EC contract no. MARE/2008/07

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

EUSeaMap

Interim Report

February 2010

Executive Summary

A consortium of partners from across four Marine Regions (Baltic, North, Celtic and western Mediterranean Seas) has joined together to deliver the requirements for EC Tender MARE/2008/07. The EUSeaMap Partnership comprises government agencies and research institutions with proven national and international expertise in marine seabed mapping and modelling. The project will build upon the highly successful INTERREG MESH[1] and BALANCE[2] projects, by harmonising the MESH EUNIS 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 habitat modelling techniques, existing maps will be improved and refined, and their coverage seamlessly extended in the specified Marine Regions.

This Interim Report of EUSeaMap summarises the progress to date. Through a review of habitat modelling and mapping in European waters, a consistent methodology has been developed across the partnership, which takes account of the diverse range of habitats found in different Regions. Preparation of spatial data for a suite of environmental variables, which form the basis of the model, is nearly complete. This includes data provided by EMODNET geology and hydrography projects[3]. The incorporation of biological data into the modelling process has begun, through the development of ecologically-relevant thresholds. A test version of the model has been successfully run for the area around Brittany, including the use of a module which will allow ready update of the maps, as new higher quality data become available in the future.

The EUSeaMap pilot webGIS has been built, through which the final habitat maps and environmental variables will be disseminated; additional functionality is in development in preparation for the live launch of the webGIS. Techniques for creating an associated confidence map have been explored, and three approaches are now under consideration following liaison with EMODNET projects. The confidence map is important to enable the variation in quality and resolution of the input data layers to be visually reflected.

The next phase of the project will finalise the thresholds to be used, and run the models to create seabed habitat maps and associated confidence maps. A series of assessments to demonstrate the applications of the maps will be carried out to highlight benefits and weaknesses of such maps, including through stakeholder feedback. An assessment of further work required to refine the maps and to extend them to other parts of European seas will be undertaken.

[1] Development of a Framework for Mapping European Seabed Habitats (www.searchMESH.net)
[2] Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning (www.balance-eu.org)
[3] Preparatory Actions for European Marine Observation and Data Network, No. MARE/2008/03, Lots 1 & 2

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1. Introduction

1.1. Background

The importance of marine 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 habitat data are highly desirable. Developments in Geographical Information Systems (GIS) have made it possible to generate predictive 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.

1.3. Progress against project schedule

The contract objectives in section 1.2 have been assigned to work packages in the EUSeaMap project plan. Table 1 shows the summary schedule for these work packages. Progress in EUSeaMap is in line with this schedule. The table also indicates the link between work packages, the section of the report which relates to that work package, and the section of the contract specification which requires each element of work. This is intended to help track progress. Work packages due to start later in 2010 will be reported in the final report, and are included in the table for completeness.

Table 1 Work packages with summary timescales for 2009-2010.

Work package	Report section (specification section)	2009										2010											
		M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1 Methods																							
1.1 Review of mapping and modelling	**2 (2.3.1)**																						
1.2 Agree methodology	**3, 4 (2.3.2)**																						
1.3 Comments on INSPIRE implementa-tion rules	**Not reported here (2.3.5)**																						
2 Data preparation																							
2.1 Data access	**5 (2.3.2)**																						
2.2 Data layer preparation	**5 (2.3.2)**																						
3 Validating thresholds																							
3.1 Define thresholds for the EUNIS classification	**5 (2.3.2)**																						
4 Modelling																							
4.1 Running models	**6.1 (2.3.2)**																						
4.2 Confidence assessment & map validation	**6.2 (2.3.2)**																						

4.3 Map update	**6.1 (2.3.2)**																						
5 Disseminating data																							
5.1 Applying data and metadata standards	**7 (2.3.3, 2.3.2.3)**																						
5.2 Making data available	**7 (2.3.3)**																						
6 Applications																							
6.1 Assessment of benefits	**Not reported here (2.3.4)**																						
7 Follow on																							
7.1 Assessment of next steps	**Not reported here (2.3.6)**																						
8 Maintenance																							
8.1 Maintenance of webGIS application	**Not reported here (2.3.7)**																						▶

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 habitats, defined by their abiotic characteristics which are relevant to the associated biological communities. Mapping of these 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 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[4] (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 parameters that define the grouping of biological communities and geophysical habitat conditions.

[4] http://www.eea.europa.eu/publications/COR0-landcover

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

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

In response to these requirements, development of the Marine Habitat Classification for Britain and Ireland, within the EC BioMar project (1992-1996) led to the release of the first full working version in 1997 (Connor 1997; Connor *et al*. 1997), based on multivariate analyses of about 30,000 biological samples. Following extensive practical use, the acquisition of new data and further analyses to extend the classification, a fully revised version (Connor *et al*. 2004; www.jncc.gov.uk/MarineHabitatClassification) was released in 2004. The classification is now well established as a standard tool for nature conservation practitioners, industry regulators and those involved in environmental assessment, survey and management. Further additions to the classification, to cover offshore and deep-water 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[5] 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 habitats for the Black Sea. The additions to the Marine Habitat Classification for Britain and Ireland mentioned above, for offshore and deep-water habitats, will also be submitted to EUNIS.

2.1.2. Difference between habitats and marine landscapes

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

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

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

The term 'marine landscape' has been widely used in this field to describe the units which are modelled. Marine landscapes work at a larger scale than 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 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 habitat types based on abiotic variables, such as substrate type, depth, light levels and energy from currents.

2.2. International European modelling programmes

Modelling 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 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 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[6] project. The international modelling programmes discussed below both use thresholds which are based on habitat classification systems – which themselves are derived from biological data and field measurements of abiotic variables.

[6] http://habmap.org

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 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 variabless, sediment, photic depth and salinity, to spatially describe the seabed in terms of broad habitat conditions available (Al-Hamdani & Reker 2007; Figure 1).

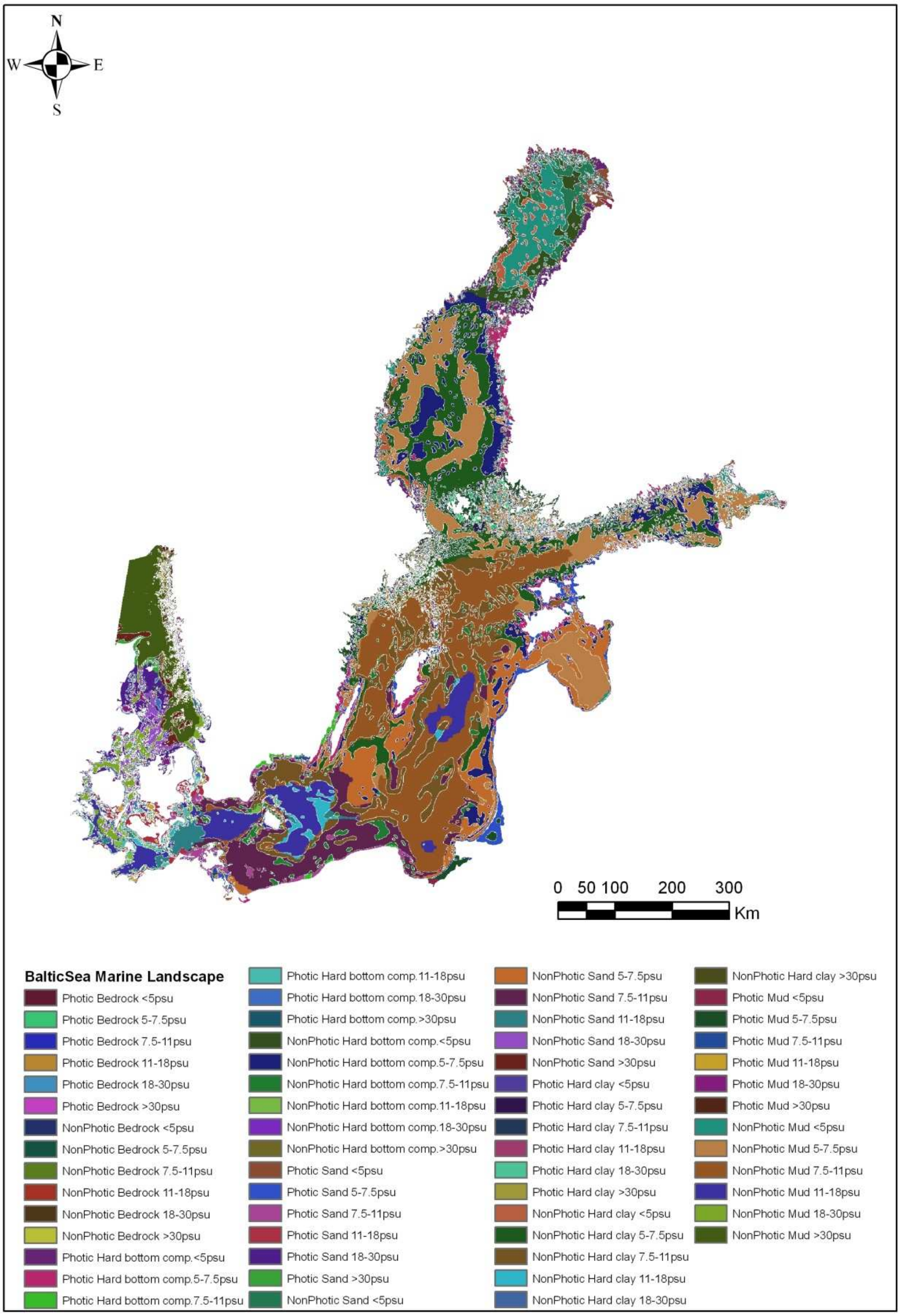

Figure 1 BALANCE marine habitat map (Al-Hamdani & Reker 2007).

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 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 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 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 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 marine habitat mapping (MESH 2008; ICES 2007). The same confidence assessment system was not extended to apply to the modelled habitat map.

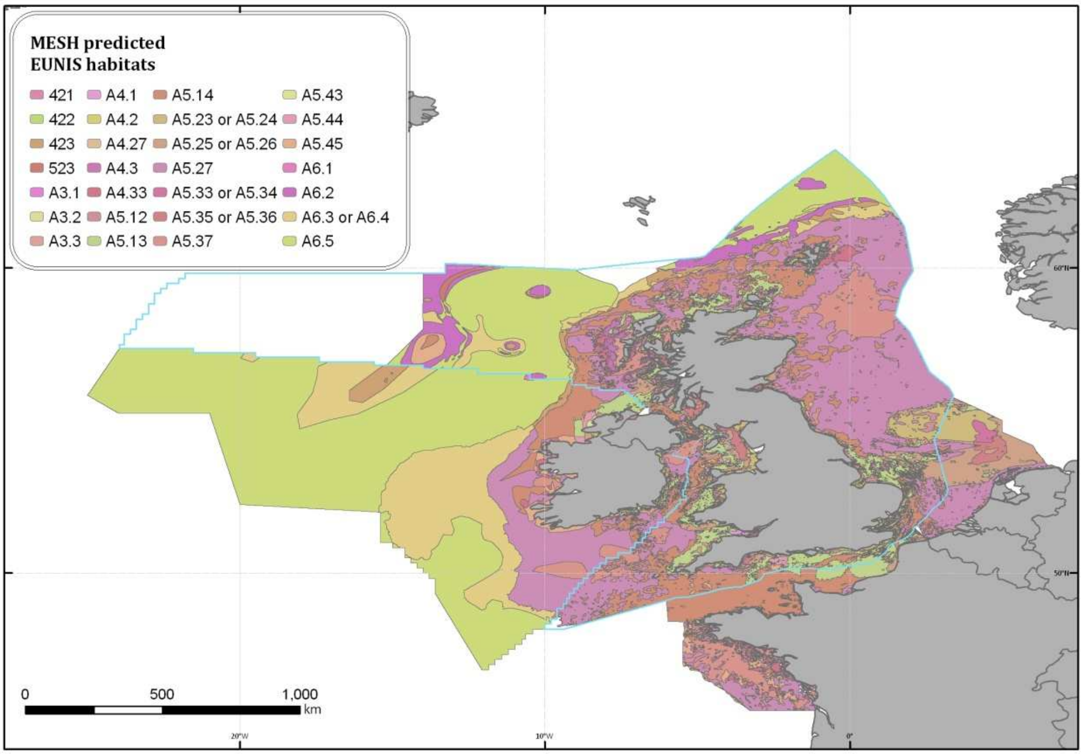

Figure 2 MESH predicted EUNIS habitats (Coltman *et al*. 2008).

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[7] and HERMES[8] 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[9] 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.

[7] www.ifremer.fr/charm

[8] www.eu-hermes.net

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

2.3.1. UKSeaMap

UKSeaMap used geological, physical and hydrological data, including model derived datasets for the water column, to predict marine habitats for the full extent of the UK continental shelf (Figure 3). The UKSeaMap project results were published in 2006, providing the first visualisation of seabed and water column features for the UK marine area (Connor *et al*. 2006). The data layers developed for UKSeaMap formed much of the basis on which MESH produced its modelled habitat maps.

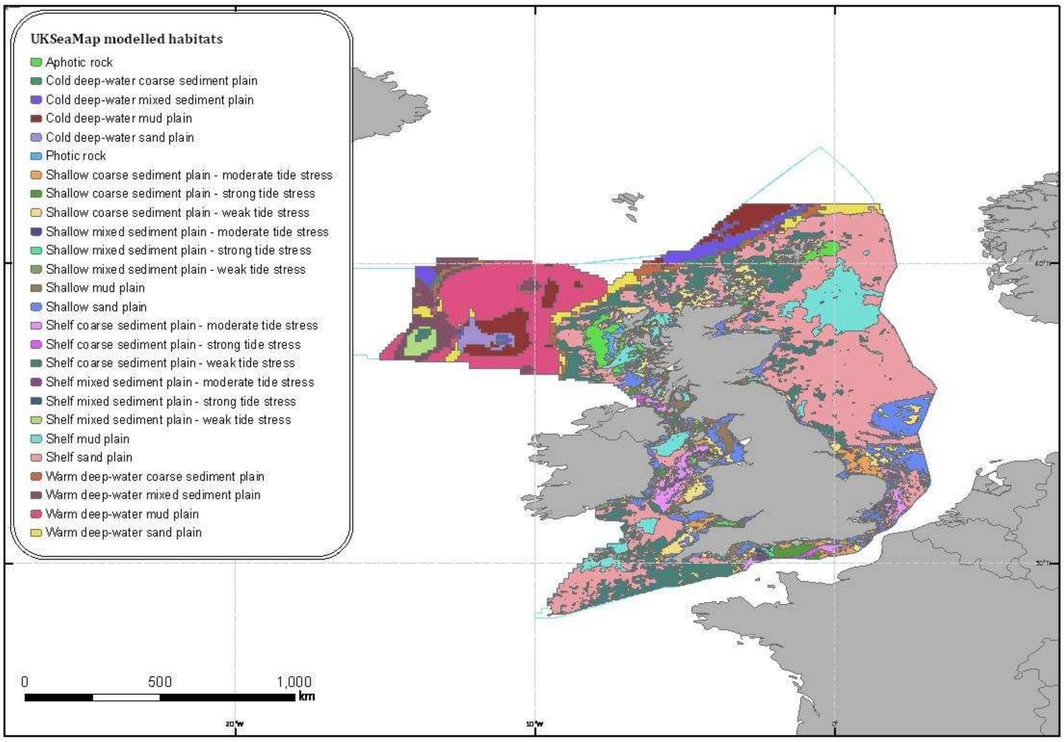

Figure 3 UKSeaMap modelled seabed types (Connor *et al*. 2006).

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 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 marine 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[10] 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 marine habitat project FINMARINET[11]. It will carry out inventories of the marine 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 habitats in new areas. Testing these predicted habitats with ground-truthing is planned in future cruises.

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[10] www.emepc.pt

[11] 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[12] (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 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 habitats over larger areas.

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

[12] 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 habitats can be modelled by the use of wide coverage abiotic variables. Here the rationale behind the main variables used in the full coverage modelling of seabed habitats at large spatial scales is examined, with particular focus on their ecological relevance.

