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Knowledge base for growth and innovation in ocean economy: Assembly and dissemination of marine data for seabed mapping – Lot #3

EUSeaMap

A European broad-scale seabed habitat map

Final Report

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List of abbreviations and acronyms

BOLAM	Bologna Area Model, limited area model used in operational meteorological forecasts
Biozone	Also called “Depth zone”, is a area of seabed vertically homogeneous in terms of its oceanographic descriptors
BSSHM	Broad-scale seabed habitat maps
CBD	Convention on Biological Diversity
DELFT3D	3D modeling suite used to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments
DCE	Danish Centre For Environment And Energy
DTM	Digital Terrain Model
EASME	European Agency for Small and Medium Enterprise
EBSA	Ecological and Biological Significant Marine Areas
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency
ETC / BD	European Topic Center on biodiversity
ETC /ICM	European Topic Center on inland and coastal marine waters
EU	European Union
EUNIS	European Nature Information System. eunis.eea.europa.eu
EurOBIS	European Ocean Biogeographic Information System (www.eurobis.org)
FP7	7 th Framework Program for Research and Technological Development
GEBCO	General Bathymetric Chart of the Oceans. www.gebco.net
GeoEcoMar	National Institute of Marine Geology and Geoecology of Romania
GIS	Geographic Information System
HCMR	Hellenic Centre for Marine Research. Greek Project partner.
HELCOM	Baltic Marine Environment Protection Commission - Helsinki Commission
IBCM	International Bathymetric Chart of the Mediterranean. www.ngdc.noaa.gov/mgg/ibcm/
ICES	International Council for the Exploration of the Sea
IEO	Spanish institute of oceanography. Project partner.
Ifremer	French Research Institute for Exploitation of the Sea. Project coordinator.
INSPIRE	Infrastructure for Spatial Information in the European Community
INTERREG	"An initiative that aims to stimulate cooperation between regions in the European Union." Funded by the European Regional Development Fund.
ISPRA	Italian Institute for Environmental Protection and Research. Project partner.
JNCC	Joint Nature Conservation Committee – UK Project partner.
JRC	Joint Research Centre of the European Commission
KDPAR	Diffuse attenuation coefficient of the photosynthetically available radiation

LAMMA	Consortium - Environmental Modelling and Monitoring Laboratory for Sustainable Development, Italy
Mc-WAF	Mediterranean-Coastal WAve Forecasting
MESH	Mapping European Seabed Habitats
MeshAtlantic	Interreg Project 2010-2013
MODEG	Marine Observation and Data Expert Group of European Commission
MFS	Mediterranean Forecasting System
MPA	Marine protected area
MSFD	Marine Strategy Framework Directive (2008/56/EC)
NETCDF	Format for description of scientific data such as wind, current, temperature
NIVA	Norwegian Institute for Water research. Project partner.
OWF	Offshore windfarm
OSPAR	Oslo-Paris Convention for the Atlantic
QA/QC	Quality Assurance/Quality Control.
RAC/SPA	Regional Activity Centre for Specially Protected Areas
RSC	Regional Sea Convention
ROMS	Regional Ocean Modeling System
WFD	Water Framework Directive
WGMHM	ICES Working Group on Marine Habitat Mapping
WP	Work Package

Executive summary

In order to most benefit from the potential offered by the European marine basins in terms of growth and employment (Blue Growth), and to protect the marine environment, we need to know more about the seafloor. European Directives, such as the MSFD, but also the Horizon 2020 roadmap explicitly called for a multi-resolution full coverage of all European seas including bathymetry, geology and habitats.

The present work, following on a suite of past initiatives, has made a big step forward in this direction. It has first boosted the collation of existing maps from surveys by setting up a framework and a procedure to encourage people to submit their maps and data. This resulted in a more attractive EMODnet seabed habitat portal and a snowball effect with more and more people willing to join. However, collation will eventually come to an end and as new creations of seabed habitat maps are so complex and time-consuming, a cost-efficient way to meet the need for a full-coverage habitat map was found to be low-resolution maps and models to predict seafloor habitat types.

The broad-scale map referred to as EUSeaMap has been created by this project and after the first two phases it now covers all European basins from the Barents Sea to Macaronesia and to the Black Sea. By harmonising mapping procedures - based on the EUNIS classification - and fostering a common understanding among seabed mappers in Europe, EUSeaMap provides today the community with a comprehensive, free and ready-to-use map that can find applications at regional scale for management and conservation issues. Tables and maps for all basins can be found in section 3 “Results and disciussions”.

The project has played a key role in giving feedback to other EMODnet communities dealing with bathymetry, geology and biology, all essential data sources for the broad-scale map. It has also improved the understanding of the EUNIS habitat classification - with a focus on the Adriatic and the Black Sea - by better specifying transitions between classes based on benthic ground-truth data. It has fostered the development of oceanographic variables such as light, waves and currents that have a strong bearing on habitats. Finally it has also been instrumental in developing map confidence assessment methods that account for the broad spatial variation in data sources quality and for uncertain boundaries between habitat classes.

The EUSeaMap methods are repeatable and ensure that the predictive maps can continue to be improved in the future, as a result either of EUNIS enhancements or increase in resolution. From today’s 250m resolution it is likely that new deliveries of enhanced source layers due to steady progress in oceanography and geophysics will enable constant refinement of the maps over time.

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1 Introduction and rationale

1.1 Quick overview of broad-scale seabed map history

The importance of seabed habitat mapping has become increasingly apparent in recent years (Andersen et al., submitted). 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. There is a growing pressure on marine ecosystems from human activities, globally, regionally and nationally (Halpern et al., 2008). In order to make informed decisions, managers and policy makers need information (e.g. data and maps) on marine species, populations and habitats and the multiple human stressors affecting these. A critical prerequisite for decision making and informed management is the availability of information, e.g. Broad-Scale Seabed Habitat Maps (BSHM) based on full-coverage environmental data.

The concept of mapping seabed habitats using marine environmental data was originally framed by Roff and Taylor (2000) and subsequently put in practice by Roff et al. (2003) for Canadian waters. Considering that mapping benthic animal and plant communities over extensive areas (i.e. at a national, regional or even continental scale) by direct sampling is impractical due to excessive costs, the authors advocated the use of enduring and recurrent seabed environmental (i.e. geological and oceanographic) factors as proxies for benthic communities. Their mapping approach consisted of i) classifying the geological and oceanographic spatial data layers into ecologically-relevant broad categories (e.g. light penetration into 'photic' or 'aphotic'; exposure to water motion into 'exposed' or 'sheltered') based on a hierarchical classification, and ii) overlaying via GIS techniques the layers classified in order to produce a map of what they defined as benthic 'seascapes' (e.g. 'Photic-Exposed-Gravel'). This pioneering study has since inspired many initiatives worldwide (for a review, see Brown et al., 2011, or Vasquez et al., 2015).

In Europe the concept was first tested by the Joint Nature Conservation Committee (JNCC) within the framework of the Irish Sea Pilot project, which produced so-called marine landscape maps for this regional sea (Vincent et al., 2004; Golding et al., 2004). Subsequently, the JNCC extended this cartography to the entire United Kingdom seas in the UKSeaMap project (Connor et al., 2006).

On an international level, two European projects simultaneously tested and applied this approach. BALANCE (2005-2007) produced a first generation of marine landscape maps for the Baltic Sea region including the Kattegat (Al-Hamdani & Reker, 2008). MESH developed a prototype BSHM for North-West Europe, for which efforts were made to adapt the method to the marine section of the EUNIS (European Nature Information System) habitat hierarchical classification scheme version 04.05, widely used across Europe by managers and scientists (Coltman et al., 2008). This EUNIS-compliant MESH approach gave a strong impetus to initiatives of broad-scale habitat mapping across Europe. First the EUSeaMap project (2009-2012) harmonised the MESH seabed habitat maps with those of the BALANCE project, and extended the method to a new region, the western Mediterranean basin (Cameron & Askew, 2011). The MeshAtlantic project (2010-2013) then extended this cartography to four extensive areas around Ireland, the Bay of Biscay, the Iberian Peninsula and the Azores Islands (Vasquez et al., 2015). In addition, national initiatives also applied the MESH method with improved resolution; in France (Hamdi et al., 2010) and in the United Kingdom (UKSeaMap 2010, McBreen et al., 2011).

1.2 The concept: survey maps and broad-scale maps

Whilst survey methods and technologies have improved dramatically in the fields of remote sensing and ground truthing, with advances such as multi-beam echo sounding and side-scan sonar able to provide highly detailed data on the seafloor, there are still many obstacles to providing full coverage maps of the seabed through these methods alone. Data collection can be prohibitively expensive and time consuming for full coverage mapping of large areas; methods that can use existing data to its highest potential to provide good coverage over areas otherwise poor in seabed habitat data are highly desirable. Developments in Geographical Information Systems (GIS) have made it possible to generate “predictive” seabed habitat maps over wide areas with continuous coverage.

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

Further to the development of this area of work over the last decade, the Seabed Habitat lot in the second phase of EMODnet (2013-2016) built upon this progress in the formation of EUSeaMap 2016. The aim of this project was to update areas previously mapped and to undertake the mapping of areas that had not yet been covered, namely the Norwegian Sea, the Canary Islands, the Adriatic Sea, the Central and Eastern Mediterranean and the Black Sea. This complete coverage was made possible by improved inputs from the other EMODnet lots and current progress in physical predictors. The work that is presented here is an attempt at producing a comprehensive coverage of the distribution of seabed habitats across Europe along with an assessment of its confidence.

2 Materials and methods

2.1 Generic method

2.1.1 Overview

The principle of the broad-scale map is to identify physical variables that are known to influence benthic communities (predictors), to classify them by finding biologically-relevant thresholds and then to match them to EUNIS habitat types. The matching step is likely to be conclusive because the physical variables are very much drawn from those expressed in the EUNIS classification, however there may be a few cases where a combination of physical variables does not have a correspondence in EUNIS. More crucially, in places like the Black Sea where the EUNIS classification does not extend so far, biotopes defined by benthos ecologists on the basis of their biological content have not been described in terms of their parent abiotic habitats. This means the exercice remains to be done: for a given biotope, is there a unique combination of the usual abiotic variables (depth, exposure, light, etc.) that mostly prevails for this biotope?

2.1.2 Resolution and extent

The full extent of the modelled area was split into 6 separate areas (Figure 2.1).

- Arctic Seas
- Greater North Sea and Celtic Seas
- Iberia, Biscay, and Macaronesia
- Baltic Sea
- Mediterranean Sea
- Black Sea

Models were run for these areas separately to allow for the most appropriate combinations of habitat descriptors and input datasets to be used in each region. Once all the models had been run, the outputs were combined into one map.

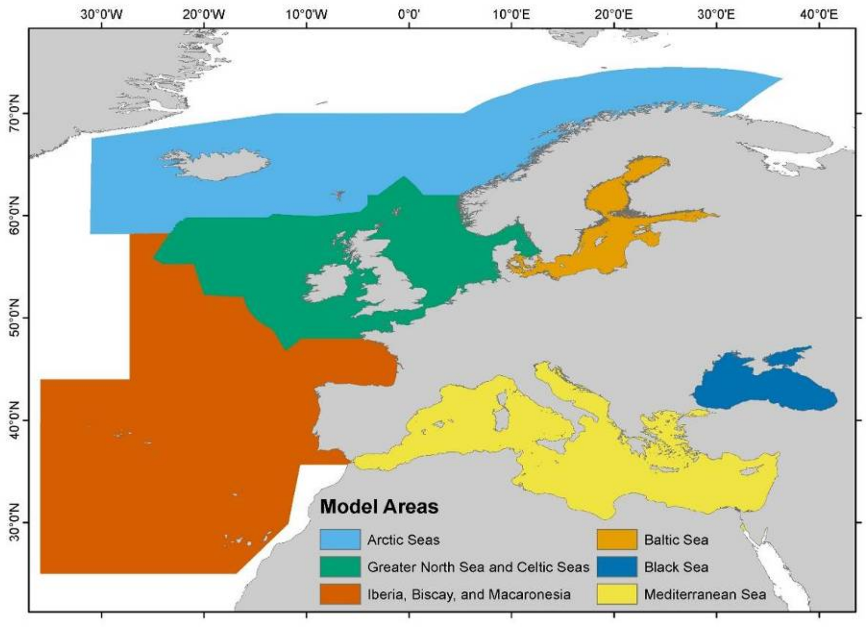


Figure 2.1: The six model areas used in phase 2 of EUSeaMap

2.2 Primary data layers

Primary data layers are single physical or chemical parameters from various types and origins that are combined to make the broad-scale map. As needed they can be combined into what is referred to as "secondary data layers", as is the case with biological zones for instance. Below is a summary table with a row for each primary data layer, listing the data source, region(s) of relevance, resolution and time-stamping. The table is followed by sub-sections containing extra information about certain noteworthy primary data layers, where relevant.

Table 2.1: Primary data layers

Name	**Origin**	**Area**	**Spatial resolution**	**Time**
Depth DTM (Whole EU)	Bathymetry lot	Whole Europe	250m	V1 Feb. 15
Depth DTM (Black Sea)	Bathymetry lot + depth lines from IO-BAS, GeoEcoMar and METU	Black sea	1 km	May 2015
Seabed substrate	Geology Lot	Whole Europe	1:1,000.000	June 2016
Seabed substrate	Geology Lot	Whole Europe (only 20% cov.)	1:250,000	June 2016
British Geological Survey DiGHardSubstrate 250k Dataset	Cooper, R., et al. 2010. User Guide for the British Geological Survey DiGHardSubstrate250k Dataset. British Geological Survey Open Report, IR/11/027.14pp.	UK continental shelf	1:250,000	2010
Semi-automated mapping of rock in the North Sea (Rock at the surface)	Downie, A.L., et al. 2016. Semiautomated mapping of rock in the North Sea. JNCC Report No. 592	North Sea	1:250,000	2016
Semi-automated mapping of rock in the English Channel and Celtic Sea (Rock at the surface)	Diesing, M. et al. 2015. Semi-automated mapping of rock in the English Channel and Celtic Sea. JNCC Report No. 569	English Channel and Celtic Sea	1:250,000	2015
Slope as a proxy for rock at the surface	See 2.2.6	Norwegian continental shelf	25 m	2012
Seabed substrate	See 2.2.3	W Mediterranean	250m	2010
Seabed substrate	See 2.2.4	W and SW Atlantic	250m	2011
Waves	ISPRA MC_WAF	Adriatic	1.2 km	2012-2015

Currents	Tessa project	Adriatic	2 km	2011-2014
Waves	ISPRA MC_WAF	All Med	4 km	2012-2015
Currents	ISPRA (from Copernicus CMEMS archives)	All Med	7 km	1999-2011
Waves	ISPRA (Kassandra project)	Black Sea	Variable	2012-2014
Currents	ISPRA (from Copernicus CMEMS archives)	Black Sea	latitude 1/16°, longitude 1/10°	1971-1984;1990-2001
Temperature	ISPRA (from Copernicus CMEMS archives)	Black Sea	latitude 1/22°, longitude 1/16°	2012-2013
Oxic / suboxic / anoxic polygons	METU (from Copernicus CMEMS archives)	Black Sea	latitude 1/22°, longitude 1/16°	2012-2013
Wave-induced kinetic energy at the seabed	French Previmer archives	French coasts	250m	2000 to 2004
Current-induced kinetic energy at the seabed	French Previmer archives	Channel and Bay of Biscaye	500m	2010 to 2015
Current speed as an indicator for current induced kinetic energy at the seabed	NORKYST800 (IMR, Albretsen et al. 2011)	Norway	800m	2008-2010
An index for wave exposure at the seabed	NIVA; wave model (Rinde et al. .2006, also described in Bekkby et al. 2015), depth adjusted (Bekkby et al. 2008)	Norway	25m	10 years average (1995-2004)
Wave-induced kinetic energy at the seabed	NOC ProWAM DHI MIKE21 Spectral wave model (from the coast out to 6km from the coast)	North Sea and Celtic Seas	12.5 km offshore 100-300m inshore	5 years (2000-2005)

Current-induced kinetic energy at the seabed	NOC POLCOMS CS20[1] NOC POLCOMS CS3 NOC POLCOMS North East Atlantic	North Sea and Celtic Seas	1.8km (2007) 10km (2007) 35km (2007)	2001
Wave exposure	Aquabiota 2010 simplified wave model (fetch-based)	Baltic Sea	25m	2002-2007
Significant wave height	DHI MIKE21 Spectral Wave Model	Baltic Sea	5.5 km	2007-2009
Wave-induced kinetic energy at the seabed	Ifremer, IOWAGA project hindcast archives (Roland and Ardhuin, 2014), WAVEWATCH III™ model (Tolman, 2009)	Bay of Biscay, inc. northern Spain and southern Irish sea	300 m inshore, 3 km offshore	5 years
Wave-induced kinetic energy at the seabed	Maretec, WAVEWATCH III™ model (Tolman, 2009)	Iberian peninsula	4 km	3 years
Wave-induced kinetic energy at the seabed	University of the Azores, WAVEWATCH III™ model (Tolman, 2009)	Azores	4 km	3 years
Current-induced kinetic energy at the seabed	Maretec, MOHID-PCOMS model archives (Mateus et al., 2012)	Iberian peninsula and northern Spain	4 km	3 years
Current-induced kinetic energy at the seabed	University of the Azores, MOHID-PCOMS model archives	Azores	4 km	3 years
Monthly, inter-annual and climatological means of Kd(PAR)	MERIS FR orbits archives	Whole Europe	250m	2005 to 2009
Monthly, inter-annual and climatological means of atmos. PAR (photosynthetically available radiation)	MERIS RR orbits archives	Whole Europe	4 km	2005 to 2009
Secchi disk measurements	METU	Black Sea		

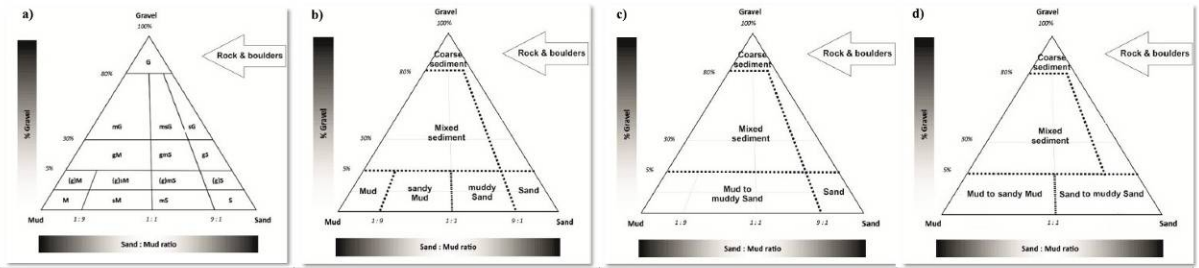
1 Run 11 was used.

Salinity and halocline	DHI MIKE3	Baltic Sea	5.5 km	2006-2008

2.2.1 Substrate

The great number of sediment classification systems used in seabed mapping in Europe have been harmonised by the EMODnet Geology Lot into a shared EMODnet schema. The harmonisation has included evaluation of the different classification schemes used in each country, classification or translation of the national data into the shared EMODnet classification system and compilation of maps into a sea-bed substrate map of European sea areas.

It was decided to follow the Folk (1954) sediment classification to include all 15 soft substrate classes and also data on rock & boulders if possible. As it could not be expected to include these 16 classes from all European seas, a hierarchy of Folk classifications (Fig. 2.2) was created with 16, 7 and 5 classes. The 7 class system (figure 2.2.b) was needed in the Mediterranean EUNIS habitats to express the variety of substrates describing Barcelona habitats along the mud-sand line. The 5 class system is almost the same as in the ur-EMODnet (Stevenson et al. 2011, 2012, Cameron and Askew 2011) with the exception that the cut-off between “Mud to muddy sand” and “Sand” has been changed from 4:1 to 9:1 to support the combination from 16 classes to 5 sediment classes of EUNIS Level 3 (Fig. 2.2 c) in in all regions, except the Mediterranean and the Black Sea, where the cut off was set to 1:1 (see Figure 2.2 d) .



Folk, 16 classes	Folk, 7 classes	EUNIS, L3 classes	EUNIS, L3 classes (Mediterranean & Black Seas)
5. Rock & Boulders	5. Rock & Boulders	5. Rock & Boulders	5. Rock & Boulders
4.4.1 muddy sandy Gravel	4. Mixed sediment	4. Mixed sediment	4. Mixed sediment
4.3.1 gravelly muddy Sand			
4.2.1 muddy Gravel			
4.1.1 gravelly Mud			
3.3.1 Gravel	3. Coarse sediment	3. Coarse sediment	3. Coarse sediment
3.2.1 sandy Gravel			
3.1.1 gravelly Sand			
2.1.2 (gravelly) Sand	2. Sand	2. Sand	2. Sand to muddy Sand
2.1.1 Sand			
1.3.2 (gravelly) muddy Sand	1.3 muddy Sand	1. Mud to muddy Sand	
1.3.1 muddy Sand			
1.2.2 (gravelly) sandy Mud	1.2 sandy Mud		1. Mud to sandy Mud
1.2.1 sandy Mud			
1.1.2 (gravelly) Mud	1.1 Mud		
1.1.1 Mud			

Figure 2.2: Three-tiered sediment classification provided by the EMODnet Geology Lot and used to make the broad-scale map (Triangles in a, b and c). Triangle in c) was used to map EUNIS level 3 substrate classes in the Atlantic, Arctic and Baltic Seas. Triangle in d) was used in the Mediterranean and Black Sea (Diagram modified from EMODnet Geology).

2.2.2 Integrated substrate features - Mediterranean seagrass beds

The EMODNET substrate layer used to model seabed habitats in the Mediterranean Sea was integrated with specific cartographic maps and point data referring to *Posidonia oceanica* meadows, *Cymodocea nodosa* beds and hard bottoms. The polygon layer was integrated in the final modelled map whereas the point layer was superimposed into the model in order to visualise the presence of these geomorphological features of conservation interest in cases where the broad scale nature of the model would not have otherwise allowed their representation. Polygon data referring to the above mentioned habitats was rasterized into the 250m pixel resolution whenever the polygon size covered the majority of the pixel area. Original habitat polygons that did not have a sufficient surface area extension to allow their inclusion in the rasterization process were treated as follows: all the polygon features lying farther than 1 km from the rasterized additional substrate layer were selected, centroids of these polygons were extracted and only those points distant more than 100 meters from each other were retained. Georeferenced point data obtained from scientific and grey literature indicating the presence of *Posidonia oceanica* in a specific region were also integrated into the point data layer. Table 13.1 in the last Appendix summarises the different cartographic data sources and bibliographic data that were considered to construct the integrative substrate layers into the modelled map.

2.2.3 Integrated substrate features – EuSeaMap 1

As part of the ur-EMODnet seabed habitats lot (hereby referenced to as EUSeaMap 1) a seabed substrate layer had to be produced for the western Mediterreanean because this area was not covered by the ur-EMODnet Geology lot. For the phase 2 we used again that layer in lieu of that produced by the EMODnet Geology lot, except where the polygons provided by the EMODnet Geology lot were at finer scale than those of the EUSeaMap1 layer, i.e. along the western Italian coast.

2.2.4 Integrated substrate features – MeshAtlantic

In the area covered by the MeshAtlantic project (Iberia, Biscay and Macaronesia, see Vasquez et al, 2015) the substrate layer provided by this project was used instead of the layer produced as part of the EMODnet Geology lot because in some places it either had a more extensive spatial coverage (e.g. in the Azores deep sea) or was at finer scale (e.g. along the French coast of the Bay of Biscay).

2.2.5 Integrated substrate features – Off Bulgaria

Off Bulgaria IO-BAS provided a recent finescale map of seabed substrate in place of the polygons provided by EMODnet Geology.

2.2.6 Integrated substrate features – Proxy for rock in Norway

Substrate data availability along the Norwegian coast is very patchy. Steep slopes are most commonly associated with large boulders and bedrock, so slope of the seabed was used as proxy for rock substrate. The high resolution (25m) bathymetry dataset by the Norwegian Hydrographic Service (produced through the National Program for Mapping Biodiversity – Coast) was used to derived a slope layer. Slopes above 10 degrees were assumed likely to be rock, as this assumption is also made in the Norwegian National Program for Mapping Biodiversity.

The assumption that rock corresponds to sleep slopes is a generalization and might not be applicable to all areas: for example glacial deposits of large boulders can appear flat when a high resolution bathymetry model is used. The confidence assessment (low confidence for the whole layer) reflects this (see Confidence appendix). However this is the best proxy that could be applied to the whole of Norway.

2.3 Making secondary data layers

Secondary data layers form the inputs to the EUNIS habitat model. In the case of the primary data layer “seabed substratum”, there is no need of an intermediate layer so the substratum class is directly tapped into the model as such. It would be the same for either salinity or oxygen where simple numerical thresholds define classes such as “low salinity” or “anoxic” which are explicit qualifiers of some EUNIS classes.

However, for the other two descriptors “biological zone” and “energy at the seabed”, specific computations involving several primary layers are necessary to arrive at significant secondary layers taking part in the model. For the former, it may be based on light energy associated with depth in the case of the identification of the infralittoral zone, or in some cases on manual delineation of topography based on depth, which is the case for upper bathyal zone delineation in some areas of the Mediterranean. To assess energy at the seabed both currents and wave climate data are associated in a simple boolean formula producing three grades of exposure.

2.4 Areas masked from the general model – River plume areas

The EUSeaMap general rules used to model the infralittoral/circalittoral boundary and habitats in each regional sea do not always work as appropriately in areas which are under the influence of high fine sediment riverine input. For this reason, such areas, hereafter referred to as river plume areas, were delimited using abiotic parameters or simply manually drawn, where abiotic parameter data did not allow to define their extent.

In the western Adriatic Sea the area influenced by the Po river plume and the smaller adjacent rivers to the south of it was delimited by considering the average surface salinity values observed in the northern part of the basin and wave energy at the seabed in the southern part of the basin, respectively 37.93 PSU and 468 $N.m^{-2}$ average energy value observed in correspondence to the maximum depth known to be affected by energy. See Fig. 2.4.1 for mask extent and section 9.1 in thresholds appendix for details on the methodology used to define the mask boundary.

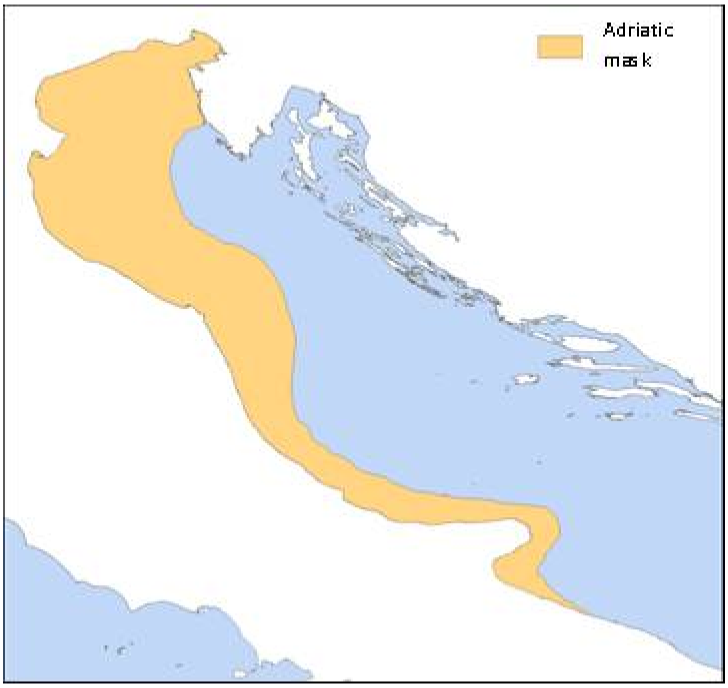


Figure 2.4.1 Adriatic river plume mask

The closed bays and very sheltered waters of the Thessaloniki gulf and bay, the Maliakos gulf, and Geras gulf in the Aegean Sea (see Fig. 2.4.2) were manually delimited on the basis of ground truth data so as to extend the masked areas to all the shallow coastal waters where the circalittoral terrigenous mud communities are present.

Figure 2.4.2: Aegean and Thessaloniki masks

The masked river plume areas influenced by the Dnieper-Bug and Danube rivers are located respectively in the northwestern Ukrainian and Romanian coasts. Initial attempts to identify the plume boundary extent through the intersection of the 15 PSU isohaline and muddy seabed were not successful. The extent of these areas (Fig. 2.4.3) was therefore manually drawn based on the presence points of engineering assemblages with ecological traits typical of the specific terrigenous habitats in this area (preference for rich nutrient areas and muddy sediments, tolerance to hypoxia). Community ground truth data for Melinna palmata - Mya arenaria - Anadara kagoshimensis and Alitta succinea was selected on the basis of species abundance biomass values (i.e. abundance of polychaetes higher than 400 individuals.m^{-2} and of molluscs higher than 25 individuals.m^{-2}).

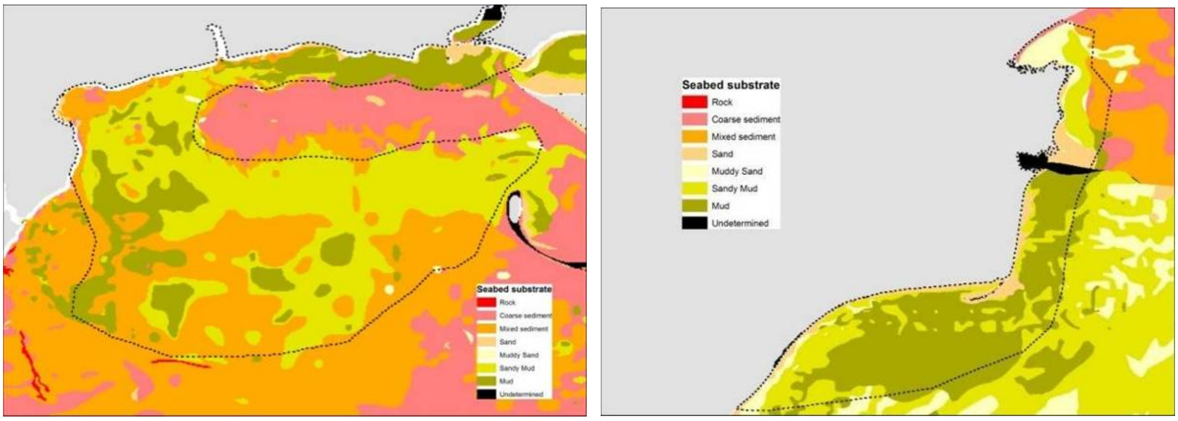


Figure 2.4.3: Left: Dnieper-Bug river plume area and right: Danube river plume area and distribution of substrate classes

2.5 Modelling habitat descriptor classes and setting boundaries

2.5.1 Rationale

Past broad-scale habitat mapping initiatives mostly used methods that delineate patterns in physical data with little to no integration of ground truth data (e.g. Roff et al, 2003; Harris et al, 2008). Other studies (e.g. Cameron and Askew, 2011; Vasquez et al, 2015) set the boundaries between the broad habitat descriptor classes that are considered in the marine section of EUNIS (e.g. 'infralittoral', 'high energy') by using observation data of the communities that occur in those habitat descriptor classes. In the EUSeaMap Project a workpackage was fully dedicated to investigating approaches to using ground-truthing data for broad-scale mapping.

The objective of this work package was to develop a method that would not only allow for the classification of physical data into discrete habitat descriptor classes, but would also provide for any pixel the probability of occurrence of those habitat descriptor classes, a measure that would be used at a later stage as an input for confidence assessment (see section 2.7). The idea was originally to work out a unique statistically sound method that could be used whatever the considered basin or habitat descriptor class. Unfortunately, this objective rapidly turned out to be unrealistic due to:

- high variability of the physical data in spatial coverage, type and quality. For example, the spatially comprehensive wave energy dataset compiled as part of the Project is an amalgamation of multiple data sets using different wave modeling techniques (e.g. Wavewatch III in France, fetch-dependent wave exposure index in Norway) of variable quality (e.g. spatial resolution ranging from 300m along UK and French coasts to 4km in Iberian Peninsula waters).
- high variability of the biological data in type. For example when it comes to the infralittoral/circalittoral boundary in the Atlantic the UK Marine Recorder provided point presence of communities indicator of either the infralittoral or the circalittoral, while in the Mediterranean Sea the available data were spatial distribution of Posidonia *oceanica*, hence polygons.
- no ground truth data available for some boundaries such as those between the Atlantic deep biological zones.

In the following we describe all the approaches that were employed. An optimal approach was worked out that required as input sample data presence/absence observation points of benthic communities (2.5.2). A second best option approach had to be developed for situations where ground truth data was not available as points but as polygons, or no ground truth data were available (2.5.3). We eventually shortly explain the method that was used for boundaries that are defined as slope changes (2.5.4) and what had to be done in the special case of the infralittoral and circalittoral biological zones inside river plumes (2.5.5).

2.5.2 Optimal approach: fitting a logistic regression model with sample point data

Within coastal marine ecosystems spatial distribution models have been used successfully to derive probabilistic distribution maps for foundation habitats such as kelp forests (e.g., Gorman et al., 2013; Bekkby et al., 2009). Typically, environmental predictor variables and presence/absence observation points are used to fit a logistic regression model.

We developed a method which employs that approach for the prediction of the broad habitat descriptor classes that are considered in the marine section of EUNIS. Each habitat descriptor class for which were available point data of observed biology were modelled by fitting a GLM (Generalised Linear Model) using the unique environmental variable that explains the occurence of the habitat descriptor class (e.g. variable 'seabed wave energy' for class 'deep circalitttoral' because this habitat descriptor class is defined as where the bottom is no longer disturbed by wave action).

The GLM is fitted with presence/absence sample point data. Presence data are observed occurrences of species/communities that occur specifically in the modelled habitat descriptor class, while absence data are observed occurrences of species/communities that occur specifically in the neighbouring habitat descriptor class (e.g. 'moderate energy' class is the neighbouring of 'high energy' class).

This provides for the habitat descriptor class a GLM equation, the shape of which is illustrated in figure 2.5.1 and the equation of which is in the following form:

$$P(X) = e^{ax+b} / (1+e^{ax+b})$$

where X is the environmental parameter value, P(X) is the probability of the habitat descriptor class occurrence, and a and b are respectively the slope and the intercept of the GLM.

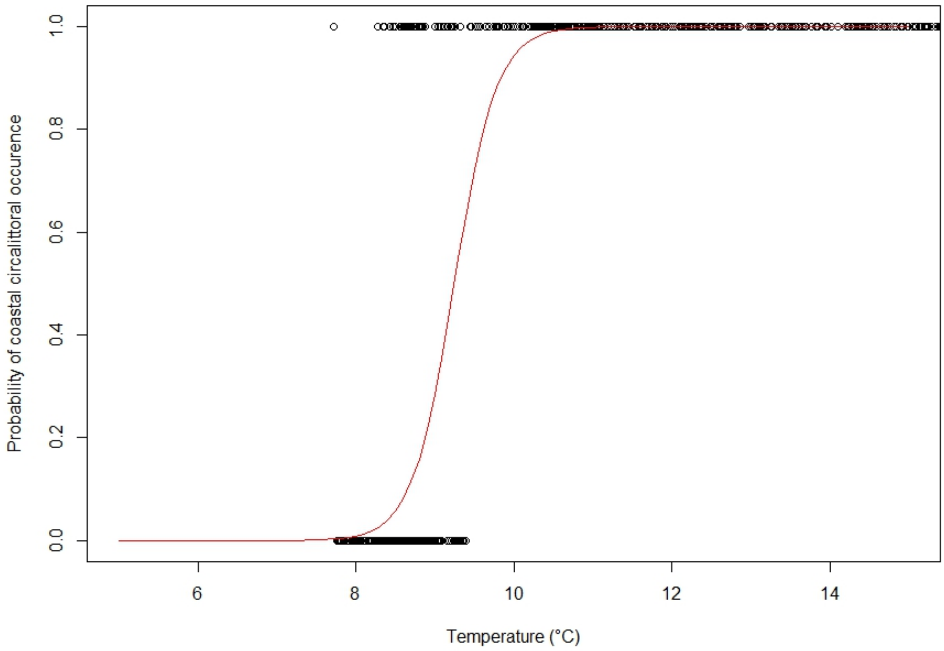


Figure 2.5.1 Example of GLM curve. It was fitted in the Black Sea for the prediction of the shallow circalittoral at its lower boundary with with deep circalittoral. The presence of the shallow circalittoral is driven by temperature. Dots are observed occurrences of species/communities that occur specifically in the shallow circalittoral (top of the graph, where y=1) and in the deep circalittoral (bottom, where y=0).

