too small to remain mappable at 250m resolution. It is noteworthy that these habitats are not immediately apparent visually because they are very small patches (groups of a few pixels).

The improvement is therefore twofold, as on one hand these additional habitats give a better description of the heterogeneity of the seabed and on other hand the finer resolution of the underlying data layers provides a more accurate map. Benefits of improving the resolution of model will vary between basins and according to proximity to the coast. At this time, reducing the pixel size below 250m in areas away from the coast (shelf, deep sea) is not judged to be a priority. Instead, a reduction in pixel size would bring most benefits in coastal zones, particularly the steeply shelving seas of the Western Mediterranean and the complex archipelago coastlines in parts of the Baltic and Celtic Seas. Furthermore, the pattern of human activities is more complex in coastal zones and thus a more detailed map at the coast could have benefits for managing these activities.

If the principle of updating the model in a more detailed version was accepted, it would also be necessary to assess resources needed to run it again. Although the actual model is fast to run, some preliminary issues need to be reviewed before updating: are there more EUNIS habitats to map, are their thresholds still valid (for example we might decide to introduce more sediment classes), are data layers consistent? As was the case with EUSeaMap a lot of tuning and iterations were necessary between the partners in charge of stitching individual data layers and an improvement of any of these layers would likely result in additional work. As a first approximation we could say a team of two - not including data preparation - during six months would probably be enough to run an update with higher resolution data layers.

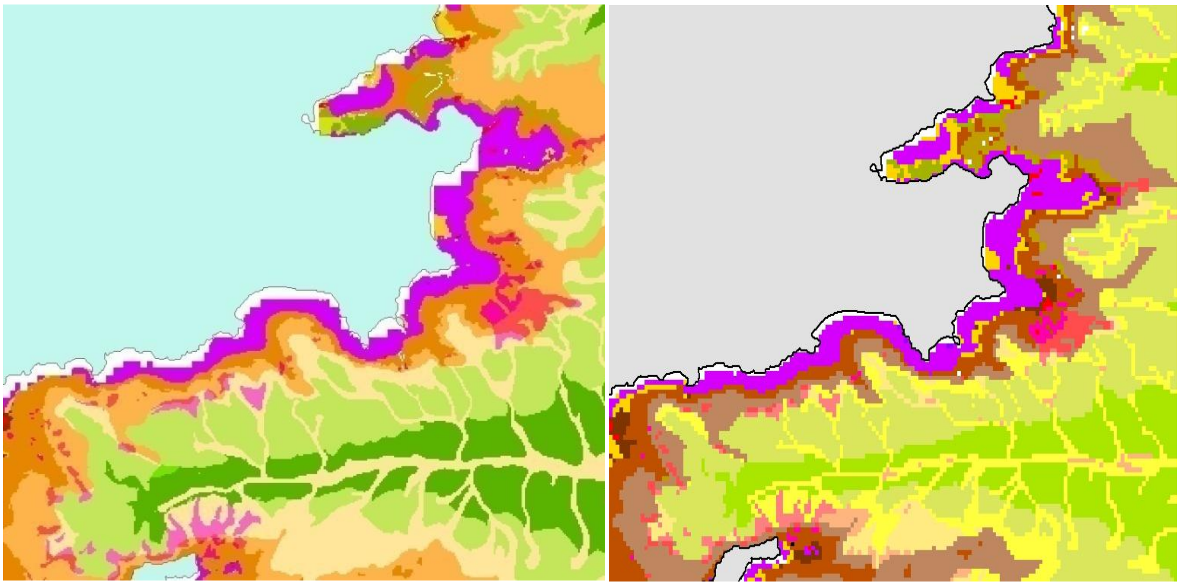

Figure 99 Modelled maps at 100m resolution (left) and 250m resolution (right) for the Saint-Tropez area, south of France.

12. Summary

This 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 projects[43]. 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 to end-users.

In the final phase of the project a series of assessments to demonstrate the applications of the maps were 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 has been provided.