3.1. Biological or depth zone

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

Where the factors determining zonation are well understood, it may be possible to use bathymetry as a surrogate for the factor causing the zonation, although with increasing distance away from the 'tested' area, this relationship may become increasingly unreliable (and hence need further validation). These factors which change with depth also vary horizontally from region to region; thus their combination to give a pattern of biological zones is often complex. A factor which works well to define zones in one region (e.g. light) may not be appropriate in another region (e.g. where wave energy might be more important). There are particular differences between zonation in the Celtic and North Sea regions to the Mediterranean (which are illustrated in Table 3), whilst there is not common agreement on zonation in the Baltic (Backer *et al*. 2004, Isæus *et al*. 2007).
Very marked horizontal bands of zonation on most rocky coasts are related to the length of time the rock is exposed by the tide. In subtidal areas, changes in wave disturbance and light with increasing depth are the main factors responsible for structuring the vertical zonation. Zonation in sediment habitats is generally much less obvious than on rocky coasts. Shallow subtidal sediments reflect a high degree of wave disturbance, with high temperature and salinity fluctuations, followed by increasingly stable conditions in deeper waters.

3.1.1. Light

Light availability in the water column and at the seabed varies considerably, affecting in particular the depth to which macrophytes (kelp, seaweeds, seagrass, e.g. *Posidonia*) can grow. Light intensity decreases with depth due to the attenuating effects of scattering and absorption (by water molecules, suspended particulate matter, phytoplankton and coloured dissolved organic matter) in the water column (turbidity). This attenuation tends to be higher in coastal waters, due to suspended and dissolved matter being washed down rivers, higher phytoplankton concentrations and suspension of sediment caused by wave action in shallow waters.

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

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

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

- Infralittoral - seagrass and photophilic[13] algae
- Upper circalittoral - sciaphilic[14] brown and red algal species
- Lower circalittoral - survival of sparse sciaphilic algae originating from the upper circalittoral
- Abyssal - no light and no plant life

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

[13] Receptive to, or thriving in light conditions

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

Table 3 Limits of infralittoral and circalittoral zones for EUSeaMap regions

Biological zone	Upper limit	Lower limit
Infralittoral	Lowest Astronomical Tide	Intersection of seabed and 1% surface light depth
Upper Circalittoral (Atlantic and Baltic)	Intersection of seabed and 1% surface light depth	Maximum depth at which seabed is affected by waves
Upper Circalittoral (Mediterranean)	Intersection of seabed and 1% surface light depth	Intersection of seabed and average 0.01% incident light fraction
Deep Circalittoral (Atlantic)	Maximum depth at which seabed is affected by waves	Shelf slope break line delimited by the slope angle change of the continental platform, or proxy (200m used in MESH)
Deep Circalittoral (Mediterranean)	Intersection of seabed and average 0.01% incident light fraction	Shelf slope break line delimited by the slope angle change of the continental platform, or proxy
Deep seas	Shelf slope break line delimited by the slope angle change of the continental platform, or proxy	n/a

The circalittoral zone starts from the lower limit of the infralittoral until the maximum depth where multicellular photosynthetic forms can exist. The assemblages found in this zone are therefore characterised by the predominant presence of sciaphilic algal communities. The lower limit of the circalittoral also coincides with the external margin of the continental shelf, identified on the basis of the slope break (usually found within the 130 and 200m depth range). The circalittoral can also be divided into upper circalittoral and lower circalittoral on the basis of the amount of light reaching the seabed. In the upper circalittoral the light reaching the bottom is estimated to range between 1% - 0.01% of the surface light thereby allowing the photosynthesis of multicellular algae. The light reaching the bottom in the upper circalittoral is sufficient to allow the photosynthesis of different brown algae communities such as the Fucales (deep water *Cystoseira* and *Sargassum* spp.), Laminariales, Desmarestiales and Sporochnales as well as red algal (rhodophycean) species. Characteristic communities present in this zone are the coralligenous assemblages consisting of more or less massive bioconstructions formed by coralline algae as well as Rhodolith (Maerl beds) consisting of loose lying, living or dead, coralline red algae, usually aggregated into masses on shell gravel mixed with coarse sand. The lower circalittoral instead is characterised by having less than 0.01% of the surface light reaching the seabed and multicellular algae are therefore generally not present in great quantities as light becomes more and more a limiting factor. Another characteristic of the circalittoral zone is that the bottom temperature ranges from 18 down to 13.5°C; temperature is discussed further in section 3.4.1)

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

3.2. Substrate

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

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

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

Seabed communities can be classified into two broad categories: namely those associated with hard substrata (epifaunal communities) and those of soft substrata (infaunal communities – with or without associated epifauna). There is, however, a complete gradation between the two, as many areas of seabed comprise mixtures of hard and soft substrata. Dealing satisfactorily with these mixtures is a major challenge in 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 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[15] 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 do

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

not have an influence is known as the wave base. Hence below the wave base currents have the only effect.

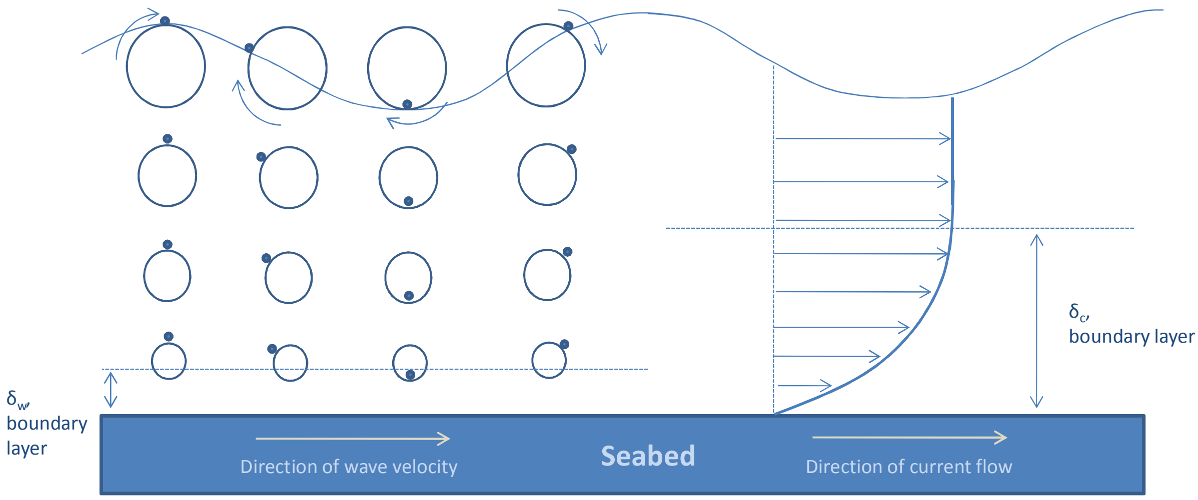

Figure 4 The construction of boundary layers by orbital velocity due to wave motion through the water column (l) and current velocity profile (r).

3.3.1. Waves

An assessment of the exposure to waves, from all directions and all seasons, can be used as a disturbance indicator. Wave statistics such as significant wave height (H_{sig}), wave period (T), 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. Others

Exceptions to the high degree of correlation between community type and seabed substrate, discussed above, are where other factors have such strong influences on the biology that the communities in such situations occur across a wider range of possible substratum types. Notable cases of these factors are reduced salinity and lowered oxygenation levels.

3.4.1. Temperature

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

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

3.4.2. 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 (below fully marine conditions at 35-33‰) leads 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.

3.4.3. 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). 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.

3.4.4. Ice cover

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

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

4. Methodology

The limits of the EMODNET projects were agreed between the various consortia to be based on ICES ecoregions[16] 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.

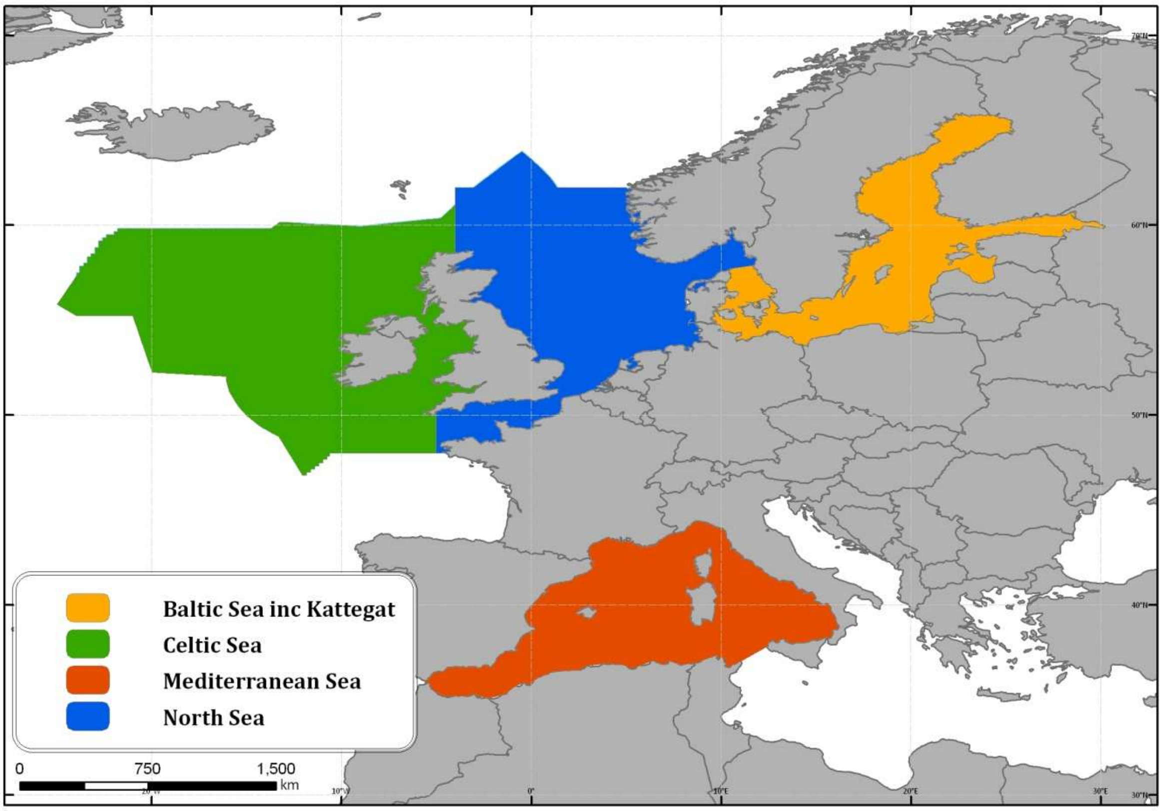

Figure 5 Extent of the EUSeaMap project. Seas are defined by ICES ecoregions with extensions to EEZs where required.

4.1. Application of EUNIS

As the only consistent system to classify European seabed habitats, EUNIS and its spatial application through modelling are at the core of this project. Although the structure of

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

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 the marine habitats based on depth and substrate type, permanent or non-permanent water cover, ice-cover and characteristics of the pelagic water column (EUNIS codes: A1 – A8) (Davies, Hill & Moss 2004). Level 3 habitats are further classified based on criteria involving abiotic variables such as the actual substrate nature (i.e. coarse sediment, sand, sandy mud), energy levels (moderate, high, low energy), temperature, light, salinity and plant cover. Differentiations between habitats based on the components of the biological communities begin to appear at level 4 (e.g. A2.24: Polychaete/bivalve-dominated muddy sand shores). However the inclusion of biological communities at level 4 is not universal across the system: Figure 6 shows an example of the EUNIS hierarchy where the level 4 habitat is Circalittoral sandy mud, A5.35.

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

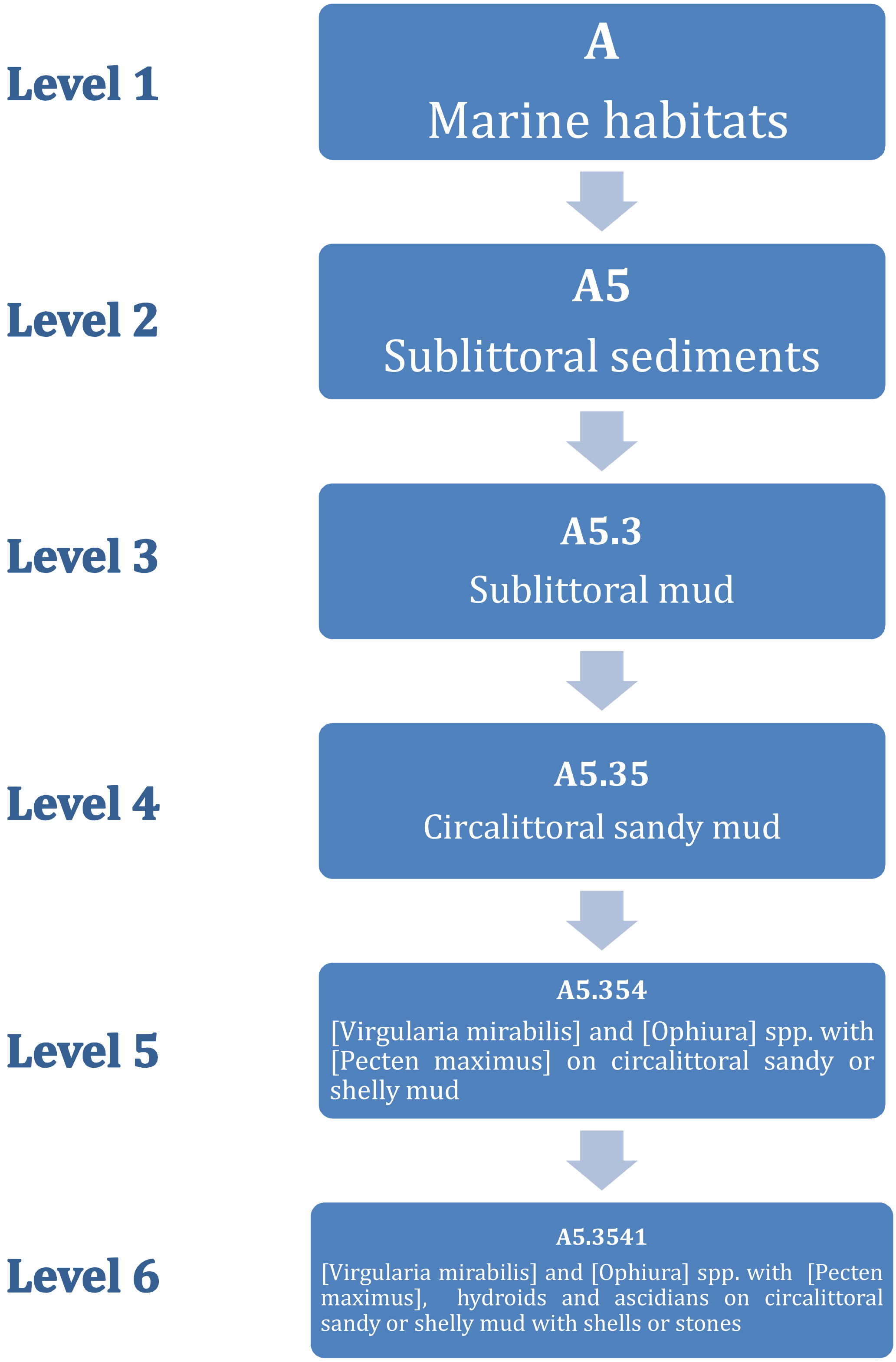

Figure 6 Example of the EUNIS hierarchy.

4.2. Modelling

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

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

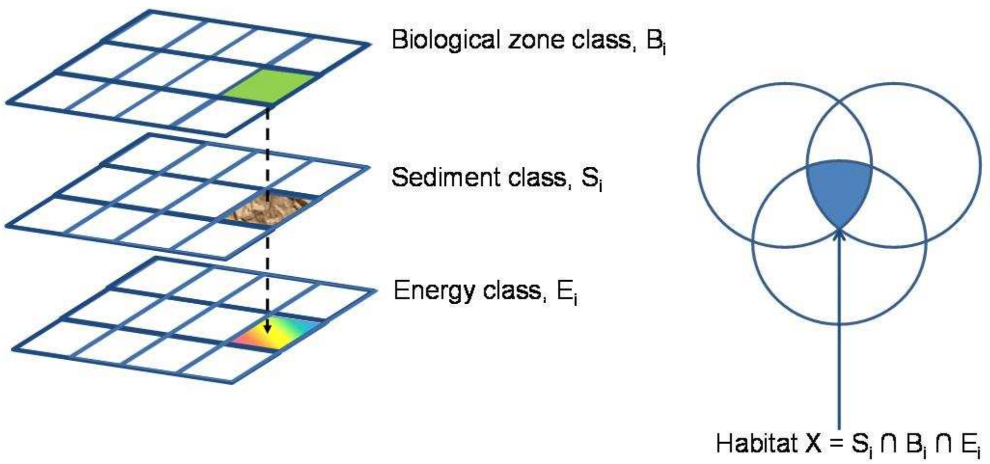

Figure 7 Illustration of raster based multicriteria evaluation.