The Receiver Operating Characteristic (ROC) curve (Pearce and Ferrier, 2000, see figure 2.5.2) is used to identify the cut-off (hereby also referred to as threshold) probability value that is employed to transform probability values in discrete presence/absence values: above this value the habitat descriptor class is predicted as present and below it is predicted as absent.

For each habitat descriptor class that could be addressed with this approach, the GLM equation was eventually used in a GIS together with a continuous layer of its corresponding environmental variable in order to scale up the GLM and hence obtain a probabilistic distribution map. The cut-off value was used to set a boundary in that map, thus transforming it in a discrete map of presence of the habitat descriptor class.

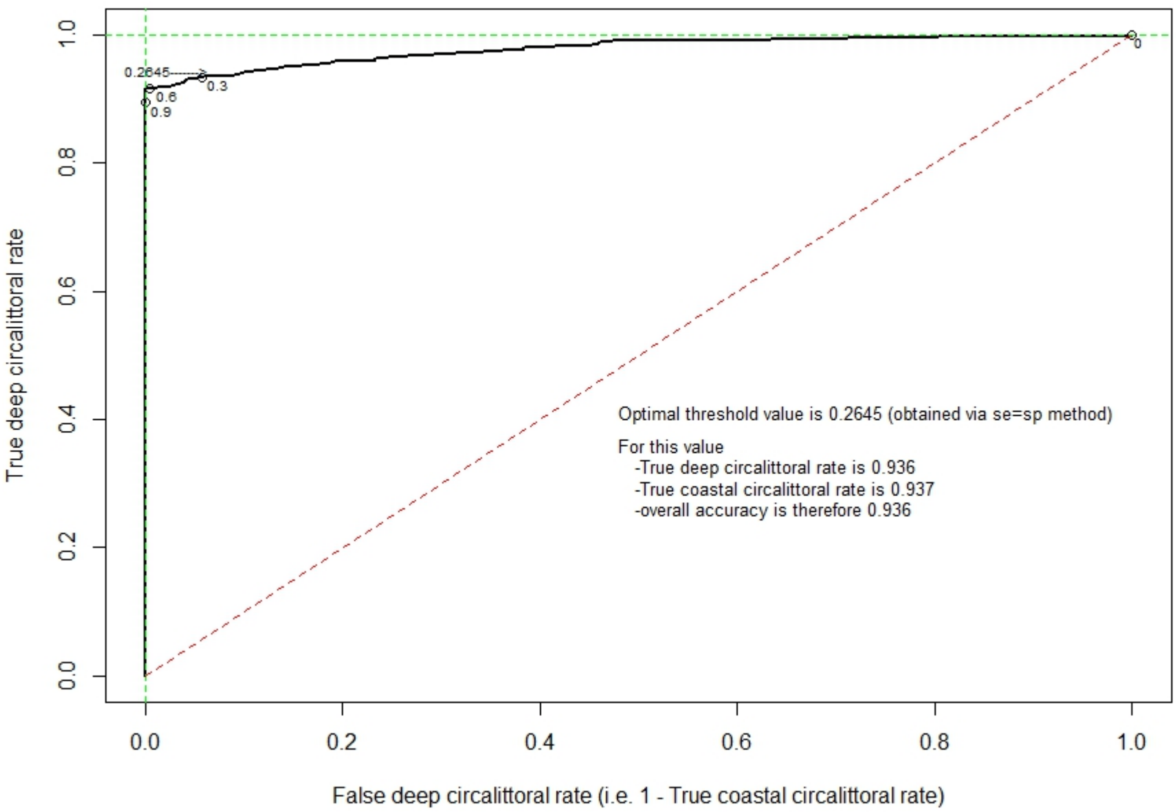


Figure 2.5.2: Example of ROC curve for the lower boundary of shallow circalittoral. The analysis leads to a decision threshold probability value of 0.265. This value gives the lowest rate of misclassification for occurrences of both shallow circalittoral and its neighbouring deep circalittoral (resp. Y and 1-X axis on the graph).

2.5.3 Alternative approach: using threshold values and fuzzy classifiers

General principles

When no presence/absence point data is available the alternative to the logistic regression modelling method for the prediction of a habitat descriptor class occurrence along a gradient of a physical parameter is to use a fuzzy classifier. Figure 2.5.3 illustrates a fuzzy classifier for one of the two boundaries of a habitat descriptor class (e.g. lower boundary of the class 'shallow circalittoral'). In abscissa are the variable values (e.g. temperature). In ordinate is the probability of occurrence for the habitat descriptor class. The shape of the fuzzy function is governed by two control points, P0 and P1. P0 (x0,0) indicates where the probability begins to increase above 0. P1(x1,1) is the point where the probability starts to be 1.

In-between is a simple straight line, whose slope a and intercept b are defined as:

a = 1 / (x1-x0)

b = -x0 / (x1-x0)

As with the GLM approach described in the previous section, a cut-off probability value has to be worked out. It is the probability value above which the habitat descriptor class will be classified as present and below which it will be classified as absent.

When x0 and x1 are determined, the equation y = ax + b can be used in a GIS together with a continuous layer of the parameter to scale up the habitat descriptor class presence probability. The cut-off probability value is subsequently used to classify the probability layer into presence of the habitat descriptor class.

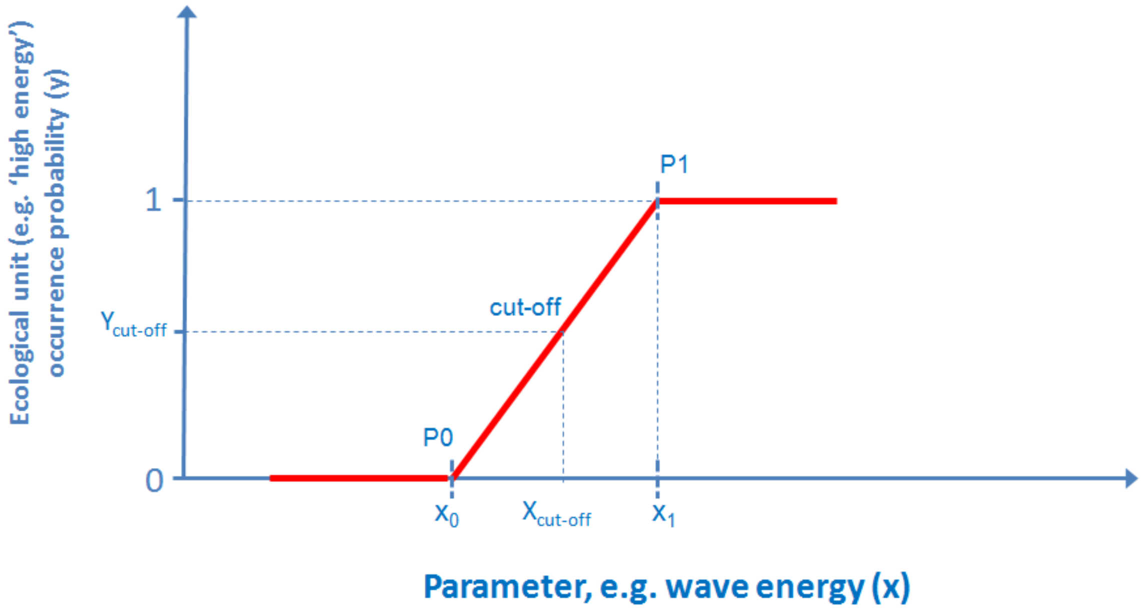


Figure 2.5.3 The fuzzy classifier shape is governed by 2 control points P0 and P1. The cut-off is the point whose y coordinate is the probability value above which the habitat descriptor class will be classified as present and below which it will be classified as absent.

Below is explained how the fuzzy boundaries X_0 and X_1 and the parameter cut-off value $X_{cut\text{-}off}$ were determined in cases where: (i) sample polygon data or boundaries provided by other studies were available, and (ii) no data were available.

Working out thresholds and fuzzy classifiers with polygon data

The boundary between the infralittoral and circalittoral zones in the Mediterranean Sea is marked by the degree of light reaching the seabottom whereby below a certain amount of light photosynthesis of seagrasses and photophilic algae cannot occur. For this reason, Posidonia *oceanica* cartographic polygon data were collated for the whole basin and a general statistical analysis was carried out considering those meadows whose lower limit is most likely influenced by decreasing light levels.

The minimum light value associated to each selected meadow was calculated using the ArcGIS zonal statistic tool. The statistical population constructed using these values was studied both in terms of the main statistical parameters and frequency. This allowed identifying the best descriptive statistical parameter (i.e. mean and median for a normal distribution). This value represents the light cut-off ($X_{cut\text{-}off}$ in fig. 2.5.3) that was used to delimit the boundary between the infralittoral and circalittoral zone. In order to identify the fuzzy control points (x_0 and x_1 in fig. 2.5.3) the deviance around the cut-off was identified using the most appropriate parameters (i.e. Standard Error in case of mean and Standard Deviation in case of median, see section 9.8 in Thresholds appendix).

Working out thresholds and fuzzy classifiers with boundaries provided by other studies

The approach used to identify deep-sea threshold in the Arctic, Greater North Sea and Celtic Seas, and Iberia, Biscay and Macaronesia model areas is the same used for the identification of the Atlantic and Arctic deep sea habitats developed for the Marine Classification for Britain and Ireland (Parry et al., 2015).

Deep-sea biozones were identified by K-means clustering using the variables depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux (POC). All input data layers are derived from the World Oceans Atlas, except from the POC, which was obtained from an in-house model at National Oceanography Centre Southampton (NOCs). The method has been developed by deep-sea experts and is currently being described in a peer reviewed paper (Bett and Jones, in prep).

Hard and fuzzy thresholds, using depth as a proxy, were calculated for each of the deep-sea biozones identified by the Bett and Jones K-means cluster analysis based on statistics output for each cluster. Hard threshold values ($X_{cut\text{-}off}$ in fig. 2.5.3) were defined as the midpoint of median depths between adjacent zones, rounded to the nearest 100m. Fuzzy threshold values (X_0 and X_1 in fig. 2.5.3) were obtained from the average of the half the inter quartile range for each adjacent biozone pair.

For more details on this process refer to the appropriate section in the thresholds Appendix.

Working out thresholds and fuzzy classifiers from literature/expert judgement

due to lack of sample data

When no exiting data were available for the identification of the cut-off value, we used a value provided by literature. As an example, for the classification of currents in the habitat descriptor classes 'high', 'moderate' and 'low' current-induced energy, we used values determined within the framework of the UKSeaMap project (McBreen et al., 2011). The fuzzy bounds were arbitrarily defined, e.g. ±10% of the cut-off value.

2.5.4 Methods for boundaries defined as slope changes

In all basins the boundary between the circalittoral and the bathyal as well as the boundary between the bathyal and the abyssal are defined as abrupt changes in slope. In the former case, the gentle slope of the continental shelf gives way to the much steeper continental slope, while in the latter an abrupt transition leads from the steep continental slope to the deep-sea abyssal plain. Those boundaries were delineated by heads-up digitalisation with the help of a slope layer that was derived from the EMODnet Bathymetry DTM.

2.5.5 Methods for classifying infralittoral and circalittoral inside river plume areas

The general rules used to model the infralittoral and circalittoral and /or habitats in each regional sea do not always work as appropriately in areas which are under the influence of high fine sediment riverine input. In those areas, fine sediment deposit driven by riverine inputs is the predominant factor believed to determine the shallow shelf benthic zoning, whereby the development of infralittoral soft bottoms communities is driven by the presence of fine superficial sands and partially muddy sand, whereas the circalittoral communities develop on sandy mud and mud substrates.

In other areas the rules for defining the biological zones inside the river plume areas were defined as follows:

- Aegean sea
  - Infralittoral: sand and muddy sand
  - Circalittoral: mud and sandy mud
- Black Sea (Dniepr and Danube rivers)
  - Infralittoral :sand, muddy sand, coarse and mixed
  - Circalittoral: mud and sandy mud

In the Adriatic Po river plume, the infralittoral occurrence was predicted by fitting a GAM (Generalised Additive Model). For further details on how the Po river plume was delineated and how the GAM was fitted refer to section 9.6 and 9.7 of the Threshold Appendix.

2.6 Making the broad-scale map

The approach used to produce the map 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.

An overview of the method is given below, with a more specific description provided in the Appendix 'Making the Broadscale Map'.

In practical terms, this process was performed in a raster-based context by using ESRI® ArcGIS ™ 10.2 with the Spatial Analyst extension. Processing workflows are designed under the ArcGIS™ Model Builder tool. The raster input data layers contain grid cells with continuous values of key environmental variables, from which the presence probability of a habitat descriptor class can be computed according to a set of defined GLM or fuzzy equation (see section 2.5). Pixels of probability layers can subsequently be assigned binary presence/absence values according to where they fall within a defined cut-off value. From those binary rasters of habitat descriptor class presence/absence, the thematic categorical raster layer that are e.g. biozones or oxygen regimes are assembled. A combination of those categorical layers is eventually performed, the result of which is the final habitat map.

The inputs to the model are i) the raster primary environmental data layers, e.g. light penetration or wave-induced energy, ii) the slope and intercept values for the GLM or fuzzy equations and iii) the cut-off values. The outputs are i) continuous raster layers of presence probability for each habitat descriptor class, ii) categorical layers such as biozones or oxygen regimes in the Black Sea, and iii) the habitat map.

All slope, intercept and cut-off values are described in the recap tables at the end of the apppendix on thresholds. For a given habitat descriptor class, due to a substantial heterogeneity of the underlying primary datasets the value of those three parameters vary spatially. As a result those 3 parameters are given to the GIS model as raster layers. For further details on this see Appendix "Making the Broadscale Map".

The working or nominal resolution was chosen as approximately 250m, since this level of resolution is generally available for most datasets. It should be noted that whilst this is the case in the coastal zone for the two key base layers (substratum and depth), it does not hold true in deep offshore areas where data tend to be found at coarser resolutions. However, one way to express the fact that source layers are not as detailed as the nominal resolution is by associating a confidence map to the final map (see section 2.7).

2.7 Confidence assessment

We developed a confidence assessment method that follows a consistent structure and method for all regions. The method is simple and flexible enough to be applied to the multitude of different data types and methods used to create the primary and secondary data layers. This will ensure that a user can easily understand the sources of uncertainty in the habitat map in any location. An overview of the method is given below, with a description of how it was applied to each individual data layer provided in the confidence Appendix.

The simple confidence assessment method resulted in a hierarchy of confidence assessments, related to the three levels of information associated with the habitat map (Figure 2.7.1).

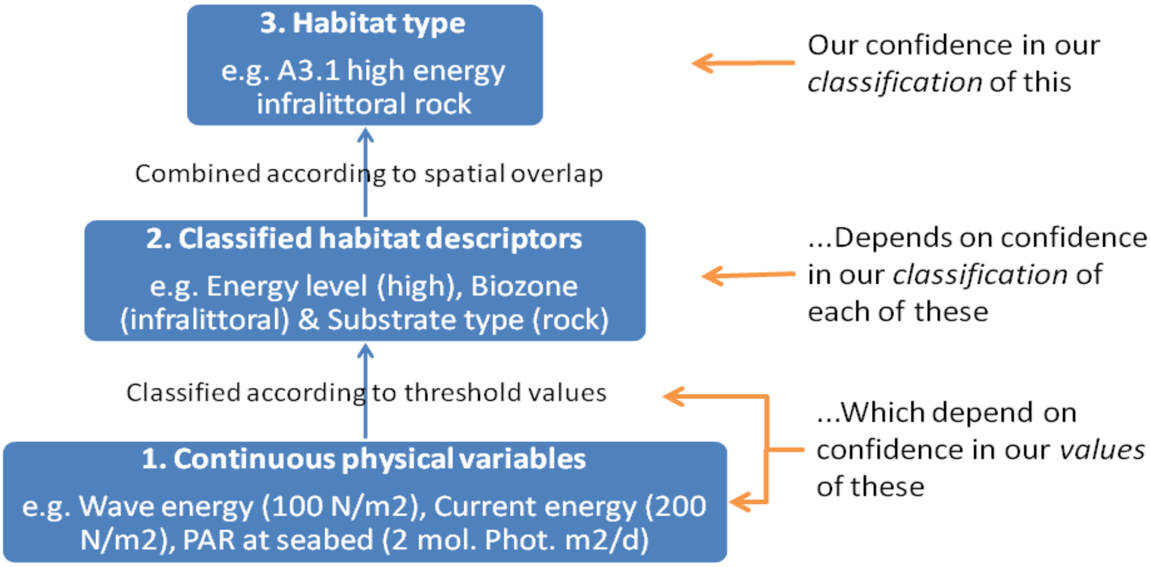


Figure 2.7.1: Diagram summarising the three levels of data involved in building EUSeaMap, and how confidence in each layer relates to the confidence of the others.

The confidence was assessed per grid cell; the principles behind the method at each of the three levels (described below) were:

- Each assessment should be simple to describe and apply, so that users can understand what they mean.
- Each assessment should result in a rating of high (H), moderate (M) or low (L) confidence. This ensures consistency across data types and regions, and reflects the lack of detail available to produce a more detailed assessment in most cases.
- Confidence in the classification of the habitat type should be derived from the confidence in the relevant habitat descriptor classes that were overlaid to determine that habitat type.
- Confidence in the classification of habitat descriptor classes should be derived from the confidence in the relevant continuous physical variables and threshold values. If this is not possible (e.g. manually classified substrate type) then confidence in the classification of habitat descriptor should be calculated by other means.

2.7.1 Confidence in values of continuous physical variables

Assessment at this level asks: "how confident can we be that the value correctly describes the conditions of a variable that influences seabed habitats"? This considered factors such as:

- **Quality of training data and methods** used to construct the model.
- **Temporal resolution**. The models that represent continuous physical variables are specific to a particular quantity (e.g. mean, maximum, median, etc.) of a particular time period when the in situ data used to train the models were collected. The suitability of this statistic in terms of what is most biologically-relevant has an effect on the confidence.
- **Spatial resolution**. This is not simply a matter of considering the resolution of the model alone; rather, three interactions need to be considered (summarised in Figure 2.7.2):

- Model resolution compared with the true variability of the variable – ideally the model resolution would match (or exceed) the true resolution. This is the most important interaction and if it is not met then the spatial resolution of the model could be considered to be poor.
- If the model resolution is suitable with respect to the true variability, then the following should be considered:
    - Model resolution compared with the final classified habitat map resolution – ideally the final map resolution would match (or exceed) the model resolution.
    - Final classified habitat map resolution compared with the true variability of the variable – ideally the final map resolution would match (or exceed) the true resolution.

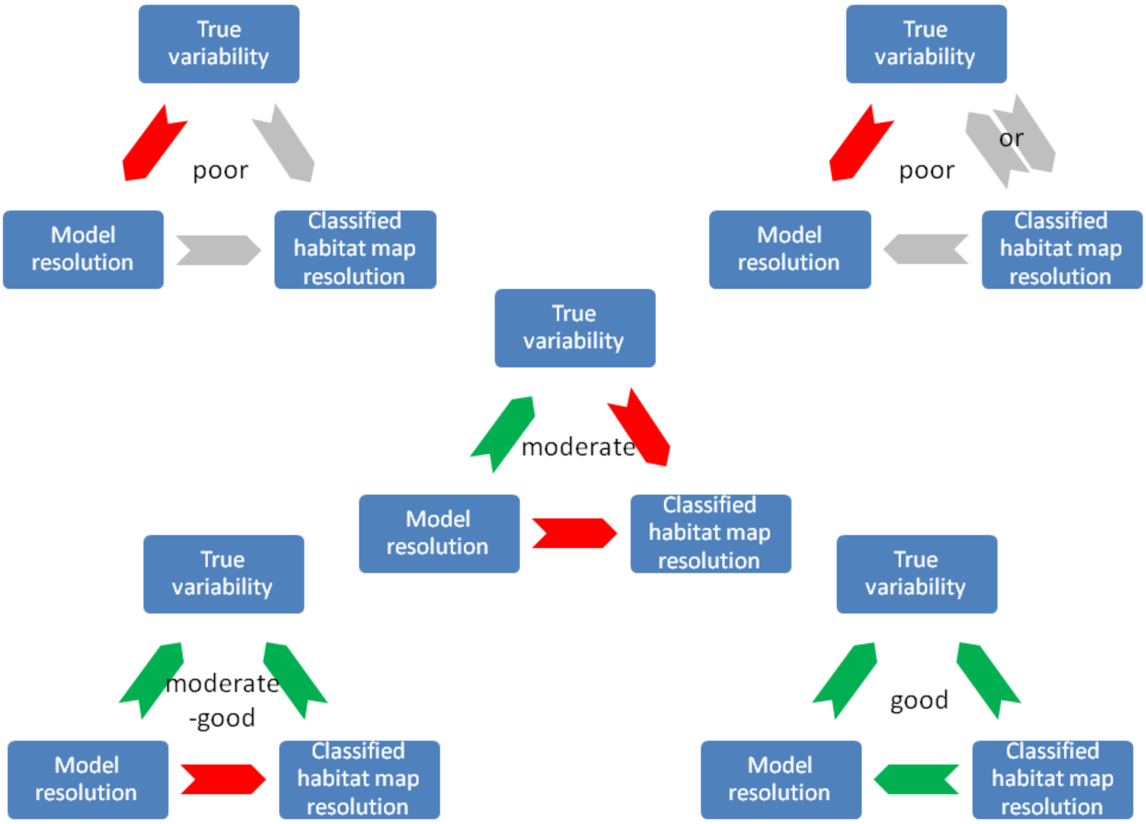


Figure 2.7.2: Different resolution scenarios and their impact on the suitability of the model resolution (from poor to good) for describing the correct habitat type. Direction of arrow indicates that a resolution matches or exceeds another. Colour of arrow indicates whether the direction is favourable (green), unfavourable (red) or irrelevant (grey).

Using a combination of available data and expert judgement, a confidence assessment at this level was carried out for each input data layer described in Table 2.7.1. A full description of each method is given in the Confidence Appendix, however an example is presented here for demonstrative purposes:

Example: Photosynthetically available radiation (PAR) at the seabed, Arctic, Atlantic and Mediterranean

Photosynthetically Active Radiation (PAR) at the seabed was calculated from three separate variables: PAR at the surface, light attenuation coefficient K_D(PAR) and depth to the seabed.

The confidence in the PAR at the seabed was therefore calculated by calculating the mean (rounded up; see Appendix 2) of two separate assessments:

1. Depth to the seabed confidence (described in Section 10.1.2 of confidence appendix)
2. PAR at the surface and K_D(PAR) confidence, described below.

Considering the qualitative assessment described in Table 2.7.1, the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 2.7.2) and applied (Figure 2.7.3 and Figure 2.7.4) for PAR at the surface and K_D(PAR).

Table 2.7.1: Qualitative assessment of confidence in AR at the surface and KD(PAR) in the Arctic, Atlantic and Mediterranean

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	The models were created using sound methods; however, there was limited ground-truthing data available.	Reports from contractors detailing the methods used.
Spatial resolution	With model resolutions of 250 m for K_D(PAR) and 4 km for PAR at the surface, it varies from good (Map resolution > Model resolution > True variability) in gradually sloping and deeper waters to poor (True variability > Model resolution) in steep, shallow waters with complex coastlines.	Expert judgement about the true variability. Number of satellite images per cell used to build models of light attenuation and PAR at the surface.
Temporal resolution	The models of light attenuation and PAR at the surface were built from five years' worth of satellite data in order to maximise the number of images per cell. These ranges of years are deemed appropriate. Annual means were used for these variables; further research is needed to confirm whether this is most suitable metric, or whether another would be better, e.g. summer mean.	Expert judgement

Table 2.7.2: Criteria used for assessing confidence in PAR at the surface and KD(PAR) in the Arctic, Atlantic and Mediterranean.

Confidence per cell	Criteria
High	39 ≤ satellite images per grid cell
Moderate	29 ≤ satellite images per grid cell < 39
Low	0 ≤ satellite images per grid cell < 29

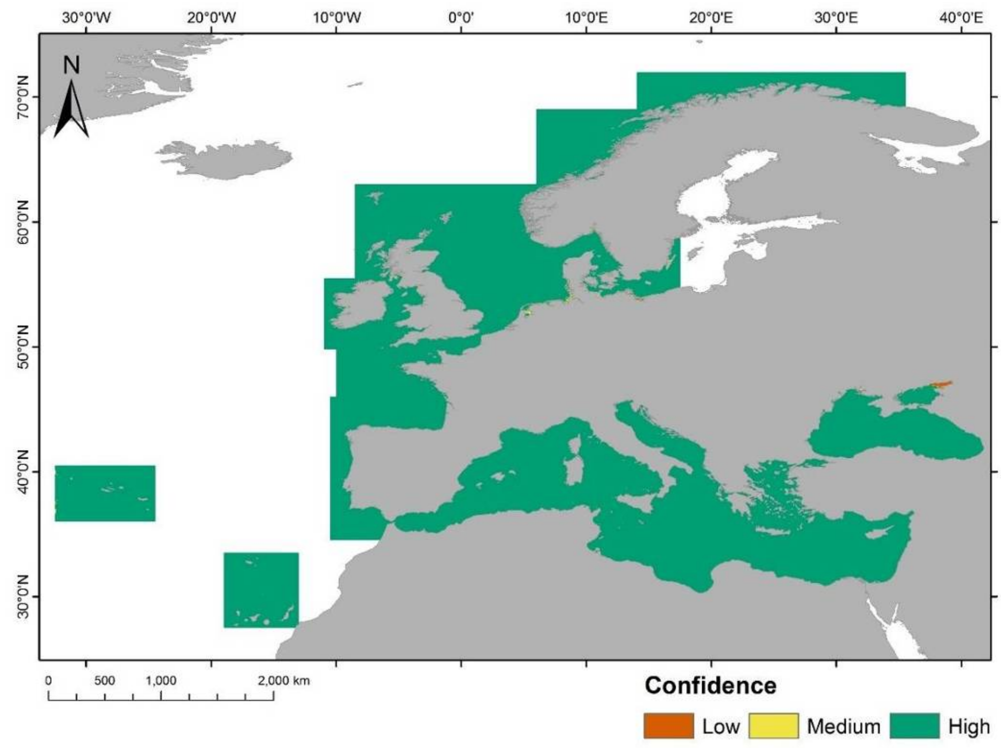


Figure 2.7.3: Confidence in PAR at the surface and KD(PAR) in the Arctic, Atlantic and Mediterranean based on number of satellite images per grid cell

Finally, the PAR at the surface and K_D(PAR) confidence and the depth at the seabed confidence (see confidence appendix) were combined using the mean (rounded up) into PAR confidence at the seabed (Fig. 2.7.4)

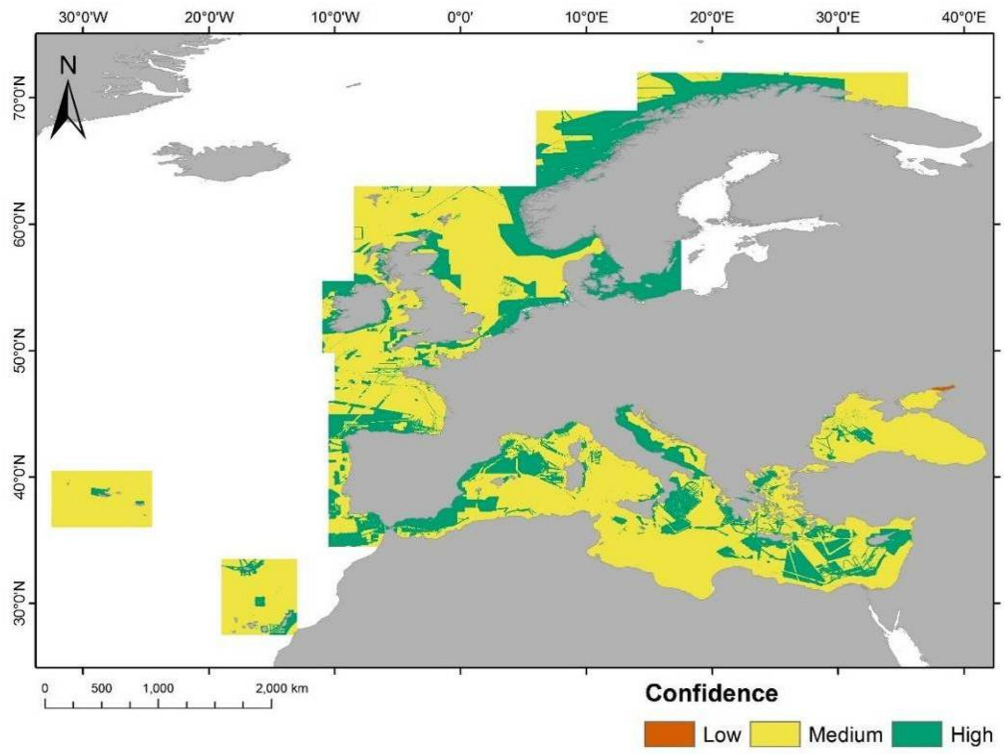


Figure 2.7.4: Confidence in PAR at the seabed in the Arctic, Atlantic and Mediterranean

2.7.2 Confidence in classification of habitat descriptor

Multiple habitat descriptor classes form the component parts of the names of habitat types, e.g. the habitat "high energy infralittoral rock" is composed of three habitat descriptor classes: energy class (high energy), biozone (infralittoral) and substrate type (rock). Classified habitat descriptors (Table 2.7.3) are predominantly created through the classification of the continuous physical variables according to biologically-relevant thresholds (as described in Section 2.7.1 above).

Table 2.7.3: Summary of habitat descriptors used in each model area (highlighted in grey). The usage of each of these depended on (a) biological relevance and (b) data availability.

Habitat descriptor	Arctic Seas	Greater North Sea and Celtic Seas	Iberia, Biscay, and Macaronesia	Baltic Sea	Black Sea	Mediterranean Sea
Biozone						
Substrate type						
Energy class						
Mask of riverine sediment input						
Oxygen regime						
Salinity regime						

Assessment at this level asks: "how confident can we be that the habitat descriptor class is correct, considering the confidence in the (a) values and (b) threshold values of the continuous physical variables (or some other method for manual delineations)"?

To assess the confidence in the classification of the habitat descriptors per cell, the *Confidence in values of continuous physical variables* was combined with the information on the uncertainty of the threshold values; these two things were combined according to the following steps.

Step 1: Create layers of confidence in classification of habitat descriptors based only on threshold uncertainty

Using the boundaries and uncertainties determined using the methods described in Section 2.5, the following methods were used to produce a layer corresponding to each class boundary, classified according to three categories: high, moderate and low.

a. For boundaries based on a single threshold value with a range of uncertainty, the 0-1 membership or predicted probability values determined according to the method described in Sections 2.7.1 and 2.7.2 were categorised according to Table 2.7.4.

Table 2.7.4: Criteria used for categorising confidence in classification of habitat descriptors based on uncertainty in the hard threshold value, where membershipmax is the maximum membership for the most likely class, membershipthreshold is the membership corresponding to hard threshold value, and range = membershipmax - membershipthreshold

Confidence per cell	Criteria
High	0.6 x range ≤ membership ≤ $membership_{max}$
Moderate	0.2 x range ≤ membership < 0.6 x range
Low	$membership_{threshold}$ ≤ membership < 0.2 x range

Note that for all cases where a GLM was not used to calculate the threshold value, $membership_{threshold}$ = 0.5 and $membership_{max}$ = 1, which simplifies to the criteria in Table 2.7.5.

Table 2.7.5: criteria used for categorising confidence in classification of habitat descriptors based on uncertainty in the hard threshold value.

Confidence per cell	Criteria
High	0.8 ≤ membership ≤ 1.0
Moderate	0.6 ≤ membership < 0.8
Low	0.5 ≤ membership < 0.6

b. For manually-drawn boundaries (method described in Section Methods for boundaries defined as slope changes

c. two horizontal For manually-drawn boundaries (method described in Section Methods for boundaries defined as slope changes

d. buffers were applied to each boundary - a narrower buffer corresponding to the boundary between low and moderate confidence and a wider buffer corresponding to the boundary between moderate and high confidence. This applies to just two sets of boundaries: circalittoral/ bathyal/ abyssal biozone boundaries in the Mediterranean and the deep circalittoral/ upper bathyal biozone boundaries in the Bay of Biscay. For more detail on how the buffers were created for these boundaries, see the confidence appendix.

Step 2: Combine layers from step 1 with Confidence in values of continuous physical variables to create a single confidence layer related to each habitat descriptor class boundary.

At this stage each grid cell had a high/ moderate / low score relating to *Confidence in the values of the continuous physical variable(s)* (e.g. salinity at the seabed) and *Confidence in the classification of the* habitat descriptors based only on threshold uncertainty. The next step was to combine these scores into a single high/ moderate/ low score per grid cell. The principles for this combination (Table 2.7.6) were based on the assumption that the main cause of uncertainty in the classification was the uncertainty in the threshold value (and proximity to that boundary).

Finally, these boundary-specific confidence layers were combined to create a single confidence layer per habitat descriptor. Because of the different ways data were used to create the different habitat descriptor layers, slightly different approaches were taken to complete this step. The details for each habitat descriptor are provided in the confidence Appendix.

Table 2.7.6: Logic used for combining confidence scores.

		Confidence in values of continuous physical variables		
		H	**M**	**L**
Confidence in classification based on threshold values	**H**	H	H	M
	M	M	M	L
	L	L	L	L

Special case: Substrate type

Substrate type is the only habitat descriptor that was pre-classified before inputting into the model, i.e. there are no continuous physical variables involved. As a result, an alternative approach was followed to produce a confidence assessment at this level for substrate type.

The substrate layer confidence was obtained from reclassification and standardisation of the confidence scores associated with each primary layer used to create the Substrate Layer of EUSeaMap 2016 (see Table 2.7.7). To each polygon of the EMODnet Geology sediment map 2016 was assigned a confidence score from 0 to 4, using a method based on the 3 steps confidence method developed at JNCC (Lillis, 2014). The approach takes into account remote sensing coverage, amount of sampling and distinctiveness of class boundaries.

Seagrass substrate classes (for the Mediterranean Sea and the waters around Canary Islands) were given a high confidence class, as the data was derived from observations (or habitat maps from survey). In Norwegian waters the extent of rock was estimated by using a modelling approach (Section 2.2.6), this type of substrate was given low confidence because it was derived from model that uses slope as a proxy for rock, instead of remote or direct observation of rock at the seabed surface.

Table 2.7.7: SubstrateConfidence - Translation from the various confidence assessments associated with substrate datasets used in EUSeaMap, into high, medium and low confidence.

Substrate confidence class	EMODnet Geology Sediments Confidence score	Integrated substrate features – EMODnet1 Confidence score	Integrated substrate features – MeshAtlantic-Confidence score	"Modelled" Rock in UK waters = Confidence score	2.2.2 Integrated substrate features – Med. and Canaries seagrass beds	Modelled Rock substrate Norway
High	3, 4	3, 4	>60	3, 4	Presence	
Medium	2 ,1	2 ,1	40-60	2 , 1		
Low	0, NoData	0, NoData	<40	0, NoData		Presence

2.7.3 Combination of class confidence to get habitat type confidence

Assessment at this level asks: How confident can we be that the habitat type is correct, considering the confidence in the habitat descriptor classes?