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Appendix I. Version Control

Build status:

Version	Date	Author	Reason/Comments	Sections
0.1	12 Sept 2010	EUSeaMap	Initial Release	All
0.2	8 Oct 2010	EUSeaMap	Comments from NC and text from partners incorporated	All
1.0	13 Oct 2010	EUSeaMap	Final amendments, release to EC	All
2.0	15 Dec 2010	EUSeaMap	Updated maps and text, application assessments. Release to EC	All
2.4	17 Feb 2011	EUSeaMap	Amendments, responses to comments	All
2.7	22 Feb 1011	EUSeaMap	Amendments prior to website upload	All
2.8	28 Feb 2011	EUSeaMap	Amendments to Acknowledgements	All
2.9	1 Mar 2011	EUSeaMap	Minor corrections	All

Amendments in this release:

Section Title	Section No.	Amendment Summary
Acknowledgements	-	Updated

Distribution:

Copy	Version	Issue Date	Issued To
Hard copy	2.9	14 Mar 2011	Iain Shepherd, DG-Mare, European Commission
Electronic	2.8	28 Feb 2011	Website download, EC DG-MARE
Electronic	2.7	22 Feb 2011	EUSeaMap partners, website download
Electronic	2.4	17 Feb 2011	Iain Shepherd, DG-Mare, European Commission
Electronic	2.1	22 Dec 2010	EUSeaMap partners

Hard copy & electronic	2.0	15 Dec 2010	Iain Shepherd, DG-Mare, European Commission
Electronic	1.0	13 Oct 2010	Iain Shepherd, DG-Mare, European Commission

Appendix II. EUNIS habitats predicted by models

Table i – EUNIS habitats for western Mediterranean Sea model with key physical variable attributes. Red text indicates habitat types not listed in the Barcelona Convention list of Mediterranean habitat types, but were indicated by the model.

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
A3	2	Infralittoral rock and other hard substrata	III.6.	HARD BEDS AND ROCKS (intended as biocenosis of infralittoral algae)	INFRA	>1% surface light - *in situ* 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 - *in situ* 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 - *in situ* data	0-45	COARSE & MIXED SEDIMENT	
A5.33	4	Infralittoral sandy mud		*No corresponding Barcelona Convention habitat type*	INFRA			SANDY MUD	
A5.34	4	Infralittoral mud		*No corresponding Barcelona Convention habitat type*	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% - *in situ* data	25-100	ROCK	
A5.46	4	Mediterranean biocoenosis of coastal detritic bottoms	IV.2.2.	Biocenosis of the coastal detritic bottom	UPPER CIRCA	<1% surface light >0.01% - *in situ* data	below P. oceanica until the break of continental	gravel, sand and shell debris / COARSE & MIXED SEDIMENT/ MUDDY	medium constant current

							slope, lower depth is 100 meters	SAND / SAND	
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% - *in situ* 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 ore 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 the beginning of the abyssal plain	ROCK	
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 *Thenea muricata*	V.1.1.1.	Facies of sandy muds with *Thenea muricata*	BATHYAL	0	from the shelf-break (150-250m) to the beginning of the abyssal plain	SANDY MUD	
A6.2	3	Deep-sea mixed substrata		*No corresponding Barcelona Convention habitat type*	BATHYAL	0	from the shelf-break (150-250m) to the beginning of the abyssal plain	COARSE & MIXED SEDIMENT	
A6.3	3	Deep-sea sand	V.2.	SANDS	BATHYAL	0	from the shelf-break (150-250m) to the beginning of the abyssal plain	SAND	
A6.4	3	Deep-sea muddy sand		*No corresponding Barcelona Convention habitat type*	BATHYAL	0	from the shelf-break (150-250m) to the beginning of the abyssal plain	MUDDY SAND	
A6.52	4	Communities of abyssal	VI.1.1.	Biocenosis of abyssal muds	ABYSSAL	0	abyssal plain	MUD / SANDY MUD	

		muds							
A6.2	3	Deep-sea mixed substrata		*No corresponding Barcelona Convention habitat type*	ABYSSAL	0	abyssal plain	COARSE & MIXED SEDIMENT	
A6.3	3	Deep-sea sand		*No corresponding Barcelona Convention habitat type*	ABYSSAL	0	abyssal plain	SAND	
A6.4	3	Deep-sea muddy sand		*No corresponding Barcelona Convention habitat type*	ABYSSAL	0	abyssal plain	MUDDY SAND	

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

Table ii – EUNIS habitats for North and Celtic Seas model with key abiotic variables for modelling.