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

Biological zone	Seabed substrate						
	Rock/Reef			Coarse Sediment	Sands and muddy sands	Muds and sandy muds	Mixed sediment
	Energy						
	High	Moderate	Low				
Infralittoral	A3.1	A3.2	A3.3	A5.13	A5.23 or A5.24	A5.33 or A5.34	A5.43
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

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

The working or nominal resolution has been chosen as approximately 250m. This was driven by the knowledge that over much of the study area this kind of resolution is generally available for most datasets. This is the case in the coastal zone for the two key base layers (substratum and depth), however it does not hold true in the offshore area where base layers tend to be found at coarser resolutions. However, one way to express the fact that source layers are not as detailed as the nominal resolution is by associating a confidence map to the final map.

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

4.3. Defining thresholds for habitats

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

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

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

4.3.1. Fuzzy classifiers

Previous efforts to model full coverage seabed habitats at large spatial scales (section 2.2 and 2.3 above) have used multicriteria evaluation with Boolean logic: a habitat falls into a distinct, finite class for each contributing variable used in the model. In other words, the thresholds are 'hard' boundaries between classes in the input variables, and hence these hard boundaries are reproduced in the final habitat map. However, this use of classical set theory is often inadequate to model 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 will be examined. When ecological thresholds can not be defined accurately (e.g. a temperature threshold of 9.0°C rather than 9.1°C) such thresholds are described as fuzzy. In this case, criteria will be set by a membership function that defines a range of values marking the low and high end of acceptance criteria for memberships of a given class. Factor values for memberships are subsequently rescaled from 0 to 1 with one being the definite high end of the range. A pixel grid cell will then be classified as being located somewhere along this continuum rather than present or absent in the class. Care will be taken that membership functions do not just use blind linear scaling between minimum and maximum values, but actually look into the inherent meaning of the values in relation to each functional unit. In many cases sigmoidal rather than linear membership functions are applied. Figure 8 illustrates an example of how these memberships may be set up. Our model can then display, for each category of each variable, the measure of membership to the category.

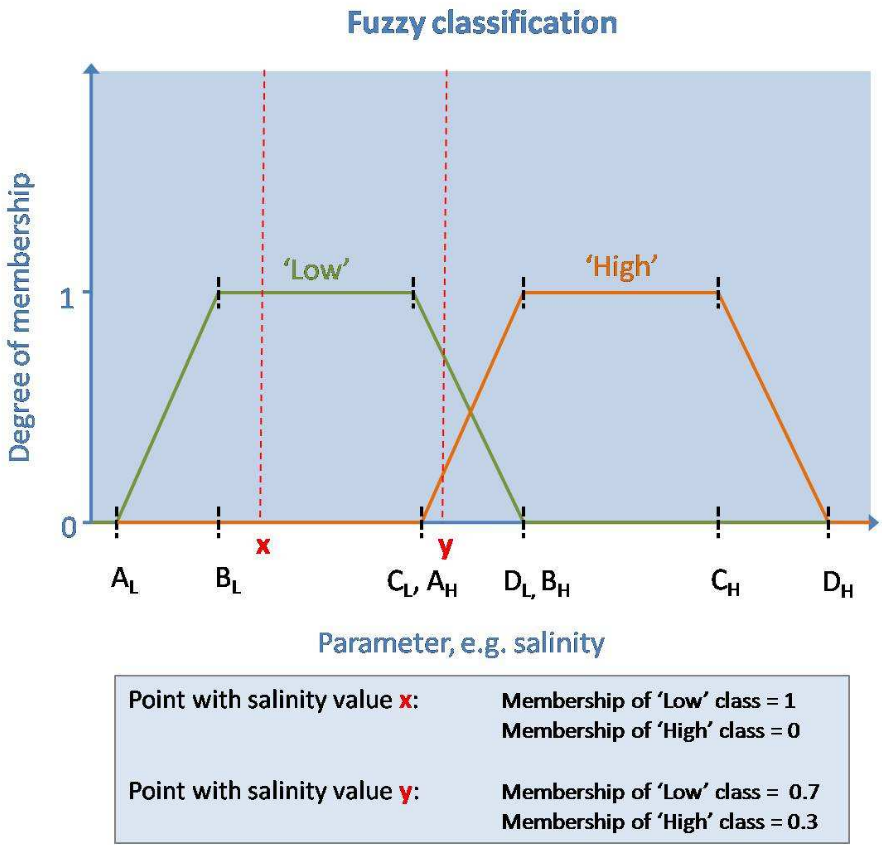

Figure 8 Fuzzy thresholds, example using two classes.

An alternative way to express variability is through the application of Bayesian logic: the use of probability as a measure of how certain that a given geographical location falls within a category as defined by a 'hard' classifier. As a measure of certainty, Bayesian logic can also be used to produce confidence maps; this is discussed further in sections 4.4 and 6.2.

4.4. Confidence

An important part of the EUSeaMap project is to provide an assessment of confidence in the final modelled 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[17]. This is not a mathematical definition like accuracy or uncertainty, but is a judgement made by the map-user and may therefore vary for any map. However, this judgment can be supported by evidence from:

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

Previous projects have followed this definition, and the MESH project developed a tool to assess the confidence in habitat maps, at www.searchmesh.net/confidence. The tool evaluates a map by scoring factors according to agreed rules, summarised in Table 5. The approach received positive feedback in international fora, including from the ICES Working Group on Marine Habitat Mapping (WGMHM)[18] and OSPAR Marine Protected Areas, Species and Habitats (MASH)[19] group. The output of the tool is a qualitative measure of confidence in a seabed habitat map. To date, this method has been used only to assess the confidence of surveyed habitat or substrate maps, for example where remote sensing data and ground-truthing data have been interpreted to produce mapped seabed types. It has not yet been applied to broad scale predictive maps.

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

Regardless of whether a qualitative or quantitative approach is used, measures of confidence in the EUSeaMap modelled habitats will intrinsically require some level of

[17] MESH definition

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

[19] www.ospar.org

assessment of the contributing data layers. Further consideration of the approaches available to achieve this is given in section 6.2.

Table 5 Simplified overview of the MESH confidence assessment tool.

Questions	Factors assessed	Scores	Final value
How good is the remote sensing?	Remote Techniques	Remote score	Overall score
	Remote Coverage		
	Remote Positioning		
	Remote Standards Applied		
	Remote Vintage		
How good is the ground-truthing?	Biological Ground-truthing Technique	Ground-truthing score	
	Physical Ground-truthing Technique		
	Ground-truthing Position		
	Ground-truthing Sample Density		
	Ground-truthing Standards Applied		
	Ground-truthing Vintage		
How good is the interpretation of the overall map?	Ground-truthing Interpretation	Interpretation score	
	Remote Interpretation		
	Detail Level		
	Map Accuracy		

5. Progress on data preparation

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 bathmetry. Progress is summarised in the following section, with a full summary of data sets collected listed in Appendix V.

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 habitats that could be modelled in the Mediterranean. The habitat types were identified by screening them from the overall Mediterranean benthic habitats list identified within the framework of the UNEP-MAP Barcelona Convention[20] 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 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.

5.1. Biological zone

5.1.1. Light attenuation

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

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

The variable K_{PAR} is the attenuation coefficient of light available for photosynthesis. It is used to calculate light attenuation values; when light attenuation values result in availability of less than 1% of surface light, there is a change in dominance of photosynthetic organisms, for example kelp and macrophytes will struggle to grow below this light threshold. The

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

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

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

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

Satellite observation of the diffuse attenuation coefficient of the down-welling spectral irradiance at wavelength 490 nm (Kd_{490}) or the diffuse attenuation coefficient for the down-welling photosynthetically available radiation (Kd_{PAR}) is an effective method to provide large extent maps of light attenuation at high spatial and temporal resolution. Several models are commonly used to derive the Kd_{490} and Kd_{PAR} maps from ocean colour satellite sensors such as the Medium Resolution Imaging Spectrometer Instrument (MERIS), the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and the Moderate Resolution Imaging Spectroradiometer (MODIS). Most of these existing models have been calibrated on open ocean waters and provide good results in these areas, but tend to underestimate the attenuation of light in turbid coastal waters.

For EUSeaMap, an improved Kd_{PAR} layer has been estimated from radiance measured by the MERIS sensor on board the European Envisat satellite (Saulquin *et al.,* in prep.). Two types of products were processed. Level 2 Reduced Resolution products (at 1 km) were processed from 2003 to 2008 over the whole western Europe area (limited by 13W, 18E, 36N, 60N), whereas, as a first attempt to get a higher level of detail, three sub-areas at Full Resolution (at 250m resolution) were also processed for the period 2007-2009 (Figure 9). These 250m products are particularly relevant for the steeper shores found in the Mediterranean. These light layers represent a further significant improvement beyond the resolution of the data. Under 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.

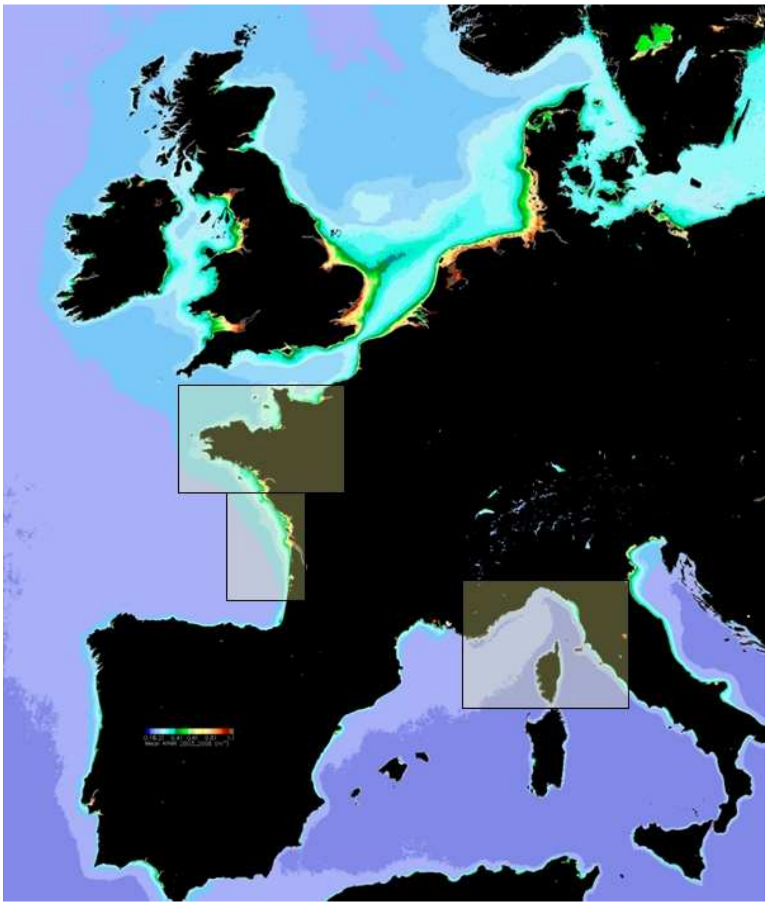

Figure 9 Overview of the MERIS swath zone (1km resolution). Boxes are full 250m resolution sub-areas.

In order to check the validity of the 1% light threshold as retrieved from satellite imagery, a comparison was carried out with ground-truth data. In the Atlantic, acoustic measurements of kelp forest from 2007 surveys in Brittany at a number of sites (Abers, Héaux de Bréhat, Triagoz, Méloine, Molène, Ile de Groix - Méléder *et al*. 2010) were plotted against the photic zone as derived from the 1km resolution K_{PAR} (Figure 10). In the Mediterranean pristine *Posidonia* beds in Corsica mapped in recent years were deemed suitable for such a comparison (as opposed to more degraded continental ones, whose limits are heavily impacted by anthropological activities) (Figure 11). There is generally good agreement between the two sets of data, which seems to confirm the soundness of the threshold definition. Ongoing testing of the 1% K_{PAR} layers are also being conducted on healthy *Posidonia* meadows of the Ligurian, Tuscan and Sardinian coastal waters in order to give further statistical robustness to the proposed modelled light layer.

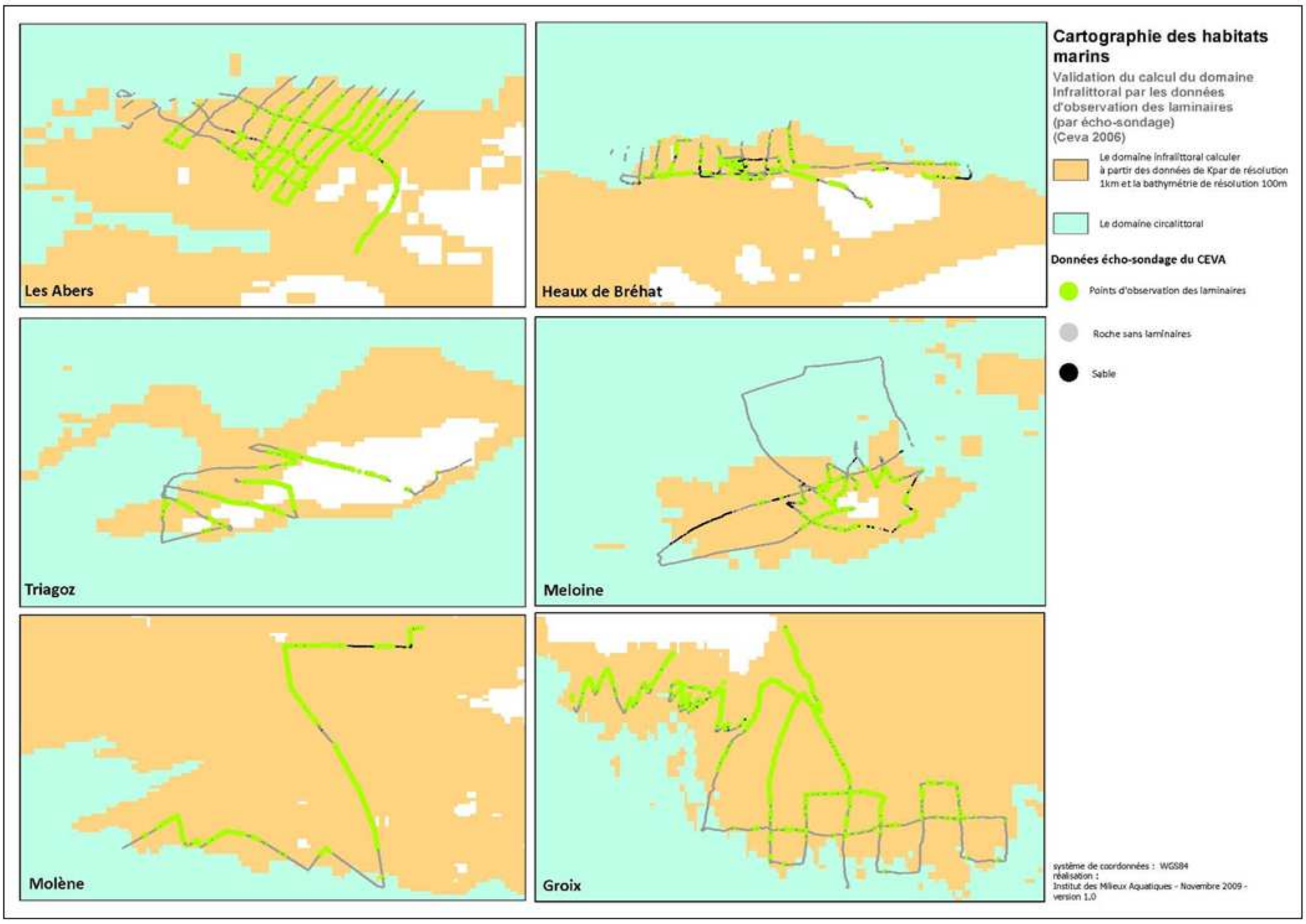

Figure 10 Echo-integration of single beam sounder data showing the presence of kelp forest (green dots, as opposed to bare rock as grey dots) overlaid on infralittoral zone (orange) from 1 km resolution Meris imager.