To obtain a single confidence layer for the final habitat type, the confidence in the classification of the relevant habitat descriptors were combined.

For each grid cell, the confidence in final habitat class was the minimum of all relevant habitat descriptor confidence scores (e.g. Figure 2.7.5).

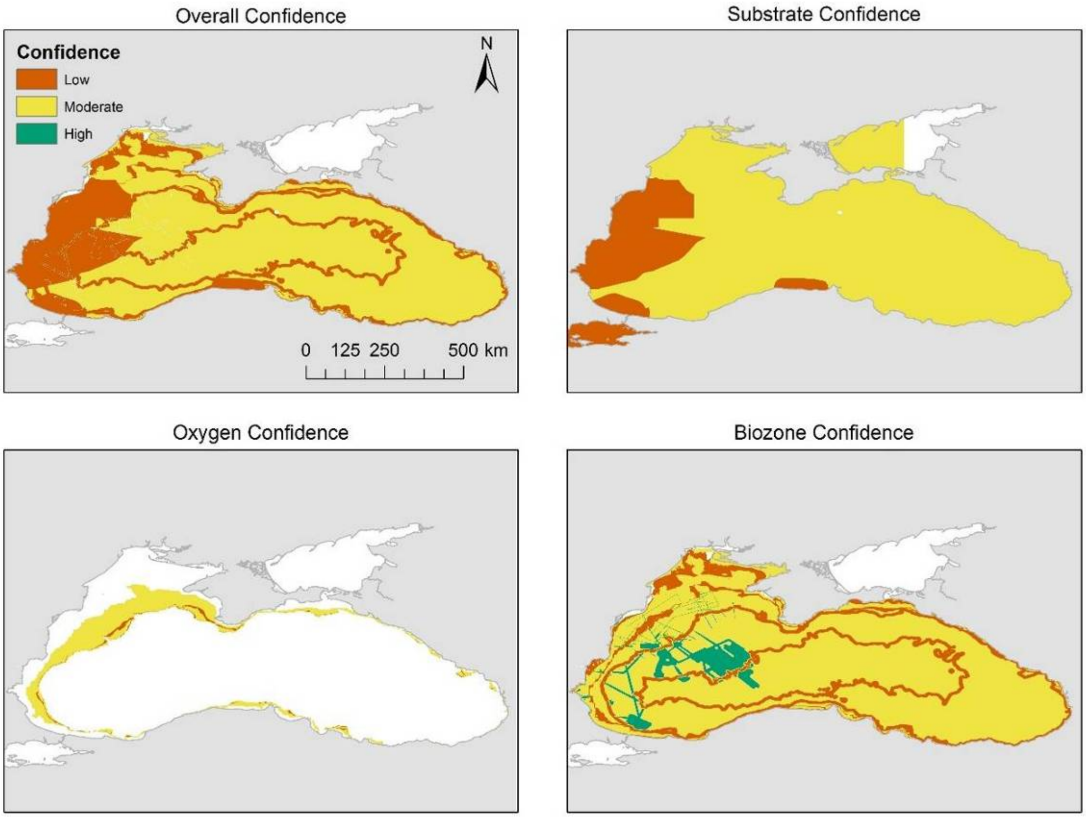


Figure 2.7.5: Demonstration of how an overall habitat confidence map (top left) is created by using the lowest confidence of the three habitat descriptors used in the Black Sea: substrate type, oxygen regime and biozone. Note that confidence in oxygen regime is only shown within the deep circalittoral biozone.

It is important to note that a habitat type confidence score is only relevant to that particular level of the classification system. For example, a cell of A3.1 high energy infralittoral rock with ‘low’ energy class confidence, ‘moderate’ biozone confidence and ‘high’ substrate type confidence would have an overall ‘low’ confidence. However, moving up the hierarchy to EUNIS level two (A3 infralittoral rock) removes the energy class; therefore, the confidence of the EUNIS level two habitat type would only consider the ‘moderate’ biozone confidence and ‘high’ substrate type confidence, resulting in an overall ‘moderate’ confidence.

3 Results and discussion

3.1 Atlantic and Arctic

3.1.1 EUNIS applicability

In most parts of Atlantic and Arctic seas, levels 3 and 4 of EUNIS version 2007-11 were deemed suitable for describing the variation in physical seabed habitat types (Table 3.1.1). The only area where the map differs from EUNIS version 2007-11 is in the deep sea, where recent studies have been able to show sub-zonation (Table 3.1.2) due to a combination of depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux ranges (Bett and Jones, in prep). The biological relevance of these divisions have been found for some parts of the Atlantic and Arctic seas (Parry et al, 2015) and further research is necessary to confirm it throughout the wider region however it is believed that there is sufficient scientific insight to extend the concept of such sub-zonation within the framework of broad-scale habitat mapping in this region.

Table 3.1.1: EUNIS habitat types in Atlantic and Arctic seas at Level 3 and 4 which can be identified from the ecological unit categories seabed substrate, biological zone and, for rock substrate, energy class. Grey cells are for those combinations that do not have a EUNIS habitat equivalent.

Biological zone	Substrate type							
	Rock/ Reef			Coarse sediment	Sand	Muddy sand OR Sandy mud	Mud	Mixed sediment
	Energy class							
	High	Moderate	Low					
Infralittoral	A3.1 Atlantic and Mediterranean high energy infralittoral rock	A3.2 Atlantic and Mediterranean moderate energy infralittoral rock	A3.3 Atlantic and Mediterranean low energy infralittoral rock	A5.13 Infralittoral coarse sediment	A5.23 Infralittoral fine sand OR A5.24 Infralittoral muddy sand	A5.33 Infralittoral sandy mud	A5.34 Infralittoral fine mud	A5.43 Infralittoral mixed sediments
Shallow circalittoral	A4.1 Atlantic and Mediterranean high energy circalittoral rock	A4.2 Atlantic and Mediterranean moderate energy circalittoral rock	A4.3 Atlantic and Mediterranean low energy circalittoral rock	A5.14 Circalittoral coarse sediment	A5.25 Circalittoral fine sand or A5.26 Circalittoral fine sand	A5.35 Circalittoral sandy mud	A5.36 Circalittoral fine mud	A5.44 Circalittoral mixed sediments

Deep circalittoral	A4.12 Sponge communities on deep circalittoral rock	A4.27 Faunal communities on deep moderate energy circalittoral rock	A4.33 Faunal communities on deep low energy circalittoral rock	A5.15 Deep circalittoral coarse sediment	A5.27 Deep circalittoral sand	A5.37 Deep circalittoral mud	A5.37 Deep circalittoral fine mud	A5.45 Deep circalittoral mixed sediments
Deep sea	A6.1 Deep-sea rock and artificial hard substrata	A6.1 Deep-sea rock and artificial hard substrata	A6.1 Deep-sea rock and artificial hard substrata	-	A6.3 Deep-sea sand OR A6.4 Deep-sea muddy sand	A6.5 Deep-sea mud	A6.5 Deep-sea mud	A6.2 Deep-sea mixed substrata

Table 3.1.2: Non-EUNIS classes used to add further discrimination to the deep sea zone in Atlantic and Arctic seas.

Biological zone		Substrate type					
Name	**Applicable regions**	**Rock**	**Coarse sediment**	**Sand**	**Muddy sand OR Sandy mud**	**Mud**	**Mixed sediment**
Atlantic Upper Bathyal	All	Atlantic upper bathyal rock or reef	Atlantic upper bathyal coarse sediment	*Atlantic upper bathyal sand or muddy sand*	*Atlantic upper bathyal sandy mud*	Atlantic upper bathyal mud	Atlantic upper bathyal mixed sediment
Atlantic Mid Bathyal	GNCS, IBM	Atlantic mid bathyal rock or reef	Atlantic mid bathyal coarse sediment	Atlantic mid bathyal sand or muddy sand	Atlantic mid bathyal sandy mud	Atlantic mid bathyal mud	Atlantic mid bathyal mixed sediment
Atlanto-Mediterranean Mid Bathyal	IBM	Atlanto-Mediterranean mid bathyal rock or reef	Atlanto-Mediterranean mid bathyal coarse sediment	Atlanto-Mediterranean mid bathyal sand or muddy sand	Atlanto-Mediterranean mid bathyal sandy mud	Atlanto-Mediterranean mid bathyal mud	Atlanto-Mediterranean mid bathyal mixed sediment
Atlantic Lower Bathyal	GNCS, IBM	Atlantic lower bathyal rock or reef	Atlantic lower bathyal coarse sediment	Atlantic lower bathyal sand or muddy sand	Atlantic lower bathyal sandy mud	Atlantic lower bathyal mud	Atlantic lower bathyal mixed sediment
Atlantic Upper Abyssal	GNCS, IBM	Atlantic upper abyssal rock or reef	Atlantic upper abyssal coarse sediment	Atlantic upper abyssal sand or muddy sand	Atlantic upper abyssal sandy mud	Atlantic upper abyssal mud	Atlantic upper abyssal mixed sediment

Atlantic Mid Abyssal	GNCS, IBM	Atlantic mid abyssal rock or reef	Atlantic mid abyssal coarse sediment	Atlantic mid abyssal sand or muddy sand	Atlantic mid abyssal sandy mud	Atlantic mid abyssal sandy mud	Atlantic mid abyssal mixed sediment
Atlantic Lower Abyssal	GNCS, IBM	Atlantic lower abyssal rock or reef	Atlantic lower abyssal coarse sediment	Atlantic lower abyssal sand or muddy sand	Atlantic lower abyssal sandy mud	Atlantic lower abyssal sandy mud	Atlantic lower abyssal mixed sediment
Atlanto-Arctic Upper bathyal	GNCS, Arctic	Atlanto-Arctic upper bathyal rock or reef	Atlanto-Arctic upper bathyal coarse sediment	Atlanto-Arctic upper bathyal sand or muddy sand	Atlanto-Arctic upper bathyal sandy mud	Atlanto-Arctic upper bathyal mud	Atlanto-Arctic upper bathyal mixed sediment
Arctic Mid Bathyal	GNCS, Arctic	Arctic mid bathyal rock or reef	Arctic mid bathyal coarse sediment	Arctic mid bathyal sand or muddy sand	Arctic mid bathyal sandy mud	Arctic mid bathyal mud	Arctic mid bathyal mixed sediment
Arctic Lower Bathyal	GNCS, Arctic	Arctic lower bathyal rock or reef	Arctic lower bathyal coarse sediment	Arctic lower bathyal sand or muddy sand	Arctic lower bathyal sandy mud	Arctic lower bathyal mud	Arctic lower bathyal mixed sediment
Arctic Upper Abyssal	Arctic	Arctic upper abyssal rock or reef	Arctic upper abyssal coarse sediment	Arctic upper abyssal sand	Arctic upper abyssal sandy mud	Arctic upper abyssal mud	Arctic upper abyssal mixed sediment

3.1.2 Thresholds

This section summarises the interpretation of the meaning of the various zones used in the mapping in terms of physical variables (Table 3.1.3) and the resultant physical variables and values used to map their extents (Table 3.1.4) in Atlantic and Arctic seas.

Table 3.1.3: Variables known or assumed to influence biological zonation of the seabed in Atlantic and Arctic seas.

Biological zone boundary	Rocky bottoms	Soft bottoms
Infralittoral / circalittoral	The limit of domination of photophilic macroalgae caused primarily by decreasing light availability. It is also associated with increasing stability in temperature, wave action and salinity (Connor et al., 2004).	A less distinct boundary but generally associated with the same variables described for rocky bottoms (Connor et al., 2004).
Shallow circalittoral / Deep circalittoral	The limit of all algae on rock caused primarily by decreasing light availability. It is also associated with further increasing stability in temperature, wave action and salinity (Connor et al., 2004).	The limit of disturbance-tolerant species caused primarily by increasing stability in wave action and temperature. It is also associated with further increasing stability in salinity and decreasing light availability (Connor et al., 2004).
Deep circalittoral / Upper bathyal	Changes in dominant fauna based on water mass properties: many variables including depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux. Can be associated with the shelf edge delimited by the slope angle change of the continental platform.	
Upper bathyal / Mid bathyal	Changes in dominant fauna based on water mass properties: many variables including depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux (Parry et al., 2015, Bett and Jones, in prep).	
Mid bathyal / Lower bathyal	Changes in dominant fauna based on water mass properties: many variables including depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux (Parry et al., 2015, Bett and Jones, in prep).	
Lower bathyal / Upper abyssal	Changes in dominant fauna based on water mass properties: many variables including depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux. Can be associated with the lower limit of the continental slope delimited by the slope angle change of the continental platform (Parry et al., 2015, Bett and Jones, in prep).	
Upper abyssal / Mid abyssal	Changes in dominant fauna based on water mass properties: many variables including depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux (Parry et al., 2015, Bett and Jones, in prep).	
Mid abyssal / Lower abyssal	Changes in dominant fauna based on water mass properties: many variables including depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux (Parry et al., 2015, Bett and Jones, in prep).	

Table 3.1.4: Thresholds used to classify the ecological units in Atlantic and Arctic seas. For more details on the method of determining each threshold, please refer to the thresholds appendix.

Habitat descriptor	Habitat descriptor class boundary	Applicable regions[2]	Variable(s)	Threshold value	Method of determining threshold
Biological zone	Infralittoral/ Shallow circalittoral	Arctic (excluding Iceland) IBM GNCS	Photosynthetically available radiation (PAR) at the seabed, $I = I_0 e^{-d.Kd(PAR)}$ With I_0 = PAR at the surface, d = depth to the seabed, and $K_d(PAR)$ = Light attenuation coefficient at depth d in relation to PAR (mean over 5 years)	0.7 mol. phot. m^2 d^{-1}	Modelling – GLM
		Azores and Canary Islands	Photosynthetically available radiation (PAR) at the seabed	Azores = 0.4 mol. phot. m^2 d^{-1} Canary Islands = 0.3 mol. phot. m^2 d^{-1}	
		Arctic (Iceland only)	Depth to the seabed and latitude	North of 64.5 N = 30m deep South of 64.5 N = 15m deep	Expert judgement
	Shallow circalittoral/ Deep circalittoral	IBM	Wave base ratio calculated by dividing wave length (mean of annual 90th percentile values over 5 (Biscay) and 3 (Iberia,	Bay of Biscay - Along French	Modelling – GLM

2 IBM = Iberia, Biscay and Macaronesia; GNCS = Greater North Sea and Celtic Seas

Habitat descriptor	Habitat descriptor class boundary	Applicable regions[2]	Variable(s)	Threshold value	Method of determining threshold
			Azores) years)) by Depth to the seabed	coast to Santander - WBR = 1.5 Bay of Biscay - Santander to La Coruña - Depth = 80m Iberian Peninsula WBR = 2.67 Azores - Depth = 80m	
		GNCS	Wave base ratio calculated by dividing wave length (mean of annual 90th percentile values over six years) by Depth to the seabed	2	Value from literature (e.g. Coltman et al., 2008)
		Arctic (Norway only)	Wave exposure index at the seabed (NIVA coastal fetch model), calculated from wind data	10000	Value from literature (e.g. Coltman et al., 2008)

Habitat descriptor	Habitat descriptor class boundary	Applicable regions[2]	Variable(s)	Threshold value	Method of determining threshold
		Arctic (all areas with no available wave models)	Depth to the seabed	80m	Expert judgement – align with GNCS boundary
	Deep circalittoral/ Upper bathyal	GNCS, Arctic	Depth to the seabed	200 m	Value from literature
		IBM	Depth to the seabed	Shelf edge	Manual/expert judgement
	Atlantic upper bathyal/ Atlantic mid bathyal	GNCS, IBM	Depth to the seabed	600 m	Modelling – k-means clustering
	Atlantic mid bathyal/ Atlantic lower bathyal	GNCS, IBM	Depth to the seabed	1,300 m	Modelling – k-means clustering
	Atlantic lower bathyal/ Atlantic upper abyssal	GNCS, IBM	Depth to the seabed	2,200 m	Modelling – k-means clustering
	Atlantic upper abyssal/ Atlantic mid abyssal	GNCS, IBM	Depth to the seabed	3,200 m	Modelling – k-means clustering
	Atlantic mid abyssal/ Atlantic lower abyssal	GNCS, IBM	Depth to the seabed	4,300 m	Modelling – k-means clustering
	Atlantic upper bathyal/ Atlanto-Arctic upper bathyal	Arctic	Depth to the seabed	North = 300 m	Modelling – k-means clustering

Habitat descriptor	Habitat descriptor class boundary	Applicable regions[2]	Variable(s)	Threshold value	Method of determining threshold
				South = 400 m	
	Atlanto-Arctic upper bathyal/Arctic mid bathyal	Arctic	Depth to the seabed	600 m	Modelling – k-means clustering
	Arctic mid bathyal/Arctic lower bathyal	Arctic	Depth to the seabed	1,300 m	Modelling – k-means clustering
	Arctic lower bathyal/Arctic upper abyssal	Arctic	Depth to the seabed	2,400 m	Modelling – k-means clustering
Energy	High/ Moderate wave energy	IBM	Kinetic energy at the seabed due to waves (mean of annual 90th percentile values over 5 (Biscay) and 3 (Iberia, Azores) years)	Bay of Biscay - Along French coast to Santander = 22 N m-2 Bay of Biscay - Santander to La Coruña = 90 N m-2 Iberian Peninsula = 44 N m-2 Azores = 44 N m-2	Modelling – GLM
		GNCS	Kinetic energy at the seabed due to waves (mean of annual 90th percentile values over six years)	70.95 N m^{-2}	Modelling – GLM

Habitat descriptor	Habitat descriptor class boundary	Applicable regions[2]	Variable(s)	Threshold value	Method of determining threshold
		Arctic	Wave exposure index at the seabed, calculated from wind data (mean of annual 90th percentile values)	500,000	Expert judgement – align with GNCS boundary
	Moderate/ Low wave energy	IBM	Kinetic energy at the seabed due to waves (mean of annual 90th percentile values over 5 (Biscay) and 3 (Iberia, Azores) years)	Bay of Biscay - Along French coast to Santander = 7.6 N m-2 Bay of Biscay - Santander to La Coruña = 60 N m-2 Iberian Peninsula = 3 N m-2 Azores = 3 N m-2	Modelling – GLM
		GNCS	Kinetic energy at the seabed due to waves (mean of annual 90th percentile values)	11.41 N m^{-2}	Modelling – GLM
		Arctic	Wave exposure index at the seabed, calculated from wind data (mean of annual 90th percentile values over six years)	100,000	Expert judgement – align with GNCS boundary
	High/ Moderate current energy	IBM	Kinetic energy at the seabed due to currents (mean of annual 90th percentile values over 5 (Biscay) and 3 (Iberia, Azores) years)	900 N m^{-2}	Modelling – GLM
		GNCS, Arctic	Kinetic energy at the seabed due to currents (mean of annual 90th percentile values over six years)	1,160 N m^{-2}	Value from literature (Connor et al, 2004)

Habitat descriptor	Habitat descriptor class boundary	Applicable regions[2]	Variable(s)	Threshold value	Method of determining threshold
	Moderate/ Low current energy	IBM	Kinetic energy at the seabed due to currents (mean of annual 90th percentile values over 5 (Biscay) and 3 (Iberia, Azores) years)	100 N m^{-2}	Modelling – GLM
		GNCS, Arctic	Kinetic energy at the seabed due to currents (mean of annual 90th percentile values over six years)	130 N m^{-2}	Value from literature (Connor et al, 2004)
Substrate	Rock/ Sediment	-	Relative proportions of gravel, sand and mud, or presence of rock	Presence of rock	Pre-classified
	Coarse sediment/ Other sediment	-	Relative proportions of gravel, sand and mud, or presence of rock	If sand:mud < 9:1 then %gravel = 80% If sand:mud > 9:1 then %gravel = 5%	Pre-classified
	Mixed sediment/ Other sediment	-	Relative proportions of gravel, sand and mud, or presence of rock	Sand:mud < 9:1 and 5% < %gravel < 80%	Pre-classified
	Fine mud/ Other sediment	-	Relative proportions of gravel, sand and mud, or presence of rock	Sand:mud < 1:9 and %gravel < 5 %	Pre-classified
	Sandy mud/ Other sediment	-	Relative proportions of gravel, sand and mud, or presence of rock	1:9 < sand:mud < 9:1 and %gravel < 5%	Pre-classified
	Sand/ Other sediment	-	Relative proportions of gravel, sand and mud, or presence of rock	Sand:mud > 9:1 and %gravel < 5%	Pre-classified

3.1.3 Habitat map and confidence map

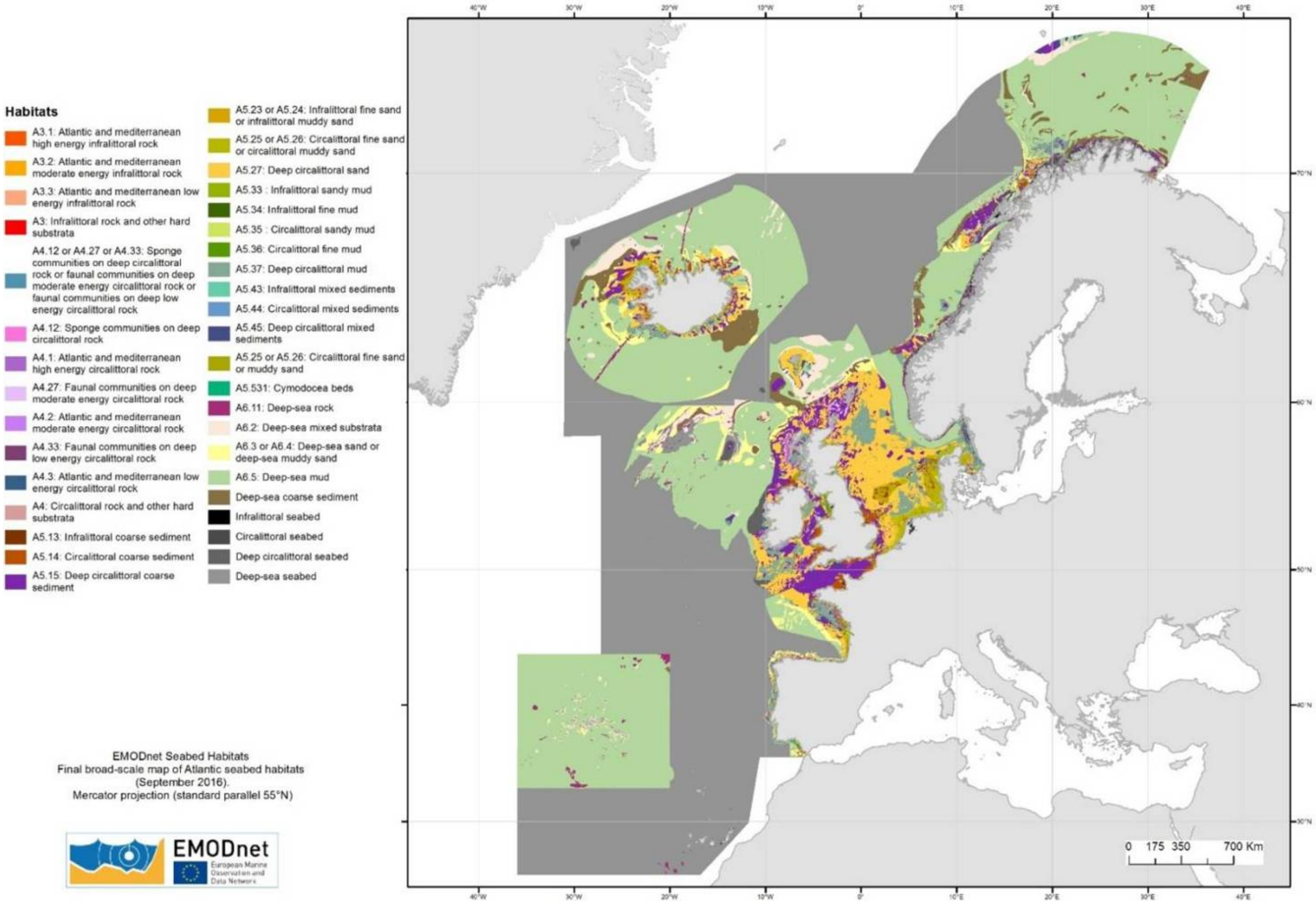


Figure 3.1.1: Final EUNIS habitat map for Atlantic and Arctic seas. Further discrimination of biological zones was made in grey areas of the deep-sea, which are not shown here because there is no substrate information.

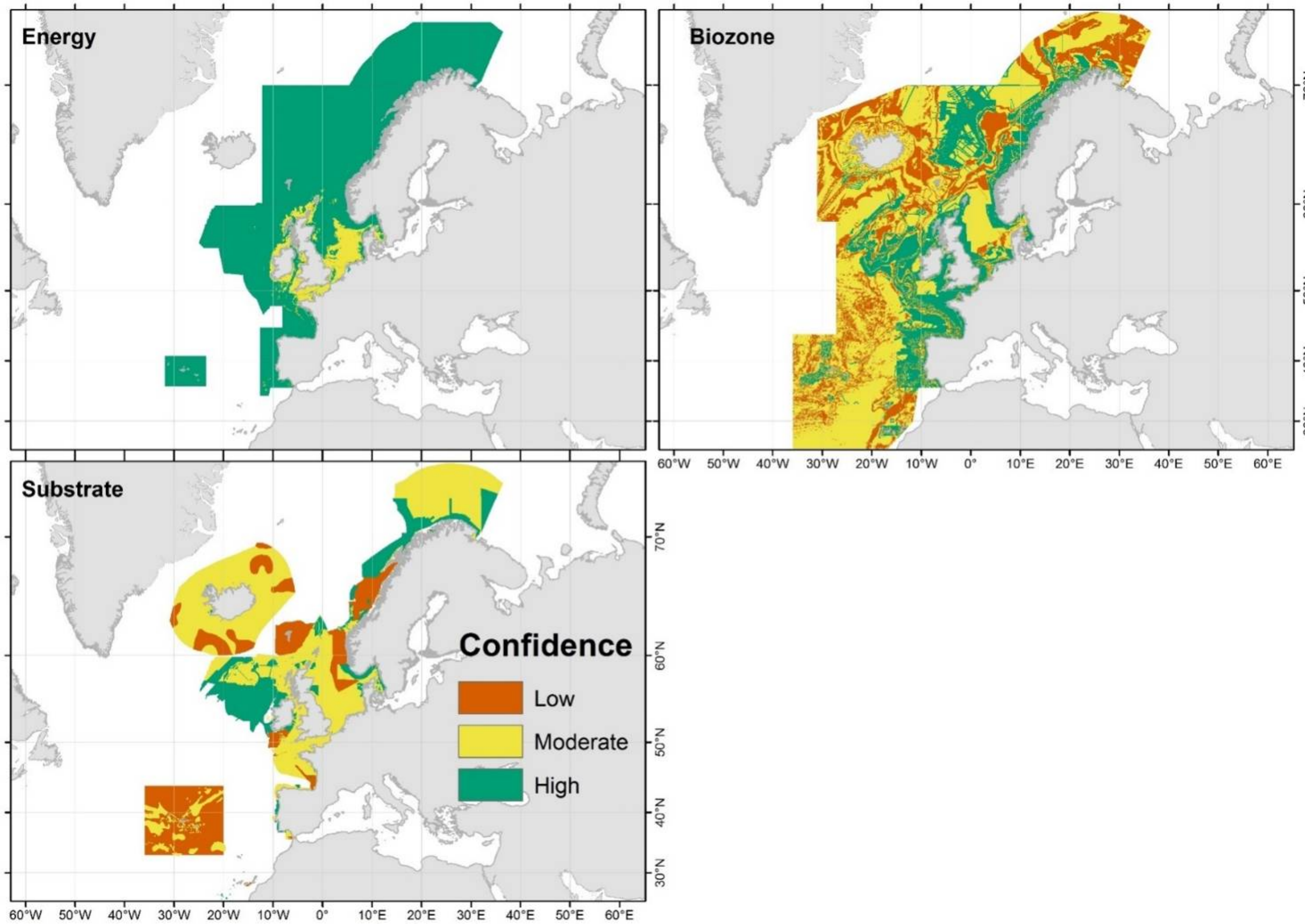


Figure 3.1.2: Confidence in the three habitat descriptors used in the Atlantic and Arctic Seas

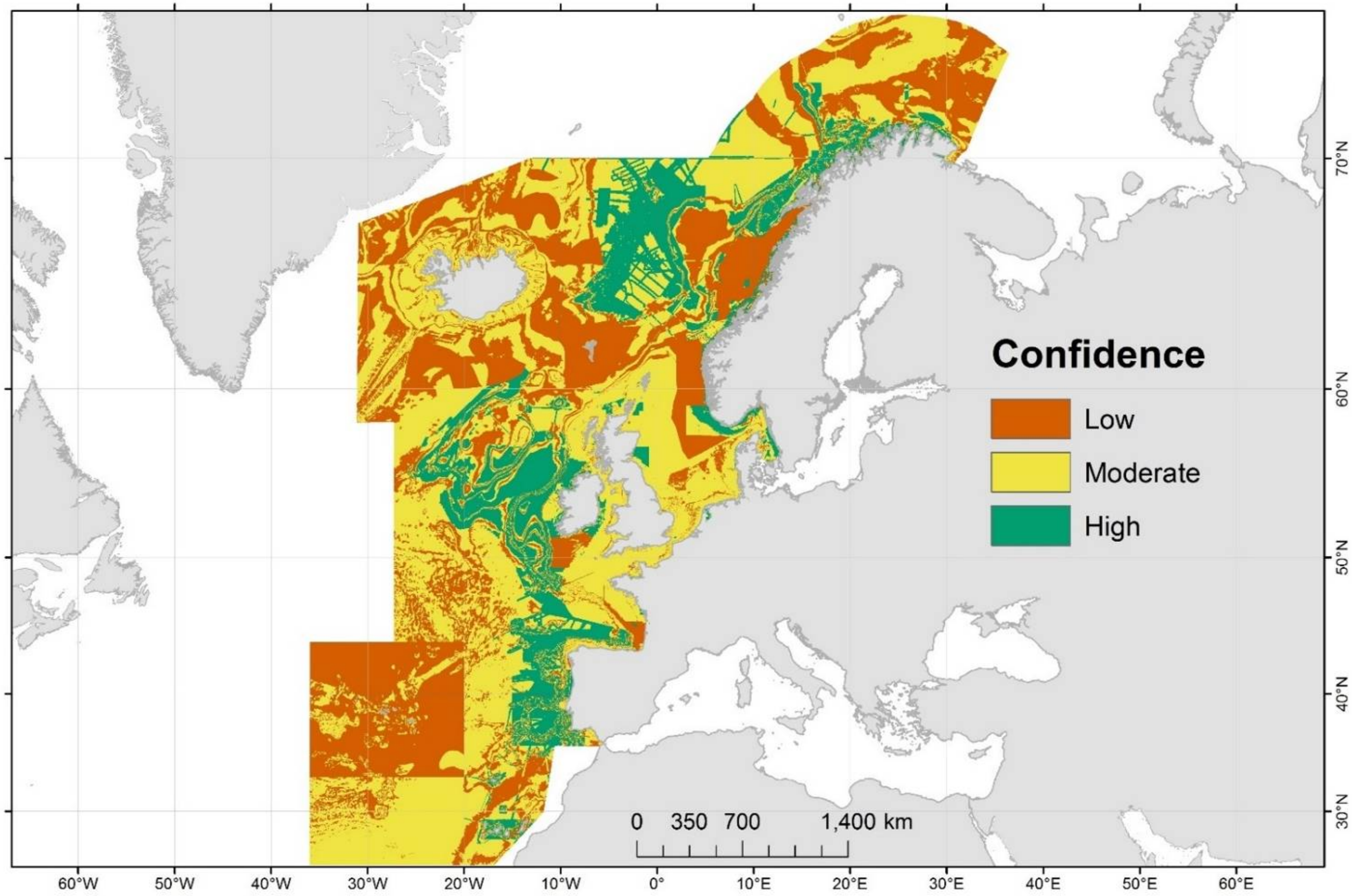


Figure 3.1.3: Overall confidence in the predicted habitat type in the Atlantic and Arctic Seas

3.2 Baltic Sea

3.2.1 EUNIS applicability

To some extent, levels 3 and 4 of EUNIS version 2007-11 were deemed suitable for describing the variation in physical seabed habitat types in the Baltic Sea (Table 3.2.1). However, compared with the adjoining Atlantic seas, tidal action is greatly reduced and salinity is more variable. Therefore, in addition to the standard EUNIS classification, an alternative classification was also mapped, which further divides each class in Table 3.2.1 into four sub-classes depending on the salinity regime: oligohaline, mesohaline, polyhaline or marine.

Table 3.2.1: EUNIS habitat types in the Baltic Sea at Level 3 and 4 which can be identified from the ecological unit categories seabed substrate, biological zone and, for rock substrate, energy class. Grey cells are for those combinations that do not have a EUNIS equivalent.

Biological zone	Substrate type							
	Rock/ Reef			Coarse sediment	Sand	Muddy sand OR Sandy mud	Mud	Mixed sediment
	Energy class							
	Exposed	Moderate	Sheltered					
Infralittoral	A3.4 Baltic exposed infralittoral rock	A3.5 Baltic moderately exposed infralittoral rock	A3.6 Baltic sheltered infralittoral rock	A5.13 Infralittoral coarse sediment	A5.23 Infralittoral fine sand OR A5.24 Infralittoral muddy sand	A5.33 Infralittoral sandy mud	A5.34 Infralittoral fine mud	A5.43 Infralittoral mixed sediments
Shallow circalittoral	A4.4 Baltic exposed circalittoral rock	A4.5 Baltic moderately exposed circalittoral rock	A4.6 Baltic sheltered circalittoral rock	A5.14 Circalittoral coarse sediment	A5.25 Circalittoral fine sand or A5.26 Circalittoral fine sand	A5.35 Circalittoral sandy mud	A5.36 Circalittoral fine mud	A5.44 Circalittoral mixed sediments
Deep circalittoral	-	-	-	A5.15 Deep circalittoral coarse sediment	A5.27 Deep circalittoral sand	A5.37 Deep circalittoral mud	A5.37 Deep circalittoral fine mud	A5.45 Deep circalittoral mixed sediments

During the course of the project, the HELCOM Underwater Biotopes system (HELCOM, 2013) was considered for use in the Baltic Sea; however, the decision was made to use EUNIS because (a) it allowed more distinction of habitat types based on physical variables alone, and (b) EUNIS was a requirement of the project.

3.2.2 Thresholds

This section summarises the interpretation of the meaning of the various zones (Table 3.2.2) and salinity classes (Table 3.2.3) used in the mapping in terms of physical variables and the resultant physical variables and values used to map their extents (Table 3.2.3) in the Baltic Sea.

Table 3.2.2: Variables known or assumed to influence biological zonation of the seabed in the Baltic Sea.

Biological zone boundary	Rocky bottoms	Soft bottoms	Relationship to HELCOM Underwater Biotopes system (HELCOM, 2013)
Infralittoral / Shallow circalittoral	The limit of domination of photophilic macroalgae caused primarily by decreasing light availability. It is also associated with increasing stability in temperature, wave action and salinity (Connor et al., 2004).	A less distinct boundary but generally associated with the same variables described for rocky bottoms (Connor et al., 2004).	Roughly equivalent to the photic/aphotic boundary in HELCOM (2013), although the meaning of the terms photic/aphotic do not themselves correspond to this boundary as some light penetrates the shallow circalittoral zone, allowing growth of sparse red algae.
Shallow circalittoral / Deep circalittoral	Changes in dominant fauna based on haline stratification; this is associated with stability in salinity, wave action and temperature and can lead to reduced oxygen concentration.		No equivalent in HELCOM (2013).