EUNIS Habitat code	EUNIS Level	EUNIS name	Zone	Biological zone variables criteria	Substrata	Energy conditions	Notes
A3.1	3	Atlantic and Mediterranean high energy infralittoral rock	Infra	>1% surface light	Rock (or other hard substrata)	High	
A3.2	3	Atlantic and Mediterranean moderate energy infralittoral rock	Infra	>1% surface light	Rock (or other hard substrata)	Moderate	
A3.31	4	Silted kelp on low energy infralittoral rock with full salinity	Infra	>1% surface light	Rock (or other hard substrata)	Low	
A4.11	4	Very tide-swept faunal communities on circalittoral rock	Circa	<1% surface light Above wavebase	Rock (or other hard substrata)	Range	Modelled jointly with A4.13 (distinct from A4.12 by biological zone)
A4.12	4	Sponge communities on deep circalittoral rock	Deep Circa	Below wavebase <200m depth	Rock (or other hard substrata)	Range	
A4.13	4	Mixed faunal turf communities on circalittoral rock	Circa	<1% surface light Above wavebase	Rock (or other hard substrata)	Range	Modelled jointly with A4.11 (distinct from A4.12 by biological zone)
A4.2	3	Atlantic and Mediterranean moderate energy circalittoral rock	Circa	<1% surface light Above wavebase	Rock (or other hard substrata)	Moderate	
A4.27	4	Faunal communities on deep moderate energy circalittoral rock	Deep circa	Below wavebase <200m depth	Rock (or other hard substrata)	Moderate	

A4.31	4	Brachiopod and ascidian communities on circalittoral rock	Circa	<1% surface light Above wavebase	Rock (or other hard substrata)		
A4.33	4	Faunal communities on deep low energy circalittoral rock	Deep circa	Below wavebase <200m depth	Rock (or other hard substrata)	Low	
A5.13	4	Infralittoral coarse sediment	Infra	>1% surface light	Coarse sediment		
A5.14	4	Circalittoral coarse sediment	Circa	<1% surface light Above wavebase	Coarse sediment		
A5.15	4	Deep circalittoral coarse sediment	Deep circa	Below wavebase <200m depth	Coarse sediment		
A5.23	4	Infralittoral fine sand	Infra	>1% surface light	Sand to muddy sand		Modelled jointly with A5.24 (distinct from A5.25 and A5.26 by biological zone)
A5.24	4	Infralittoral muddy sand	Infra	>1% surface light	Sand to muddy sand		Modelled jointly with A5.23 (distinct from A5.25 and A5.26 by biological zone)
A5.25	4	Circalittoral fine sand	Circa	<1% surface light Above wavebase	Sand		
A5.26	4	Circalittoral muddy sand	Circa	<1% surface light Above wavebase	Mud to sandy mud		Modelled jointly with A5.25 (distinct from A5.23 and A5.24 by biological zone)
A5.27	4	Deep circalittoral sand	Deep circa	Below wavebase	Sand to muddy sand		

				<200m depth			
A5.33	4	Infralittoral sandy mud	Infra	>1% surface light	Mud to sandy mud		Modelled jointly with A5.34 (distinct from A5.35 and A5.36 by biological zone)
A5.34	4	Infralittoral fine mud	Infra	>1% surface light	Mud to sandy mud		Modelled jointly with A5.33 (distinct from A5.35 and A5.36 by biological zone)
A5.35	4	Circalittoral sandy mud	Circa	<1% surface light Above wavebase	Mud to sandy mud		Modelled jointly with A5.36 (distinct from A5.33 and A5.34 by biological zone)
A5.36	4	Circalittoral fine mud	Circa	<1% surface light Above wavebase	Mud to sandy mud		Modelled jointly with A5.35 (distinct from A5.33 and A5.34 by biological zone)
A5.37	4	Deep circalittoral mud	Deep circa	Below wavebase <200m depth	Mud to sandy mud		
A5.43	4	Infralittoral mixed sediments	Infra	>1% surface light	Mixed sediments		
A5.44	4	Circalittoral mixed sediments	C irca	<1% surface light Above wavebase	Mixed sediments		
A5.45	4	Deep circalittoral mixed sediments	Deep circa	Below wavebase <200m depth	Mixed sediments		
A6.11*	4	Deep-sea bedrock	Bathyal classes and Abyssal	Below shelf break > 200m depth	Rock (or other hard substrata)		