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

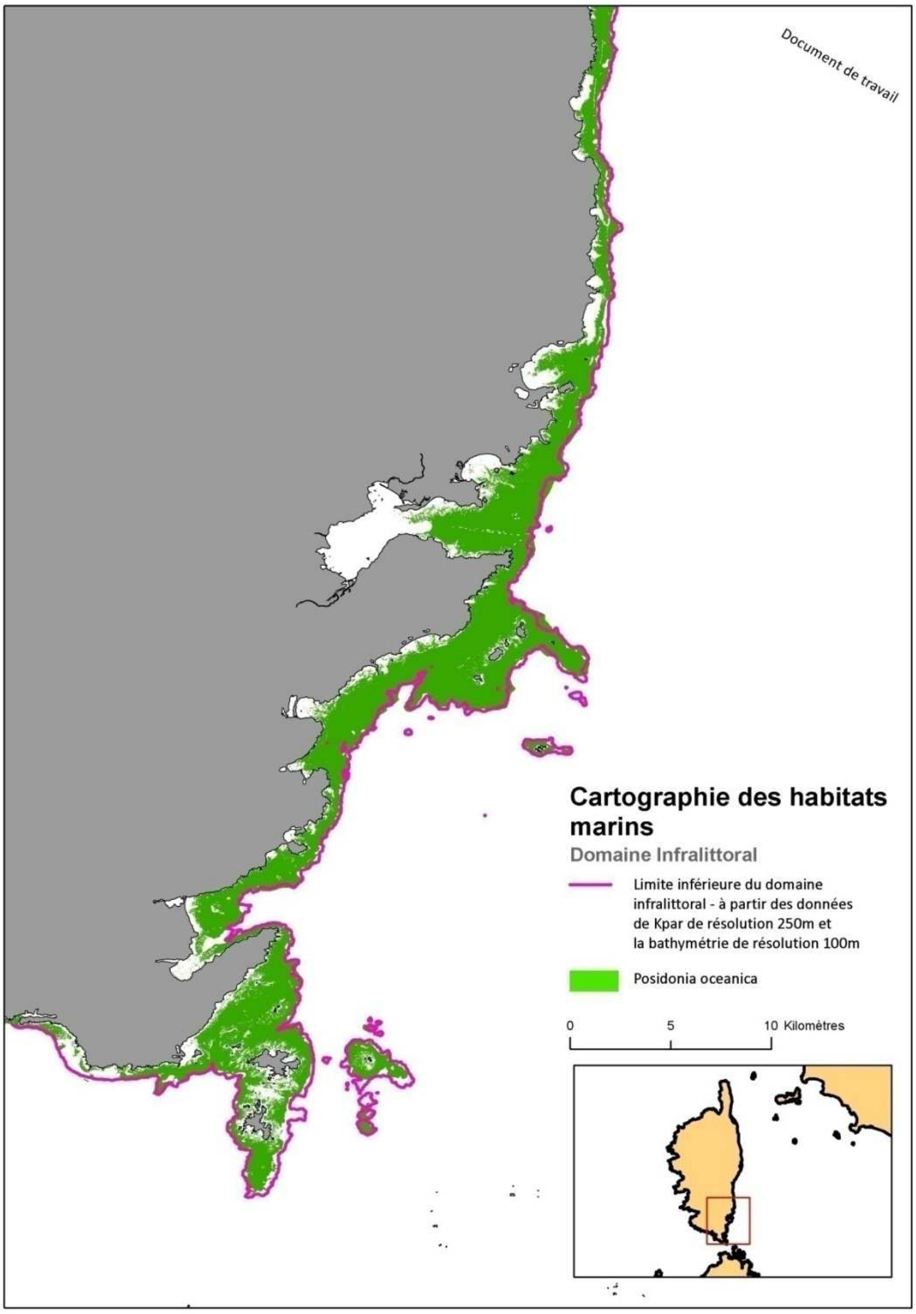

Figure 11 Comparison of 1% light contour from MERIS imagery (250m resolution) with seagrass bed outlines in Corsica.

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

Secchi depth data were obtained via the International Council for the Exploration of the Sea (ICES): Aarup's collection (Aarup 2002) covering 1902 to 1998 and additional data covering 1999 to 2008. Also the Finnish Environment Institute (SYKE) provided further data points for the years 2000 to 2008. For the interpolation of the light layer, only data from 1980 or later and covering months from which a reliable estimate of the growing season (March to October) mean could be derived were used. In total, the interpolation was based on data for 5738 locations.

At many of these locations, Secchi depths had been measured repeatedly, and monthly means were calculated. The main growing season from March to October was covered with at least one measurement per month at 277 locations. For these, "growing season means" were calculated, which were strongly correlated to the monthly means from April to October. Thus, a linear regression function was determined for each of these months (R^2 ranging from 0.77 to 0.86; Figure 12). For the locations where data were not available for the whole March to October period, but at least for one of the months between April and October, the growing season mean was estimated based on the month with the best-fitting regression line.

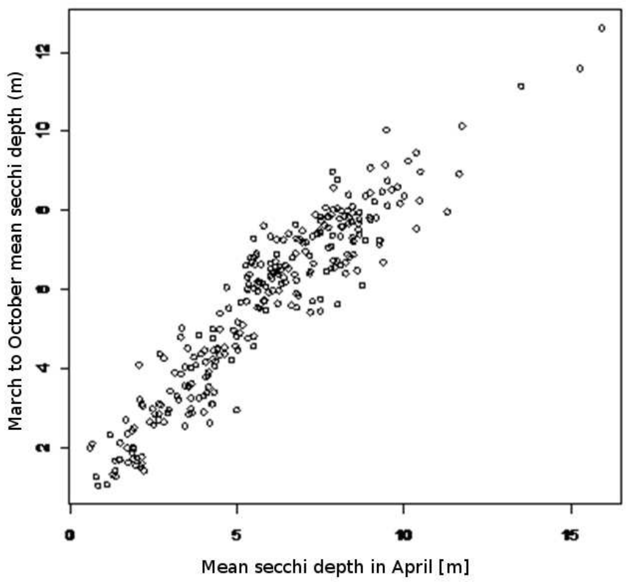

Figure 12 Scatter plot of April mean secchi depths vs. growing season (March to October) mean secchi depths, n=277.

However, this approach neglects inter-annual variability, and the density of data points was spatially very variable. To avoid pseudo-patchiness, the study area was subdivided into squares with a side length of 10km. For each square, the growing season means of all data points within were averaged and assigned to the points' mean centre. A secchi depth raster with a spatial resolution of 200m was then interpolated from the mean centres based on local trend surfaces. Cross-validation showed a mean error caused by the interpolation of below 1m and without a clear spatial pattern. Finally, a low pass filter was applied.

To derive euphotic zone depths from secchi depths, conversion factors ranging from 1.7 to 3.5 have been suggested in literature (Al-Hamdani and Reker, 2007, and references therein; Holmes 1970). For the Skagerrak and Kattegat, the secchi depths were compared to euphotic zone depths derived from Aqua-MODIS satellite imagery at 1km resolution. A factor of three gave the best fit. This is backed up by Holmes (1970). Figure 13 shows the final euphotic zone depth raster.

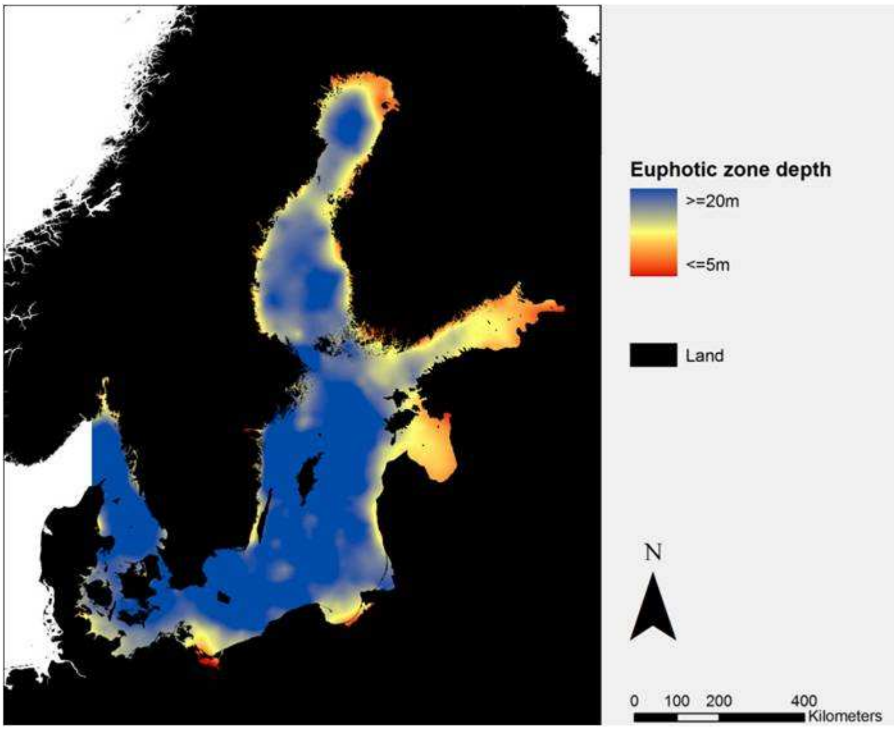

Figure 13 Euphotic zone depths for the Baltic Sea derived from secchi data.

North and Celtic

For the North and Celtic sea regions, light thresholds for the distribution of kelp had been investigated in the MESH project. The light thresholds were examined using 9km SeaWiFS light data and biotope records in UK waters from JNCC's Marine Recorder database. These biotope records are classified using the MNCR classification[21]. The MESH analysis examined the fraction of incident light reaching the seabed for both circalittoral rock biotopes (where kelp would not be present) and infralittoral rock biotopes (only where kelp was known to be present). As a result of these investigations, the light threshold for the infralittoral zone (based on the presence of kelp) was changed from 1% to 2.36%. However, since both a higher resolution light dataset (Aqua-MODIS at 4km) and an increased number of biological

[21] MNCR = Marine Nature Conservation Review classification for Britain and Ireland (version 04.05). This can be translated to EUNIS codes using the correlation table, available at:

http://www.jncc.gov.uk/pdf/EUNIS_Correlation_2006_20090924.pdf.

records are now available, the light thresholds for the infralittoral zone were re-examined. Results suggested a return to the 1% light threshold for the lower limits of kelp distribution. Differences between these results and the MESH results are attributed primarily to a higher resolution light dataset.

5.1.2. Bathymetry

Bathymetry is one of the key deliverables for EUSeaMap from the EMODNET hydrography project. The DTM being developed by the EMODNET hydrography consortium will be a minimum of a quarter minute resolution, with the latest half minute resolution GEBCO (General Bathymetric Chart of the Oceans) release incorporated for areas where sufficient data cannot be made available. The expected delivery of this dataset is the beginning of May 2010.

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 is being used.

5.2. Substrate

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

For the North Sea, Celtic Seas and Baltic Sea, tests were carried out on the relationship between biological communities (benthic samples classified to EUNIS scheme) and results of particle size analysis (PSA) at the same locations. A clear relationship was not found between substrate and biological communities at EUNIS level 4, or at progressively more detailed levels in the EUNIS hierarchy. At EUNIS level 3, there are strong relationships between the biological communities and the PSA data. Our results indicated that the classes previously used in UKSeaMap and subsequently in MESH were still the most appropriate divisions of the Folk classification (Figure 14) 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 (Figure 15). The map includes seven substrate types; hard substrates have been split into rocks and boulders (where boulder data were resolvable), with till[22] also shown as this was considered by the group a particularly relevant substrate type for Baltic and northern North Sea regions. The resulting

[22] Unsorted glacial deposits with no stratification.

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.

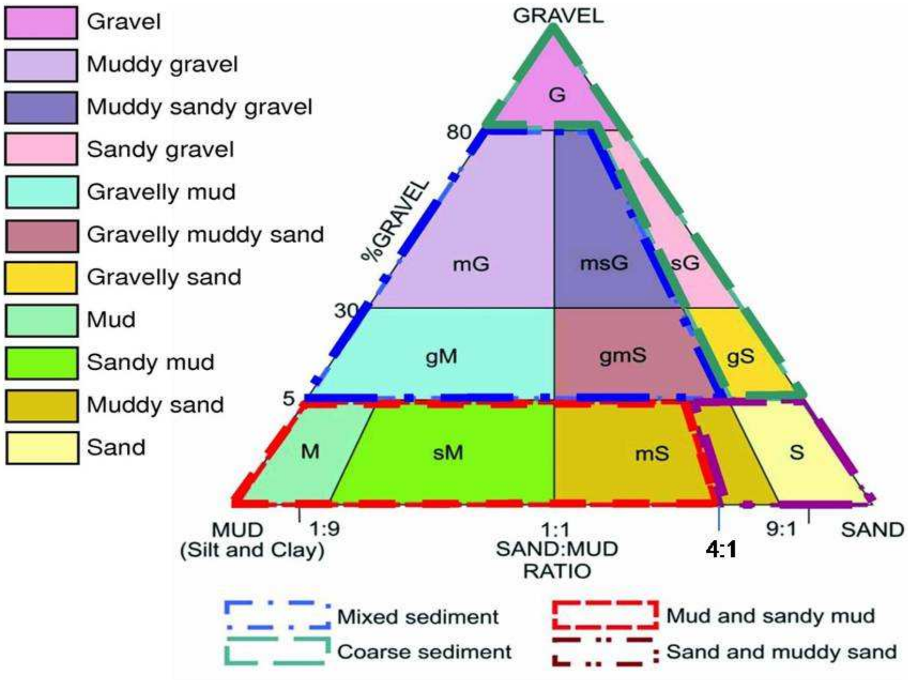

Figure 14 Folk classification of sediment types, with aggregated groups to be used in EUSeaMap project. Note the modified ratio threshold for the category Sand and muddy sand.

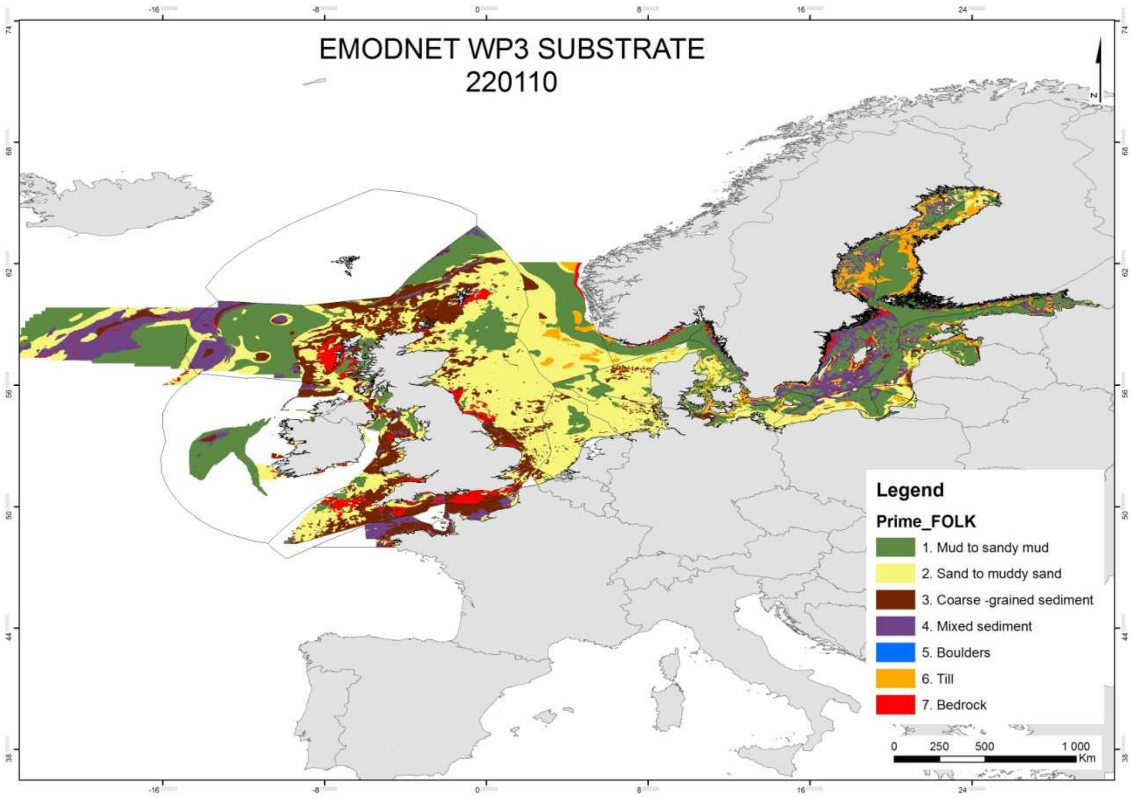

Figure 15 EMODNET geology project draft substrate map.

In UK waters, the sediment data previously available for MESH has been improved, through work to combining recent deep-sea mapping outputs (Porrit & Jacobs 2009) with important additional data for hard substrates at or near the seabed surface. These changes have been combined with an updated sediment map (DigSBS v2, unpublished) and inshore substrate data, originally compiled for the Water Framework Directive (Rogers *et al*. 2003).