Table 3.2.3: Biological relevance of salinity class boundaries in the Baltic Sea.

Salinity class boundary	Explanation
Oligohaline / Mesohaline	Tolerance limit of a number of marine species.
Mesohaline / Polyhaline	Tolerance limit of kelp, echinoderms and others.
Polyhaline / Marine	Tolerance limit of many stenohaline marine species.

Table 3.2.3: Thresholds used to classify the ecological unit in the Baltic Sea. For more details on the method of determining each threshold, please refer to the thresholds appendix.

Habitat descriptor	Habitat descriptor class boundary	Variable(s)	Threshold value	Method of determining threshold
Biological zone	Infralittoral/ Shallow circalittoral	Depth to seabed divided by Secchi disk depth.	1.6 in the oligohaline 2.5 in the mesohaline	Value from literature (Cameron and Askew, 2011)
	Shallow circalittoral/ Deep circalittoral	Probability of being below the deep halocline	0.9 (in the mesohaline only)	Value from literature (Cameron and Askew, 2011)
Energy class	High/ Moderate energy	Wave exposure index at the surface, calculated from wind data (mean of annual 90^{th} percentile values over 5 years)	600,000	Expert judgement – align with GNCS boundary
	Moderate/ Low energy	Wave exposure index at the surface, calculated from wind data (mean of annual 90^{th} percentile values over 5 years)	60,000	Expert judgement – align with GNCS boundary
Salinity class	Polyhaline / Marine	Salt concentration in the water at the seabed	30 psu	Value from literature (Cameron and Askew, 2011)
	Mesohaline / Polyhaline	Salt concentration in the water at the seabed	18 psu	Value from literature (Cameron and Askew, 2011)
	Oligohaline / Mesohaline	Salt concentration in the water at the seabed	4.5 psu	Value from literature (Cameron and Askew, 2011)
Substrate type	Rock/ Sediment	Relative proportions of gravel, sand and mud, or presence of rock	Presence of rock	Pre-classified
	Coarse sediment/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock	If sand:mud < 9:1 then %gravel = 80% If sand:mud > 9:1 then %gravel = 5%	Pre-classified
	Mixed sediment/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock	Sand:mud < 9:1 and 5% < %gravel < 80%	Pre-classified
	Fine mud/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock	Sand:mud < 1:9 and %gravel < 5 %	Pre-classified
	Sandy mud/ Other sediment	Relative proportions of gravel, sand and mud,	1:9 < sand:mud < 9:1	Pre-classified

		or presence of rock	and %gravel < 5%	
	Sand/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock	Sand:mud > 9:1 and %gravel < 5%	Pre-classified

3.2.3 Habitat map and confidence map

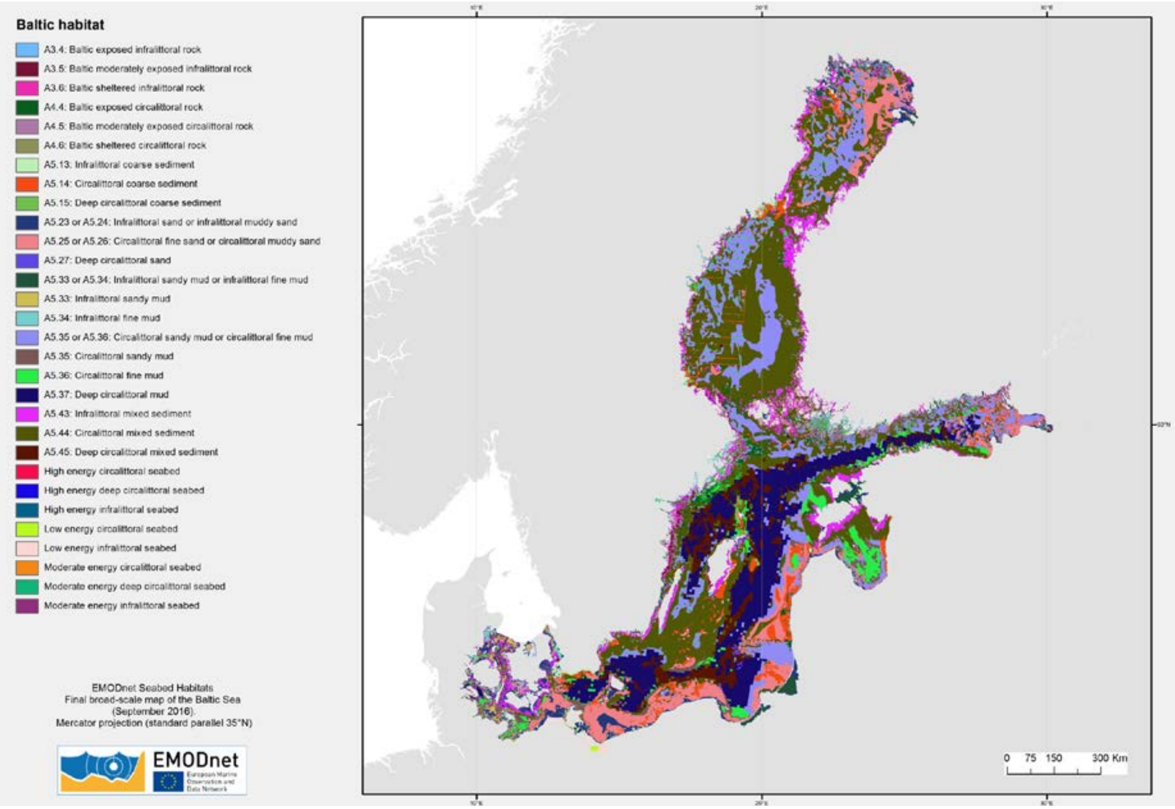


Figure 3.2.1: Final EUNIS habitat map for the Baltic Sea. Further discrimination based on salinity is not shown here because they do not fit into the EUNIS classification system.

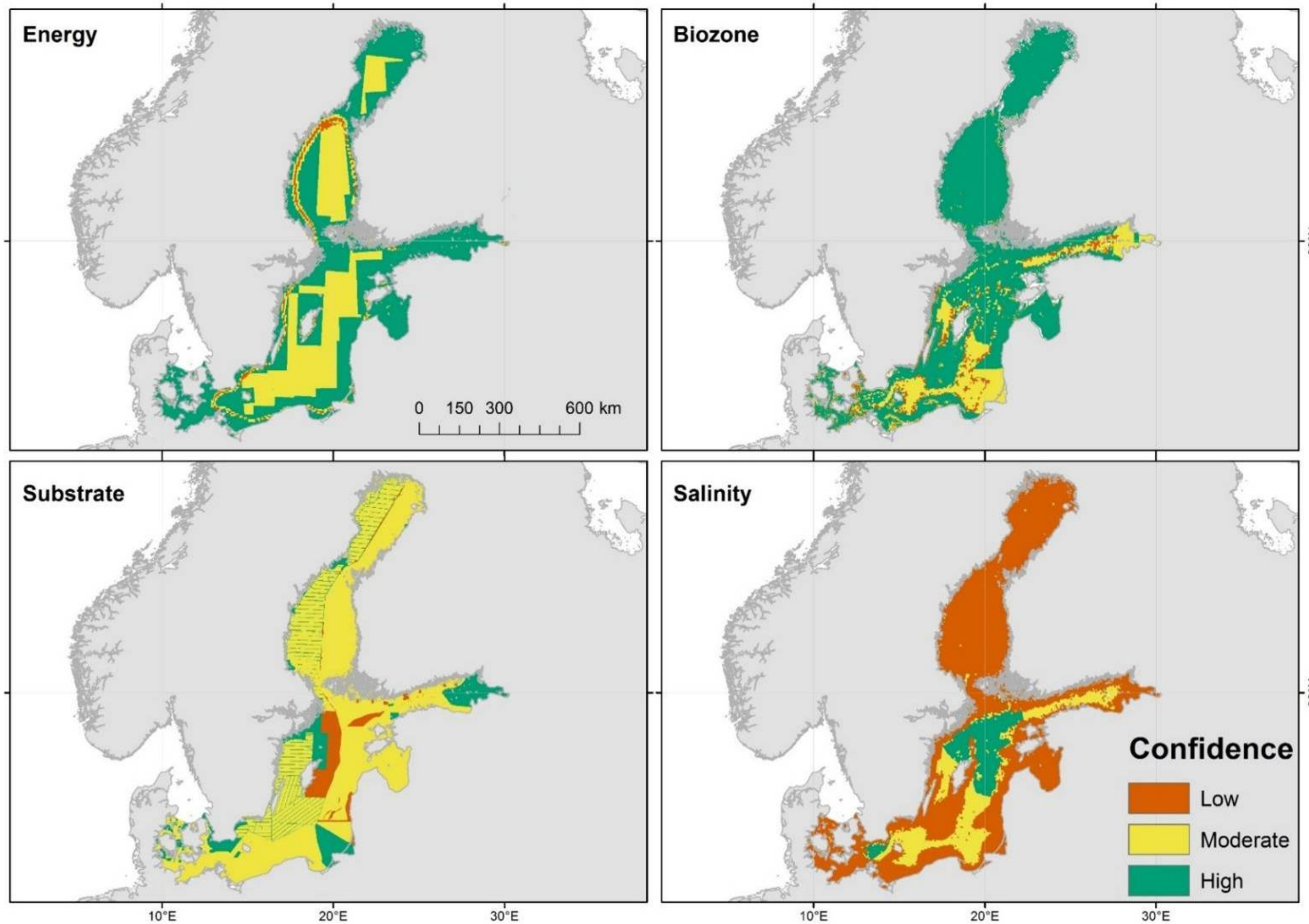


Figure 3.2.2: Confidence in the four habitat descriptors used in the Baltic Sea

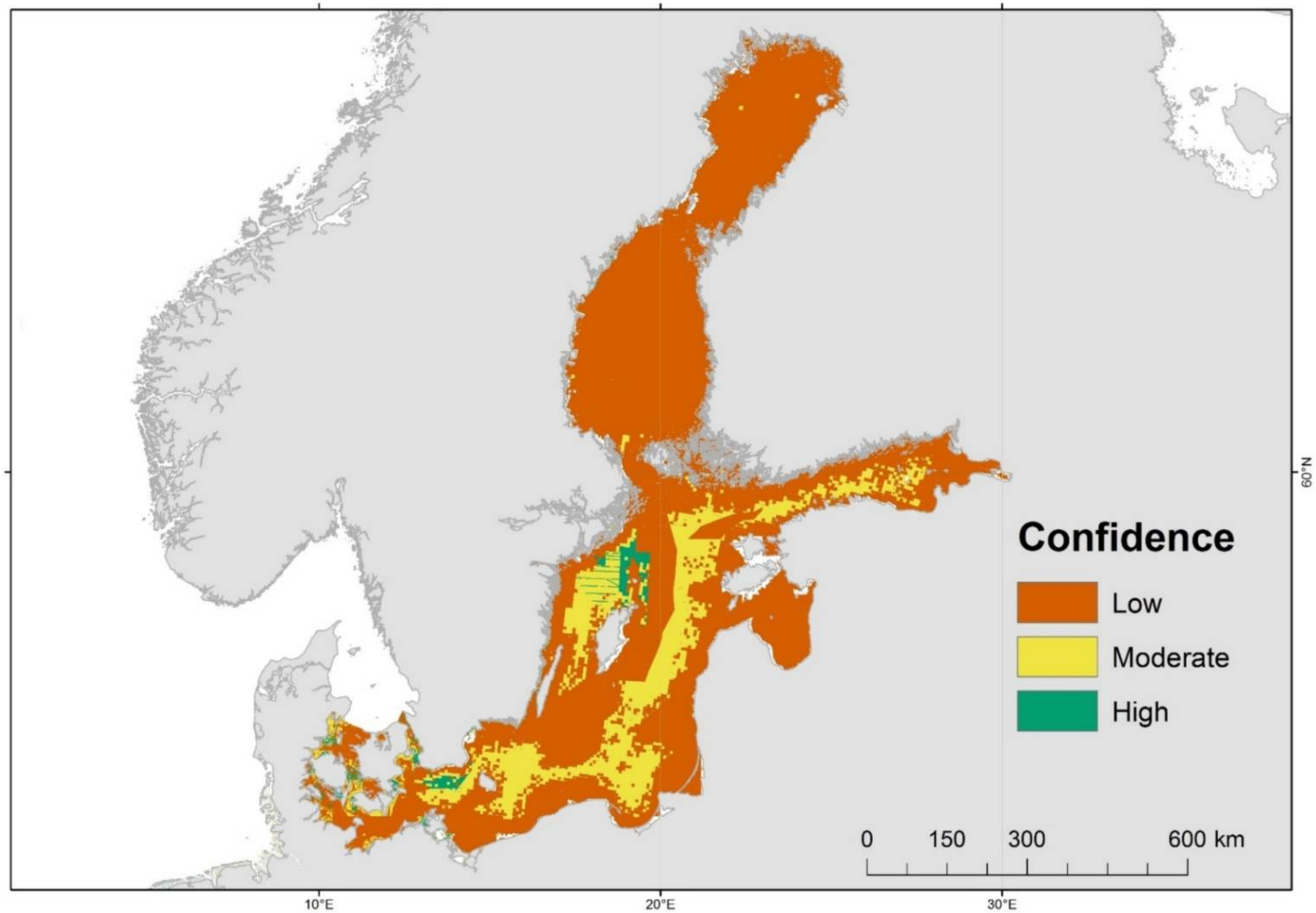


Figure 3.2.3: Overall confidence in the predicted habitat type in the Baltic Sea.

3.3 Mediterranean Sea

3.3.1 EUNIS applicability

The Mediterranean broad scale habitats were modeled using the same approach identified in urEmodnet for the western Mediterranean (Askew and Cameron, 2011). This consisted in first identifying the benthic assemblages (or groups of assemblages) whose extension is such that they can be portrayed at a broad scale level and then identifying the qualifying environmental factors that can be used to model each assemblage distribution (i.e.substrate classes, depth zones, estimated light reaching the sea bottom). Table 3.3.1 summarizes the assumptions made to streamline known Mediterranean benthic assemblages into broad scale habitat classes. This procedure was feasible because a regional benthic habitat classification scheme based on benthic zonation rules involving biological zones and substrate class combinations exists within the framework of the Barcelona convention (UNEP, 2006) and because the Barcelona convention habitat categories have been included within the EUNIS 2007-2011 habitat classification scheme.

This approach deviates marginally from that used in the Atlantic Ocean where the EUNIS 2007-2011 Folk 5 substrate classes each allow to model distinctly different broad scale habitats. In the Mediterranean Sea merging of more than one substrate class was often necessary in order to model a given broad scale habitat type. This is particularly evident in the circalittoral soft bottoms where, in the absence of spatial layers qualifying for bioclastic / biogenic features that would allow to model the detritic bottoms (derived for example from shelly debris), the coarse and mixed habitat class was sometimes considered together with other soft bottom classes to model specific habitat types (i.e. Mediterranean animal communities of coastal detritic bottoms, Mediterranean communities of shelf-edge detritic bottoms). All modeled broad scale habitats have an equivalent EUNIS habitat code (version 2007-2011), consisting mostly in EUNIS level 3 and 4 codes (See table 3.10). However the EUNIS numbering behind the broad habitats does not always follow a sequential numerical order (i.e. some habitats belonging to different biological zones have same number of EUNIS level 2 codes). This is due to the fact that the biological zone repartition used in EUSEAMAP (i.e. infralittoral, circalittoral, bathyal and abyssal) is not completely coincident with the EUNIS (version 2007; http://www.eea.europa.eu/themes/biodiversity/eunis/eunis-habitat-classification) level 2 marine benthic habitat classification structure, which considers the infralittoral and circalittoral soft bottoms as belonging to the single EUNIS category “A5 – sublittoral sediment” and the bathyal and abyssal zones as belonging to the single EUNIS category “A6 – deep sea”. The EUNIS marine habitat classification was under revision during the project. In the proposed revised EUNIS version the four above mentioned biological zones are described in level 2 though the circalittoral and bathyal zones will be subdivided into subzones.

Two specific aspects worth mentioning regarding the different modeling procedure adopted in the Mediterranean:

- The absence of a subdivision of the circalittoral habitats into a “shallow” and a “deep” section which otherwise appears in the other modeled basins. In the Mediterranean circalittoral zone where it was recognized that decreasing light conditions influence the zonation of several “sciaphilic” assemblages of the shallow circalittoral, there is no environmental parameter that can be used to univocally model circalittoral habitats in two distinct subzones. Light on the seafloor is however used to model some circalittoral habitats from others.
- River influenced coastal areas are modeled with different rules from the remaining parts of the basin. The considerations behind the river plume areas are described in sections 2 and 4 of the present report.

The modeled broad scale habitats are listed in table 3.10. Some uncertain habitats are present in the final modeled output (indicated in orange background). These habitats occur in the sandy mud and muddy infralittoral and their uncertainty is likely determined by poor substrate data quality or by poor biological zone boundary delimitation. In the latter case, this may be due to coastal areas where sediment apposition from land based sources is high and contributes to the formation of shallow water circalittoral muddy assemblages (i.e. coastal terrigenous muds) rather than the expected light driven infralittoral sandy and rocky assemblages. The table also indicates the presence of some unexpected habitats (blue cells with white text) occurring in the deeper areas of the bathyal and abyssal zones. This condition is similar to that experienced in urEMODnet western Mediterranean map. The modeled habitat output in fact highlighted the presence of habitats with substrate types that were previously unknown from a benthic point of view and which need further investigation in terms of describing the expected benthic assemblages associated to them.

Table 3.3.1: List of expected Mediterranean broad-scale habitat with a description of the associated biological assemblages

Broad scale habitat name	Description of Mediterranean benthic assemblages and equivalent Barcelona convention habitat name
A3 Infralittoral rock and other hard substrata	*III.6 Hard beds and rocks (contains Biocenosis of infralittoral algae)*
A5.13 Infralittoral coarse and mixed sediment	III.3 Coarse sands with more or less mud (contains Biocenosis of coarse sands and fine gravels mixed by the waves, Biocenosis of coarse sands and fine gravels under the influence of bottom currents)
A5.23 Infralittoral fine sand	III. 2. Fine sands with more or less mud (contains Biocenosis of fine sands in very shallow waters, Biocenosis of well sorted fine sands, Biocenosis of superficial muddy sands in sheltered waters *)*
A4.26 Mediterranean coralligenous communities moderately exposed to hydrodynamic action OR A4.32 Mediterranean coralligenous communities sheltered from hydrodynamic action	IV.3.1 Coralligenous biocenosis
A5.46 Mediterranean animal communities of coastal detritic bottoms	*IV.2.2 Biocenosis of the coastal detritic bottom*
A5.38 Mediterranean biocoenosis of muddy detritic bottoms	IV.2.1 Biocenosis of the muddy detritic bottom
A5.39 Mediterranean biocoenosis of coastal terrigenous muds	IV.1.1. Biocoenosis of coastal terrigenous muds
A4.27 Faunal communities on deep moderate energy circalittoral rock	IV.3.3 Biocenosis of shelf-edge rock
A5.47 Mediterranean communities of shelf-edge detritic bottoms	IV.2.3 Biocenosis of shelf-edge detritic bottoms
A6.11 Deep-sea bedrock	V.3 Hard beds and rocks (includes Biocenosis of deep sea corals, Caves and ducts in total darkness)

A6.3 Deep-sea sand	V. 2. SANDS (includes Biocenosis of bathyal detritic sands with *Gryphus vitreus)*
A6.511 Facies of sandy muds with *Thenea muricata*	V. 1. 1. 1. Facies of sandy muds with *Thenea muricata (Biocenosis of bathyal muds)*
A6.51 Mediterranean communities of bathyal muds	V. 1. 1. 2. Facies of fluid muds with *Brissopsis lyrifera,* V. 1. 1. 3. Facies soft muds with *Funiculina quadrangularis* and *Aporrhais serresianus,* V. 1. 1. 4. Facies of compact muds with *Isidella elongata,* V. 1. 1. 5. Facies with *Pheronema grayi (Biocenosis of bathyal muds)*
A6.52 Communities of abyssal muds	VI. 1. 1. Biocenosis of abyssal muds

Table 3.3.2: EUNIS habitat types in the Mediterranean at Level 3 and 4 which can be identified from the ecological unit categories seabed substrate and biological zone. Orange cells are for those combinations that are considered as uncertain (i.e. the habitat is not clearly classified but occurs in some places).

Biological zone			Substrate type					
			Rock/ Reef	**Coarse and mixed sediment**	**Sand**	**Muddy sand**	**Sandy mud**	**Mud**
Infralittoral			A3 Infralittoral rock and other hard substrata	A5.13 Infralittoral coarse sediment	A5.23 Infralittoral fine sand	A5.23 Infralittoral fine sand	A5.33 Infralittoral sandy mud	A5.34 Infralittoral fine mud
Circalittoral	**Fraction of light at seabed**	**> 0.0001**	A4.26 Mediterranean coralligenous communities moderately exposed to hydrodynamic action OR A4.32 Mediterranean coralligenous communities sheltered from hydrodynamic action	A5.46 Mediterranean faunal communities of coastal detritic bottoms	A5.46 Mediterranean faunal communities of coastal detritic bottoms	A5.46 Mediterranean faunal communities of coastal detritic bottoms	A5.38 Mediterranean biocoenosis of muddy detritic bottoms	A5.39 Mediterranean biocoenosis of coastal terrigenous muds

		< 0.0001	A4.27 Faunal communities on deep moderate energy circalittoral rock	A5.47 Mediterranean communities of shelf-edge detritic bottoms	A5.47 Mediterranean communities of shelf-edge detritic bottoms	A5.47 Mediterranean communities of shelf-edge detritic bottoms	A5.47 Mediterranean communities of shelf-edge detritic bottoms	A5.39 Mediterranean biocoenosis of coastal terrigenous muds
Bathyal			A6.11 Deep-sea bedrock	A6.2 Deep-sea mixed substrata	A6.3 Deep-sea sand	A6.4 Deep-sea muddy sand	A6.511 Facies of sandy muds with *Thenea muricata*	A6.51 Mediterranean communities of bathyal muds
Abyssal			A6.11 Deep-sea bedrock	A6.2 Deep-sea mixed substrata	A6.3 Deep-sea sand	A6.4 Deep-sea muddy sand	A6.52 Communities of abyssal muds	A6.52 Communities of abyssal muds

Table 3.3.3: EUNIS habitat types within Mediterranean river plume areas, which are identified from the data layers seabed substrate and biological zone. Grey cells are for those combinations that don't occur in these areas.

Biological zone	Substrate type					
	Rock	**Coarse sediment**	**Sand**	**Muddy sand**	**Sandy mud**	**Mud**
Infralittoral	A3 Infralittoral rock and other hard substrata	A5.13 Infralittoral coarse sediment	A5.23 Infralittoral fine sand	A5.23 Infralittoral fine sand	-	-
Circalittoral	A4 Circalittoral rock and other hard substrata	A5.14 Circalittoral coarse sediment	A5.25 Circalittoral fine sand	A5.26 Circalittoral muddy sand	A5.35 Circalittoral sandy mud	A5.36 Circalittoral fine mud

3.3.2 Thresholds

This section summarises the interpretation of the meaning of the various zones (Table 3.3.4) used in the mapping in terms of physical variables and the resultant physical variables and values used to map their extents (Table 3.3.5) in the Mediterranean.

Table 3.3.4: Variables known or assumed to influence biological zonation of the seabed in the Mediterranean.

Biological zone boundary	Rocky bottoms	Soft bottoms	River plume areas
Infralittoral / Circalittoral	The limit of photophilic macroalgae caused by decreasing light availability.	The limit of marine phanerogams (seed-producing plants such as seagrass) associated with decreasing light availability.	The lowest depth limit of the muddy sand and sand bottoms influenced by the high riverine input.
Circalittoral / Bathyal	Shelf edge delimited by the slope angle change of the continental platform		N/A
Bathyal / Abyssal	Shelf slope break delimited by the slope angle change of the continental platform		N/A

Table 3.3.5: Thresholds used to classify the ecological units in the Mediterranean. For more details on the method of determining each threshold, please refer to the thresholds appendix.

Habitat descriptor	Habitat descriptor class boundary	Variable(s)	Threshold value	Method of determining threshold
Biological zone	Infralittoral/ Circalittoral (outside of river plume areas)	Photosynthetically available radiation (PAR) at the seabed, $I = I_0 \, e^{-d.Kd(PAR)}$ With I_0 = PAR at the surface, d = depth to the seabed, and	1.82 mol. phot. m^2 d^{-1}	Modelling - GLM

		K_d(PAR) = Light attenuation coefficient at depth d in relation to PAR (mean over five years)		
	Infralittoral/ Circalittoral (in river plume areas)	Probability of sand and muddy sand, based on GAM using wave energy at sea bottom, depth and geographic position (latitude and longitude) as predictor variables.	GAM probability of 0.48	Modelling - GAM
	Circalittoral/ Bathyal	Depth to the seabed	Shelf edge	Manual/expert judgement
	Bathyal/ Abyssal	Depth to the seabed	Foot of slope	Manual/expert judgement
Substrate type	Rock/ Sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	Presence of rock	Pre-classified
	Coarse & mixed sediment/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	%gravel > 5 %.	Pre-classified
	Fine mud/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	Sand:mud < 1:9 and %gravel < 5 %	Pre-classified
	Sandy mud/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	1:9 < sand:mud < 1:1 and %gravel < 5 %	Pre-classified
	Muddy sand/Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	1:1 < sand:mud < 9:1 and %gravel < 5 %	Pre-classified
	Sand/Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	Sand:mud > 9:1 and %gravel < 5 %	Pre-classified

3.3.3 Habitat map and confidence map

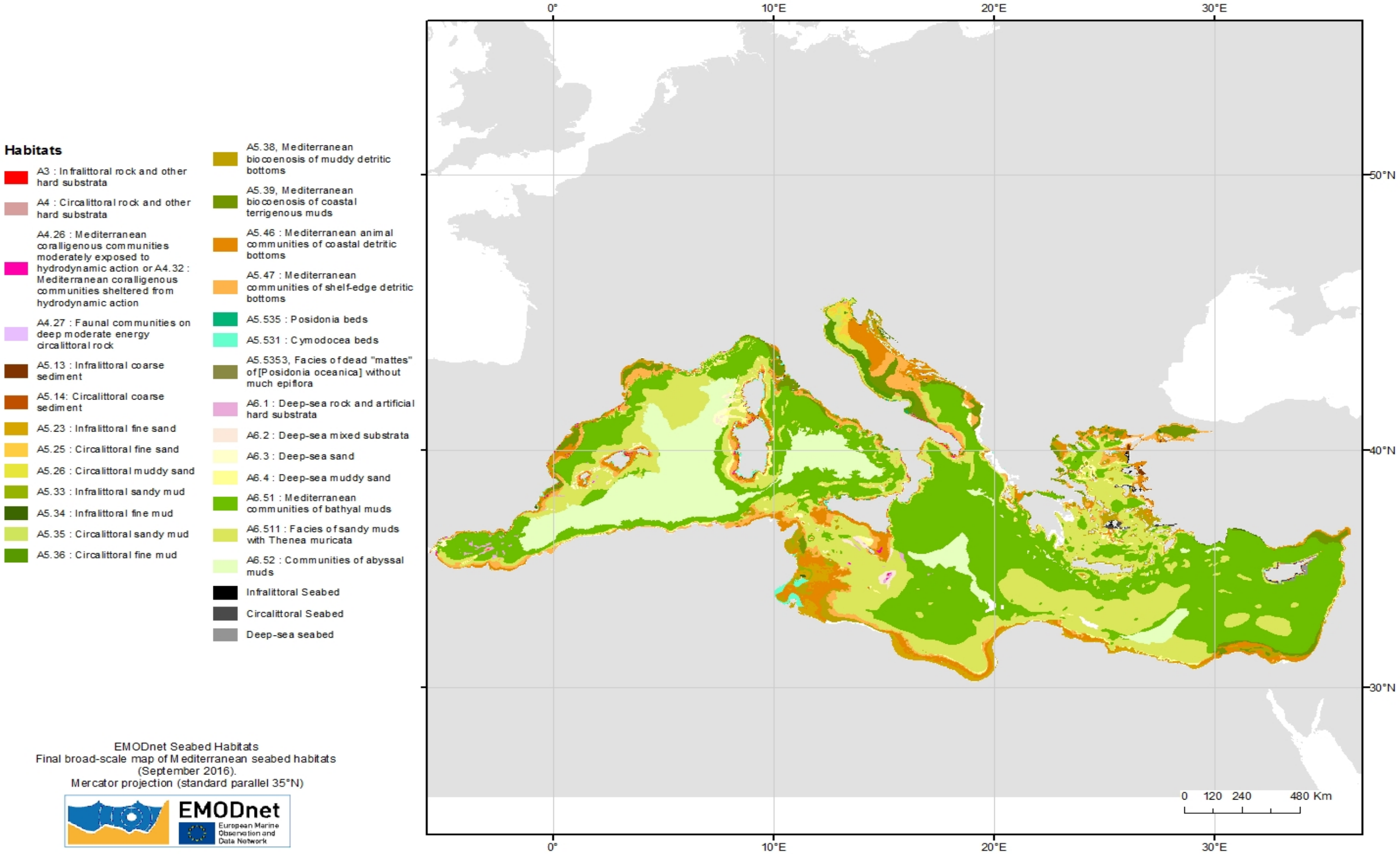


Figure 3.3.1: Final EUNIS habitat map for the Mediterranean.

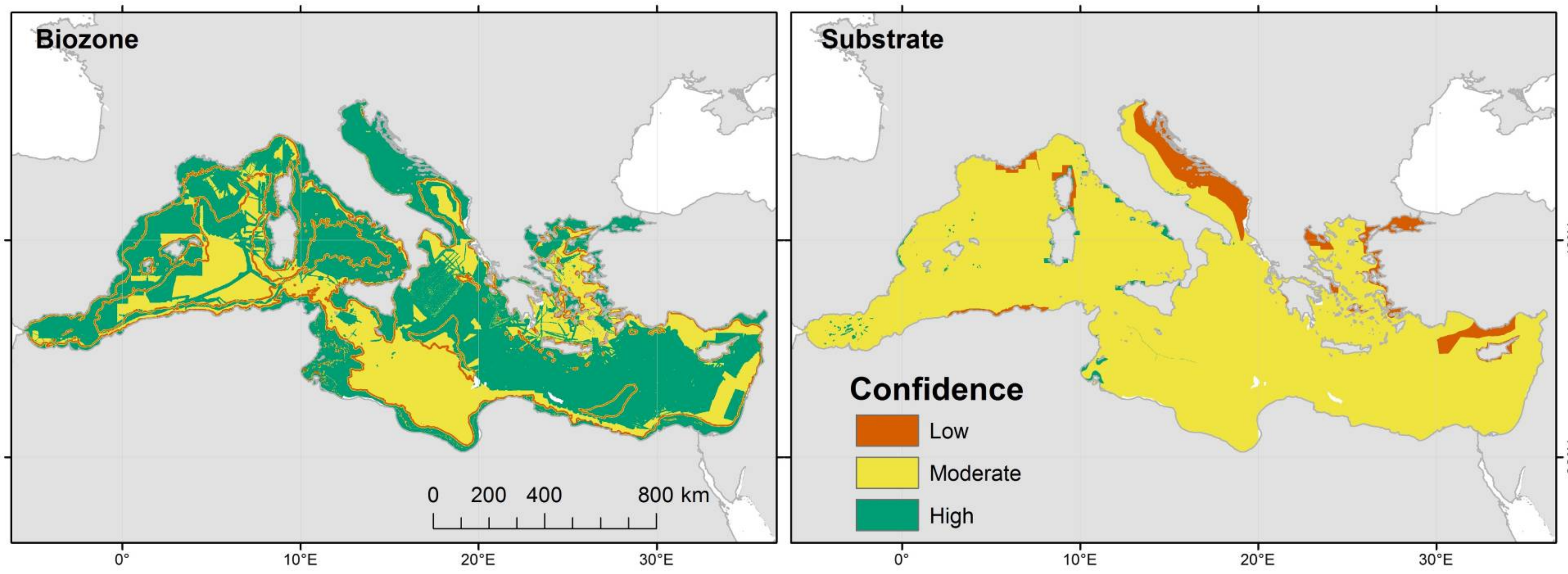


Figure 3.3.2: Confidence in the two habitat descriptors used in the Mediterranean Sea

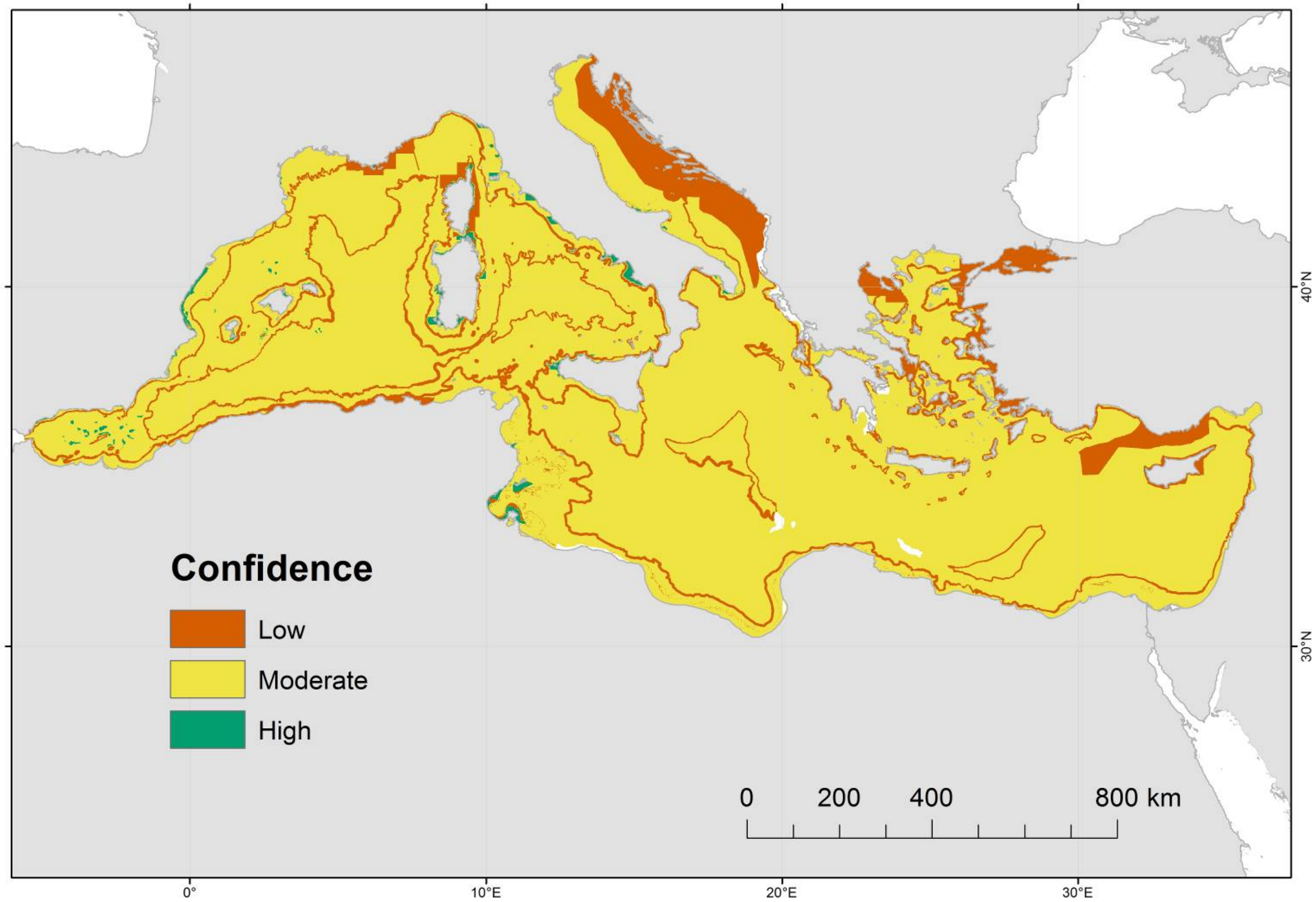


Figure 3.3.3: Overall confidence in the predicted habitat type in the Mediterranean Sea

3.4 Black Sea

3.4.1 EUNIS applicability

In the Black Sea noticeable efforts were placed in compounding all available literature on the distribution of benthic habitats and their relative relationship with abiotic parameters. It is to be noted that at a basin wide level there is no concerted agreement over a unambiguous list of known benthic assemblages nor any hierarchical classification scheme according to which these assemblages are sorted out. In the Black Sea this work remained to be undertaken because there has never been a task force capable of exhaustively tackling this issue, and some current Black Sea habitats listed in EUNIS are mostly adaptations of Mediterranean types using modifiers. Effort was placed in defining a pan Black Sea list of assemblages that could be portrayed at a broad scale and identifying the environmental variables that are likely to influence their distribution. This was done by checking literature and ground truth data for all identified assemblages and associated environmental parameters. A broad-scale Black Sea habitat list containing the known benthic assemblages occurring throughout the basin and the abiotic variables known to influence them is provided in Table 3.4.1.