				proxy			
A6.2*	3	Deep-sea mixed substrata	Bathyal classes and Abyssal	Below shelf break > 200m depth proxy	Mixed substrata		
A6.3*	3	Deep-sea sand	Bathyal classes and Abyssal	Below shelf break > 200m depth proxy	Sand		Modelled jointly with A6.4 (as not sufficient information in substrata layer)
A6.4*	3	Deep-sea muddy sand	Bathyal classes and Abyssal	Below shelf break > 200m depth proxy	Muddy sand		Modelled jointly with A6.3 (as not sufficient information in substrata layer)
A6.5*	3	Deep-sea mud	Bathyal classes and Abyssal	Below shelf break > 200m depth proxy	Mud		

* All deep sea habitats modelled with further biological depth zonation following Howell (2010). See Table 3 of main report for details.

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 (Leonardo Tunesi) at Progetto CARG, Rome, Italy, 29-30 September 2009.

EUSeaMap: Towards common spatial seabed data - Presentation at the Maritime and coastal information systems (Natalie Askew), 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. Ifremer/Jean-François Bourillet.

EUSeaMap project: Modelling European seabed habitats - A focus on the western Mediterranean. Information poster 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 (Jacques Populus) at Mesh-Atlantique kick-off meeting, Lisbon, Portugal, 31 May 2010.

Estimation of the diffuse attenuation coefficient Kdpar 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. Bertrand Saulquin, ACRI_ST.

EUSeaMap: Modelling European seabed habitats – Presentation (Jacques Populus) 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 (Mickaël Vasquez) 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. Sofia Wikström.

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

EEA/EIONET activities related to the work area Maritime – roadmaps, assessments, indicators - Presentation at the EIONET workshop (Andrus Meiner, EEA), Copenhagen, Denmark, 25th -26th October 2010

Appendix IV. Data sources summary

Region: Baltic sea						
Model Layer (&/or thresholds)	**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. *Oceanologia* 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	
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	O2/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	
Light threshold (mesohaline and oligohaline)	Depth limit of plant- or algal-dominated communities	Diving transects, classified into preliminary EUNIS classes using the BalMar tool	1980-2009	Swedish National Database for phytobenthic monitoring; Alleco ltd.	10 m2	SEPA, Alleco ltd.
Light threshold (polyhaline and euhaline)	Depth limit of kelp (Laminaria spp. or Saccharina latissima)	Diving transects	1996-2009	Swedish National Database for phytobenthic monitoring	10 m2	SEPA
Energy thresholds	Occurrence of shallow Fucus communities and species-rich phanerogam communities	Diving transects, classified into preliminary EUNIS classes using the BalMar tool	1980-2009	Swedish National Database for phytobenthic monitoring; Alleco ltd.	10 m2	SEPA, Alleco ltd.
Salinity threshold	Occurrence of communities of Fucus, Furcellaria lumbricalis, other red algae and occurrence of Mytilus edulis	Diving transects, classified into preliminary EUNIS classes using the BalMar tool	1995-1996; 2001-2009	Swedish National Database for phytobenthic monitoring; Bergström & Bergström 1999. Nordic Journal of Botany 19: 375-383.	10 m2	SEPA