The Western Mediterranean is not part of the EMODNET Geology project; instead in this region standardising sediment data are being standardised as part of EUSeaMap, to create seabed substrate information which is essential for 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) will be used.

Partners have started converting their maps into an agreed classification as follows: coarse sand and gravel, sand, muddy sand, sandy mud, mud, hard substrate. 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.

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, the EUSeaMap partners are investigating alternative variables which measure energy at the seabed independently from substrate type, such as kinetic energy and derivatives of current velocity. 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 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 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.

As part of UKSeaMap 2010, a UK seabed habitat modelling project running in parallel to EUSeaMap, energy layers have been produced for the North and Celtic seas. Energy layers are built on POL[23] 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 the DHI Spectral Wave model used to augment the coastal areas where the ProWAM model resolution was inadequate. Data and findings from UKSeaMap 2010 are made available and integrated with work under EUSeaMap. In the northern part of the western Mediterranean basin (roughly north of Balearic Islands) an energy model has been built on PREVIMER[24] wave and current models (WAVEWATCH III at resolution of 10km and MENOR model at 1km respectively). The Mediterranean model was run at a time step of three hours for a period of three years (2001 and 2007-2009). Methods used to combine the effects of waves and currents for bed shear stress are based on Soulsby (1997). Appendix III provides some theoretical considerations.

[23] Proudman Oceanographic Laboratories

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

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 coasts of Russia, Latvia, Lithuania, Germany and Denmark, using the Simplified Wave Model (SWM; Isæus 2004). These grids have been added to a set of grids earlier calculated for Sweden, Finland, Estonia and Poland, resulting in a seamless coverage of modelled wave exposure for the Baltic coasts. SWM was calculated with the software WaveImpact 1.0, as described in Isæus (2004). 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 often have not been collected, or are confidential, and therefore are not available for use in modelling. The method has been used by other authors (Bekkby *et al*. 2009; Bekkby *et al*. 2008a-c; Bekkby & Isaeus 2008; Eriksson *et al*. 2004; Florin *et al*. 2009; Sandman *et al*. 2008; Sandström *et al*. 2005; Snickars *et al*. 2010; Soldal *et al*. 2009; Sundblad *et al*. 2009).

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[25] for period 2002-2007. A total of 26 wind

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

stations were used, and the wind data were divided in sixteen compass directions, each representing an angular sector of 22.5°.

The SWM was calculated by multiplying the value of each cell in the corresponding fetch grid by the mean wind speed for each wind direction separately, resulting in sixteen new grids. Finally the mean value of all grids was calculated in an overlay analysis. The separate SWM grids (25m cell size) were integrated into three seamless descriptions of wave exposure along the coasts of Russia, Latvia, Lithuania, Germany and Denmark. In turn, these grids were integrated with earlier calculated grids for Sweden, Finland, Estonia and Poland into a seamless SWM-coverage for the Baltic coasts (Figure 16).

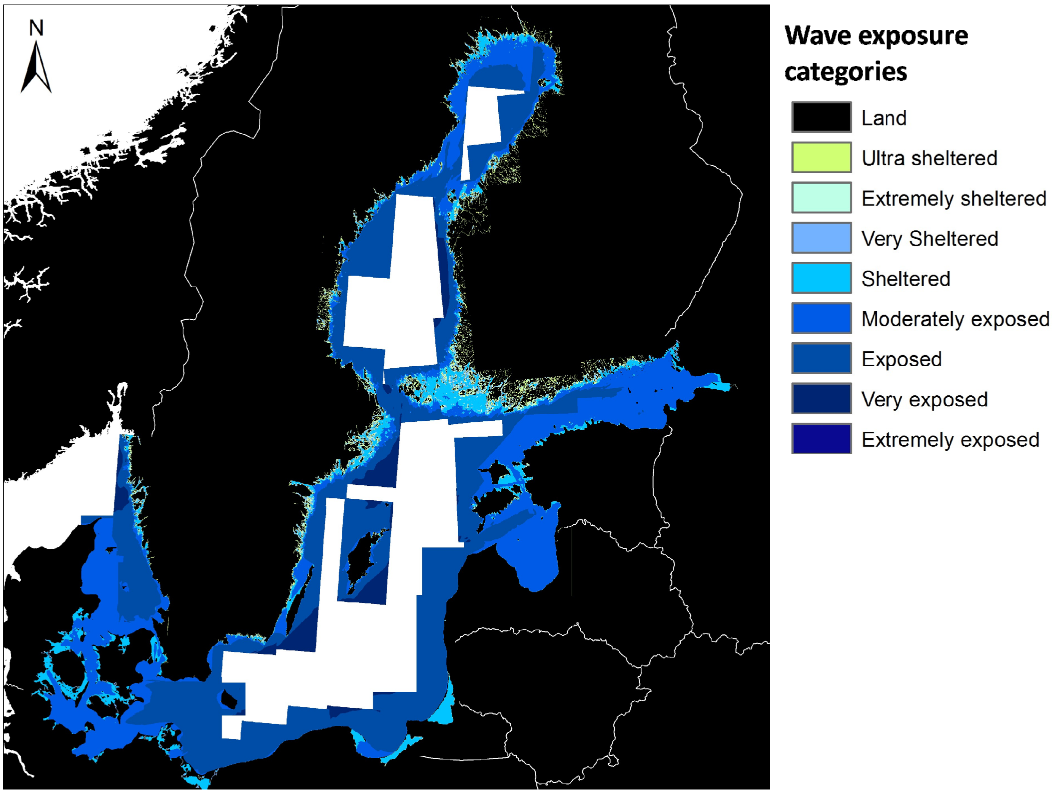

Figure 16 Results of the wave exposure model for the Baltic Sea.

5.4. Others

5.4.1. Temperature and salinity

In the Baltic, temperature and salinity regimes are of importance to the distribution of biological communities, but were considered secondary variables in the marine landscape modelling of the BALANCE project (Al-Hamdani & Reker 2007). The EUSeaMap project will investigate the development of thresholds for these variables. Therefore bottom temperature and salinity have 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 both modeled parameters has been calculated. The variance of bottom temperature and salinity is a good indicator of conditions favoured by species with relatively high tolerance.

From modeled temperature and salinity, density data layers have been developed reflecting biological conditions generated by stratification: the strength of static stratification measured by the Brunt-Väisälä frequency, which is the frequency at which a vertically displaced fluid parcel will oscillate within a statically stable environment. Based on several years of 3D hydrodynamic modelling the maximum Brunt-Väisälä frequency has been calculated for each grid point, and the exceedence of the 90% value of the Brunt-Väisälä frequency has been calculated in the bottom waters. The former parameter reflects the total stability and strength of stratification in the water column, while the latter provides an index of the rate of pycnocline[26] interference at the seabed. Both situations have potentially large influence on both the bio-productivity and biodiversity at the seabed in the Baltic Sea.

5.4.2. Ice cover

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

0-90 days of ice cover

91-150 days of ice cover

>150 days of ice cover

As a lower priority variable, it is not necessary to review the thresholds for ice cover. These categories have historically been applied by convention when presenting ice cover in the Baltic Sea. Furthermore, it is difficult to obtain sufficient raw data for analysis.

[26] An vertical zone of rapidly changing density in seawater, usually through the combined effects of temperature and salinity stratification.

6. Progress on modelling & confidence

6.1. Modelling methodology

6.1.1. General principles

Progress has centred on basic principles, with several key elements agreed and adopted by the project.

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 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 needs to be further addressed when it comes to final map drafting and filtering.

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. Such refinements will be looked into in the coming months.

6.1.2. Pre-processing data layers

Before the main model to produce potential habitat classes is run, some specific modules are necessary to compute the depth zones. Either these modules are run separately, which provides a way of checking their outputs, or they are appended to the main model for the whole process to be run in one go. Practical tests need to be made before this decision can be taken. Obviously the latter way, being more straightforward is preferable in terms of updating capability because it involves less individual operations and does not generate intermediate data files. An example of a standalone module is given in Figure 17 to compute the raster layer of the infralittoral zone. The output of this routine is a binary file coded "1" for infralittoral grid cells and "0" elsewhere.

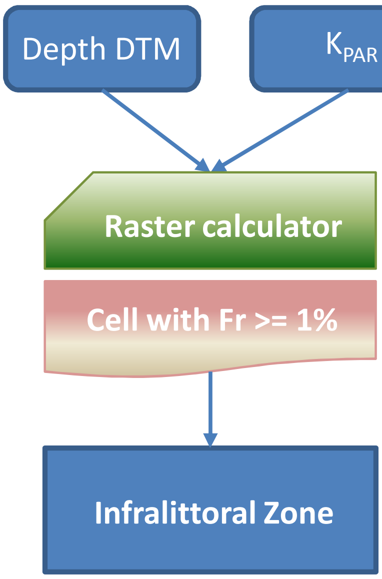

Figure 17 Module generating the infralittoral zone raster layer

Computations involving statistics such as K_{PAR}, wave base or energy are so specific that they must remain standalone and only their final output can be incorporated into the model.

6.1.3. Model testing

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

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

Figure 18 shows a test model built with the ArcGIS™ model builder. It uses a data set collated previously for marine habitat modelling in the MESH project, and so has a similar structure to that which the EUSeaMap model will have. It includes in its bottom left part the specific module for computation of the infralittoral zone as shown in Figure 17. It differs in terms of energy since only currents but no waves are used in the energy computation. The model is run in geographic coordinates. The right part represents the projection of the result into a metric coordinate system such as a Lambert azimuthal equal area projection. The model was run for an area approximately 300 x 150 grid cells, taking about 30 seconds; applying it to one of the basins such as the Mediterranean (~7000 x 2500 grid cells) could take as little as a couple of hours. The result of the computation is shown in Figure 19.

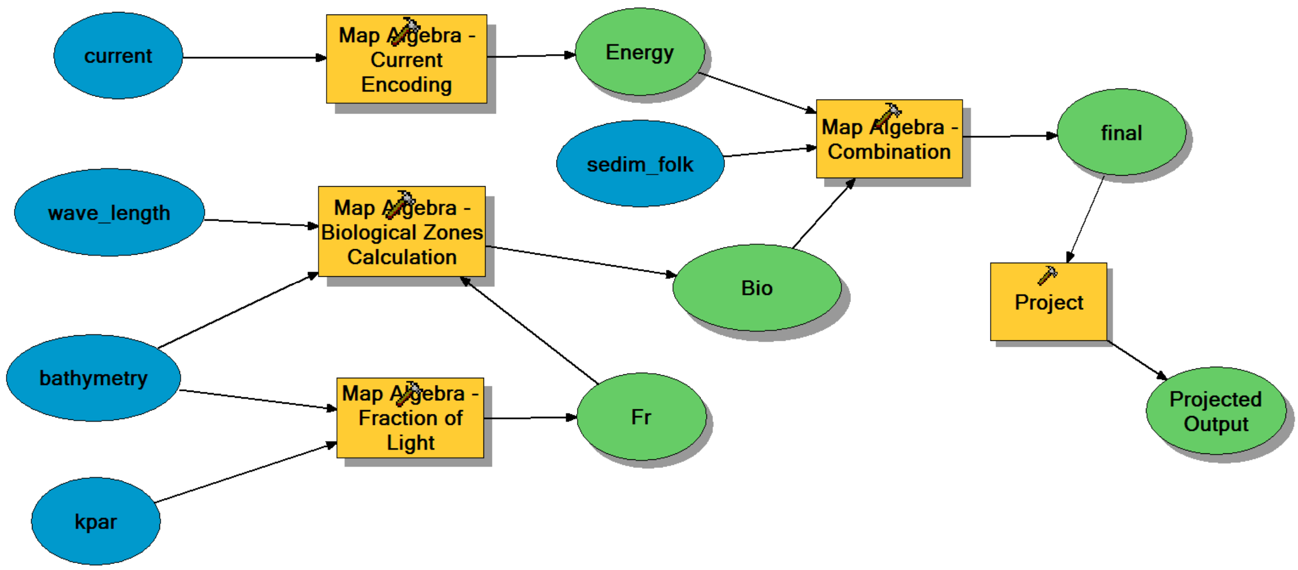

Figure 18 Model builder from ESRI® ArcGIS™ (spatial analyst), illustrating the construction of habitat map by combination of primary input layers.

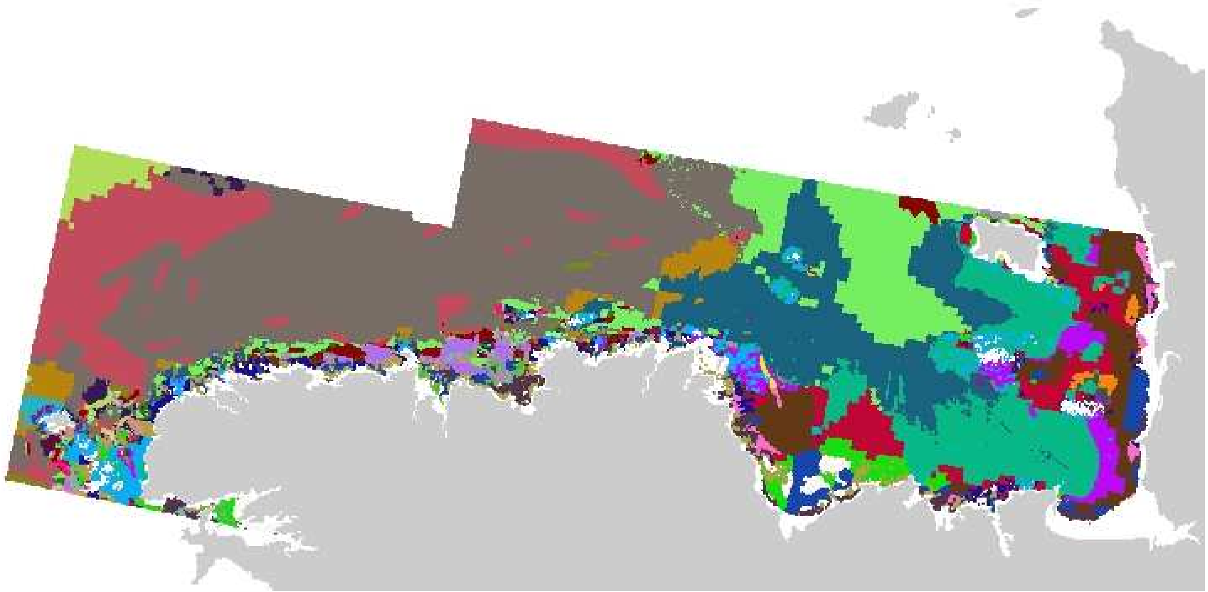

Figure 19 Result of test model run in North-Brittany

6.1.4. Priority habitats

Some habitats are recognised as remarkable or priority habitats. This is the case of some OSPAR priority habitats[27], such as seagrass or maerl beds, or other habitats such as kelp forest. In EUNIS these 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 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 habitats which will be further investigated for inclusion in the final map.

In the Mediterranean, seagrass beds (*Posidonia oceanica* and *Cymodocea nodosa*) are 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 habitat in an area (e.g. chronic exposure to environmental degradation aspects such as river run-offs, pollution, localised thermal and freshwater inputs, continuous illegal trawling/dredging activity and anchoring pressure). There is a difficulty in accommodating seagrass patches of relatively small area with respect to the coarseness of the map with a cell cize of ~6 ha. However, a key characteristic of *Posidonia oceanica* is that the species engineers the substrate, to the extent that in existing Mediterranean sediment maps *Posidonia* beds are in fact mapped as a substrate type in

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

their own right. This opens the possibility to include *Posidonia* beds as an addition substrate type, and thus preserve it through the modelling process. Mediterranean partners are now deciding whether this will be possible with existing seagrass maps, at national scales, and if these can be made available by intellectual property right owners.

On the French Atlantic coast, kelp is a habitat that has been the subject of modelling processes in recent years. Kelp coverage has been modelled based on relationships established between field data and descriptors of the same kind as those used in EUSeaMap, which made it possible to distinguish three types of infralittoral rock (kelp meadow, kelp forest and kelp absence) at a resolution of 300 metres (Méléder *et al*. 2010). It is suggested that this kelp coverage is provided as an 'overlay' to the more broad-scale modelling. There is also great opportunity to use the kelp coverage in work to assess the benefits, and drawbacks, of the EUSeaMap products.