While the general approach to naming the Black Sea habitats was to be consistent with the rest of EUNIS (Table 3.4.2), there are a few key areas where the standard terminology differs from EUNIS:

- Coarse and mixed sediment were added to the substrate considerations necessary to model some circalittoral assemblages known to occur on sand and mud. The addition of coarse and mixed sediments as a determining modelling variable is justified on the basis that these assemblages occur on sand and muddy bottoms characterized by a high proportion of shelly debris. Since no additional layers were provided by EMODnet Geology regarding the presence of bioclastic/biogenic material the only way to model the above-mentioned habitat types was to add the category “coarse and mixed” to the substrate type of these habitats.
- As with the Mediterranean, while the definitions of the EUNIS biological zones have generally been consistently applied across entire regions in this project, it was deemed unsuitable treat areas under the influence of high fine sediment riverine input in the same way as the rest of the Black Sea. Therefore, the variables used to define the infralittoral / circalittoral boundary were different (
- Table **3.**4.2).

Table 3.4.1: List of expected Black Sea broad-scale habitat with a description of the associated biological assemblages.

Broad scale habitat name	Description
Infralittoral sand (Plume)	Fine sand with *Lentidium mediterraneum*
Infralittoral muddy sand (Plume)	*Cerastoderma glaucum, Mya arenaria, Anadara kagoshimensis*
Circalittoral coarse and mixed sediment (Plume)	Diverse faunal assamblages due to hetergenous substrate dominated by bivalves *Mytilus galloprovincialis, Spisula subtruncata, Acanthocardia paucicostata* and polichaetes *Nephtys hombergii*
Circalittoral terrigenous muds (Plume)	Danube and Dnieper plume areas (Mud with *Melinna palmata, Mya arenaria, Alitta succinea, Nephtys hombergii)*
Infralittoral rocks with photophilic algae	*Cystoseira barbata* + *Ulva rigida*+ *Polysiphonia subulifera* *Cladophora spp. - Ulva rigida - Ulva intestinalis - Gelidium spp.*
Infralittoral coarse and mixed sediment	Infralittoral shelly gravel and sand with *Chamelea gallina* and *Mytilus galloprovincialis*
Infralittoral sand and muddy sand	Shallow fine sands with *Lentidium mediterraneum, Tellina tenuis* Medium to coarse sands with *Donax trunculus* Infralittoral sand with *Chamelea gallina* (with *Cerastoderma glaucum, Lucinella divaricata, Gouldia minima*) (depends of region) Muddy sand with burrowing thalassinid *Upogebia pusilla/Pestarella candida*
Infralittoral mud and sandy mud	Mud and sandy mud with *Upogebia pusilla* Sandy mud and mud with seagrass meadows
Circalittoral rock	Sciaphilic algae *(Phyllophora* spp. + *Polysiphonia* spp. + Apoglosium + *Zanardinia* spp.+ *Gelidium* spp.), sponges and hydroids
Shallow circalittoral shelly organogenic sand (clean shelly debris without mud)	*Mytilus galloprovincialis* biogenic reefs *Coccotylus truncatus & Phyllophora crispa* on shelly organogenic sand
Shallow circalittoral mud and organogenic sandy mud/muddy sand	Muds with *Abra nitida - Pitar rudis - Spisula subtruncata, Acanthocardia paucicostata* and *Nephtys hombergii* Muddy sand with *Dipolydora quadrilobata* meadows and *Mytilus galloprovincialis* biogenic reefs
Deep circalittoral coarse mixed sediments	Shelly muds with *Modiolula phaseolina*

Deep circalittoral sand and sandy mud	Sand and sandy mud with tunicates
Deep circalittoral mud	Mud with *Terebellides stroemii, Pachycerianthus solitarius, Amphiura stepanovi*
Deep circalittoral suboxic calcareous muds	White muds with *Bougainvillia muscus (ramosa)* and nematode communities (RO)
Deep circalittoral anoxic muds	Anoxic muds
Bathyal anoxic muds	
Abyssal seabed	

Table 3.4.2: Habitat types in the Black Sea which can be identified from the ecological unit categories seabed substrate, biological zone and, within the deep circalittoral, oxygen conditions. Grey cells are for those combinations that don't occur, pink cells are for those that are acknowledged, orange cells are for those that are considered as uncertain (i.e. the habitat is not acknowledged but occurs in some places), and blue cells (and white letters) are for those that are unexpected (i.e. the combination requires further investigation where it occurs).

Biological zone	Substrate type						
	Rock/ Reef	Coarse sediment	Sand	Muddy sand	Sandy mud	Mud	Mixed sediment
Infralittoral	Infralittoral rock	Infralittoral coarse and mixed sediment	Infralittoral sand and muddy sand	Infralittoral sand and muddy sand	Infralittoral mud and sandy mud	Infralittoral mud and sandy mud	Infralittoral coarse and mixed sediment
Shallow circalittoral	Circalittoral rock	Shallow circalittoral shelly organogenic sand	Shallow circalittoral shelly organogenic sand	Shallow circalittoral mud and organogenic sandy mud/muddy sand	Shallow circalittoral mud and organogenic sandy mud/muddy sand	Shallow circalittoral mud and organogenic sandy mud/muddy sand	Shallow circalittoral mud and organogenic sandy mud/muddy sand
Deep circalittoral — Oxygen conditio — Oxic		Deep circalittoral mixed sediments	Deep circalittoral sand	Deep circalittoral mixed sediments	Deep circalittoral mixed sediments	Deep circalittoral mud	Deep circalittoral mixed sediments

		Suboxic		Deep circalittoral suboxic coarse sediment	Deep circalittoral suboxic sand	Deep circalittoral suboxic muddy sand	Deep circalittoral suboxic sandy mud	Deep circalittoral suboxic calcareous muds	Deep circalittoral suboxic mixed sediment
		Anoxic		Deep circalittoral anoxic coarse sediment	Deep circalittoral anoxic sand	Deep circalittoral anoxic muddy sand	Deep circalittoral anoxic sandy mud	Deep circalittoral anoxic muds	Deep circalittoral anoxic mixed sediment
Bathyal			-	Bathyal anoxic coarse sediment	Bathyal anoxic sand	Bathyal anoxic muddy sand	Bathyal anoxic sandy mud	Bathyal anoxic muds	Bathyal anoxic mixed sediment
Abyssal			-	Abyssal seabed	Abyssal seabed	Abyssal seabed	Abyssal seabed	Abyssal seabed	Abyssal seabed

Table 3.4.3: Habitat types within Danube and Dnieper river plume areas, which are identified from the data layers seabed substrate and biological zone. Grey cells are for those combinations that do not occur in these areas.

Biological zone	**Substrate type**				
	Coarse sediment	**Sand**	**Muddy sand**	**Sandy mud**	**Mud**
Infralittoral	-	Infralittoral sand	Infralittoral muddy sand	-	-
Circalittoral	Circalittoral coarse and mixed Sediment	-	-	Circalittoral terrigenous muds	Circalittoral terrigenous muds

3.4.2 Thresholds

This section summarises the interpretation of the meaning of the various zones (Table 3.4.4) used in the mapping in terms of physical variables and the resultant physical variables and values used to map their extents in the Black Sea.

Table 3.4.4: Variables known or assumed to influence biological zonation of the seabed in the Black Sea.

Biological zone boundary	Rocky bottoms	Soft bottoms	River plume areas
Infralittoral / circalittoral	The limit of photophilic macroalgae caused by decreasing light availability.	Maximum depth at which the seabed is affected by stormy waves (7-8 Beaufort).	The lowest depth limit of the muddy sand and sand bottoms influenced by the high riverine input.
Shallow circalittoral / Deep circalittoral	Maximum depth at which seabed is affected by seasonal variations in temperature.		N/A
Deep circalittoral / Bathyal	Shelf edge delimited by the slope angle change of the continental platform		N/A
Bathyal / Abyssal	Shelf slope break delimited by the slope angle change of the continental platform.		N/A

Table 3.4.5: Thresholds used to classify the habitat descriptors in the Black Sea.

Habitat descriptor	Habitat descriptor class boundary	Variable(s)	Threshold value	Method of determining threshold
Biological zone	Infralittoral/ Circalittoral (rocky bottoms outside of river plume areas)	Depth to the seabed	14 m	Manual/expert judgement (bathymetric cut: *Cystoseira* presence/absence)
	Infralittoral/ Shallow Circalittoral (soft bottoms outside of river plume areas)	Depth to the seabed	19 m	Statistical
	Infralittoral/ Circalittoral (in river plume areas)	Seabed substrate type (pre-classified)	Presence of Sand or Muddy sand (Infralittoral) vs Presence of Coarse sediment, sandy mud or mud (Circalittoral)	Pre-classified
	Shallow Circalittoral/ Deep Circalittoral (soft bottoms)	Temperature at the seabed (95^{th} percentile values integrated over 2 summers)	9.7 °C	Modelling - GLM
	Circalittoral/ Bathyal	Depth to the seabed	Shelf edge	Manual/expert judgement

	Bathyal/ Abyssal	Depth to the seabed	2,100 m	Expert judgement
Oxygen conditions	Oxic/ Suboxic	Seawater density - sigma-theta (for December 1993)	Polyline corresponding to the intersection of the isopycnic 15.6 $kg.m^{-3}$ surface with the seabed	Statistical
	Suboxic/ Anoxic	Seawater density - sigma-theta (for December 1993)	Polyline corresponding to the intersection of the isopycnic 16.4 $kg.m^{-3}$ surface with the seabed	Statistical
Substrate	Rock/ Sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	Presence of rock	Pre-classified
	Coarse sediment/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	If sand:mud < 9:1 then %gravel = 80 %. If sand:mud > 9:1 then %gravel = 5 %	Pre-classified
	Mixed sediment/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	Sand:mud < 9:1 and 5 % < %gravel < 80 %	Pre-classified
	Fine mud/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	Sand:mud < 1:9 and %gravel < 5 %	Pre-classified
	Sandy mud/ Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	1:9 < sand:mud < 1:1 and %gravel < 5 %	Pre-classified
	Muddy sand/Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	1:1 < sand:mud < 9:1 and %gravel < 5 %	Pre-classified
	Sand/Other sediment	Relative proportions of gravel, sand and mud, or presence of rock (pre-classified)	Sand:mud > 9:1 and %gravel < 5 %	Pre-classified

3.4.3 Habitat map and confidence map

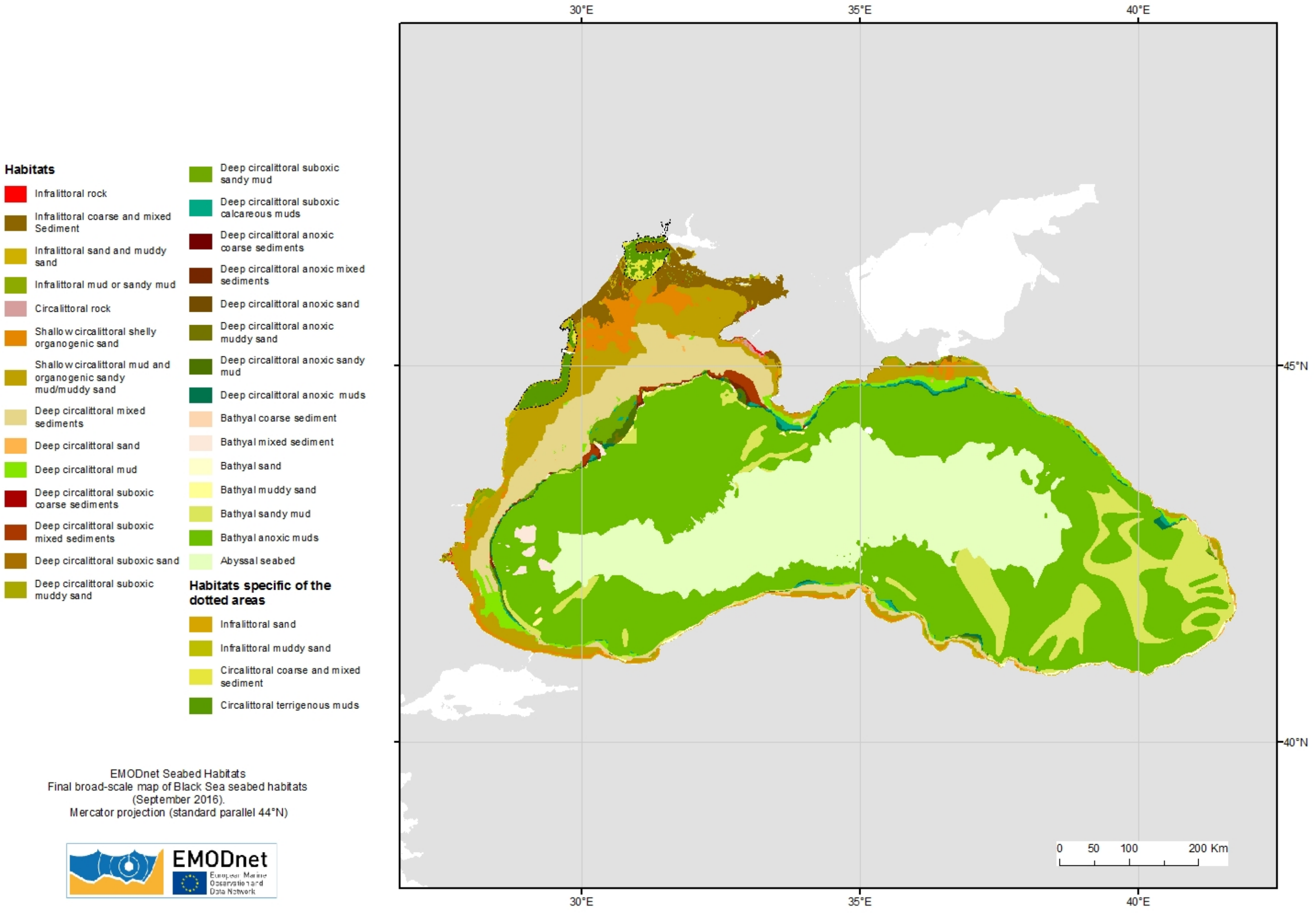


Figure 3.4.1: Final EUNIS habitat map for the Black Sea.

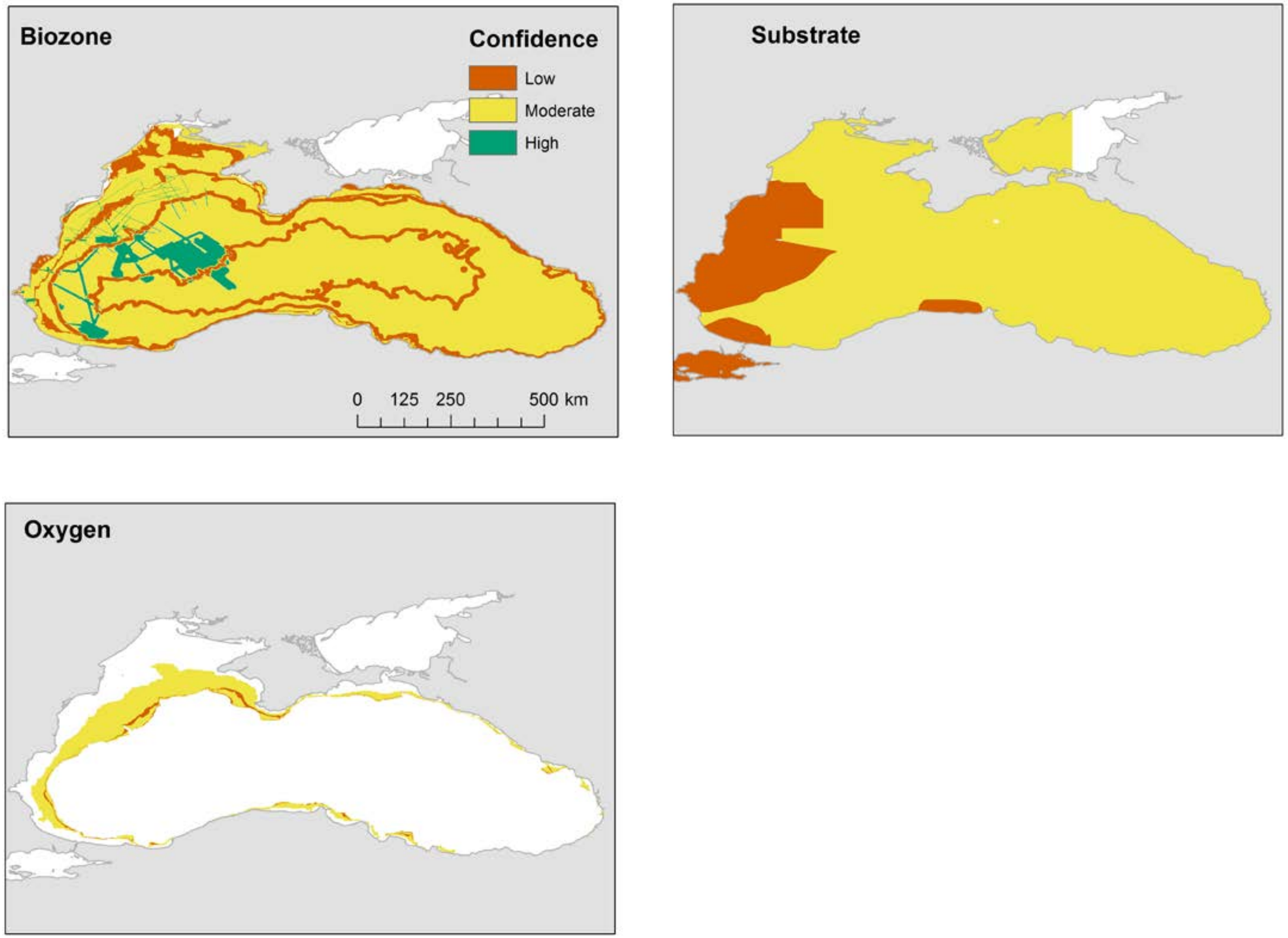


Figure 3.4.2: Confidence in the three habitat descriptors used in the Black Sea

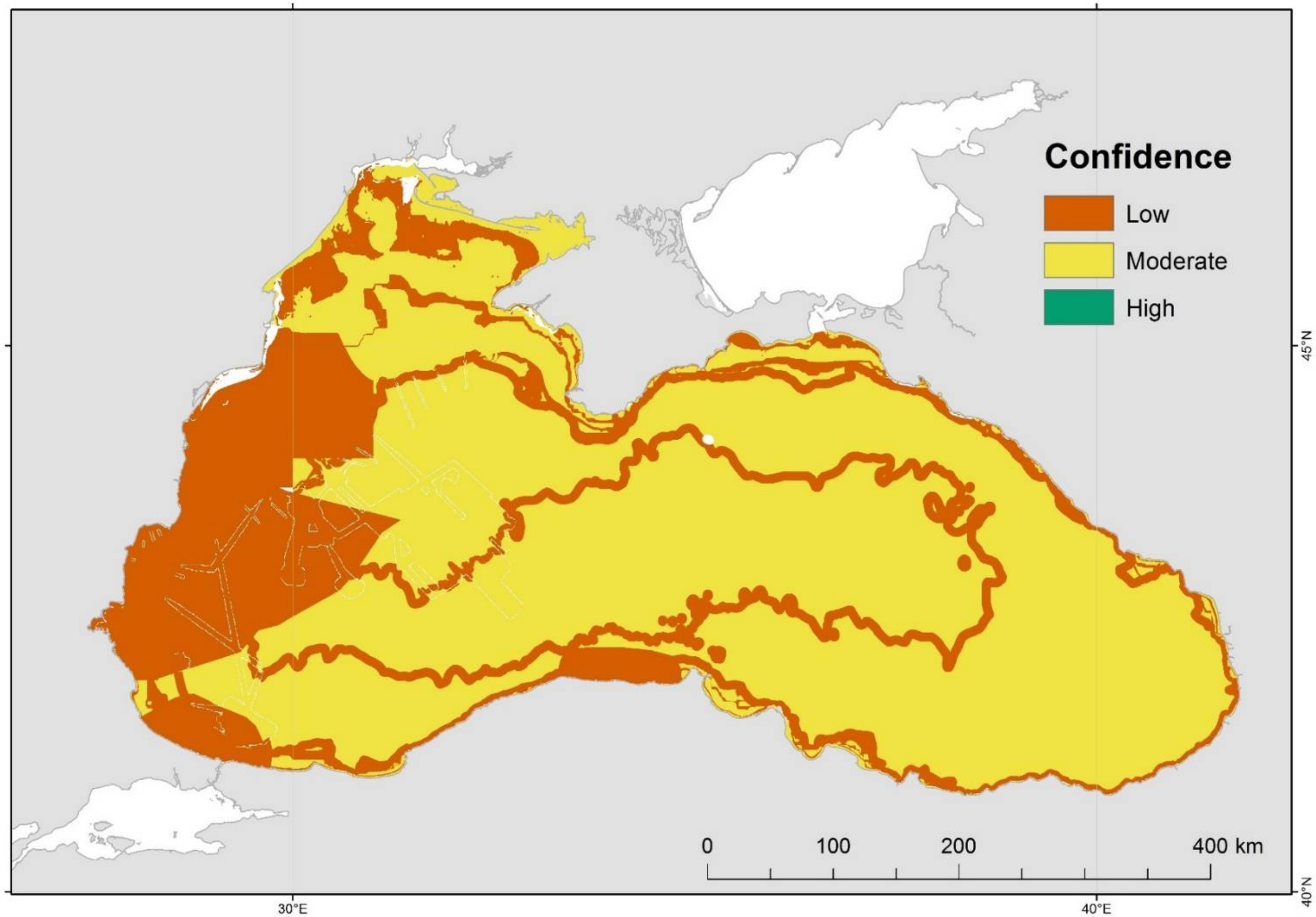


Figure 3.4.3: Overall confidence in the predicted habitat type in the Black Sea

4 Disseminating the maps: the web portal

The final habitat maps are available from the EMODnet Seabed Habitats portal (http://www.emodnet-seabedhabitats.eu). Also available are raster layers of the continuous physical variables and classified habitat descriptors that were used in the production of EUSeaMap 2016, along with their associated confidence layers. The web portal comprises of information webpages regarding the project itself and its outputs and a “webGIS” aspect, containing an interactive map, data download page and metadata search function. The initial build of the website and webGIS was derived from the existing EUSeaMap, which EMODnet Seabed Habitats superseded. This initial portal was then developed further towards the particular requirements of the current project identified by guidance from the EMODnet Secretariat, portal users and expertise within the project partners.

4.1 Interactive map

Over the project, several improvements were made to the user interface of the interactive map. The user interface (UI) was streamlined to improve user experience and aid viewing of the map on congested screens such as projections, with the ability to hide the side panel and move the toolbox away from the map view itself and the table of contents was rearranged following user feedback, providing more intuitive layer groupings to aid users in finding relevant datasets.

We revised the original system of storing and disseminating habitat maps from surveys as a single combined dataset with overlaps removed. Instead we held habitat maps collated through work package 3 as full individual datasets, displayed together using one of three rough scale groups (broad, medium or fine), but accessible as an individual dataset by the user when downloading the data packages or viewing the survey on the interactive map. This allows end-users to have control over how they use and combine the individual survey maps, and fills a requirement for a European storage location for habitat mapping data. The original MESH approach is still an option for the user; recombining the individual habitat maps by their confidence score will result in an equivalent product.

Through JNCC’s close work with the OSPAR commission, the Seabed Habitats portal is currently the official location of the OSPAR database of threatened and/or declining habitats, and is referenced by OSPAR through their data access page and metadata. The dataset is available to view on the interactive map – filterable by OSPAR habitat through the Map Query page of the portal – and the full public dataset is available to download.

Following feedback from the steering committee review of the portal, we improved the links between the metadata search page and interactive map to allow the user to directly view only the survey map in question and improved the query page to add functionality to filter by OSPAR habitat, zoom to country EEZ and turn on relevant map layers when filtering by EUNIS habitat.

The download page features zipped packages of the available datasets, available freely and without login for ease of access, though retaining basic usage statistics. The original system of offering the large habitat maps from survey datasets as a single composite layer was first developed to offer the individual datasets as multi-dataset zip packages. We have now developed this even further to offer available maps as individual downloads should the user require this. This enables users to more precisely select the maps which they would like to download, decreasing wait time, server load and unwanted data for users.

In addition, following the request of the steering committee we developed the download page to allow users to arrive at the page with downloads preselected. This enables all downloads to be handled via the download page and links from layers in the interactive map to their respective downloads to be retained; a user can now easily follow a data layer on the interactive map right through to the final download outcome.

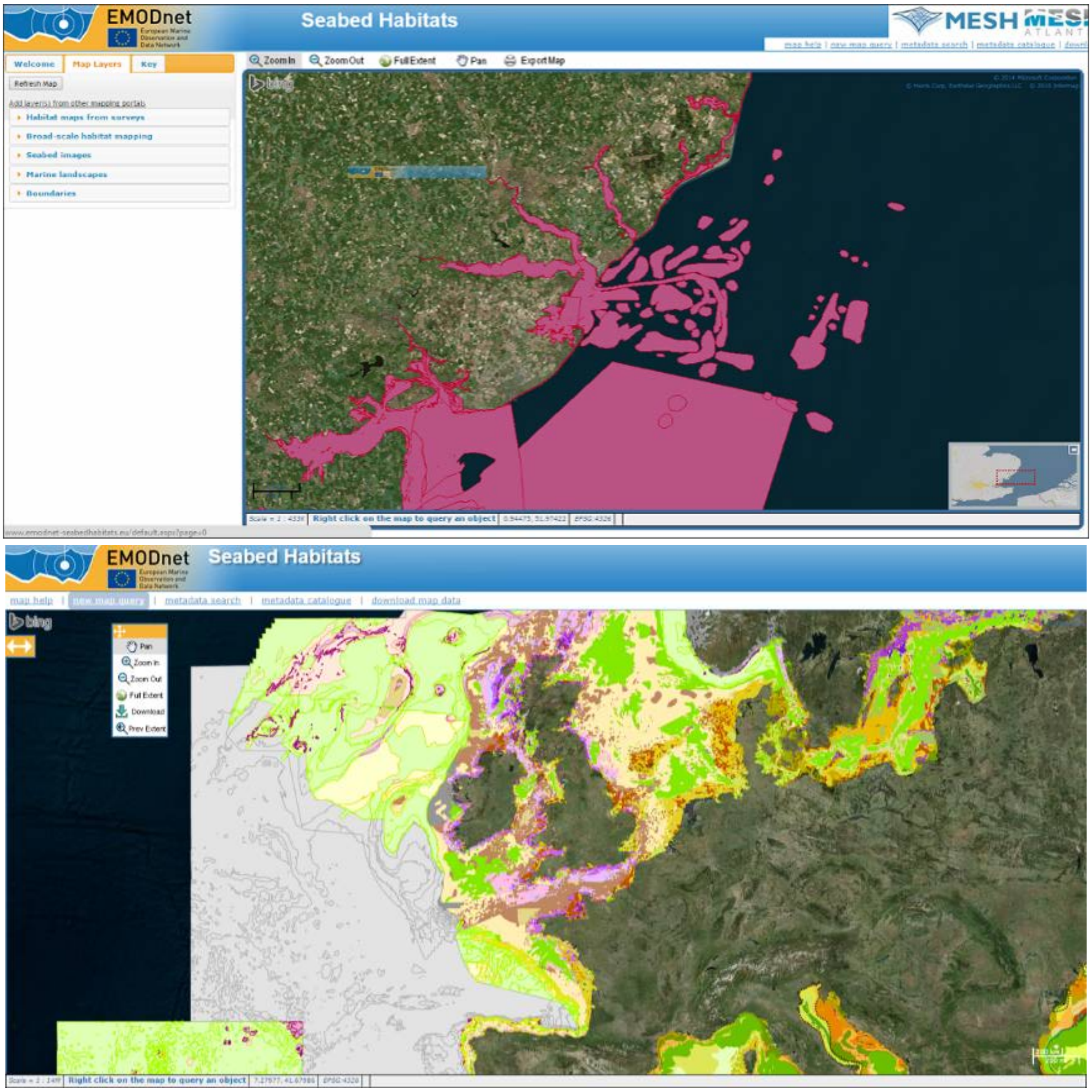


Figure 4.1: Comparison of interactive map original format (top), and new format (bottom) showing larger viewing extent and ability to hide the side panel.

4.2 Data standards

Following on from the MESH project, the project has continued to lead in data standards for European habitat mapping. The MESH data exchange formats have been subsumed as the EMODnet Seabed Habitat Data Exchange Formats (DEFs) and updated through the project. Following efforts to collate data regarding habitats identified within Annex I of the EU's Habitats Directive, we created a new 'habitats directive' DEF. Links and compliance between the DEFs and the INSPIRE data specifications have been maintained through consultation with the INSPIRE team, resulting in the full INSPIRE compliance of the 'translated habitat' and 'habitats directive' DEFs. Use of common data standards amongst datasets available through the portal has resulted in their increased ability for use in external projects requiring data collation and integration into composite products.

4.3 Data contribution & guidance

A 'Contributing data' section was added to the portal to guide potential data suppliers in the preparation of standardised survey data. The development of this section resulted in a standard step-by-step process for potential suppliers to follow and the creation of ArcGIS/python tools to enable users to standardise and validate their own data.

5 Using the maps

Our overarching objective has been to achieve a pan-European overview of the use of broad-scale seabed habitat maps (BSSHM) developed by UKSeaMap, BALANCE, MESH, MeshAtlantic and EUSeaMap with regard to the implementation of the EU Marine Strategy Framework Directive and also in regard to some related processes based on the Ecosystem Approach.

The MSFD aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. The Directive enshrines in a legislative framework the Ecosystem Approach to the management of all human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. In order to achieve GES by 2020, each Member State is required to develop a strategy for its marine waters (or Marine Strategy) including an Initial Assessment as well as Programmes of Measures. In addition, because the Directive follows an adaptive management approach, Marine Strategies must be kept up-to-date and reviewed every 6 years. Given the legislative requirements, especially with regard to the contents of the Initial Assessment in combination with the Ecosystem Approach, Member States are in practice required not only to carry out comprehensive monitoring and assessment activities but also to include the best available knowledge, i.e. maps of broad-scale seabed habitats developed in parallel to MSFD implementation processes.

In order to describe and document the use of broad-scale seabed habitat maps developed by previous projects and now updated by EUSeaMap 2, work has focused on the following 2 key activities, as well as 2 lesser tasks in relation to an initial literature survey as well as a description of the history of broad-scale seabed habitat maps development in Europe:

5.1 Survey questionnaire

A survey based on a questionnaire has been carried out to gather information on the use of BSSHMs in assessment and reporting in Europe, in particular in work related to MSFD and Marine Protected Areas assessments. The questionnaire was divided into 4 parts dealing with the following aspects: Part 1: MSFD initial assessment (7 questions), Part 2: next MSFD assessment and MSFD indicators development (8 questions), Part 3: Marine Protected Area evaluations (11 questions) and Part 4: Profile of the respondent (3 questions). Respondents were given the option to omit answering a section (parts 1, 2 and 3 only) if they were not involved in that particular part of the work, by answering “no” to the first question at each section. Part 1 included 4 questions aimed at understanding whether a BSHM was available for the country (or part of the country) and used in the 2012 first EU member state MSFD assessment (as per Art. 8 of MSFD directive). The questionnaire allowed respondents to provide comments and specify which maps, if any, were used. In part 2 similar questions were asked about the likely use of BSHM for the next MSFD assessment, to be prepared for 2018. Two optional questions were included with the aim of gathering examples of use of BSSHM for the purpose of MSFD GES determination and monitoring, as some countries are in the process of developing indicators (as per art. 10 of MSFD directive). Part 3 focussed on the use of BSHMs for Marine protected areas (MPA), for site selection and in network assessments. Respondents were given the opportunity to provide further details on the BSHM used, the types of assessment carried out and the geographic scale of the analysis. The contact details of the respondent and the country assessed were collected in Part 4. Contact details were used if further clarification on answers was required. The questionnaire was sent to the members of the Marine Expert Group (established under the EU Nature Directives) and the Marine Strategy Co-ordination Group comprising 23 European Union Member States having jurisdiction over marine waters. Members of the group were given the option to forward the questionnaire to national experts where necessary. The survey was thus directed at a total of 141 experts, representing an average of 6.1 respondents per Member State. A notification email was sent to the contacts providing the online link to the questionnaire, explaining the reasons of the survey and defining the BSSHM concept. The survey was kept open for 4 weeks and a reminder was sent to non-respondents 10 days after the first email.

5.2 MPA assessment within Regional Sea Conventions

The technical reports produced within the framework of RSCs were queried with an internet specific search, directed at RSC portals, so as to identify MPA related network assessments dealing with seabed habitats. These reports were screened so as to identify the MPA assessments which were carried out at a marine regional/sub-regional scale with the support of BSSHMs. A synthesis of each report was constructed containing information on: the year of assessment, the marine geographic region object of assessment, the name and typology of the broad scale habitat map considered, and a brief synthesis on the aspects for which the habitat map was used in the MPA assessment. The bibliography of each analysed RSC report on MPA network assessments was also screened in order to identify other existing regional/sub-regional/national assessments that may have used BSHMs within MPA related assessments. In such cases the reports of the national assessments were also analysed in the same manner as the RSC reports. Considerable resources have been spent on a synthesis of the results of the above described activities with the aim of submitting by the end of September 2016 the following manuscript to Frontiers in Marine Science's new Research Topic 'Horizon Scan 2017: Emerging Issues in Marine Science': "On the use of broad-scale seabed habitat maps in the context of ecosystem-based management".

Further, we are - as a spin out activity from EUSeaMap 2 - aiming to follow up on how key EUSeaMap 2 deliverables, i.e. the updated broad-scale seabed maps are being used by Regional Marine Conventions and by competent national authorities with regard to both regional marine quality status reporting and the upcoming MSFD Initial Assessment. A few uses of EUSeaMap 2 products have already now been identified, e.g. the second HELCOM Ecosystem Health Assessment, also known as HOLAS II (see also page 39).

Finally, the relevance of broad-scale habitat maps also appears in the analyses made by the Checkpoints, as is touched upon in section 7.

6 Outlook for higher resolution

High resolution case studies were designed to give prospective guidance for phase three in two ways: i) assessing the present state of the art of data coverage to take the broad-scale resolution from 250 to 100m (the latter being a phase 3 requirement), ii) producing 100m resolution examples on a regional basis, iii) assessing very high resolution (at 50 and even 25m) to show their particular value on local examples, as an incentive to target future efforts.