Region: Celtic sea						
Model Layer (&/or thresholds)	**Variable**	**Data Set**	**Date**	**Source**	**Resolution/Scale**	**Owner of Intellectual Property Rights**
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	Wave base	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
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
Energy	Kinetic energy at seabed due to waves	EUSeaMap energy layers	2000 - 2005	NOC ProWAM and ABPMer bespoke coastal model (based on DHI MIKE Spectral Wave) Contract JNCC C10-0198-0316 (produced under contract by ABPMer/NOC)	0.003 dd grid	EUSeaMap
Energy	Kinetic energy at seabed due to tidal currents	EUseaMap energy layers	2001	NOC CS20, CS3 and NEA tidal models Contract JNCC C10-0198-0316 (produced under contract by ABPMer/NOC)	0.003 dd grid	EUSeaMap
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
Thresholds	Light, energy	Marine Recorder database (Snapshot July 2010)	N/A	Marine survey data from JNCC, the UK Statutory Nature Conservation Bodies (SNCBs), Marine Environmental Data and Information Network (MEDIN), Seasearch and Local Record Centres.	n/a (point data)	Public domain

Region: North sea

Model Layer (&/or thresholds)	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 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	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
Energy	Kinetic energy at seabed due to waves	EUSeaMap energy layers	2000 - 2005	NOC ProWAM and ABPMer bespoke coastal model (based on DHI MIKE Spectral Wave) Contract JNCC C10-0198-0316 (produced under contract by ABPMer/NOC)	0.003 dd grid	EUSeaMap

Energy	Kinetic energy at seabed due to tidal currents	EUseaMap energy layers	2001	NOC CS20, CS3 and NEA tidal models Contract JNCC C10-0198-0316 (produced under contract by ABPMer/NOC)	0.003 dd grid	EUSeaMap
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
Thresholds	Light, energy	Marine Recorder database (Snapshot July 2010)	N/A	Marine survey data from JNCC, the UK Statutory Nature Conservation Bodies (SNCBs), Marine Environmental Data and Information Network (MEDIN), Seasearch and Local Record Centres.	n/a (point data)	Public domain

Region: Western Mediterranean sea						
Model Layer (&/or thresholds)	**Variable**	**Data Set**	**Date**	**Source**	**Resoluti on/ 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	Diviacco 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
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 / Biological thresholds	Bathymetry / Substrate / Meadows	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 / Biological thresholds	Bathymetry / Substrate / 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
Depth Zone/ Substrate	Bathymetry / Substrate (inc. Geology / Geomorphology / Mineralogy)	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 / Biological thresholds	Bathymetry/ Substrate / Meadows	Programa de Planeamiento y actuaciones en la Costa. Plan de Ordenación del Litoral	1988-2000	Cartografía para el plan de Ordenación del Litoral. Dirección General de Costas. Tramos del Sur de Formentera, N. de Menorca, S. de Castellon y Barcelona	1: 25,000	Dirección General de Costas. Ministerio de Obras Públicas
Depth Zone/ Substrate / Biological thresholds	Bathymetry/ Substrate / Meadows (also contains info on Fish gorunds / Marine Sanctuaries / Anthropogenic features / Artificial reefs)	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). Unpublised	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.,çLastras, 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	2001-2005	Comas, M. (grid unpublished). Several papers	50 m grid	IACT (Granada). CSIC

		Iberia). Grid				
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 precontinent 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 Cap D'Ail. Contrat Communauté d'Agglomération Nice-Côte d'Azur.	1:5 000	Communauté d'Agglomération Nice Côte d'Azur, Conseil Général 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'ecologie marine - Etude Complementaire au contrat de Baie des Golfes de Lerins. 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 - Méditerranée)	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

Substrate	Posodonia 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	Posodonia 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
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 Mugel - 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 Environnnement