6.2. Confidence methods

A spatial assessment of confidence in the EUSeaMap modelled habitats is considered to be a final product alongside the habitat maps themselves. It is important that 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 been exploring three methods to create confidence maps, as discussed in section 4.4 above:

1. Quantitative assessment of uncertainty of values in input data layers
2. Qualitative assessment of input data layers based on modified MESH confidence assessment
3. Quantitative assessment of the probability of conditions being suitable for a particular habitat type, based on fuzzy classifiers

It is likely that EUSeaMap will use a combination of these approaches.

Quantitative methods to assess uncertainty in the input data layers have been developed as part of a contract[28] to improve datasets available to support the implementation of the UK's Marine and Coastal Access Act[29]. Several data layers were developed that are suitable for broad scale marine mapping and are being used in work to in UK habitat modelling work. The development of these layers included significant effort in assessing the confidence associated with the layers. A quantitative measure of confidence was obtained through a

[28] Accessing and developing the required biophysical datasets and datalayers for Marine Protected Areas Network planning and wider marine spatial planning purposes. Report No. 1: Task 1C. Assessing the confidence of broad scale classification maps. Jointly funded by Department for Environment Food and Rural Affairs (Defra), Joint Nature Conservation Committee (JNCC), Countryside Council for Wales (CCW), Natural england (NE), Scottish Government, Department of Environment Northern Ireland (DOENI) and Isle of Man Government.

29 Marine and Coastal Access Act 2009 (c. 23): www.opsi.gov.uk/acts/acts2009/ukpga_20090023_en_1

statistical assessment of errors associated with all variables used to construct the input data layers (biological zone and confidence). The assessment of errors in the input variables examined 3 key areas:

1. Errors associated with the raw data measurements
2. Errors in data processing
3. Natural spatial and temporal variability

Probability layers were developed by looking at the spatial variability of errors between the modelled data and known *in situ* data. For example, one of the environmental variables assessed is wave disturbance. Wave buoy data obtained from CEFAS were used to assess the ProWAM wave model and generate probability distribution functions for wavelengths. Similarly bathymetry was assessed to produce probability distribution functions for water depths that can be applied to each grid cell. These were then intersected to calculate how likely a grid cell was to be at a depth beyond the wave base, and hence 'undisturbed': the deep circalittoral zone of EUNIS (figure 20). Such a process was carried out for all of the environmental variables contributing to the biological zone layer. These 'certainty' layers can be intersected – reflecting the process of combining environmental variables in the model – to produce an overall 'certainty' layer.

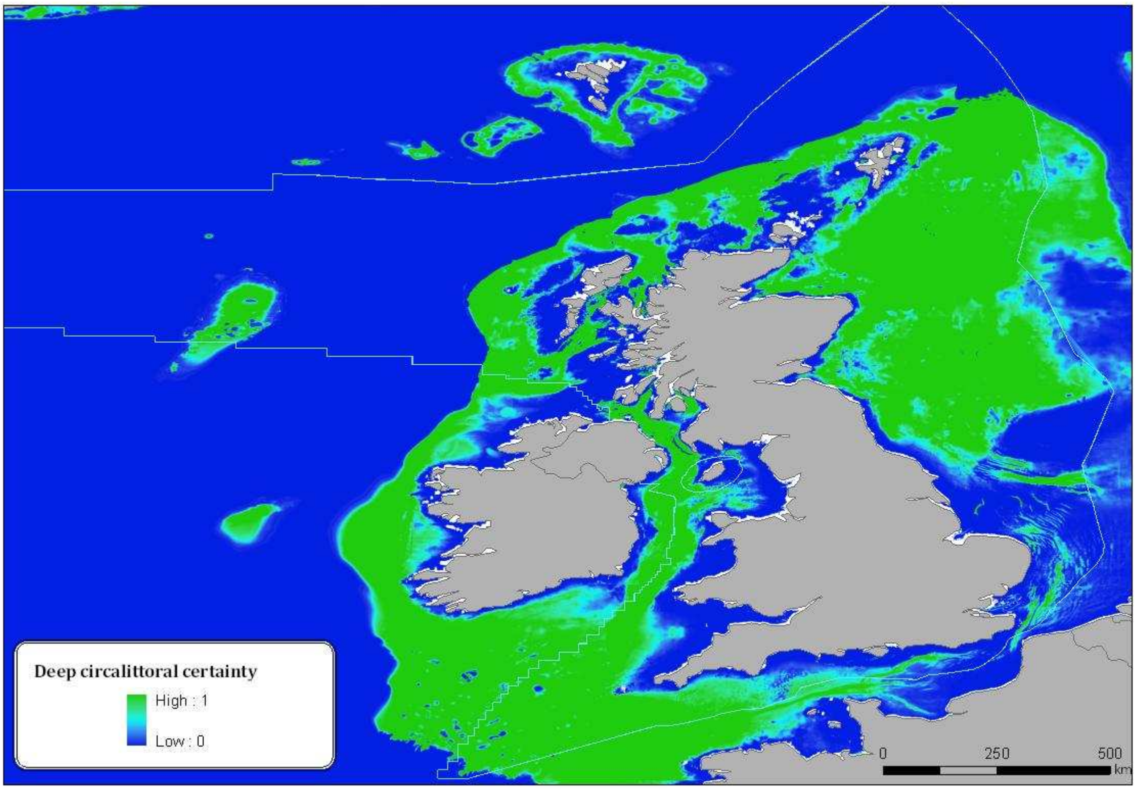

Figure 20 Example of probabilistic approach to confidence assessment. Certainty associated with classifying grid cells as being above or below the threshold for the Deep circalittoral zone (based on wave base) shown on a continuous scale from 0 to 1.

However, given the variety of data sources across the EUSeaMap basins, it was felt that computing a probability of occurrence of each input parameter for the whole EUSeaMap area, including sourcing sufficient *in situ* data required for such calculations, is beyond the scope of this contract. The partners are still investigating whether it could be a valuable approach for some input data layers. It is important that the final confidence map can show which data sets require improvements in future, and where. It is necessary to provide a regional assessment, rather than a local one; this process will provide some insight into what is needed to construct more detailed confidence assessments in the future.

The qualitative assessment approach scores each model input layer according to the quality of each constituent and computes a weighted sum of these scores. The MESH confidence assessment tool is currently being adapted to assess substrate input data, applying it at the polygon level rather than the survey level as before. The consortium has been active in liaising with other EMODNET preparatory lots. In particular the EMODNET geology project has undertaken data collation for their deliverables with confidence assessment in mind, and there has been good dialogue on how the MESH confidence assessment tool might be adapted to the substrate layer they are providing.

Fuzzy thresholds are also regarded as an important step in describing and quantifying any uncertainties underlying the classification of seabed habitats from abiotic variables, where a significant proportion of uncertainties arise as a result of insufficient knowledge of ecological thresholds in the selected regions. 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. Application of fuzzy or 'soft' classifiers to the input layers allows for controlling this potential bias (Figure 21).

Further work is underway to determine how confidence assessments can be best approached within the partnership. Metadata is important to the evaluation of data layers for confidence has already been a consideration throughout the data preparation work stream.

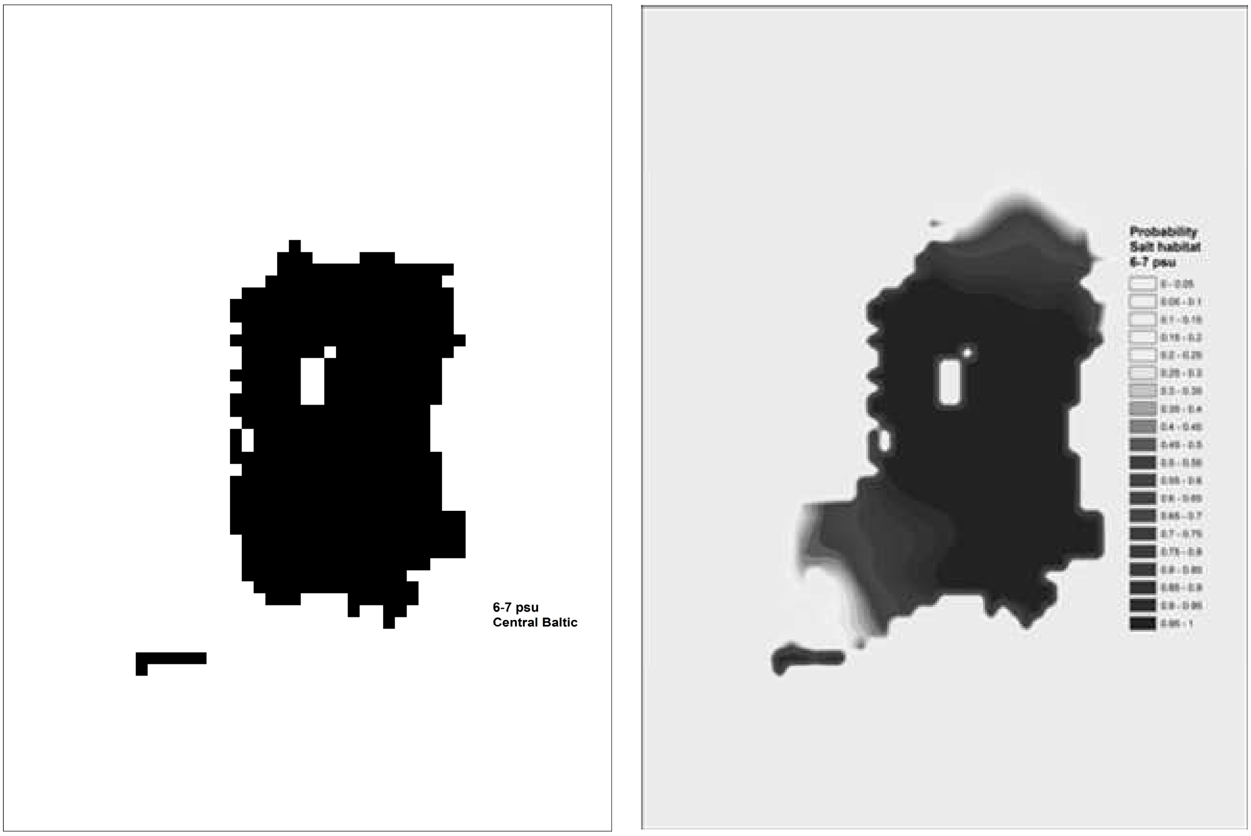

Figure 21: Example of a hard (left panel) and soft classification (right panel) of a fictitious habitat defined by a salinity range of 6-7 psu. The differences can be observed in the boundary zones of the habitat, where the soft classification results in a gradient of habitat membership.

7. Making data available

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

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

The data will conform to Open GIS Consortium[30] standards for exchange of geographical information. This is necessary for Web Mapping Services to function. The metadata will meet the ISO19115 and ISO19119 standards, and SeaDataNet common vocabularies will be used where appropriate in the metadata and data formats. A review of SeaDataNet common vocabularies[31] has been carried out to identify vocabulary already defined by SeaDataNet which is appropriate to describing modelled seabed habitat maps. Ten vocabularies have been selected which could be incorporated into the metadata of the final datasets

- SeaDataNet sea areas
- ICES ROSCOP data types
- Role definitions
- SeaDataNet Geospatial Feature Types
- SeaDataNet device categories
- SeaDataNet access Restriction Policies
- SeaDataNet geographic coordinate reference frames
- SeaDataNet agreed parameter groups
- BODC data storage units
- INSPIRE themes

A prototype webGIS has been built, using the open source software MapServer and the OpenLayers API. The modelled seabed habitat map has not been produced at this stage in

[30] www.opengeospatial.org

[31] http://seadatanet.maris2.nl/v_bodc_vocab/welcome.aspx

the project, so it is not shown on the webGIS. Instead test data layers are currently loaded on the EUSeaMap webGIS, such as the predicted EUNIS seabed habitat map created by MESH. As background layers are finalised, they will be loaded onto the webGIS.

The webGIS currently has the following functionality:

- Standard GIS functions of pan, zoom (in, out, back to previous extent, to full extent), query attributes
- Tool to select map objects
- Tool to print map to .pdf
- Individual layers downloadable
- Legend
- Mechanism for users to send comments and receive feedback by email

A login system for users to access restricted datasets is in development. Currently functionality for several different methods of access and download are being evaluated to determine which will be the most secure, and practical to maintain. When input data layers start to be loaded (in summer 2010), Web Mapping Services and metadata will be put in place; while the available layers are test data it is not appropriate to the layers through WMS. The live public launch of the webGIS is planned for September 2010, when the background and foreground data layers will be available. Meanwhile, work will focus on developing Web Mapping Services and associated metadata, as well as branding the site using the EMODNET logo and banner. Online instructions will be available for the public launch, to allow users to use the webGIS efficiently as well as to understand the EUSeaMap aims and methods used to create the modelled seabed habitat maps.

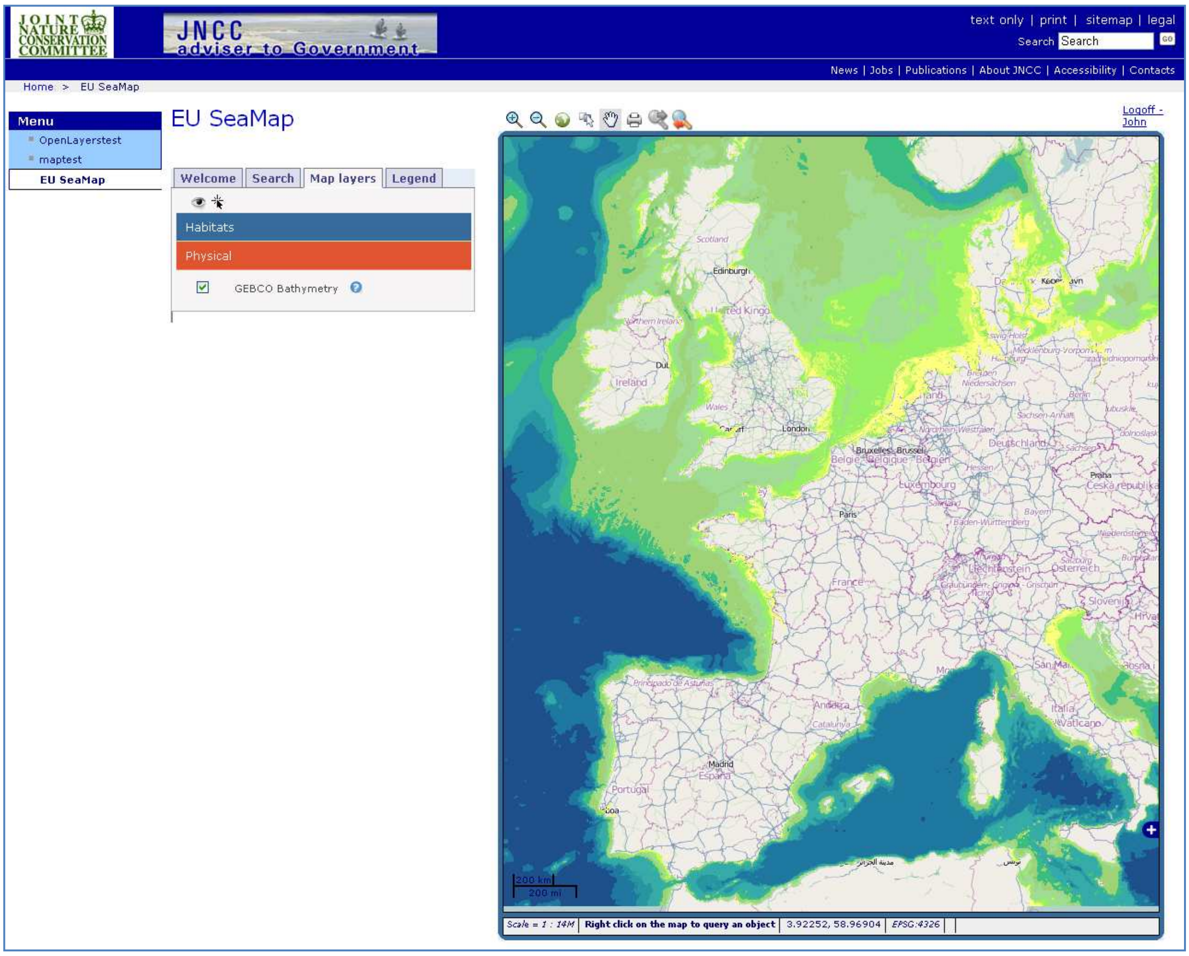

Figure 22 The EUSeaMap pilot webGIS, showing an example physical data layer, GEBCO bathymetry for the project area, and map layers tab.