6.1 Assessment of increased 100m resolution feasibility

The Bathymetry lot provided us with an overview of the data sources their current 250m DTM pixel values originate from. The depth value that is assigned to each pixel of that DTM has one of the following origins (Fig 6.1.1): i) averaged survey depth soundings, ii) composite DTM, iii) interpolation, or iv) GEBCO DTM.

The first category (blue-green in Fig. 6.1.1) contains pixels whose values are averaged survey depth soundings. These were considered as good candidates for 100m resolution if the number of soundings per pixel is at least 4. Composite DTMs having their own native resolution, so good candidates for the 100m model are those with a resolution around 100m. Regarding pixels derived from interpolation, in the EMODnet DTM the distance between those pixels and the measured values that were used for their interpolation is typically much higher than 100m. Therefore pixels coming either from GEBCO DTM or from an interpolation were considered as not eligible for a 100m resolution model. Finally, the 1km resolution of the GEBCO DTM is by definition much coarser than 100m, which makes it unsuitable.

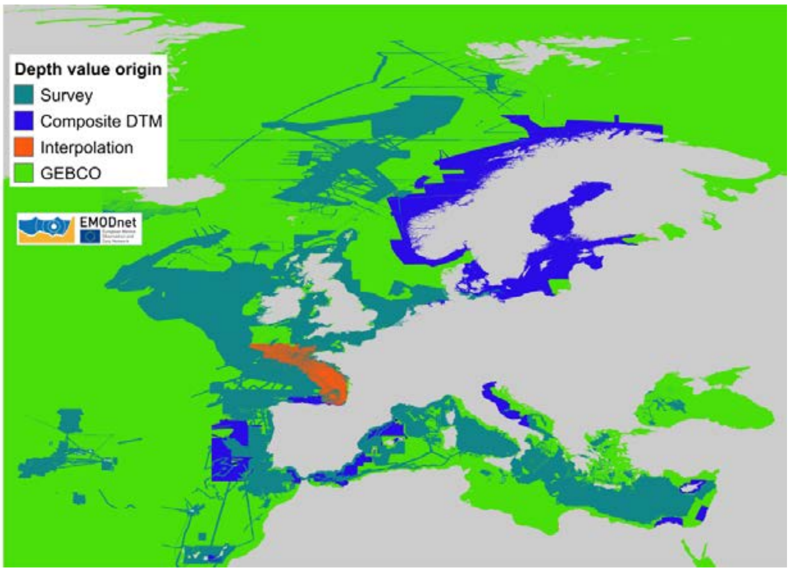


Figure 6.1.1: Origin of the EMODnet 250m DTM depth values

As a result, the coverage of a potential 100m model resulted from areas where the current EMODnet DTM 250m pixel values were calculated from at least 4 depth soundings along with the coverage of 100m resolution composite DTMs (Fig. 6.1.2).

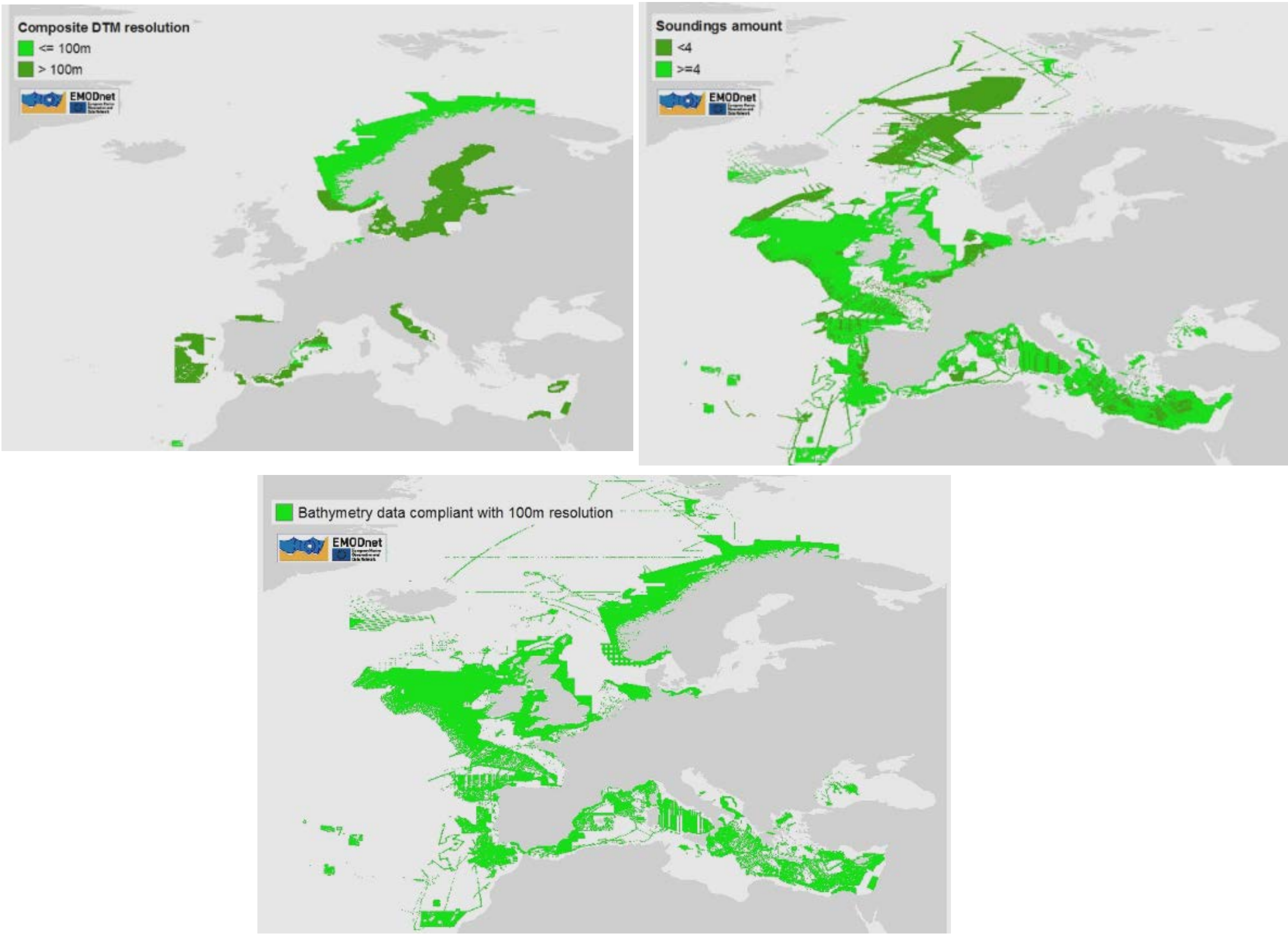


Fig. 6.1.2: Overview of: Top left, composite DTMs; Top right, density of soundings; Bottom: Resultant coverage of potential 100m bathymetry DTM

As far as substrate is concerned, the Geology lot recently delivered a 1/250000 coverage for seabed sediment. This scale was deemed compatible with a resolution of 100m. Figure 6.1.3 shows this coverage throughout Europe.

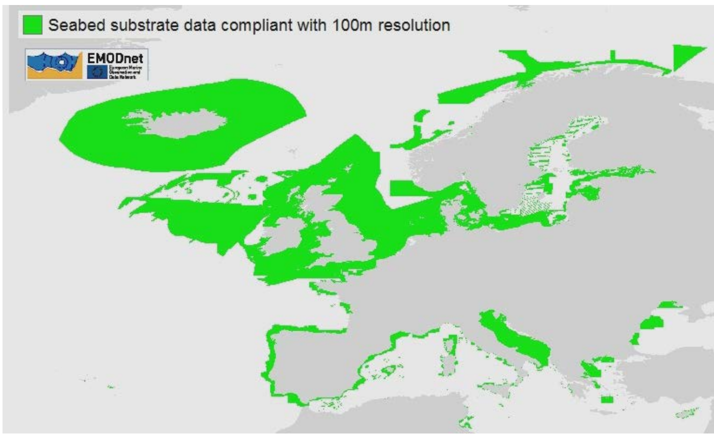


Figure 6.1.3: Coverage of seabed substrate suitable for a 100m model.

The resolution of light penetration data is 250m (from MERIS pixels). Given the fact that water transparency values generally exhibits weak gradients and that these KdPAR values are modulated by depth values, we deem this resolution to remain compatible with a 100m habitat model provided the depth DTM is reliable (not always the case e.g. in Greek waters).

Exposure at the seabed is more of an issue because, even though a lot of progress has been made in recent years, only in the UK, France and possibly parts of Norway where a high resolution fetch model is available could the datasets meet the requirements of the 100m model. The rest of Europe, except for a limited number of sub-areas (e.g. in Italy), is not yet in a position to produce this high resolution model.

In summary, if we regard substrate as the overall limiting factor Figure 6.1.3 roughly shows where a 100m model would be feasible, a key element for designing phase 3. This positive note should be moderated in view of the low resolution of wave and current data which strongly limits the accuracy in identifying rocky seabed EUNIS classes, mostly occurring in the coastal zone but also partly on the shelf.

6.2 High resolution case studies

Attempts were made on two sites in eastern UK and western Italy to produce maps at a resolution four times better that the project standard, i.e. 50m, with even a 25m refinement in Italy. The purpose was twofold: (i) to show, when generalising from 25m to 250m, what the information loss was, (ii) to assess in which conditions such a map could be an acceptable surrogate to survey maps, hence providing a means of increasing seabed maps coverage.

6.2.1 High resolution case study on the East of Scotland, Greater North Sea

For an area to the east of Scotland, we collaborated with EMODnet Geology to produce a habitat map in the same area as they conducted a case study to use statistical modelling to predict sediment types as opposed to the manual delineation common in the majority of the EMODnet Geology substrate product (Diesing, 2015).

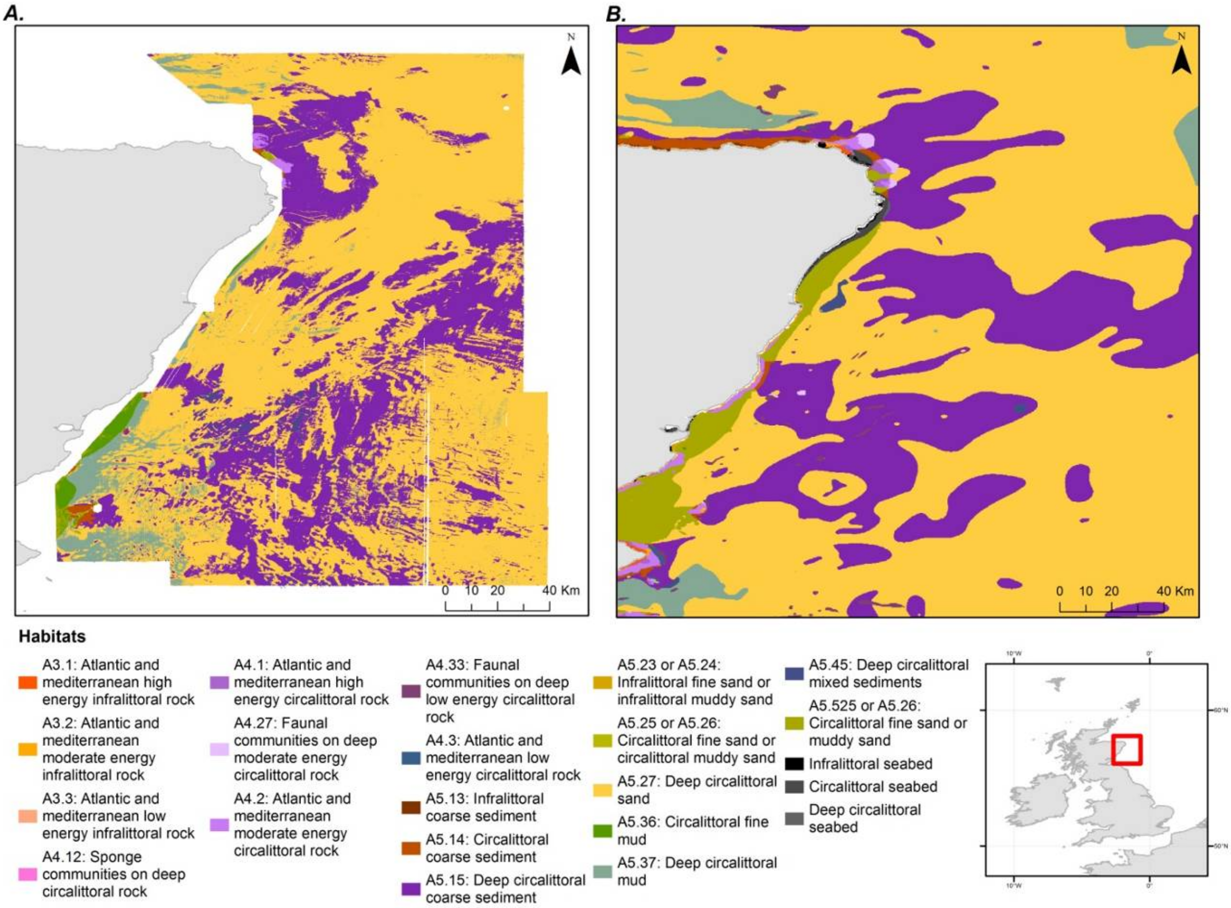


Figure 6.2.1: Side by side comparison of the HR case study in the East of Scotland (A) and the EMODnet broad-scale map of Atlantic Seabed habitats (B).

In this area the following input datasets were used:

- Seabed substrate: EMODnet Geology provided the map of predicted seabed sediments at a resolution of 50 m. We used the outputs of a recent rock-mapping exercise in the North Sea (Downie et al, 2016) to supplement the sediment map.
- Depth to Seabed: the same bathymetry dataset as used by the EMODnet Geology case study (at a resolution of 50 m) was also provided by Cefas for the same area as the substrate dataset.

The model was run according to the same rules as for the broad-scale map in the Greater North Sea, but using a grid resolution of 50 m (Fig. 6.2.1). For the other layers, this meant regridding them to a finer resolution than their information should permit; however, the result is a habitat map that makes the best use of the available depth and substrate data in this area.

6.2.2 High resolution case study on Pontine Islands, Western Mediterranean

The availability of high resolution substratum data allows in specific and spatially reduced areas to test the improvement of seabed habitat modelling with respect to the entire broad scale habitat map produced by this project. In this exercise the number of modelled habitats is the same as that of the broad scale map in the Western Mediterranean. Three different high resolution models were tested: 25, 50 and 100m.

The Pontine Islands are a Tyrrhenian Sea archipelago located in front of the Gaeta Gulf (distance about 50 km). The archipelago is the result of volcanic activity and consists of 6 islands.

High resolution models in this test site were carried out using the following layers:

- Substrate: CARG map 1:50000 converted into 25-50-100 and 250m grid resolution;
- Bathymetry: mosaic of the 25 m resolution layer derived from the hydrographic service and 5 m resolution layer derived from multibeam survey converted into 25-50 and 100m resolution layers;
- Percentage of light reaching the seabottom calculated using the KdPAR layer available for the broad-scale model and the bathymetric layer at the resolution requested by the case study;
- Posidonia meadows collected cartographies.
- The comparison between the resulting modelled maps at different scales with the broad scale habitat map obtained using the Geology lot delivery highlights different issues (Fig. 6.2.2). The most important aspect is the possibility to model habitat of conservation interest but characterised by small areas of hard bottom.
- Other aspects are more strictly linked to the accuracy of the high resolution input data which allow to better identify the boundaries between biozones and/or habitats. Finally, this exercise highlights the importance to simply convert the original map into a raster (i.e. by applying automatic GIS rules such as the maximum combined area within each pixel) instead of deleting features impossible to map at that theoretical scale.

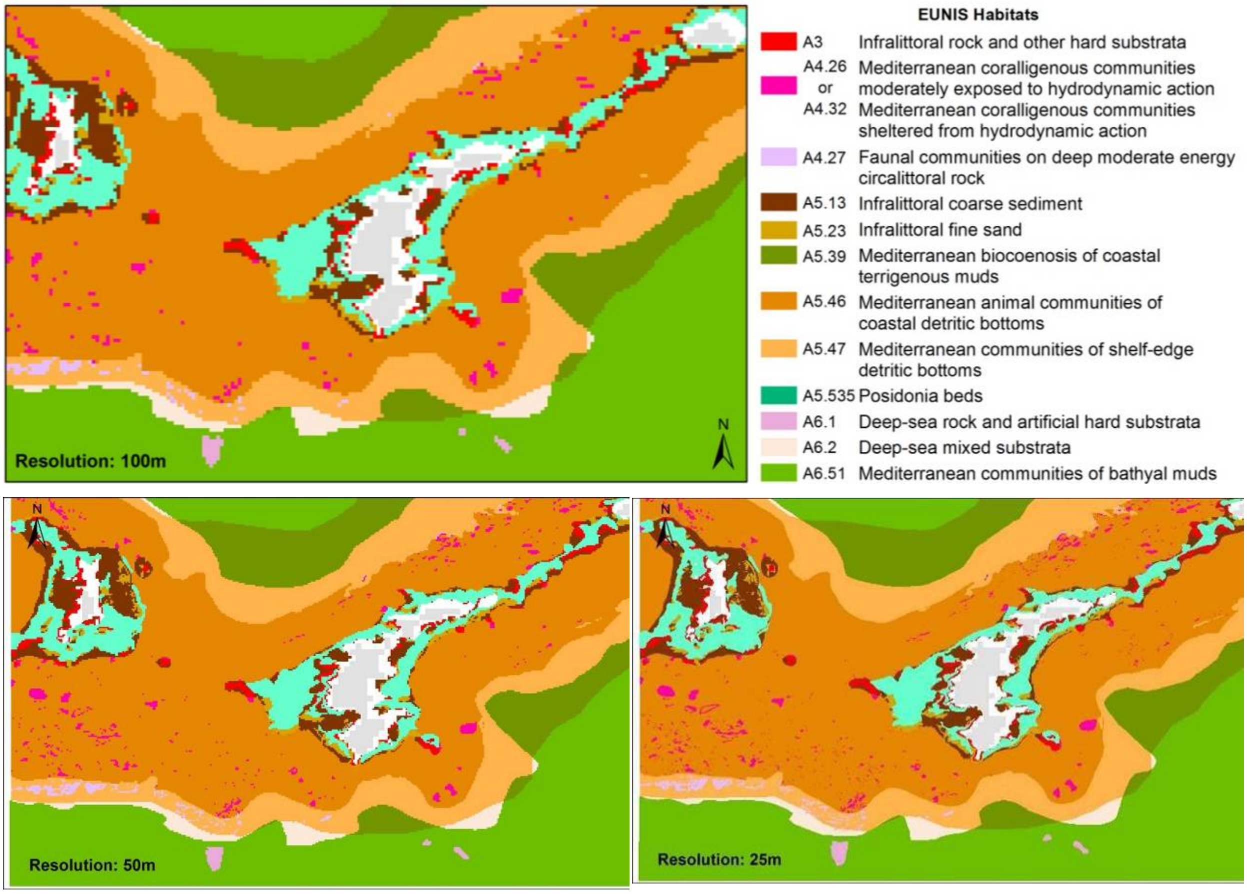


Fig. 6.2.2: High resolution model at resolution 100m (top), 50m (bottom left) and 25m (bottom right).

7 Conclusion

The first consistent broad-scale seabed habitat map covering all European basins has been developed in this project based on a 250m resolution.

One of its key achievements was in the Black Sea to find a relation between biological habitats – as they are known to Black Sea benthos ecologists – into their parent abiotic habitats according to EUNIS. This lead to extensive discussions made even more complex by i) the presence of large river plume in the western part, ii) the particular oxygen regime of the Black Sea that introduces the need for specific biozones. Eventually some relations between benthic species and biozones were established, which is going to be a valuable progress in the design of EUNIS for the Black Sea.

Looking to the future a feasibility study for the improvement of resolution has shown that this was closely linked to the quality of seabed substrate maps. Today a rough and ready 20% coverage at 1/250000 (compatible with a 100m pixel size) is available for Europe, but no doubt subsequent efforts of our geologist colleagues in phase 3 will reveal hidden data sources bound to increase this figure. Note that this figure is conservative for the coastal zone where maps with more detailed scales are quite often found. Along with constant improvements in oceanographic data (light, waves, currents, salinity, oxygen) and with an enhanced DTM, there is scope for reasonable coverage throughout Europe, albeit with high discrepancies between Member States.

Another qualitative step would be to try to enhance the biological content of the broad-scale map everywhere a detailed habitat map is not available. Today the only expression of biologyin the map is through what is referred to as “biozones”, i.e. depth zones governed by the presence of certain species or habitats. The way to integrate sample data into large polygons representing abiotic EUNIS classes is a challenge that phase 3 might tackle.

Finally, another strand of work is modeling individual habitats (e.g. kelp or coralligenous), a process that generates maps of presence probability of these habitats. The relevance of merging these with the broad-scale map is also a captivating future prospect.

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9 Thresholds appendix

9.1 Defining thresholds for Atlantic shelf biozones

The threshold value of light at the seabed used to draw the infralittoral/circalittoral biozone boundary was defined using a generalised linear model (GLM). The input data were a combination of i) presence points of communities indicator of rocky infralittoral (e.g. kelp) and communities indicator of rocky circalittoral data from the UK Marine Recorder[3] database and ii) kelp presence and pseudo-absence data generated from data on the lower growth limit of kelp in Norway. 5799 points indicator of infralittoral occurence and 3130 points indicator of circalittoral occurence were used. For each point a value of PAR at the seabed was derived from KdPAR and surface PAR values provided by the full-coverage gridded datasets produced as part of the Project and a depth value measured during the sample point acquisition. As a result the GLM's slope and intersect were respectively 1.076 and -0.777 and a ROC analysis led to a probability threshold of 0.49 (corresponding to a seabed PAR value of 0.7 $mol.pho.m^{-2}.d^{-1}$).

For the boundary between the shallow and the deep circalittoral, which is acknowledged in the Atlantic as the depth at which the seafloor is no longer disturded by wave action, we chose to use the ratio wave length/water depth (λ/h) as a proxy and attempted to use the GLM approach to predict the shallow/deep circalittoral occurence given values of λ/h; However, a lack of data related to those biozones, a lack of a clear indicator species or community, and a high variability of the input data in quality, coverage and type meant that we could use that approach in a limited area only, the Bay of Biscay, where there were both accurate wave data and sample point data of communities indicator of the two biozones. For the prediction of the deep circalittoral, the slope and the intercept of the GLM (p-value < 10e-12) were respectively 19.2 and -28.7 and the ROC analysis provided an optimal threshold probability value of 0.41 (equivalent to λ/h=1.5).

In the Iberian Peninsula the wave model was much coarser, thus due to the inconsistency between the λ values provided by this model and those provided by the model in the Bay of Biscay the GLM could not be scaled up in this area. Neither could it be in the Azores an other areas in Northern Spain (from Santander to La Coruña) and Southern Spain (off strait of Gibraltar) where a lack of wave data meant that we used depth as a proxy. For all those areas where for various reasons the GLM could not be used, we identified threshold values that spatially coincided with the boundary caused by the GLM in the Bay of Biscay; As a result the threshold defined for the Iberian Peninsula was λ/h=2.7 and in areas where depth was used as a proxy the threshold was -80m. The fuzzy limits were defined based on expert judgement: +- 0.5 λ/h in the Iberian Peninsula, +-15m where depth is used as a proxy.

In the Greater North Sea and Celtic Seas we decided to use the same threshold as for phase 1, i.e. λ/h=2. In Norway, we had a different variable – a fetch-dependent wave exposure index – therefore to produce a continuous boundary in Norway we identified a wave exposure threshold that spatially coincided with the boundary caused by the λ/h threshold worked out for the Celtic and Greater North Seas. This wave exposure index threshold was 10000. The fuzzy limits were defined based on expert judgement: +-0.4 λ/h in the Greater North Sea and Celtic Seas, and +-2000 wave exposure index in Norway.

[3] http://jncc.defra.gov.uk/marinerecorder

Table 9.1.1: Recap of thresholds and fuzzy limits

	Threshold	Fuzzy thresholds to add/substract
Infralittoral/circalittoral	PAR = 0.7 mol.pho.m-2.d-1	NA (because GLM method)
Shallow circalittoral/deep circalittoral Bay of Biscay	λ/h = 1.5	NA (because GLM method)
Shallow circalittoral/deep circalittoral Greater North Sea and Celtic Seas	λ/h=2	0.4
Shallow circalittoral/deep circalittoral Iberian Peninsula	λ/h=2.7	0.5
Shallow circalittoral/deep circalittoral Norway	Wave exp. index = 10000	2000
Shallow circalittoral/deep circalittoral From Santander to La Coruña Off strait of Gibraltar Azores	Depth = 80m	15

9.2 Defining thresholds for deep-sea biozones in the Atlantic and Arctic

9.2.1 Introduction

The Antarctic deep-sea biozones cover all areas of the models that are at a depth greater than 200m (the lower limit of the deep circalittoral biozone). Although the deep-sea biozones are not required for the EUNIS habitat classification (all deep-sea habitats are captured under one “A6: Deep-Sea Bed”), deep-sea biozones are distinguished in the MSFD Benthic Broad Habitat Types classification system.

9.2.2 Method

Potential biogeographic zones (PBZ) at the seabed were obtained by K-means clustering using the variables depth, salinity, temperature, dissolved oxygen and particulate organic carbon flux (POC). All input data layers are derived from the World Oceans Atlas, except from the POC, which was obtained from an in-house model at National Oceanography Centre Southampton (NOCs). The method has been developed by deep sea experts and is currently being described in a peer reviewed paper (Bett and Jones, in prep).

As the Bett and Jones model has a coarse resolution (0.25 degrees), approximate depths associated with the PBZ boundaries at the seabed have been determined to allow modelling biozones in areas with steep bathymetry.

Depth proxies for boundaries were defined as the midpoint of median depths for adjacent zones and rounded to the nearest 100m, as in Parry et al 2015. Fuzzy limits were obtained from the average of the half the inter quartile range (IQR) for each adjacent biozone pair. Figure 9.2.1 shows an example of how box plots of different deep-sea biozones are used to identify median depths of each zone and work out fuzzy limits from the IQR.

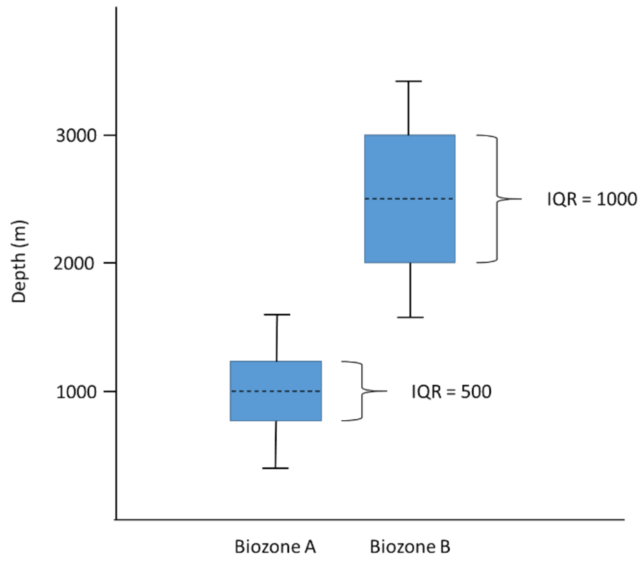

Figure 9.2.1: Mock example demonstrating how box plots are used to define the hard and fuzzy thresholds between two adjacent deep-sea biozones. The median depth value for each biozone is shown by the dashed line and the IQR is equal to the box height. For Biozone A the median is 1000m and the IQR is 500m. For Biozone B the median is 2500m and the IQR is 1000m.

In the example shown in Figure 9.2.2.1 the hard threshold between Biozone A and Biozone B would be 1750m (the midpoint between the median of Biozone A and Biozone B), which is rounded to 1800m. Using the same example the fuzzy threshold would be +/- 375m around the hard threshold, calculated from the average of half the IQR of the adjacent biozones ((500/2) + (1000/2)) / 2.

9.2.3 Results

In the Bett and Jones study (in prep) 17 clusters were identified for the Atlantic and Arctic (Table 9.2.1).

Table 9.2.1: Clusters identified for the Atlantic and Arctic from the deep sea biogeography model (Bett and Jones, in prep) and corresponding biozone names

Cluster code	Biozone name
AR-01	Arctic ice fringe
AR-02	Atlanto-Arctic upper bathyal
AR-03	Atlanto-Arctic upper bathyal
AR-04	Arctic mid bathyal
AR-05	Arctic lower bathyal
AR-06	Arctic upper abyssal
AT-01	Atlantic upper bathyal
AT-02	Atlantic upper bathyal
AT-03	Atlantic mid bathyal
AT-04	Atlanto-Mediterrean mid bathyal
AT-05	Atlantic lower bathyal
AT-06	Atlantic upper abyssal (a)
AT-07	Atlantic upper abyssal (b)
AT-08	Atlantic mid abyssal (a)
AT-09	Atlantic mid abyssal (b)
AT-10	Atlantic lower abyssal (a)
AT-11	Atlantic lower abyssal (b)

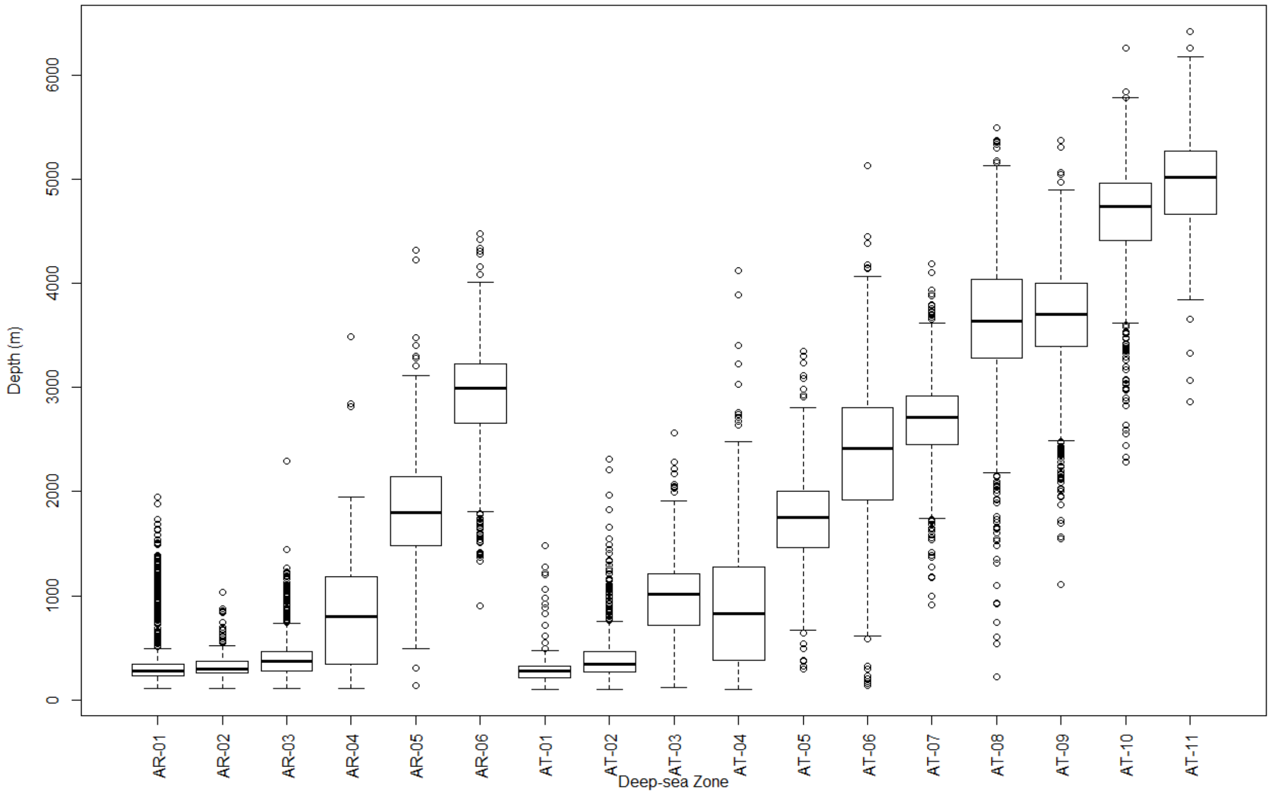

Figure 9.2.2: Box plots of clusters identified for the Atlantic and Arctic from the deep sea biogeography model (Bett and Jones, in prep)

Arctic region

For the threshold analysis, the arctic region is bounded to the north by the edge of the Arctic EUSeaMap model and to the south west by the Faroe–Shetland Channel. The biogeographic model shows that the Channel clearly affects the distribution of the water masses.

The upper limit of the deep sea (deep circalittoral/ Atlantic upper bathyal) in Norwegian waters was chosen to be 200m depth, not the edge of the continental shelf (which is located at about 500m depth on average). From discussion with deep sea experts and a review of the literature it emerged that deep sea biological assemblages can often occur on the Norwegian continental shelf. If the shelf edge was taken as the deep circalittoral/upper bathyal threshold, the influence of Atlantic water on the deeper areas of the Norwegian shelf would be missed, as the Atlantic upper bathyal PBZ is located shallower than 300m (and mostly on the Norwegian shelf in the Bett and Jones model.

Median and distribution of the depth values for each cluster is shown in Fig. 9.2.2 as boxplots. Cluster AR-01, corresponding to the Arctic Ice Fringe, was excluded from the analysis because it is located outside the EUSeaMap boundaries. Data from clusters AR-02 and AR-03 were analysed as a single cluster, because depth ranges and water mass characteristics were not significantly dissimilar, as suggested by the Bett and Jones model. The depth ranges suggested for biozones in Norwegian, Icelandic and UK Arctic waters to be used in EUSeaMap 2016, are shown in Table 9.2.2.

Table 9.2.2: Depth ranges for deep sea biozones in Arctic waters

	Depth threshold (m)	Fuzzy thresholds to add/substract, (m)
Atlantic upper bathyal/Atlanto-Arctic upper bathyal	300	74
Atlanto-Arctic upper bathyal/Arctic mid bathyal	600	248
Arctic mid bathyal/Arctic lower bathyal	1300	377
Arctic lower bathyal/Arctic upper abyssal	2400	310

Atlantic region

For the purpose of deep-sea threshold analysis in Atlantic waters the data analysed covers a region in the European NE Atlantic between the southern edge of the Faroe Shetland Channel to 25˚ latitude North.

Cluster AT-01 and AT02 are very similar in characteristics and depth ranges, and have been considered as a single cluster (or water mass proxy) corresponding to Atlantic Upper Bathyal (see Table 9.2.1). AT-03 and AT-04 are found at a similar range of depths, however the model shows that the characteristics of AT04 are very different from AT 03, as it has much higher salinity and temperature and low oxygen content. This has been identified as the influence of Mediterranean deep waters in the Atlantic, which spread north along the continental slope reaching Porcupine Bank (52.5˚ latitude). From the interpretation of their model output the deep-sea experts also suggest a north/south divide of Atlantic abyssal deep sea zones at about 40˚ latitude. This results in the pairs of clusters AT-06 and AT-07; AT08 and AT-09; AT10 and AT11 to be located at similar depth ranges but being considered as slightly different biozones, hence split into a and b.

Deep sea thresholds in the Atlantic are therefore dependent on both depth and latitude. Results are summarised in Tables 9.2.3 and 9.2.4 as two options arose in the analysis depending on the type of approach chosen:

- Simplified approach (Table 9.2.3): The data from the abyssal zones (a) and (b) (see Table 9.2.3) are joined together. This results in the same abyssal deep-sea threshold all over the Atlantic area. Also, the Atlantic mid-bathyal and Atlanto-Mediterranean mid-bathyal have the same depth thresholds, but they will be named differently depending whether they are south or north of the Porcupine bank (52.5 degrees).
- Detailed approach (Table 9.2.4). The North/South divide in the abyssal biozone is considered in the analysis and the (a) and (b) clusters are treated separately when calculating the midpoint between adjacent biozones. This results in 11 combinations of depth ranges and latitude thresholds. However, it is not recommended to include (a) or (b) in the name of the biozone, so fundamentally in the EUSeaMap model the number of biozones for the Atlantic and UK waters could be kept the same (7 biozones), as for the simplified approach, or new names should be created (e.g Atlantic northern lower abyssal and Atlantic southern lower abyssal).