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
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., MIMAULT 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., MIMAULT 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., MIMAULT 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., MIMAULT 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
Depth Zone/ Substrate/ Biological	Bathymetry/ Substrate / Meadows	Estudio geomorfológico y ambiental del SE de Ibiza y NE de Formentera.	2008	Proyecto Interno IEO.Internal report. Unpublished	1:10,000	Instituto Español de Oceanografía (IEO)
Substrate	Posidonia	Mapa fisiográfico de la bahía de Palma	1992	Díaz del Rio V., Somoza L., Goy J.L., Zazo C., Rey J., Hernández-Molina F.J., Mateu G. Mapa fisiográfico de la bahía de Palma	1:25,000	Instituto Español de Oceanografía (IEO)
Substrate	Posidonia	GIS de la Generalitat de Catalunya. Praderies de Fanerògames Marines del litoral catalá	1992	Praderies de Fanerògames Marines. Tipificació del fons marí del litoral català, amb especial atenció a les zones amb praderies de fanerògames marines.	1:50,000	Generalitat de Catalunya
Substrate	Bionomy	Tipologia de fons marí Cabrera	2000	Govern de les Illes Balears. Tipologia de fons marí Cabrera	1:5,000	Govern de les Illes Balears
Substrate	Sediments	Fondos de la Plataforma continental Balear. 19 hojas	1994	Govern de les Illes Balears. Mapa sedimentos de la Plataforma continental balear.	1:5,000	Govern de les Illes Balears.Conselleria de Pesca

Substrate	Substrate / Meadows	Tipología de fons marí Ses Salines de d'Eivissa i Formentera	2002	Govern de les Illes Balears. Parque natural de Evissa y Formentera	1:25,000 - 1:50,000	Govern de les Illes Balears.Conselleria de Medi Ambient
Depth Zone/ Substrate/ Biological	Bathymetry / Substrate / Meadows	Estudio Ecocartográfico de la zona litoral	2000 - 2005	Estudio ecocartográfico de la zona litoral. Provincias de Valencia y Alicante	1:25,000	Ministerio de Fomento. Dirección General de Costas
Substrate	Substrate / Posidonia	Carta bionómica de Alicante.	1998	Ramos-Esplá A. Informe XVI/98 sobre praderas de Posidonia oceanica de la provincia de Alicante. Internal report. Unpublished	1:30.000	Generalitat Valenciana. Dirección Territorial de Alicante de la Conselleria de Medio Ambiente
Substrate	Substrate / Posidonia	Mapa bionómico de la isla de Nueva Tabarca	1985	Ramos-Esplá, A. 1985. Contribución al conocimiento de las biocenosis bentónicas litorales de la isla Plana o Nueva Tabarca (Alicante). In: La reserva marina de la Isla Plana o Nueva Tabarca (Alicante). A. Ramos-Esplá (ed.): 111-148. Universitat d'Alacant, Servei de Publicacions. Alicante, España.	1:5,000	Ramos-Esplá, A.. Universitat de Alicante
Substrate	Substrate / Meadows	Mapa bionómico de los fondos de la isla de Benidorm	1991	Ramos, A.A., Sánchez LIzaso, J.L., Aranda, A. & Guillén, J.E. (1993). Estudio bionómico de los fondos de la Isla de Benidorm (SE Ibérico). Publ. Esp. Inst. Español Oceanogr. 11: 431 - 439.	1:5,000	Ramos-Esplá, A.. Universitat de Alicante
Substrate/ Biological	Substrate / Posidonia	Mapa bionómico del litoral de Murcia	1998	R. Ballester, J.C. Calvín, I. Franco, A.M. Martínez, A. Marín, A. Belmonte, J.M. Ruiz. El litoral sumergido de la región de Murcia.	1:25.000	Gob. Region Autonoma de Murcia. Dirección General de Medio Natural.
Energy	Wave energy at seabed	WaveWatch III model	Jun 2007 to Apr 2009	Previmer/SHOM and Ifremer	0.1° x 0.1° NetCDF	Previmer/SHOM and Ifremer
Energy	Tidal energy at seabed	MFS model	Jun 2007 to Apr 2009	INGV	0.625° x 0.625° NetCDF	INGV

Energy	Tidal energy at seabed	Previmer model	Jun 2007 to Apr 2009	Previmer/Ifremer	0.014° x 0.01° NetCDF	Previmer/Ifremer
Energy	Tidal and wave energy at seabed	Ifremer model	Jun 2007 to Apr 2009	Previmer/Ifremer	0.625° x 0.625° NetCDF	Previmer/Ifremer
Energy	Tidal and wave energy at seabed	Ifremer model	Jun 2007 to Apr 2009	Previmer/Ifremer	0.014° x 0.01° NetCDF	Previmer/Ifremer