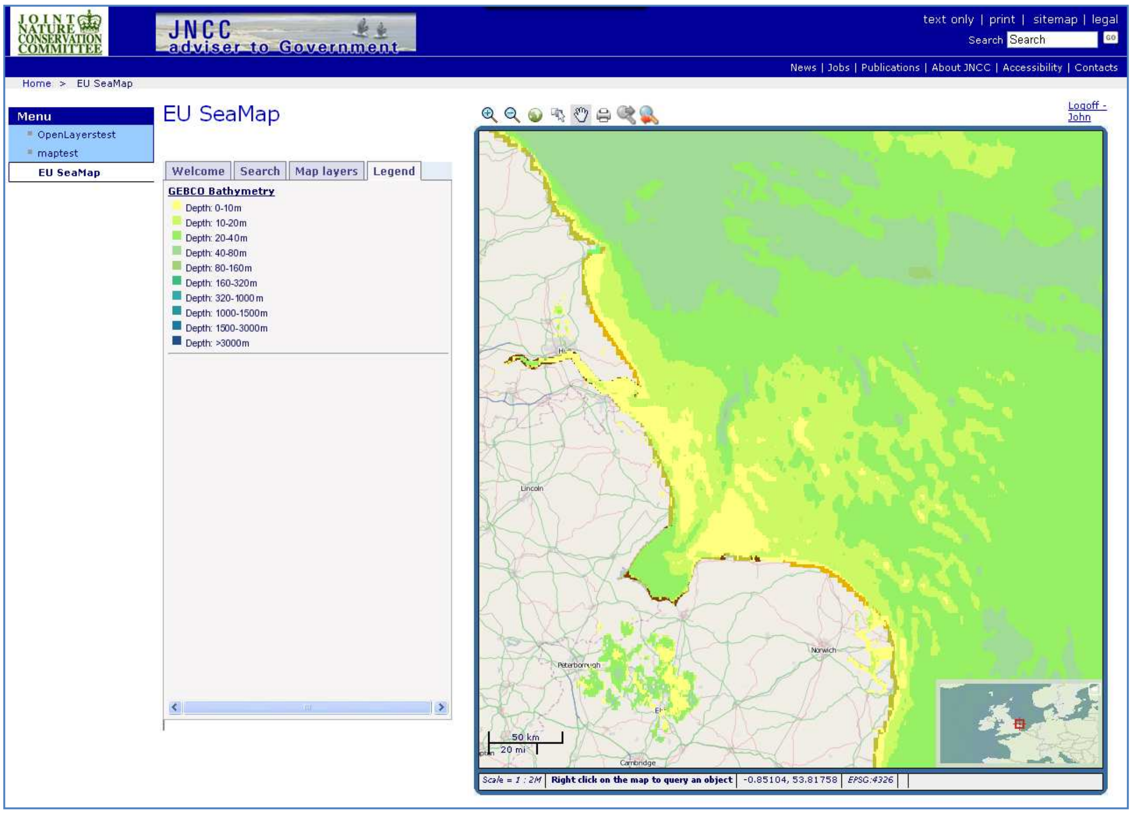

Figure 23 Zoom of GEBCO bathymetry, showing legend tab. Note location window in lower right corner.

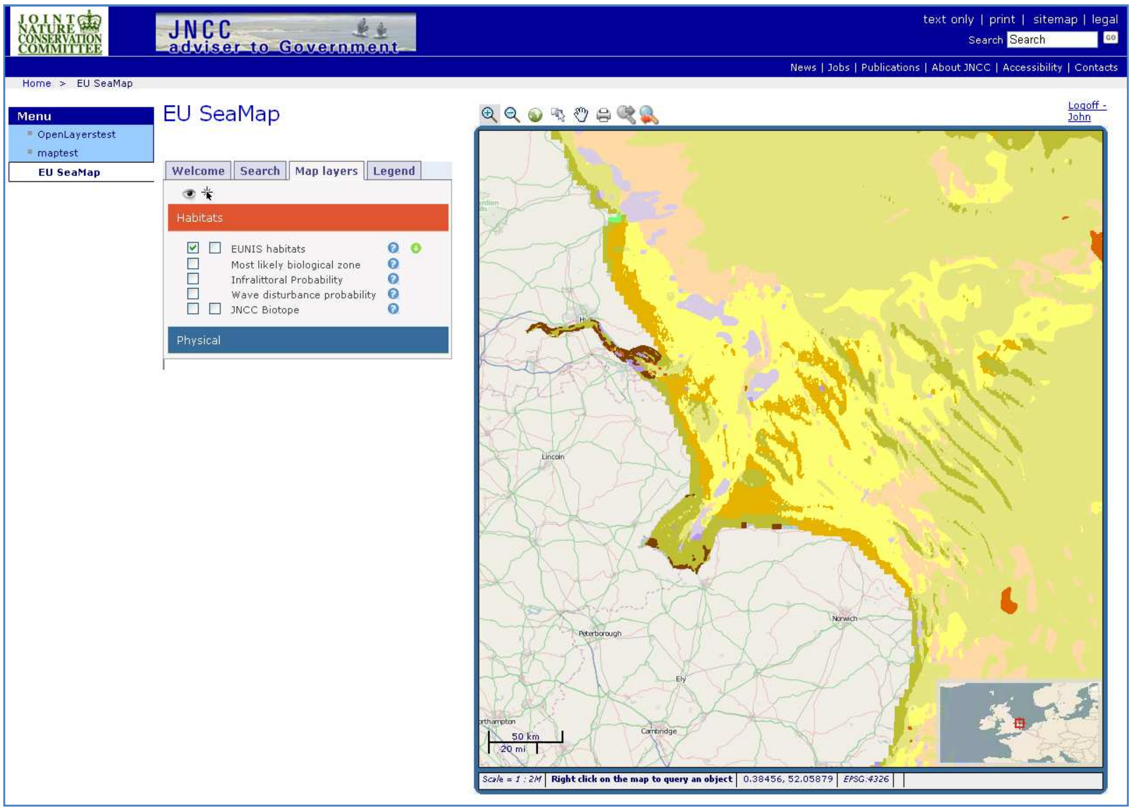

Figure 24 An example habitats data layer, the MESH modelled EUNIS habitats. Note download button next to layer name.

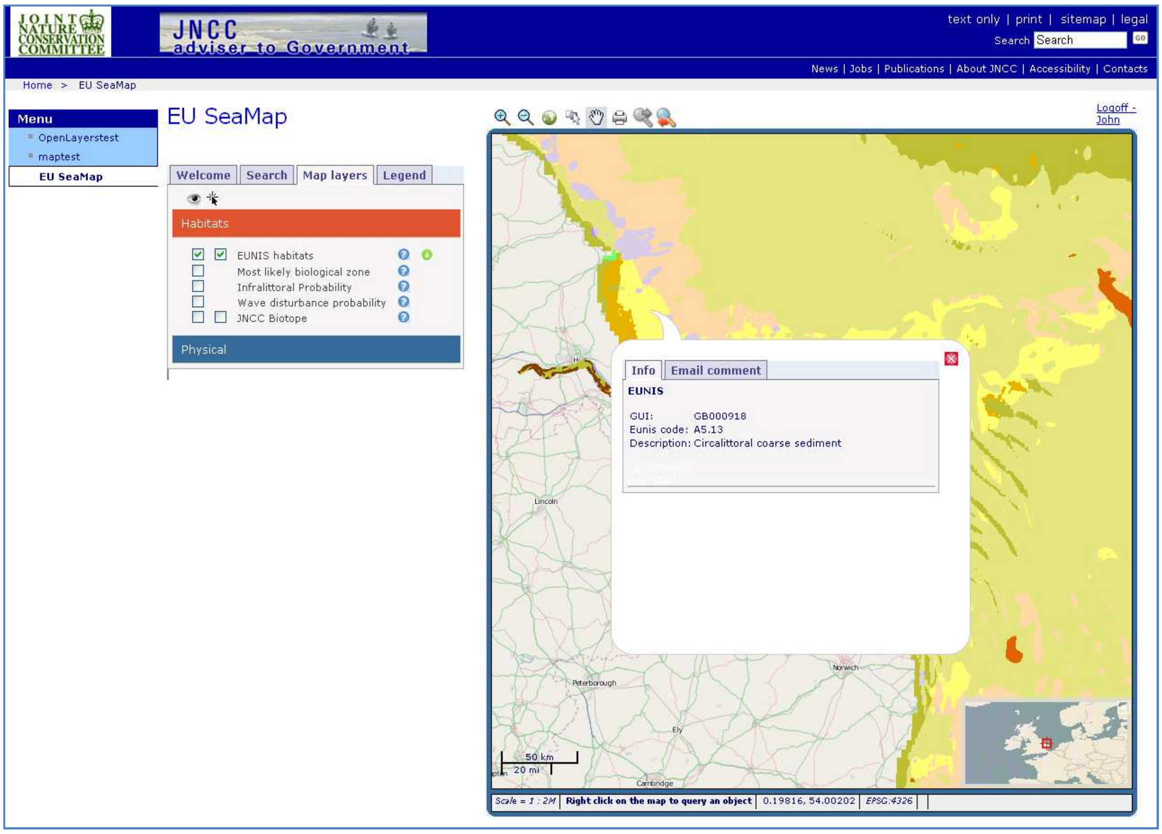

Figure 25 An example habitats data layer, the MESH modelled EUNIS habitats. The pop-up window is reached by right-clicking on the map; the info tab in this window gives information about the habitat encountered at that point. The pop-up window also has a facility to comment on the layer via email.

8. Summary

This Interim Report of EUSeaMap summarises the progress to date. Through a review of habitat modelling and mapping in European waters, a consistent methodology has been developed across the partnership, which takes account of the diverse range of habitats found in different Regions. Preparation of spatial data for a suite of environmental variables, which form the basis of the model, is nearly complete. This includes data provided by EMODNET geology and hydrography projects. The incorporation of biological data into the modelling process has begun, through the development of ecologically-relevant thresholds. A test version of the model has been successfully run for the area around Brittany, including the use of a module which will allow ready update of the maps, as new higher quality data become available in the future.

The EUSeaMap pilot webGIS has been built, through which the final habitat maps and environmental variables will be disseminated; additional functionality is in development in preparation for the live launch of the webGIS. Techniques for creating an associated confidence map have been explored, and three approaches are now under consideration following liaison with EMODNET projects. The confidence map is important to enable the variation in quality and resolution of the input data layers to be visually reflected.

The next phase of the project will finalise the thresholds to be used, and run the models to create seabed habitat maps and associated confidence maps. A series of assessments to demonstrate the applications of the maps will be carried out to highlight benefits and weaknesses of such maps, including through stakeholder feedback. An assessment of further work required to refine the maps and to extend them to other parts of European seas will be undertaken.

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Appendix I. Version Control

Build status:

Version	Date	Author	Reason/Comments	Sections
2.0	12 Feb 2010	EUSeaMap	Final amendments, release to EC	All
1.5	11 Feb 2010	EUSeaMap	Comments from partners incorporated	All
1.0	9 Jan 2010	JNCC	Comments from NC and FMcB incorporated.	All
0.1	15 Dec 2009	Andy Cameron	Initial Release	All

Amendments in this release:

Section Title	Section No.	Amendment Summary

Distribution:

Copy	Version	Issue Date	Issued To
Electronic	2.0	12 Feb 2010	Iain Shepherd, DG-Mare, European Commission
Electronic	1.4	10 Feb 2010	EUSeaMap partners
Electronic	1.0	4 Feb 2010	EUSeaMap partners

Appendix II. EUNIS habitats – Western Mediterranean

EUNIS Habitat code	EUNIS Level	EUNIS name (in parenthesis eventual notes)	Barcelona Code	Barcelona Convention name	Zone	Light	Bathymetry (or slope where appropriate)	Substrate	Energy conditions	Bottom temp
A3	2	Infralittoral rock and other hard substrata	III.6.	HARD BEDS AND ROCKS (intended as biocenosis of infralittoral algae)	INFRA	>1% surface light - *in situ* data	1-45 max	bedrock, boulders and cobbles / ROCK		
A5.23	4	Infralittoral fine sands	III.2.	Fine sands more or less muddy	INFRA	>1% surface light - *in situ* data	0-45	fine homogenous granulometry and well sorted fine sands / SAND		
A5.28	4	Infralittoral Mediterranean biocenosis of superficial muddy sands in sheltered waters	III.2.3.	Biocenosis of superficial muddy sands in sheltered waters	INFRA	>1% surface light - *in situ* data	0-45	MUDDY SAND		Eurithermic
A4.26	4	Mediterranean coralligenous communities moderately exposed to hydrodynamic action (we intend Coralligenous beds)	IV.3.1	Coralligenous	UPPER CIRCA	<1% surface light >0.01% - *in situ* data	25-100	ROCK		13-18
A5.51	4	Maerl beds (we intend Rhodoliths beds in general [also occurs in infralittoral])	VI.2.2.1; VI.2.2.2	Biocenosis of coarse sands and fine gravels under the influence of bottom currents Maërl facies (= Association with [Lithothamnion corallioides] and [Phymatolithon calcareum]) (can also be found as facies of the biocenosis of coastal detritic) and Association with rhodolithes	UPPER CIRCA	<1% surface light >0.01% - *in situ* data	25-100	coarse sands and fine gravels of organogenous origin; circalittoral coastal detritic bottoms / COARSE SAND OR GRAVEL / MUDDY SAND	High-medium constant current	

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 slope, lower depth is 100 meters	gravel, sand and shell debris / COARSE SAND OR GRAVEL / MUDDY SAND	medium constant current	
A5.38	4	Mediterranean biocoenosis of muddy detritic bottoms	IV.2.1.	Biocenosis of the muddy detritic bottom	UPPER CIRCA	<1% surface light >0.01% - *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	medium - high	

								of fine sand and mud rather than gravel / SANDY MUD		
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		
A6.3	3	Deep-sea sand	V.2.	SANDS	BATHYAL		from the shelf-break (150-250m) to the beginning of the abyssal plain	MUDDY SAND		
A6.52	4	Communities of abyssal muds	VI.1.1.	Biocenosis of abyssal muds	ABYSSAL	0	abyssal plain	MUD		
A3	2	Infralittoral rock and other hard substrata	III.6.	HARD BEDS AND ROCKS (intended as biocenosis of	INFRA	>1% surface light - *in situ* data	1-45 max	bedrock, boulders and cobbles / ROCK		

				infralittoral algae)						
A5.23	4	Infralittoral fine sands	III.2.	Fine sands more or less muddy	INFRA	>1% surface light - *in situ* data	0-45	fine homogenous granulometry and well sorted fine sands / SAND		
A5.28	4	Infralittoral Mediterranean biocenosis of superficial muddy sands in sheltered waters	III.2.3.	Biocenosis of superficial muddy sands in sheltered waters	INFRA	>1% surface light - *in situ* data	0-45	MUDDY SAND		Eurithermic
A4.26	4	Mediterranean coralligenous communities moderately exposed to hydrodynamic action (we intend Coralligenous beds)	IV.3.1	Coralligenous	UPPER CIRCA	<1% surface light >0.01% - *in situ* data	25-100	ROCK		13-18
A5.51	4	Maerl beds (we intend Rhodoliths beds in general [also occurs in infralittoral])	VI.2.2.1; VI.2.2.2	Biocenosis of coarse sands and fine gravels under the influence of bottom currents Maërl facies (= Association with [Lithothamnion corallioides] and [Phymatolithon calcareum]) (can also be found as facies of the biocenosis of coastal detritic) and Association with rhodolithes	UPPER CIRCA	<1% surface light >0.01% - *in situ* data	25-100	coarse sands and fine gravels of organogenous origin; circalittoral coastal detritic bottoms / COARSE SAND OR GRAVEL / MUDDY SAND	High-medium constant current	
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 slope, lower depth is 100 meters	gravel, sand and shell debris / COARSE SAND OR GRAVEL / MUDDY SAND	medium constant current	
A5.38	4	Mediterranean biocoenosis of muddy detritic bottoms	IV.2.1.	Biocenosis of the muddy detritic bottom	UPPER CIRCA	<1% surface light >0.01% - *in situ*	below P. oceanica until beginning of	very sandy mud or muddy sand, compact mud rich	sedimentati on slow;	

						data	continental slope	in shell debris, gravel and sand present but with constant mud predominance / SANDY MUD	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 / 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	ROCK		

							plain			
A6.51	4	Mediterranean communities of bathyal muds	V.1.1.	Biocenosis of bathyal muds	BATHYAL	0	from the shelf-break (150-250m) to the beginning of the abyssal plain	fluid to compact mud (Clayey usually compact, yellowish or bluish, sometimes a bit sandy / MUD		
A6.511	5	Facies of sandy muds with *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		
A6.3	3	Deep-sea sand	V.2.	SANDS	BATHYAL		from the shelf-break (150-250m) to the beginning of the abyssal plain	MUDDY SAND		
A6.52	4	Communities of abyssal muds	VI.1.1.	Biocenosis of abyssal muds	ABYSSAL	0	abyssal plain	MUD		

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

Appendix III. Computation of energy for the Mediterranean

I Presentation of the area

- No tides
- Permanent currents at shelf break
- Strong currents due to winds
- Waves linked with winds

=> Need to consider the interaction between currents and waves

II Data available

II-1) Currents :

- North part :
  - From **IFREMER/PREVIMER** Project
  - Resolution : ~1 km
- South :
  - From MFS
  - Resolution : ~6 km

II-2) Waves :

- From **IFREMER/PREVIMER** Project
- Resolution : ~10 km

Wave variables are bilinearly interpolated on currents grid cells.