Fuzzy limits in Atlantic and UK waters

Fuzzy limits were calculated as average of half the IQR (Table 9.2.5), as described for the Arctic waters.

Table 9.2.3: Biozones depth and latitude threshold for the NE Atlantic including UK, Azores and Canaries waters obtained using the simplified approach.

Biozones - simplified approach	Depth ranges (m)	Latitude
Atlantic upper bathyal	200-600	
Atlantic mid bathyal	600-1300	North of 52.5 deg. N
Atlanto-Mediterranean mid bathyal	600-1300	South of 52.5 deg N
Atlantic lower bathyal	1300-2200	
Atlantic upper abyssal	2200-3200	
Atlantic mid abyssal	3200-4300	
Atlantic lower abyssal	>4300	

Table 9.2.4: Biozones depth and latitude threshold for the NE Atlantic including UK, Azores and Canaries waters, obtained using the detailed approach. *Atlantic lower bathyal has been artificially split into North and South, however the original cluster is a single one (AT_05), so the latitude thresholds were chosen to be the same as for the adjacent mid-bathyal zone.

Biozones - Detailed approach	Depth ranges (m)	Latitude
Atlantic upper bathyal	200-600	
Atlantic mid bathyal	600-1400	North of 52.5 deg. N
Atlanto-Mediterrean mid bathyal	600-1300	South of 52.5 deg N
Atlantic lower bathyal	1400-2200	North of 52.5 deg. N *
Atlantic lower bathyal	1300-2100	South of 52.5 deg N *
Atlantic upper abyssal (a)	2100-3000	South of 40 deg N
Atlantic upper abyssal (b)	2200-3200	North of 40 deg N
Atlantic mid abyssal (a)	3000-4300	South of 40 deg N
Atlantic mid abyssal (b)	3200-4200	North of 40 deg N
Atlantic lower abyssal (a)	>4200	North of 40 deg N
Atlantic lower abyssal (b)	>4300	South of 40 deg N

Table 9.2.5: Fuzzy limits for deep sea depth thresholds in the NE Atlantic including UK, Azores and Canaries waters. Depth thresholds calculated using the simplified approach.

	Depth threshold (m)	**Fuzzy thresholds to add/substract- % of depth threshold**	**Fuzzy thresholds to add/substract (m)**
Atlantic upper bathyal/Atlantic mid bathyal	600	31	184
Atlantic upper bathyal/ Atlanto-Mediterranean mid bathyal	600	31	184
Atlantic mid bathyal/Atlantic lower bathyal	1300	22	283
Atlanto-Mediterranean mid bathyal/Atlantic lower bathyal	1300	22	283
Atlantic lower bathyal/Atlantic upper abyssal	2200	13	288
Atlantic upper abyssal/Atlantic mid abyssal	3200	10	319
Atlantic mid abyssal/Atlantic lower abyssal	4300	8	327

9.2.4 Discussions and summary of thresholds.

Although thresholds between biozones have been based on depth and the cluster analysis where possible, this was not always achievable. Some water masses are separated by geological or oceanographic features which have not been directly factored into this analysis.

For example, there are three mid bathyal biozones and as previously discussed the atlanto-mediteranian and Atlantic mid bathyal biozones were separated based on latitude, however there was no clear latitudional split between the Atlantic and Arctic mid bathyal. Instead these biozones were separated using a mask which closly follows the limit of these two biozones as proposed in Bett and Jones (see the red dashed line in Figure 9.2.3).

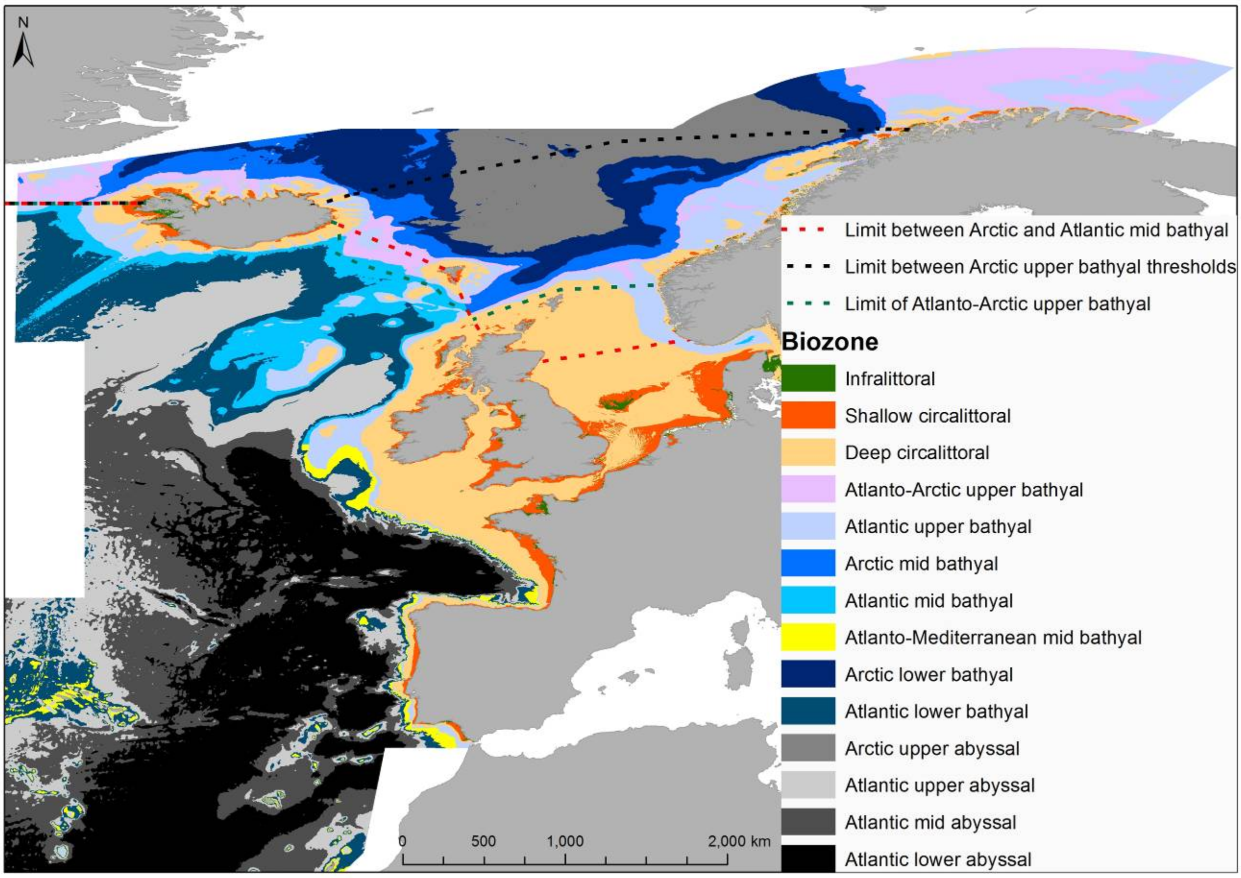

Figure 9.2.3: Map showing the limits of masks used to separate Arctic biozones that use different threshold values from adjacent biozones.

The Bett and Jones model was used in a similar way to identify the region in which there is an influence of the Atlanto-Arctic upper bathyal biozone (see the green dashed line in Figure 9.2.3). North of this limit the upper bathyal is split between the Atlantic and Atlanto-Arctic upper bathyal, south of this limit there is no Atlanto-Arctic upper Bathyal.

In addition to this, review of the EUSeaMap 2016 modeld biozones highlighted that the 300m depth threshold between the Atlantic upper bathyal and Atlanto-Arctic upper bathyal biozones produced a very narrow and sometimes non existant Atlantic upper bathyal biozone. This was the case for areas along the continental slope of the Faroe Shetland Channel and Norway, where the slope is steepest. The affected areas were separated with areas south of the mask having the threshold between the Atlantic upper bathyal and Atlanto-Arctic upper bathyal biozones increased to 400m (see the black dashed line in Figure 9.2.3 and Table 9.2.6). This change also resulted in a better match with the Bett and Jones model output.

The advantage of the use of the detailed approach in the Atlantic (Table 9.2.4) is that is more comprehensive and better reflects the variations in abyssal water properties found at about 40˚ latitude by the biogeographic model (note that the exact location of this physical boundary is not clear for all abyssal zones in the model output). However, the detailed approach introduces an artificial split of the Atlantic lower bathyal zone into a North and South zone, which was originally identified by the biogeographical model as a single cluster. The difference in depth ranges in the two approaches is not very significant. The maximum difference in depth threshold is of 200m between the deepest boundary of the Atlantic upper abyssal (a) and that of the Atlantic upper abyssal (b), otherwise all other thresholds differ by 100m, which is within our approximations margins.

Considering the above and that the optimal number of clusters in the biogeographic model can vary between 10 and 20, (which would make the 40 deg latitude split less meaningful) it was decided to use the simplified approach. Thresholds used to define the deep sea biozones of NE Atlantic and Arctic in EUSeaMap 2016 are summarised in Table 9.2.6. Ideally biological deep sea assemblage data from the whole NE Atlantic and Arctic should be used to improve the threshold analysis.

Table 9.2.6: Summary Table: Depth thresholds and fuzzy thresholds for each biozone class in the deep Atlantic and Arctic sea used in EUSeaMap 2016.

Area	Biozone boundary	Depth threshold (m)	Fuzzy threshold to add/subtract (m)
Arctic (N)	Atlantic upper bathyal/Atlanto-Arctic upper bathyal	300	74
Arctic (S)	Atlantic upper bathyal/Atlanto-Arctic upper bathyal	400	57
Arctic	Atlanto-Arctic upper bathyal/Arctic mid bathyal	600	248
Arctic	Arctic mid bathyal/Arctic lower bathyal	1300	377
Arctic	Arctic lower bathyal/Arctic upper abyssal	2400	310
Atlantic (N of 52.5 deg N)	Atlantic upper bathyal/ Atlantic mid bathyal	600	184
Atlantic (N of 52.5 deg N)	Atlantic mid bathyal/Atlantic lower bathyal	1300	283
Atlantic	Atlantic lower bathyal/ Atlantic upper abyssal	2200	288
Atlantic	Atlantic upper abyssal/ Atlantic mid abyssal	3100	319
Atlantic	Atlantic mid abyssal/ Atlantic lower abyssal	4100	327
Atlantic (S of 52.5 deg N)	Atlantic upper bathyal/Atlanto-Mediterranean mid bathyal	600	184
Atlantic (S of 52.5 deg N)	Atlanto-Mediterranean mid bathyal/ Atlantic lower bathyal	1300	283

9.3 Defining thresholds for energy levels in the Atlantic

9.3.1 Categories of exposure to waves

In order to identify threshold values for the boundaries between Low/Moderate wave exposure categories on one hand, and Moderate/High wave exposure categories on the other hand, a selection of sample points indicator of each category was made from the UK Marine Recorder[4] database, version Feb 2015. In that database, to each record is assigned a biotope (i.e. EUNIS level 5-6) and a wave exposure category provided by expert judgement (i.e. assigned *in situ* by a field operator). The biotopes were organised in a pivot table by exposure categories assigned by expert judgement, so that to each biotope was assigned a percentage of database records falling in one or the other expert judgement wave exposure

[4] http://jncc.defra.gov.uk/marinerecorder

category. This helped select sound indicator biotopes for the GLMs. For instance, the biotope 'Sparse sponges, Nemertesia spp. and Alcyonidium diaphanum on circalittoral mixed substrata' (code A4.135 in EUNIS), although classified as 'high energy' in EUNIS, was not selected to feed the GLM because only 48% of its records in the database were also classified by expert judgement as 'high wave energy'. As a general rule we selected a biotope if there was at least 85% of agreement between the EUNIS energy level and the expert judgement wave exposure category. Table 9.3.1 summarizes the biotopes that were used as indicator of one of the three energy levels.

Table 9.3.1 Marine recorder database biotopes that were selected as indicator of low, moderate or high wave energy category for the GLM analyses

Biotope Code	Biotope Description	Category
CR.LCR.BrAs	Brachiopod and ascidian communities	Low
CR.LCR.BrAs.AmenCio	Solitary ascidians, including Ascidia mentula and Ciona intestinalis, on wave-sheltered circalittoral rock	Low
CR.LCR.BrAs.AmenCio.Ant	Solitary ascidians, including Ascidia mentula and Ciona intestinalis, with Antedon spp. on wave-sheltered circalittoral rock	Low
CR.LCR.BrAs.AntAsH	Antedon spp., solitary ascidians and fine hydroids on sheltered circalittoral rock	Low
CR.LCR.BrAs.NeoPro	Neocrania anomala and Protanthea simplex on sheltered circalittoral rock	Low
CR.LCR.BrAs.NeoPro.FS	Neocrania anomala and Protanthea simplex on very wave-sheltered circalittoral rock	Low
CR.LCR.BrAs.NeoPro.VS	Neocrania anomala, Dendrodoa grossularia and Sarcodictyon roseum on variable salinity circalittoral rock	Low
IR.LIR.IFaVS	Faunal communities on variable or reduced salinity infralittoral rock	Low
IR.LIR.IFaVS.MytRS	Mytilus edulis beds on reduced salinity infralittoral rock	Low
IR.LIR.K.LhypCape	Silted cape-form Laminaria hyperborea on very sheltered infralittoral rock	Low
IR.LIR.K.LhypLsac.Gz	Grazed, mixed Laminaria hyperborea and Laminaria saccharina on sheltered infralittoral rock	Low
IR.LIR.K.Lsac	Laminaria saccharina on very sheltered infralittoral rock	Low
IR.LIR.K.Lsac.Ft	Laminaria saccharina forest on very sheltered upper infralittoral rock	Low
IR.LIR.K.Lsac.Gz	Grazed Laminaria saccharina with Echinus, brittlestars and coralline crusts on sheltered infralittoral rock	Low
IR.LIR.K.Lsac.Ldig	Laminaria saccharina and Laminaria digitata on sheltered sublittoral fringe rock	Low
IR.LIR.K.Lsac.Pk	Laminaria saccharina park on very sheltered lower infralittoral rock	Low
IR.LIR.K.Sar	Sargassum muticum on shallow slightly tide-swept infralittoral mixed substrata	Low
IR.LIR.KVS.Cod	Codium spp. with red seaweeds and sparse Laminaria saccharina on shallow, heavily-silted, very sheltered infralittoral rock	Low
IR.LIR.KVS.LsacPsaVS	Laminaria saccharina and Psammechinus miliaris on variable salinity grazed infralittoral rock	Low
IR.LIR.Lag.FChoG	Mixed fucoids, Chorda filum and green seaweeds on reduced salinity infralittoral rock	Low

Biotope Code	Biotope Description	Category
CR.MCR.CSab.Sspi.As	Sabellaria spinulosa, didemnids and other small ascidians on tide-swept moderately wave-exposed circalittoral rock	Moderate
CR.MCR.EcCr.FaAlCr.Flu	Flustra foliacea on slightly scoured silty circalittoral rock	Moderate
CR.MCR.SfR.Pid	Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay	Moderate
CR.MCR.SfR.Pol	Polydora sp. tubes on moderately exposed sublittoral soft rock	Moderate
IR.AlcByH.Hia	Hiatella arctica, bryozoans and ascidians on vertical infralittoral soft rock	Moderate
IR.LIR.K.LhypLsac	Mixed Laminaria hyperborea and Laminaria saccharina on sheltered infralittoral rock	Moderate
IR.LIR.K.LhypLsac.Ft	Mixed Laminaria hyperborea and Laminaria saccharina forest on sheltered upper infralittoral rock	Moderate
IR.MIR.KR.HiaSw	Hiatella arctica and seaweeds on vertical limestone / chalk.	Moderate
IR.MIR.KR	Kelp and red seaweeds (moderate energy infralittoral rock)	Moderate
IR.MIR.KR.Ldig.Bo	Laminaria digitata and under-boulder fauna on sublittoral fringe boulders	Moderate
IR.MIR.KR.Ldig.Pid	Laminaria digitata and piddocks on sublittoral fringe soft rock	Moderate
IR.MIR.KR.Lhyp.Ft	Laminaria hyperborea forest and foliose red seaweeds on moderately exposed upper infralittoral rock	Moderate
IR.MIR.KR.Lhyp.Sab	Sabellaria spinulosa with kelp and red seaweeds on sand-influenced infralittoral rock	Moderate
IR.MIR.KR.LhypTX.Pk	Laminaria hyperborea park and foliose red seaweeds on tide-swept lower infralittoral mixed substrata	Moderate
CR.HCR.DpSp	Deep sponge communities (circalittoral)	High
CR.HCR.DpSp.PhaAxi	Phakellia ventilabrum and Axinellid sponges on deep, wave-exposed circalittoral rock	High
CR.HCR.FaT.CTub.Adig	Alcyonium digitatum with dense Tubularia indivisa and anemones on strongly tide-swept circalittoral rock	High
CR.HCR.XFa.ByErSp.DysAct	Mixed turf of bryozoans and erect sponges with Dysidia fragilis and Actinothoe sphyrodeta on tide-swept wave-exposed circalittoral rock	High
CR.HCR.XFa.ByErSp.Eun	Eunicella verrucosa and Pentapora foliacea on wave-exposed circalittoral rock	High
CR.HCR.XFa.CvirCri	Corynactis viridis and a mixed turf of crisiids, Bugula, Scrupocellaria, and Cellaria on moderately tide-swept exposed circalittoral rock	High
IR.HIR.KFaR	Kelp with cushion fauna and/or foliose red seaweeds	High
IR.HIR.KFaR.Ala	Alaria esculenta on exposed sublittoral fringe bedrock	High
IR.HIR.KFaR.Ala.Myt	Alaria esculenta, Mytilus edulis and coralline crusts on very exposed sublittoral fringe bedrock	High
IR.HIR.KFaR.AlaAnCrSp	Alaria esculenta forest with dense anemones and crustose sponges on extremely exposed infralittoral bedrock	High
IR.HIR.KFaR.FoR.Dic	Foliose red seaweeds with dense Dictyota dichotoma and/or Dictyopteris membranacea on exposed lower infralittoral rock	High
IR.HIR.KFaR.LhypFa	Laminaria hyperborea forest with a faunal cushion (sponges and	High

Biotope Code	Biotope Description	Category
	polyclinids) and foliose red seaweeds on very exposed upper infralittoral rock	
IR.HIR.KFaR.LhypR	Laminaria hyperborea with dense foliose red seaweeds on exposed infralittoral rock	High
IR.HIR.KFaR.LhypR.Ft	Laminaria hyperborea forest with dense foliose red seaweeds on exposed upper infralittoral rock	High
IR.HIR.KFaR.LhypR.Pk	Laminaria hyperborea park with dense foliose red seaweeds on exposed lower infralittoral rock	High

To each sample point was assigned a value of percentile 90th wave-induced kinetic energy extracted from the continous gridded data layer produced for the UK waters. Two GLMs were fitted, one for the Low/Moderate wave energy categories (187 records for Low, 262 for Moderate), one for the Moderate/High categories (526 records for High, 250 for Moderate). The GLM slope, intercept and the probability threshold were -0.07, 1.236 and 0.61 (corresponding to a kinetic energy of 11.41 $N.m^{-2}$) for Low/Moderate, and 0.013, -0.642 and 0.57 (corresponding to a kinetic energy of 70.95 $N.m^{-2}$) for Moderate/High.

Those GLMs were scaled up in all areas covered by the UK wave-induced kinetic energy continuous layer. In other areas, the pixel values of the various gridded layers that were available or produced as part of the Project were not consistent with that of the UK layer because they were derived from other wave models using different wave modeling techniques, had a different temporal coverage or a different horizontal resolution.

In the French Bay of Biscay, more specifically in French waters and in Spain west to Santander, the gridded data available was a wave climatology with high resolution (300m) alongshore. No sample data with a clear indicator species or community was available, thus it was not possible to fit a GLM and we tried to identify wave kinetic energy thresholds that spatially coincided with the boundaries caused by the GLMs in the UK waters. From Santander to La Coruña and off the Strait of Gibraltar, a coarse continuous layer was available. So we tried to work out a threshold value that spatially coincided with the boundaries used for the Bay of Biscay. At least, in the Azores and the Iberian Peninsula we used the continuous layer and set of thresholds used by Monteiro et al. 2015. All results are described in table 9.3.2.

Table 9.3.2 Thresholds used for High/Moderate/low exposure to waves in the Atlantic

	Kinetic energy threshold ($N.m^{-2}$)	**Fuzzy thresholds to add/substract ($N.m^{-2}$)**
High/Moderate Greater North Sea and Celtic Seas	70.95	NA (because GLM method)
High/Moderate Bay of Biscay	22	5
High/Moderate From Santander to La Coruña Off strait of Gibraltar	90	5
High/Moderate Azores and Iberian Peninsula	43.7	5
Moderate/Low	11.41	NA (because GLM method)

Greater North Sea and Celtic Seas		
Moderate/Low Bay of Biscay	7.6	3
Moderate/Low From Santander to La Coruña Off strait of Gibraltar	60	5
Moderate/Low Azores and Iberian Peninsula	3	1

9.3.2 Categories of exposure to currents

Due to lack of ground truthing data, no GLM could be performed for modeling the high/moderate/low categories of exposure to currents. In the Greater North Sea and Celtic Seas we used the same thresholds as for phase 1 of EUSeaMap, i.e. 1160 $N.m^{-2}$ (+-10 for fuzzy limits) for the high/moderate boundary and 130 $N.m^{-2}$ (+-10 for fuzzy limits) for moderate/low.

Table 9.3.3 Thresholds used for High/Moderate/low exposure to currents in the Atlantic

	Kinetic energy threshold ($N.m^{-2}$)	**Fuzzy thresholds to add/substract ($N.m^{-2}$)**
High/Moderate Greater North Sea and Celtic Seas	1160	10
High/Moderate Bay of Biscay, Azores, Iberian Peninsula	900	70
Moderate/Low Bay of Biscay	130	10
Moderate/Low Bay of Biscay, Azores, Iberian Peninsula	100	70

In other areas (Bay of Biscay, Azores, Iberian Peninsula) we had a different continuous layer of current-induced kinetic energy, the values of which were inconsistent with those of the layer used in the Greater North Sea and Celtic Seas. There we tried to identify thresholds that gave similar patterns to those in the Greater North Sea and Celtic Seas where the two kinetic energy gridded layers overlapped. As a result we used 900 $N.m^{-2}$ (+-70 fuzzy range) and 100 $N.m^{-2}$ (+-70 fuzzy range).

9.4 Defining thresholds for Icelandic shelf biozones

The 2016 EMODnet Geology substrate dataset included Iceland for the first time. To make the best use of the information available in the area, depth to the seabed was used as a variable to define shelf biozones in Icelandic waters. This was done to enable the classification of habitats that could be defined on substrate type and biozone alone.

The depth thresholds used to separate the Infralittoral, shallow circalittoral and deep circalittoral were based on expert judgement (Julian Burgos, personal communication, June 2016). The depth of the infralittoral zone in the North and South of Iceland is expected to be different due to the influence of glacial melt waters in the south of Iceland. The 64.5 degrees North latitude was chosen as the division between North and South Iceland. A threshold of 30 m (+- 10% fuzzy threshold) was chosen in the North and 15m (+- 10% fuzzy threshold) was chosen in the South.

Between the shallow and deep circalittoral biozone, a threshold of 80 m (+- 10% fuzzy threshold) was chosen. This was the same in both the North and South and is consistent with the depth thresholds for this boundary used elsewhere, such as the Bay of Biscay and the Azores.

The thresholds used for shelf biozones around Iceland are summarised in Table 9.4.1 and the resulting biozones are shown in Figure 9.4.1. Deep-sea biozones are as described in section 9.3

Table 9.4.1: Thresholds used for biozones on Iceland continental shelf, North and South of 64.5 degree of latitude.

	Depth threshold (m)	Fuzzy thresholds to add/substract (m)
Infralittoral/Shallow circalittoral North	30	3
Infralittoral/Shallow circalittoral South	15	1.5
Shallow circalittoral/Deep circalittoral North and South	80	8

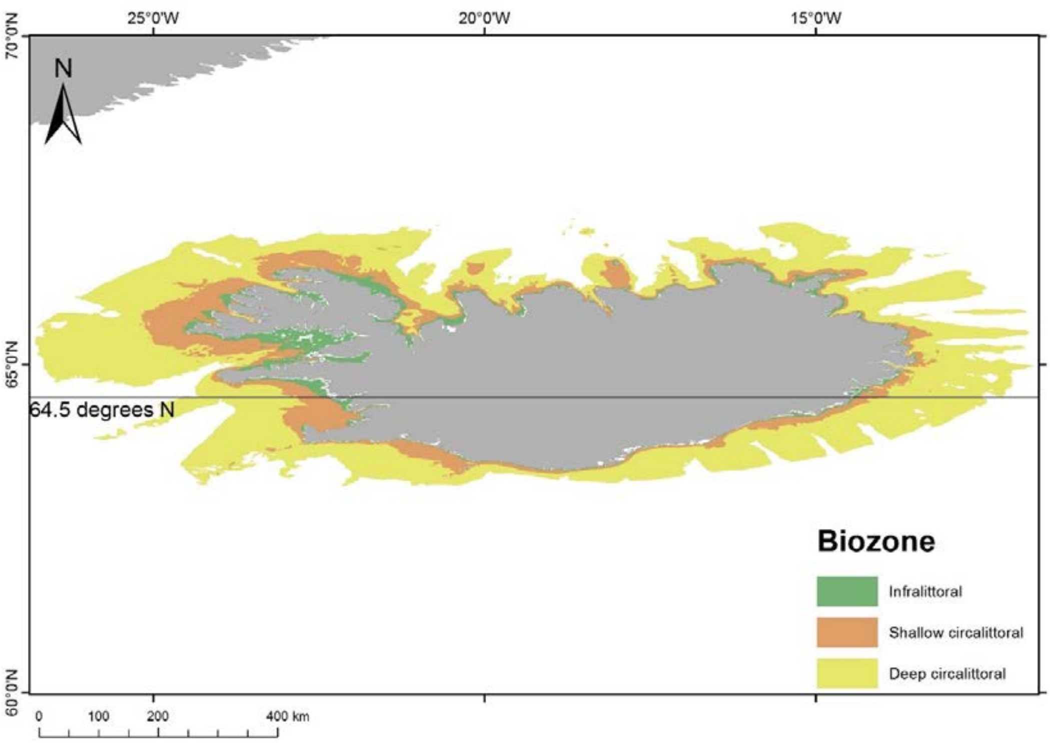

Figure 9.4.1 Iceland shelf biozones and the location of the

64.5 degrees North latitude.

This has demonstrated the feasibility of including Iceland in EUSeaMap, however the accuracy of the biozone models could be much improved by accessing more appropriate input variables such as light levels at the seabed, and the depth of the wave base.

9.5 Defining thresholds in the Black Sea

9.5.1 Biological zones

Table 9.5.1 lists the benthic communities that were considered are indicator of the biological zones. We therefore used existing sample point data of those communities to fit the thresholds.

Table 9.5.1: communities considered as indicator of each biological zone

Biozone	Indicator communities
Infralittoral hard bottom	*Cystoseira barbata + Ulva rigida+ Polysiphonia subulifera Cladophora spp. - Ulva rigida - Ulva intestinalis - Gelidium spp.*
Circalittoral hard bottom	Sciaphilic algae *(Phyllophora* spp. + *Polysiphonia* spp. + Apoglosium + *Zanardinia* spp.+ *Gelidium* spp.), sponges and hydroids
Infralittorral Soft bottom	Infralittoral shelly gravel and sand with *Chamelea gallina* and *Mytilus galloprovincialis*
	Shallow fine sands with *Lentidium mediterraneum, Tellina tenuis*
	Medium to coarse sands with *Donax trunculus*
	Infralittoral sand with *Chamelea gallina* (with *Cerastoderma glaucum, Lucinella divaricata, Gouldia minima*)
	Muddy sand with burrowing *thalassinid Upogebia pusilla/Pestarella candida*
	Mud and sandy mud with *Upogebia pusilla*
	Sandy mud and mud with seagrass meadows
Shallow circalittoral soft bottom	*Mytilus galloprovincialis* biogenic reefs
	Coccotylus truncatus & Phyllophora crispa on shelly organogenic sand
	Muds with *Abra nitida - Pitar rudis - Spisula subtruncata, Acanthocardia paucicostata* and *Nephtys hombergii*
	Muddy sand with *Dipolydora quadrilobata meadows* and *Mytilus galloprovincialis* biogenic reefs
Deep circalittoral soft bottom	Shelly muds with *Modiolula phaseolina*
	Sand and sandy mud with tunicates
	Mud with *Terebellides stroemii*, *Pachycerianthus solitarius*, *Amphiura stepanovi*

Infralittoral - shallow circalittoral boundary on soft bottoms

In the Black Sea the boundary between the infralittoral and the shallow circalittoral on soft bottoms is defined as the maximum depth at which seabed is no longer affected by stormy waves. The appropriateness of data from the Kassandra wave model[5] for modelling the infralittoral and shallow circalittoral was assessed. Kassandra covers the whole Black Sea

[5] http://kassandra.ve.ismar.cnr.it:8080/kassandra

with triangular features having a resolution that varies from around 0.5-1.5 km along the Romanian coast to a much coarser resolution alongshore in other parts of the Sea, 7-15km (figure 9.5.1). As a result, this model was deemed inappropriate for broadscale habitat mapping at the EUSeaMap resolution (250m).

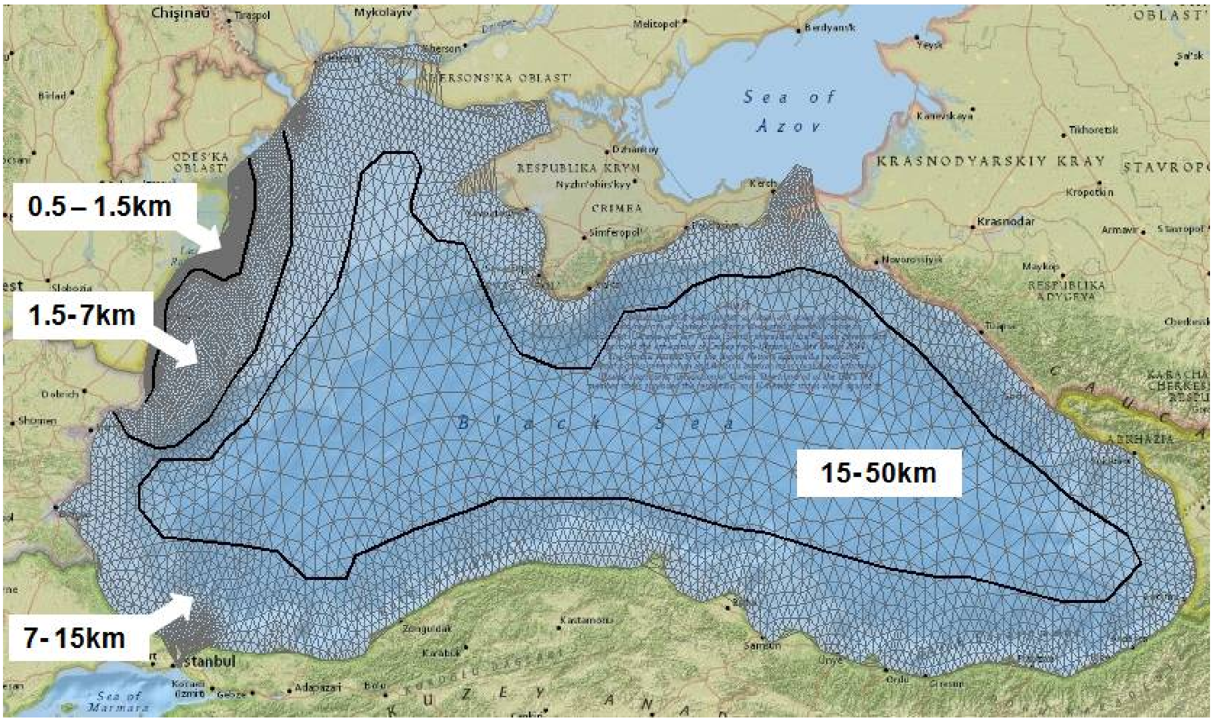

Figure 9.5.1: the Kassandra wave model triangular network, with a very high resolution along the Romanian coast and a much coarser alongshore resolution elsewhere.

Considering the lack of appropriate wave data, bathymetry was used as a proxy. For each sample point indicator of infralittoral or shallow circalittoral (see table 9.5.1), values were extracted from the EMODnet Bathymetry DTM. Figure 9.5.2 shows the distribution of depth values for each biological zone. From those distributions we decided to use -10m and -30m as fuzzy boundaries (thus 0.05 and 1.5 as respectively slope and intercept of the fuzzy equation) and -20m as hard threshold.

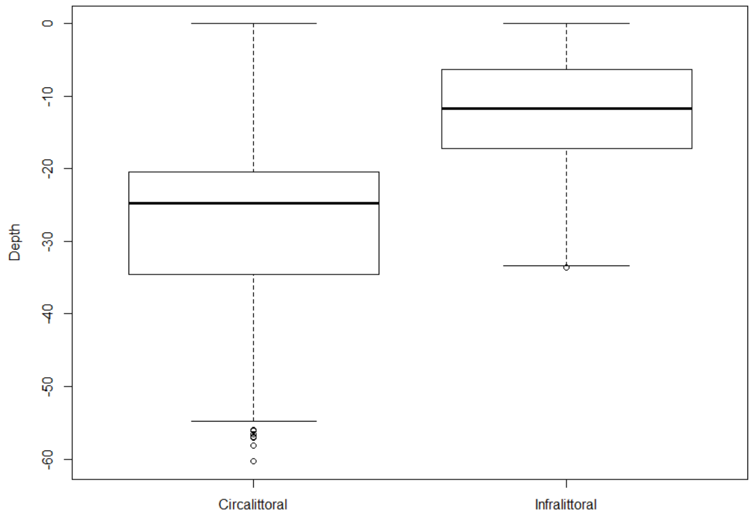

Figure 9.5.2: Depth distribution for infralittoral and circalittoral on soft bottoms

Infralittoral - Shallow circalittoral boundary on hard bottoms

On hard bottoms the limit between the infralittoral and the circalittoral is marked by the end of the domination of photophilic macroalgae caused primarily by decreasing light availability. Our intention was to perform a GLM in order to predict the probability of infralittoral / circalittoral occurence given values of light PAR at the seabed. we collated from OBIS sample points of communities that characterise the infralittoral and the circalittoral (see table 9.5.1). We managed to collate 250 points of infralittoral communities but only 5 points of circalittoral communities. This number of circalittoral points and the balance between that number and that of infralittoral points were deemed inappropriate to fit a GLM. We also decided to use depth as a proxy instead of light PAR. From the distribution of depth values for the points of infralittoral and circalittoral communities (Figure 9.5.3) we opted for values -12m and -16m as fuzzy boundaries (thus 0.25 and 4 as respectively slope and intercept of the fuzzy equation) and -14m as hard threshold.