Period: 2001 and from june 2007 to april 2009

III Method

III-1) Currents

Data available used : z (height), H0 (bathymetry), XE (sea surface height above sea level), UZ (Eastward sea water velocity), VZ (Northward sea water velocity)

- **Bed shear stress related to currents** :

$$Ub = \frac{\pi.H}{T\sinh\left(\frac{2\pi}{L}d\right)}$$

With ρ density of water

z_{layer1} height of the first layer above the bottom

u_{layer1} the associated speed

$z0$ roughness length

z0 is taken constant equal to 0.1 mm.

III-3) Waves

Data available used: Hs (significant height), fp (wave peak frequency), bathymetry, dp (wave peak direction, used for wave-current interaction).

The linear wave theory is used. Depth is large with respect to wave amplitude and wave steepness is slow, which is ill-adapted to shallow areas)

- Wavelength L :

$$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi.d}{L}\right)$$

With *g* gravity *T* period

d water depth *L* wavelength

solved using Newton-Raphson iterative method

- Bottom orbital velocity Ub :

For a monochromatic wave :

$$Ub = \frac{\pi . H}{T \sinh\left(\frac{2\pi}{L} d\right)}$$

With *T* period *d* water depth

H wave height *L* wavelength

In real sea conditions: $H=H_{rms}$, $T=T_p$ are chosen here (Whitehouse 2000)

- Bed shear stress related to waves :

$$\boxed{\tau_w = \frac{1}{2}\rho f_w Ub^2}$$

With f_w wave friction factor (calculated with Swart, 1974)

Ub bottom orbital velocity

ρ density of water

III-3) Combined waves and currents

- The interactions between waves and current are non-linear. Soulsby,1997 :

$$\tau_m = \tau_c \left[1 + 1.2 \left(\frac{\tau_w}{\tau_w + \tau_c} \right)^{3.2} \right]$$

$$\tau_{cw} = \left[\left(\tau_m + \tau_w \left| \cos \varphi \right| \right)^2 + \left(\tau_w \left| \sin \varphi \right| \right)^2 \right]^{0.5}$$

where τ_m represents the average shear stress in the current direction,

τ_{cw} is the maximum shear stress generating during a wave period,

φ is the angle between the current and wave directions.

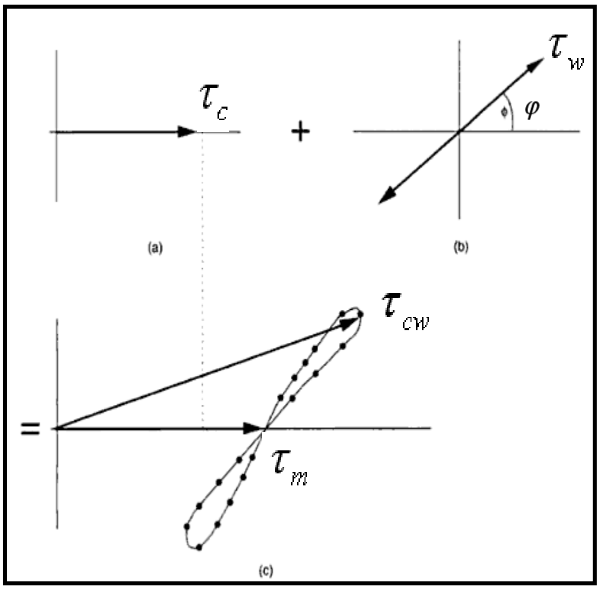

Figure A Schematic diagram of non-linear interaction of wave and current bed shear-stresses (Soulsby et al.,1993))

IV Results : percentile 90 of combined waves/currents bed stress

Computations concern 2001 and June 2007 – April 2009.

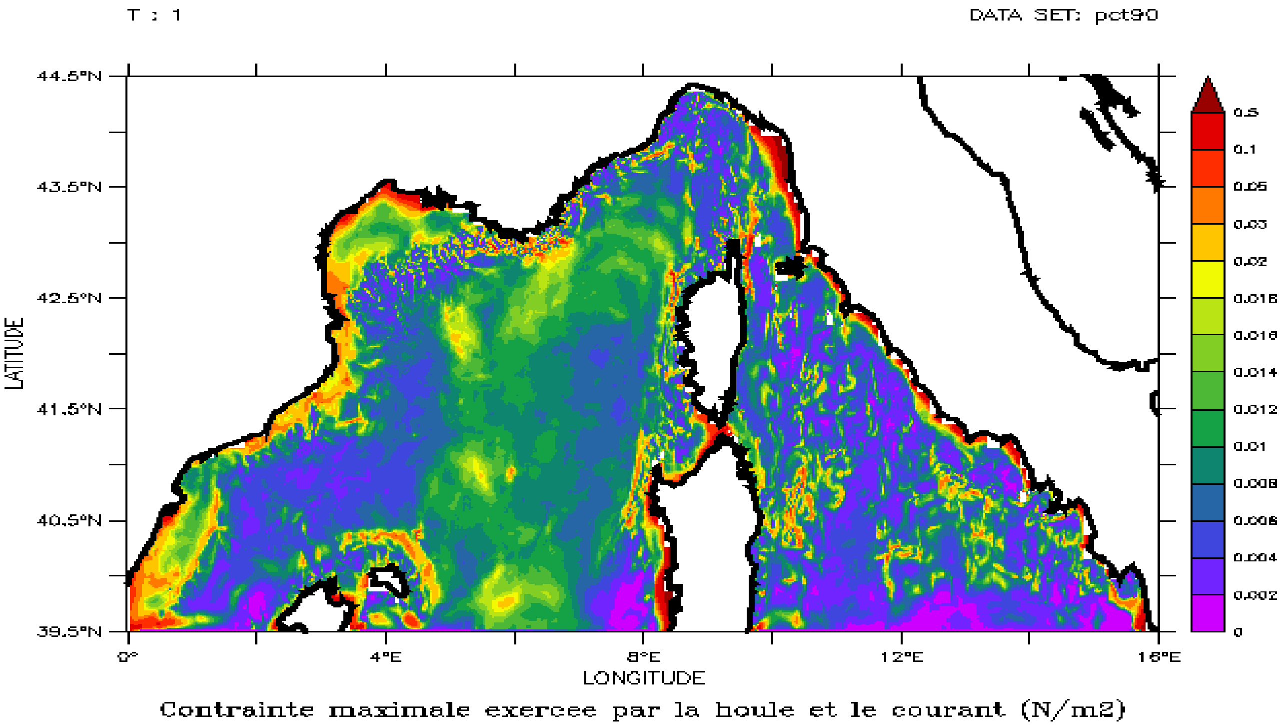

Figure B: 90 percentile of the maximum combined wave/current bed stress generated during a wave period.

Appendix IV. Publicity log

Estimation of the diffuse attenuation coefficient Kdpar using MERIS satellite reflectances for European coastal waters – paper to be presented at the 2010 European Space Agency (ESA) Living Planet Symposium in Bergen, Norway, 28 June – 2 July 2010.

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

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

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

EUSeaMap project: Modelling European seabed habitats - A focus on the western Mediterranean. Information poster to be presented at 39th CIESM (The Mediterranean Science Commission) in Venice, Italy, 10-14 May 2010.

Appendix V. Data sources summary

Region: Baltic sea						
Model Layer	**Variable**	**Data Set**	**Date**	**Source**	**Resolution/Scale**	**Owner of Intellectual Property Rights**
Substrate	Sediment	EMODNET Geology	NA	EMODNET Geology (Various)	1:1,000,000	Public access
Biological depth zone	Bathymetry	GEBCO_08 Grid	NA	The GEBCO_08 Grid, version 20090202, www.gebco.net	30 arcsecond grid	
Biological depth zone	Bathymetry	BALANCE	NA	BALANCE	Sources: 1:250,000 to 1:1,000,000 Raster: 250m grid	GEUS, GTK, SGU (joint)
Biological depth zone	Bathymetry	EMODNET Hydrography DTM	NA	EMODNET Hydrography DTM	15 arcsecond grid	Public domain
Biological depth zone	Light	Light secchi data (ICES/Aarup 2002, ICES, SYKE)	1980 - 2008	Aarup, T. (2002). Transparency of the North Sea and Baltic Sea – a Secchi depth data mining study. *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	

Region: Celtic sea

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

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

Region: North sea

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

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

Region: Western Mediterranean sea						
Model Layer	**Variable**	**Data Set**	**Date**	**Source**	**Resolution/ Scale**	**Owner of Intellectual Property Rights**
Substrate	Sediments/geology	"Geological Map of the Italian Seas"	2005-2008	CARG - Geological Cartography. sheets number 464, 465, 466, 467, 484, 485, 486 (in press).	1:25,000-1:50,000	ISPRA
Substrate	Hard bottom/ seagrasses	Atlante degli habitat marini della Liguria.	1973-2006	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	Bathymetry / Substrate	Estudio de la Plataforma Continental Española (ESPACE project)	1999-2007	Sanz, J.L.; Tello, O.; Hermida, N.; Fernández-Salas, L.M.; Pastor, E.; Rivera, J.; González, J.L.; Cubero, P.; Godoy, D.; Alcalá, C.; Contreras, D.; Torres, A.; Alfageme, V.M.; Pérez, J.I.; Redondo, B.C.; Velasco, D; González, F. Estudio de la Plataforma Continental Española. Cartographic Serie. Sheets: 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57. 33 maps	1:50,000.	Instituto Español de Oceanografía (IEO) / Secretaría General de Pesca Marítima (MAPA)
Depth Zone /Substrate	Bathymetry / Substrate (inc. Meadows)	Estudio de la Plataforma Continental Española (ESPACE project)	1999-2009	Sanz, J.L.; Tello, O.; Hermida, N.; Fernández-Salas, L.M.; Pastor, E.; Rivera, J.; González, J.L.; Cubero, P.; Godoy, D.; Alcalá, C.; Contreras, D.; Torres, A.; Alfageme, V.M.; Pérez, J.I.; Redondo, B.C.; Velasco, D; González, F. Estudio de la Plataforma Continental Española. Cartographic Serie. Sheets: 10, 11, 43, 44, 45, 46, 58, 59, 60, 61 (un published)	1:50,000.	Instituto Español de Oceanografía (IEO) / Secretaría General de Pesca Marítima (MAPA)
Depth Zone/ Substrate	Bathymetry / Substrate	Cartas de pesca del mar de Alborán. (CARPEMA project)	2002-2007	Cartas de pesca del Mar de Alborán. Sheets:MA-1, MA-2; MA-3; MA-4, MA-5; MA-6; MA-7; MA-8; MA-9; MA-10, MA-11; MA-12; MA-13	1:200,000.	Instituto Español de Oceanografía / Secretaría General de Pesca Marítima
Depth Zone	Bathymetry	Plan Hidrográfico y Oceanográfico de la Zona Económica Exclusiva Española. Baleares	1999	Instituto Hidrográfico de la Marina / Instituto Español de Oceanografía. Sheets:9, 10, 11, 13, 14, 15. 18 maps	1:200,000	Instituto Hidrográfico de la Marina
Substrate	Substrate	Mapa del Cuaternario de España	1996	Instituto Tecnológico y GeoMinero de España	1:1,000.000.	Instituto Tecnológico y GeoMinero de España

Depth Zone/ Substrate	Bathymetry/Substrate	Mapa geologico de la plataforma continental española y zonas adyacentes a 1:200.000.	1990-2004	Mapa geologico de la plataforma continental y zonas adyacentes a 1:200.000. Sheets: 32/25-FIGUERAS, 35/42-BARCELONA, 41/42-TORTOSA/TARRAGONA, 72/73-ALICANTE, 79-MURCIA, 84/85-S.ALMERÍA/GARRUCHA Y CHELLA/LOS GENOVESES	1:200,000	Instituto Tecnológico y GeoMinero de España (ITGE)
Depth Zone/ Substrate	Substrate	Mapa geomorfológico de España y del margen continental.	2005	Mapa geomorfológico de España y del margen continental.	1:1,000,000	Instituto Geológico y Minero de España (IGME)
Depth Zone/ Substrate	Bathymetry/ Substrate (inc. Meadows)	Plan de Ordenación del Litoral	1988- 2000	Cartografía para el plan de Ordenación del Litoral. Dirección General de Costas. Tramos de Valencia y Barcelona	1: 25,000	Dirección General de Costas. Ministerio de Obras Públicas
Depth Zone/ Substrate	Bathymetry/ Substrate (inc. Meadows)	Sistema de Información Geográfica del IEO. SIGFOMAR and SIDFOMAR Projects	1998-2010	Sistema de Información Geográfica del IEO. SIGFOMAR and SIDFOMAR Projects (1995-2009). Sanz, J.L.; Tello, O.; Hermida; N., Pastor, E.; Cubero, P.; López, V.; Lobato, A.	Cartographic synthesis of several confidence and scale maps incorporated to a GIS on Spanish continental margins.	Instituto Español de Oceanografía (IEO)
Depth Zone	Bathymetry	Continental margin of Cataluña. Grid		Canals, M. (Synthesis of several works). 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 Iberia). Grid	2001-2005	Comas, M. (grid unpublished). Several papers	50 m grid	IACT (Granada). CSIC
Depth Zone	Bathymetry	Morpho-Bathymetry of the Mediterranean Sea. DTM	2008	CIESM - IFREMER. Morpho-Bathymetry of the Mediterranean Sea	1:3,000,000	CIESM - IFREMER

Substrate	Substrate	IBCM-Sed		IBCM. Unconsolidate bottom surface sediments (ICBM sed). www.ngdc.noaa.gov/mgg/ibcm	1 : 1,000,000	IOC - IBCM
Substrate	Sediments/geology	Carte des formations superficielles sous-marines entre Port-Barcarès et Saint-Cyprien (Pyrénées Orientales)	1986	AUGRIS C. , MEAR Y., « Carte des formations superficielles sous-marines entre Port-Barcarès et Saint-Cyprien - Pyrénées Orientales », 1986, Ifremer, Université de Perpignan, Région Languedoc-Roussillon.	1:20 000	Ifremer, Université de Perpignan, Région Languedoc-Roussillon
Substrate	Sediments/geology	Cartographie des plates-formes sous-marines de la Corse entre 0 et 100m de profondeur - LIMA 1	2001 and 2004	GUENNOC P., PALVADEAU E., PLUQUET F., MORANDO A., VAIRON J. (2001) - LIMA, Cartographie des plates-formes sous-marines de la Corse entre 0 et 100m de profondeur, BRGM/RP-51523-FR, 53 p., 16 fig., 6 tabl., 4 pl., 9 cartes (hors texte). et PLUQUET F., GUENNOC P., GARLAN T., PALVADEAU E., (2004) - La plate-forme sous-marine de Corse : cartographie « historique » des formations superficielles à partir des levés anciens du SHOM (1884-1891), Bull. Soc. Sci. hist. nat. Corse, 606-607, 111-132.	1: 100 000	BRGM, OEC, DIREN Corse, Agence de l'Eau Rhône Méditerranée & Corse, Ifremer, SHOM
Substrate	Sediments/geology	Carte géomorphologique du précontinent languedocien	1973 and 1986	GOT H., 1973, « Etude des corrélations tectonique-sédimentation au cours de l'histoire quaternaire du 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	2007	HOLON F., DESCAMP P., 2007. CARTOGRAPHIE ET ANALYSE DES	1:5 000	Communauté d'Agglomération Nice Côte

		Antibes et Cap d'Ail		BIOCENOSES MARINES ENTRE ANTIBES ET CAP D'AIL. Contrat Communauté d'Agglomération Nice-Côte d'Azur.		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

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