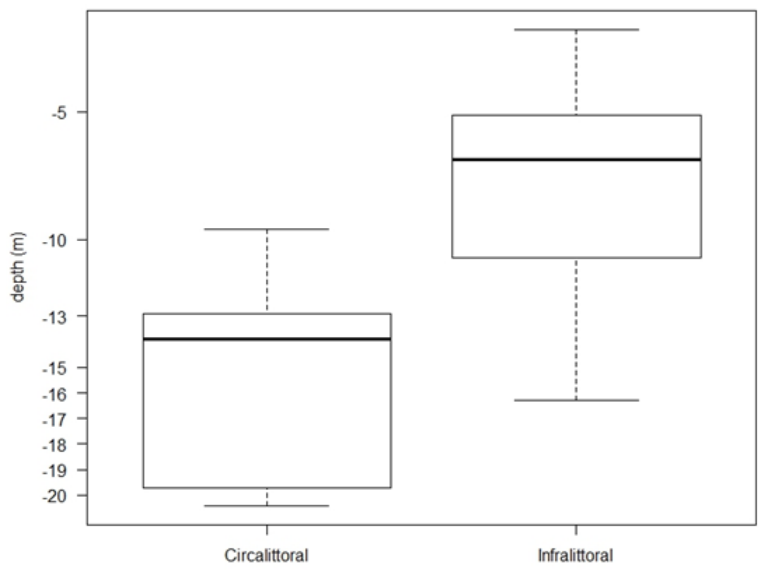

Figure 9.5.3: Depth distribution for infralittoral and circalittoral on hard bottoms

Shallow circalittoral - Deep Circalittoral

In the Black Sea the circalittoral on soft bottoms is divided in shallow and deep circalittoral, and the limit between those two zones is defined as the maximum depth at which seabed is affected by temperature seasonal variations. Occurences of shallow circalittoral and deep circalittoral assotiations (see table 9.5.1) were collated, respectively 747 and 567. For each occurence a value of temperature was extracted from the temperature grid climatology (see table 2.2 in the main report). A GLM was fitted with those values and a ROC analysis was performed in order to determine the cut-off value. As a result, the slope and the intercept of the GLM (p-value < 2e-16) were respectively 3.74 and -34.59 and the ROC analysis provided an optimal threshold probability value of 0.27 (equivalent to a temperature of 9.0°C).

Table 9.5.2: Thresholds used for biozones in the black sea

	Threshold	Fuzzy thresholds to add/substract (m)
Infralittoral/circalittoral Hard bottoms	Depth=14m	4
Infralittoral/Shallow circalittoral Soft bottoms	Depth=20m	10
Shallow circalittoral/Deep circalittoral	Temperature=9°C	NA because GLM method

9.5.2 Oxygen regimes

Table 9.5.3 lists the type of sample points that were used as indicator of the different oxygen class, thus that we used in order to work out thresholds.

Table 9.5.3 communities considered as indicator of each biological zone

Descriptor class	Indicator groundtruth data
Oxic	Presence of deep circalittoral macrobenthic communities
Suboxic	Absence of deep circalittoral macrobenthic communities Presence of meiobenthic communities
Anoxic	Absence of meiobenthic communities

For the habitat descriptor "oxygen regime" and its classes oxic/suboxic/anoxic we chose to use the water density at the seabed as a proxy. It was not possible to compute a continuous raster layer of density at the seabed. Instead we computed from Copernicus CMEMS archives a set of polylines corresponding to the intersection of individual isopycnic surfaces with the seabed. The approach that we used was to plot all polylines together with sample points of groundtruh point data indicator of the oxic and suboxic areas, and visually choose the two polylines that best separated the point observations of the different oxygen classes. Those two best polylines turned out to be the polyline corresponding to the intersection of the 15.6 kg.m^{-3} isopycnic surface with the seabed for the oxic/suboxic boundary, and the polyline corresponding to the intersection of the 16.4 kg.m^{-3} isopycnic surface with the seabed for the suboxic/anoxic boundary. With those polylines three polygons (i.e. one per oxygen class) were made and given as a preclassified input dataset to the GIS model.

9.6 Defining the threshold values for the Adriatic Sea river plume area boundary

The Adriatic mask area refers to the marine sector influenced by the river input, it followed that the definition of the mask boundaries should be based on the abiotic variables that are most correlated to freshwater input such as salinity, temperature and turbidity. The distribution of these parameters was analysed in order to identify the datasets that best match up to the expected spatial delimitation of the area most influenced by the mud and sandy mud rise into the shallow coastal areas. Several salinity (expressed in PSU), temperature (expressed in °C) and wave energy (expressed in N/m2). The salinity layer was constructed based on the Adriatic Sea salinity database (1999-2013) which was created with data derived from the Mediterranean Sea operational model developed within the MyOcean project[6]. The turbidity layer was evaluated based on the pure kdpar value which reflects the light permeability in the first centimeters of the water column (Saulquin et al., 2013). Wave energy was estimated by using the Mediterranean Coastal Wave Forecasting (Mc-waf) system, operational at ISPRA since September 2012.

After a number of tests conducted, combining the selected abiotic parameters (temperature, salinity, turbidity) surface salinity was determined to be a good proxy capable of defining the extent of the area influenced by riverine input. Considering that the mean surface salinity in the southern part of the Adriatic is 38.44 PSU, 38.28 PSU in the central part and 37.93 in the northern part of the basin, the salinity threshold used to define the limit of the mask (area of the northwestern Adriatic influenced by Po river) with respect to the rest of the basin (outside the Po influence) was defined as the annual mean surface salinity observed in the Northern Adriatic Sea (37.93 PSU). In light of the above, grid cell values characterized by annual mean surface salinity values lower than 37.93 PSU were considered adequate surrogates capable of defining the spatial extent of the Adriatic sea influenced by fine sediment apposition driven by the Po river input (Fig. 9.6.1).

Figure 9.6.1: Draft mask area calculated based on surface salinity

The salinity threshold application defined above excluded the marine coastal area to the south of the Gargano peninsula, in which the influence of the Po river is still active and where fine sediment apposition occurs very close to the shoreline. In this area wave energy is the principal parameter influencing sediment distribution and therefore a low wave energy value is responsible for fine sediment apposition. This variable was therefore used for further

[6]MyOcean, MyOcean2 and their follow up are projects founded by the European Commission within the GMES Program

delimiting the external boundaries of the mask. The wave energy layer used was that specifically produced during the project (resolution of 1.4 km for the whole basin). The average energy values observed in correspondence to the maximum depth known to be affected by wave energy (approximately 25m) were therefore calculated. The obtained mean energy value (468 N/m2) was considered the limit for the deepest part of the mask, where wave energy affecting sediment apposition is at minimum. The mean value + half the SD was considered the upper limit of fine sediment apposition induced by wave action based on the assumption that the standard deviation is considered as an estimate of the random error of the measurement. The resulting threshold limits identify a coastal belt where wave energy at the seabed is low and consequently compatible with fine sediment apposition.

In conclusion, the external boundary of the mask area (Fig. 9.6.2) was defined by combining the data defining the spatial limits of marine areas characterised by lowest annual average surface salinity together with that of areas where wave energy on sea bottom influences the deposition of fine sediments. The above mentioned procedure therefore allowed to intercept the spatial extent of the Adriatic where the river induced fine sediment flux combined with wave energy on the sea bottom is most likely contributing to deposition of fine sediment at shallow depths and influencing the benthic zoning pattern of assemblages.

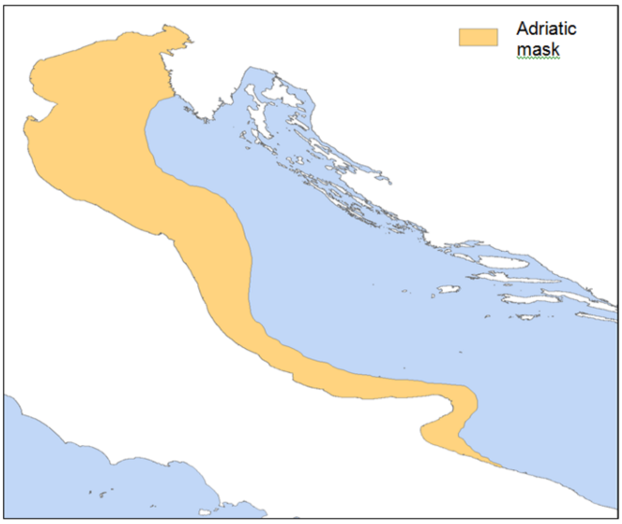

Figure 9.6.2: Final Adriatic mask area identified using surface salinity and sea bottom wave energy

9.7 Definition of the infralittoral/circalittoral boundary threshold in the Adriatic Sea river plume area

In the area influenced by the Po River, the definition of the infralittoral /circalittoral zone boundary required an alternative approach that deviates from the standard one used in the Mediterranean Sea which is based on the amount of light reaching the seabottom. The infralittoral /circalittoral boundary in this river plume area was defined on the basis of different environmental parameters.

The biological assumption behind the development of the statistical method is that infralittoral soft bottom assemblages, whose spatial extension is such that they can be cartographically represented in a broad scale map (where 1 pixel is equivalent to 250m), are mostly composed by sandy and muddy sand substrates. Infralittoral assemblages characterized by other substrates such as gravel,mud or sandy mud are generally either very small or very superficial (i.e. biocenosis of sheltered superficial waters) and would hardly be portrayable in such a broad scale map with the exception of cases limited to transitional and lagoon waters.

In cases where sandy mud and muddy bottoms should extend over large surface areas in shallow waters these are likely to host circalittoral assemblages. Circalittoral sandy bottom assemblages instead are expected to occur at deeper depths than those characterizing the shallow infralittoral sandy assemblages.

A GAM analysis was run to investigate the influence of specific environmental available variables on the distribution of sediment apposition in order to identify an alternative threshold to define the infralittoral / circalittoral boundary within the Adriatic mask. The variables considered were the sediment classes described in the higher resolution Emodnet Geology delivery map. The sediment datasets were used to define the response variable according to the grain size logic described above where sand and muddy sand are considered proxies for the distribution of the infralittoral zone and sandy mud and mud presence are indicative of the circalittoral zone.

The abiotic variables considered as predictors were: wave energy at sea bottom (log10 kinetic wave energy), depth and geographic position (latitude and longitude) of each sediment data point. The first and second variables are directly related to the typology of sediment size deposition; whereas the latter can be assumed as a proxy for distance from the mouth of Po River emissary. The grid used to extract the training and the test data sets is that of the wave energy (approximately 1.2 Km), from which the centroids were used to extract and relate all the other variables (response and predictors).

The model with the best ratio between deviance explained and GCV value was chosen. The predictive accuracy of the presence/absence model was tested on the test dataset and evaluated using the threshold-independent Receiver-Operating Characteristic (ROC) plot and the estimation of the area under the Receiver Operating Characteristic curve (AUC). The performance of the presence/absence model was good, as indicated by the estimated value of AUC (0.9) in the ROC plot. The optimum probability threshold for model was estimated and the 0.48 “Maxkappa” value were selected as threshold. The probability GAM map was classified into low (1), medium (2), and high (3) confidence based on the percentage distance of the hard threshold: +/- 50% of 0.48 gives the boundaries of the low and medium confidence and +/-95% of 0.48 gives the boundaries of the medium and high confidence.

The infralittoral/circalittoral presence raster resulting from this work was given as a preclassified input dataset to the GIS model.

9.8 Defining thresholds for Mediterranean shelf biozones

Only two biozones are considered in the Mediterranean Sea, infralittoral and circalittoral, and their boundary is defined as Posidonia *oceanica* meadows lower growth limit. Polygon data of Posidonia Meadows spatial distribution were collated for the entire region.

The meadow selection process was based on a two step approach. The first step consisted in selecting meadows based on two parameters based on the following order: i. meadows with a morphological lower limit defined as “progressive”; ii. meadows reaching depths > 30.4 (> 26.6 for the Adriatic). The selected meadows were then further queried so as to retain those with the following lower limit characteristics: (i) % of plagiotrope rhizome cover >30%; (ii) leaf cover >25%; (iii) shoot density classified as High, Good or Moderate ranking. The chosen evaluation scales are based on meadow ranking criteria used within the framework of regional evaluation and indicator frameworks (UNEP 2011, Pergent et al.1995, Montefalcone 2009). Expert advice on the overall status of the meadow was sometimes considered when information on the above parameters was missing.

The frequency histogram constructed using the minimum light values occurring within these meadows shows a log-normal distribution (Figure 9.8.1). Based on this distribution the geometric mean was chosen as the statistical parameter best describing the amount of light reaching the seabottom in correspondence to the Posidonia oceanica lower limit. This value of 1.82 $mol.pho.m^{-2}.d^{-1}$ was considered as the light threshold identifying the boundary between the infralittoral and circalittoral zone. Considering the distribution of light values, the fuzzy range was defined as [1.19 - 2.27].

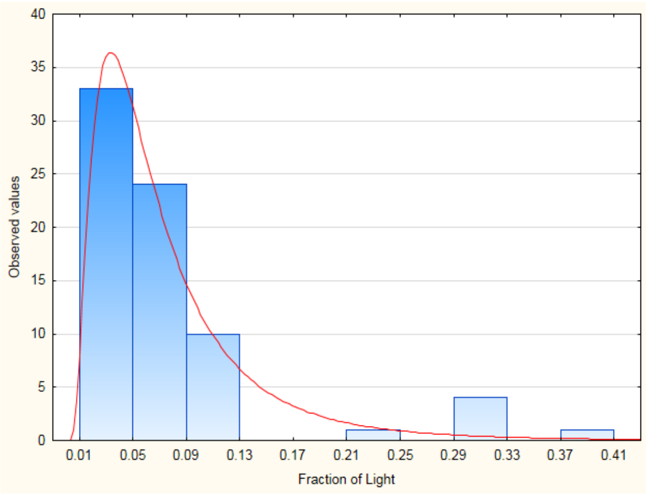

Fig.9.8.1: Frequency histogram of modelled minimum light value on seabottom observed for the selected Posidonia meadows

9.9 References

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9.10 Recap thresholds tables

The tables below recap for each boundary and descriptor class the classification method employed as well as the slope and intercept of the GLM or fuzzy equation and the probability threshold. Those 3 figures, namely slope, intercept and probability threshold, are those that feed the GIS model workflow. Other figures are provided here for information because they are mode meaningful than slope, intercept and probability thresholds, namely the threshold in the unit of the explanatory variable (column "Variable threshold") and, when the classification method is a fuzzy rule, the X1 and X0 values, i.e. the values at which the probability starts to be respectively 1 and 0. We remind that for fuzzy classification method slope = 1/(X1-X0); intercept = -X0/(X1-X0). For further details on GLM and fuzzy classification refer to the main report, section "Modelling habitat descriptor classes and setting boundaries".

9.10.1 Atlantic and Arctic shelf biozones

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
infralittoral/circalittoral	GLM-ROC	infralittoral	1.076	-0.777	0.49	Seabed PAR (mol. pho.m^{-2}.d^{-1})	0.7	NA	NA
		circalittoral	-1.076	0.777	0.51			NA	NA
shallow circalittoral/deep circalittoral Norway	Fuzzy	shallow circalittoral	0.000714	-6.286	0.5	Wave Exposure Index	10000	10200	8800
		deep circalittoral	-0.000714	7.286	0.5			8800	10200
shallow circalittoral/deep circalittoral Greater North Sea and Celtic Seas	Fuzzy	shallow circalittoral	1.25	-2	0.5	Wave wave length/depth	2	2.4	1.6
		deep circalittoral	-1.25	3	0.5			1.6	2.4
shallow circalittoral/deep circalittoral Bay of Biscay	GLM-ROC	shallow circalittoral	-19.2	28.7	0.59	Wave wave length/depth	1.5	NA	NA
		deep	19.2	-28.7	0.41			NA	NA

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
		circalittoral							
shallow circalittoral/deep circalittoral Iberian Peninsula	Fuzzy	shallow circalittoral	1	-2.2	0.5	Wave wave length/depth	2.7	3.2	2.2
		deep circalittoral	-1	3.2	0.5			2.2	3.2
shallow circalittoral/deep circalittoral From Santander to La Coruña, Off strait of Gibraltar	Fuzzy	shallow circalittoral	0.0333	3.1667	0.5	Depth (m)	-80	-65	-95
		deep circalittoral	-0.0333	-2.1667	0.5			-95	-65

9.10.2 Atlantic deep-sea biozones

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
Atlantic upper bathyal/Atlantic mid bathyal	Fuzzy	Atlantic upper bathyal	0.0027	2.13	0.5	Depth (m)	-600	-416	-784
		Atlantic mid bathyal	-0.0027	-1.13	0.5			-784	-416
Atlantic upper bathyal/ Atlanto-Mediterranean mid bathyal	Fuzzy	Atlantic upper bathyal	0.0027	2.13	0.5	Depth (m)	-600	-416	-784
		Atlanto-Mediterranean mid bathyal	-0.0027	-1.13	0.5			-784	-416
Atlantic mid bathyal/Atlantic lower bathyal	Fuzzy	Atlantic mid bathyal	0.0018	2.797	0.5	Depth (m)	-1300	-1017	-1583
		Atlantic lower	-0.0018	-1.797	0.5			-1583	-1017

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
		bathyal							
Atlanto-Mediterranean mid bathyal/Atlantic lower bathyal	Fuzzy	Atlanto-Mediterranean mid bathyal	0.0018	2.797	0.5	Depth (m)	-1300	-1017	-1583
		Atlantic lower bathyal	-0.0018	-1.797	0.5			-1583	-1017
Atlantic lower bathyal/Atlantic upper abyssal	Fuzzy	Atlantic lower bathyal	0.0017	4.319	0.5	Depth (m)	-2200	-1912	-2488
		Atlantic upper abyssal	-0.0017	-3.319	0.5			-2488	-1912
Atlantic upper abyssal/Atlantic mid abyssal	Fuzzy	Atlantic upper abyssal	0.0016	5.516	0.5	Depth (m)	-3200	-2881	-3519
		Atlantic mid abyssal	-0.0016	-4.516	0.5			-3519	-2881
Atlantic mid abyssal/Atlantic lower abyssal	Fuzzy	Atlantic mid abyssal	0.0015	7.075	0.5	Depth (m)	-4300	-3973	-4627
		Atlantic lower abyssal	-0.0015	-6.075	0.5			-4627	-3973

9.10.3 Atlantic exposure to waves

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
High/moderate Greater North Sea and Celtic Seas	GLM-ROC	High	0.013	-0.642	0.57	Kinetic energy (N.m^{-2})	70.95	NA	NA
		Moderate	-0.013	0.642	0.43			NA	NA
High/moderate Bay of Biscay	Fuzzy	High	0.1	-1.7	0.5	Kinetic energy (N.m^{-2})	22	27	17
		Moderate	-0.1	2.7	0.5			17	27
High/moderate From Santander to La Coruña Off strait of Gibraltar	Fuzzy	High	0.1	-8.5	0.5	Kinetic energy (N.m^{-2})	90	95	85
		Moderate	-0.1	9.5	0.5			85	95
High/moderate Azores and Iberian Peninsula	Fuzzy	High	0.1	-3.87	0.5	Kinetic energy (N.m^{-2})	43.7	48.7	38.7
		Moderate	-0.1	4.87	0.5			38.7	48.7
Moderate/Low Greater North Sea and Celtic Seas	GLM-ROC	Moderate	0.07	-1.236	0.39	Kinetic energy (N.m^{-2})	11.41	NA	NA
		Low	-0.07	1.236	0.61			NA	NA
Moderate/Low Bay of Biscay	Fuzzy	Moderate	0.167	-0.767	0.5	Kinetic energy (N.m^{-2})	7.6	10.6	4.6
		Low	-0.167	1.767	0.5			4.6	10.6
Moderate/Low From Santander to La Coruña Off strait of Gibraltar	Fuzzy	Moderate	0.1	-5.5	0.5	Kinetic energy (N.m^{-2})	60	65	55
		Low	-0.1	6.5	0.5			55	65
Moderate/Low	Fuzzy	Moderate	0.5	-1	0.5	Kinetic energy	3	4	2

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
Azores and Iberian Peninsula		Low	-0.5	2	0.5	($N.m^{-2}$)		2	4

9.10.4 Atlantic and Arctic exposure to currents

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
High/moderate Greater North Sea, Celtic Seas and Norway	Fuzzy	High	0.05	-57.5	0.5	Kinetic energy ($N.m^{-2}$)	1160	1170	1150
		Moderate	-0.05	58.5	0.5			1150	1170
High/moderate Bay of Biscay, Azores, Iberian Peninsula	Fuzzy	High	0.00714	-5.929	0.5	Kinetic energy ($N.m^{-2}$)	900	970	830
		Moderate	-0.00714	6.929	0.5			830	970
Moderate/Low Greater North Sea and Celtic Seas	Fuzzy	Moderate	0.05	-6	0.5	Kinetic energy ($N.m^{-2}$)	130	140	120
		Low	-0.05	7	0.5			120	140
Moderate/Low Bay of Biscay, Azores, Iberian Peninsula	Fuzzy	Moderate	0.00714	-0.214	0.5	Kinetic energy ($N.m^{-2}$)	100	170	30
		Low	-0.00714	1.214	0.5			30	170

9.10.5 Artic deep-sea biozones

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
Atlantic upper bathyal/Atlanto-Arctic	Fuzzy	Atlantic upper bathyal	0.0068	2.5	0.5	Depth (m)	-300	-226	-374

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
upper bathyal		Atlanto-Arctic upper bathyal	-0.0068	-1.5	0.5			-374	-226
Atlanto-Arctic upper bathyal/Arctic mid bathyal	Fuzzy	Atlanto-Arctic upper bathyal	0.0020	1.71	0.5	Depth (m)	-600	-352	-848
		Arctic mid bathyal	-0.0020	-0.71	0.5			-848	-352
Arctic mid bathyal/Arctic lower bathyal	Fuzzy	Arctic mid bathyal	0.0013	2.22	0.5	Depth (m)	-1300	-923	-1677
		Arctic lower bathyal	-0.0013	-1.22	0.5			-1677	-923
Arctic lower bathyal/Arctic upper abyssal	Fuzzy	Arctic lower bathyal	0.0016	4.37	0.5	Depth (m)	-2400	-2090	-2710
		Arctic upper abyssal	-0.0016	-3.37	0.5			-2710	-2090

9.10.6 Icelandic shelf biozones

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
Infralittoral/Shallow circalittoral North	Fuzzy	Infralittoral	0.1667	5.5	0.5	Depth (m)	-30	-27	-33
		Shallow circalittoral	-0.1667	-4.5	0.5			-33	-27
Infralittoral/Shallow circalittoral South	Fuzzy	Infralittoral	0.3333	5.5	0.5	Depth (m)	-15	-13.5	-16.5
		Shallow circalittoral	-0.3333	-4.5	0.5			-16.5	-13.5
Shallow circalittoral/Deep circalittoral	Fuzzy	Shallow circalittoral	0.0625	5.5	0.5	Depth (m)	-80	-72	-88
		Deep	-0.0625	-4.5	0.5			-88	-72

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
North and South		circalittoral							

9.10.7 Black Sea shelf biozones

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
Infralittoral/circalittoral Hard bottoms	Fuzzy	Infralittoral	0.05	1.5	0.5	Depth (m)	-14	-10	-30
		Circalittoral	-0.05	-0.5	0.5			-30	-10
Infralittoral/Shallow circalittoral Soft bottoms	Fuzzy	Infralittoral	0.25	4	0.5	Depth (m)	-20	-12	-16
		Shallow circalittoral	-0.25	-3	0.5			-16	-12
Shallow circalittoral/Deep circalittoral	GLM-ROC	Shallow circalittoral	3.74	-34.59	0.27	Temperature (°C)	9.0	NA	NA
		Deep circalittoral	-3.74	34.59	0.73			NA	NA

9.10.8 Mediterranean shelf biozones

Boundary	Classification method	Descriptor class	Slope	Intercept	Probability threshold	Explanatory variable	Variable threshold	Fuzzy X1	Fuzzy X0
Infralittoral/circalittoral	Fuzzy	Infralittoral	0.926	-1.102	0.58	Seabed PAR (mol. pho.$m^{-2}.d^{-1}$)	1.82	2.27	1.19
		Circalittoral	-0.926	2.102	0.42			1.19	2.27

10 Confidence appendix

10.1 Confidence in values of continuous physical variables

The overall method for this assessment is described in Section 2.7 of the main report. The following sections describe the confidence assessment method applied for each data layer described in Table 2.1.

10.1.1 Depth to the seabed, all regions

The EMODnet Bathymetry project was the source of the depth to the seabed dataset (a digital elevation model (DEM). The project also produced a 'quality indicator', which gave score between 0 (high quality) and 1 (low quality) to each cell, *i*, according to the following equation:

$$quality_i = \left(\frac{(age\ of\ survey)_i}{age\ of\ oldest\ survey}\right)\left(1 - \frac{\log\left(no.of\ soundings_i + 1\right)}{\log\left(\max number\ of\ soundings + 1\right)}\right)$$

The first term can be considered as the 'relative age' of the data in the cell, being relative to the age of the oldest survey in the DEM. The second term can be considered as the 'relative sampling effort' for the grid cell, being relative to the cell with the highest sampling effort in the DEM. SHOM (2016) gives a full rationale and description of the method, but a summary of the factors that affect the confidence in the depth model are summarised in Table 10.1.3. Following receipt of the quality indicator scores, the EMODnet Seabed Habitats project categorised the scores into "high", "moderate" and "low" confidence. This was done by visually observing the effect of different thresholds and establishing which would result in the most helpful range of confidence scores (Table Figure 10.1.1).

Table 10.1.3: Qualitative assessment of confidence in depth to the seabed in all regions.

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	A range of survey and modelling techniques were used to create the data used in the DEM, from satellite-derived gravity data to single- and multi-beam echo sounder data.	In some areas information of the original data sources and processing steps were available, but not everywhere. However, the date of the original survey can act as a useful proxy for quality of original data and methods.
Spatial resolution	With a model resolution of 250 m, it varies from good (Map resolution > Model resolution > True variability) in flat areas with high sampling effort to poor (True variability > Model resolution) in steep, heterogeneous areas with low sampling effort.	Sampling effort (number of soundings per grid cell). Approximation of the heterogeneity of the seabed based on variation in depth with horizontal distance.
Temporal	The DEM was built by collating depth data from various sources	Date of original survey was usually available, otherwise an estimate

resolution	from a variety of years. While depth in most areas of the seabed do not vary greatly over time, some more energetic sediment environments do. Furthermore, the year of survey can often correlate with and therefore act as a useful proxy for the quality of the data.	was made.

Table 10.1.4: criteria used for assessing confidence in depth to the seabed in all regions.

Confidence per cell	Criteria
High	0 ≤ EMODnet Bathymetry confidence score < 0.06
Moderate	0.06 ≤ EMODnet Bathymetry confidence score < 0.6
Low	0.6 ≤ EMODnet Bathymetry confidence score ≤ 1

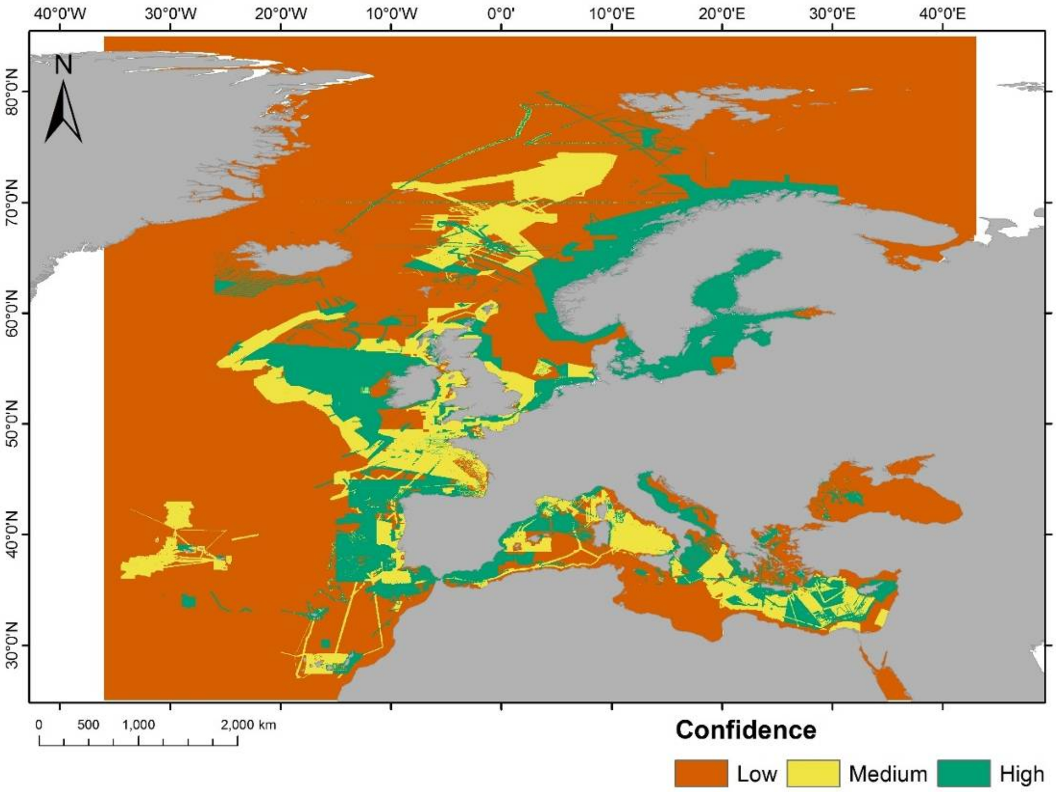

Figure 10.1.1: Confidence in depth to the seabed in all regions

10.1.2 Photosynthetically available radiation (PAR) at the seabed, Arctic, Atlantic and Mediterranean

PAR at the seabed was calculated from three separate variables: PAR at the surface, light attenuation coefficient K_D(PAR) and depth to the seabed. The confidence in the PAR at the seabed was therefore calculated by calculating the mean (rounded up) of two separate assessments:

- Depth to the seabed confidence (described in Section Depth to the seabed, all regions Depth to seabed : Secchi disk depth ratio, Baltic Sea)

- PAR at the surface and K_D(PAR) confidence, described below

Considering the qualitative assessment described in Table 10.1.5, the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 10.1.6) and applied (Figure 10.1.2) for PAR at the surface and KD(PAR).

Table 10.1.5: qualitative assessment of confidence in PAR at the surface and KD(PAR) in the Arctic, Atlantic and Mediterranean.

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	The models were created using sound methods; however, there was limited ground-truthing data available.	Reports from contractors detailing the methods used.
Spatial resolution	With model resolutions of 250 m (K_D(PAR)) and 4 km (PAR at the surface), it varies from good (Map resolution > Model resolution > True variability) in gradually sloping and deeper waters to poor (True variability > Model resolution) in steep, shallow waters with complex coastlines.	Expert judgement about the true variability. Number of satellite images per cell used to build models of light attenuation and PAR at the surface.
Temporal resolution	The models of light attenuation and PAR at the surface were built from five years' worth of satellite data (2005 – 2009) in order to maximise the number of images per cell. These ranges of years are deemed appropriate. Annual means were used for these variables; further research is needed to confirm whether this is most suitable metric, or whether another would be better, e.g. summer mean.	Expert judgement

Table 10.1.6: criteria used for assessing confidence in PAR at the surface and KD(PAR) in the Arctic, Atlantic and Mediterranean.

Confidence per cell	Criteria
High	39 ≤ satellite images per grid cell
Moderate	29 ≤ satellite images per grid cell < 39
Low	0 ≤ satellite images per grid cell < 29

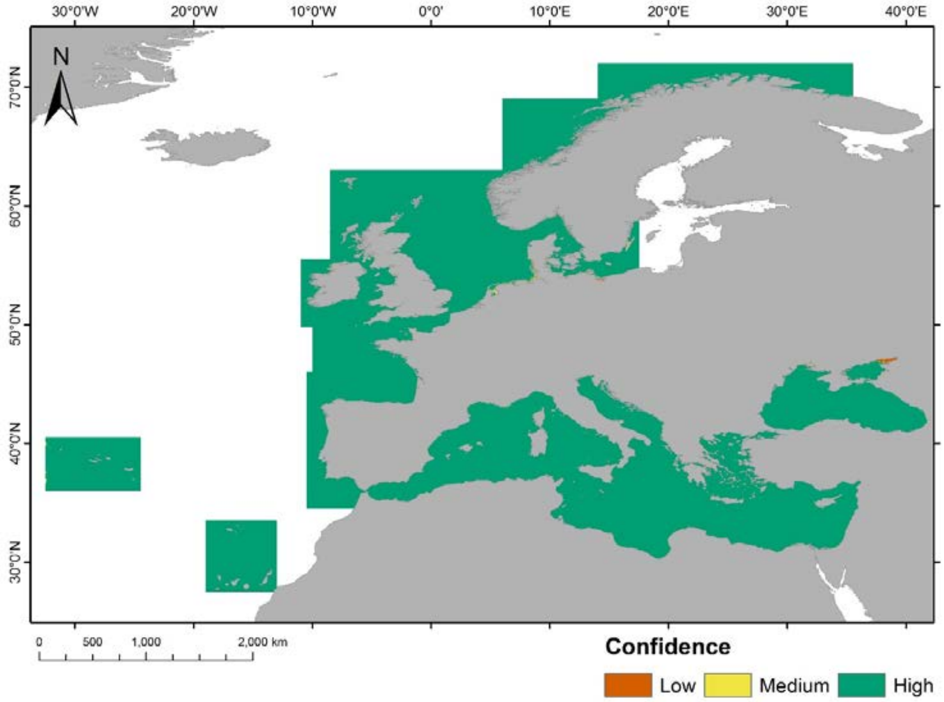

Figure 10.1.2: confidence in PAR at the surface and KD(PAR) in the Arctic, Atlantic and Mediterranean

Finally, the PAR at the surface and KD(PAR) confidence (Figure 10.1.2) and the depth at the seabed confidence (Figure 10.1.1) were combined using the mean (rounded up, Figure 10.1.3).

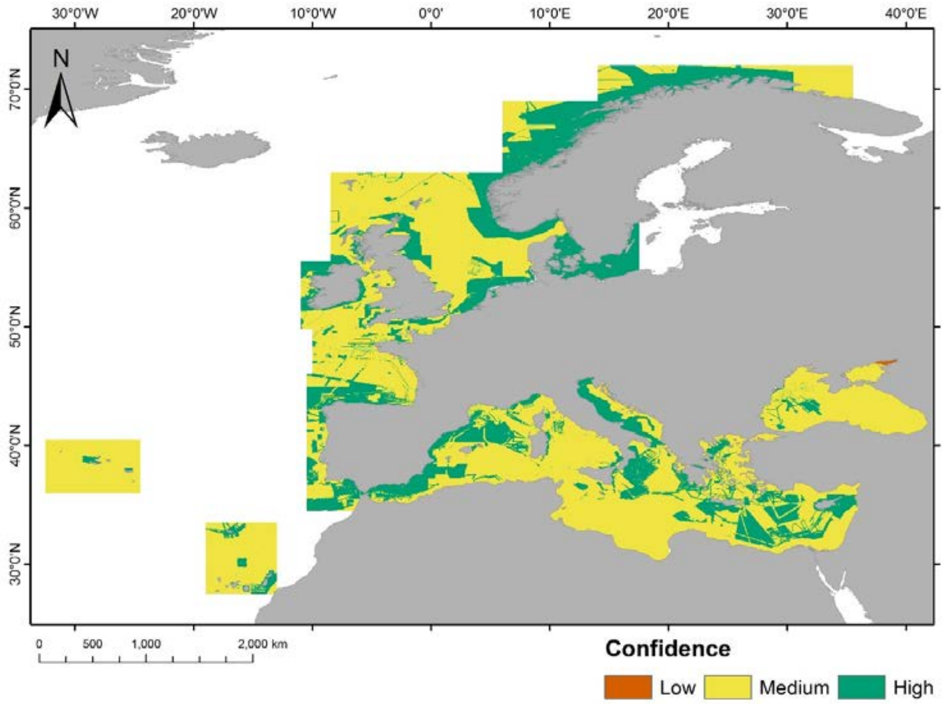

Figure 10.1.3: confidence in PAR at the seabed in the Arctic, Atlantic and Mediterranean

10.1.3 Depth to seabed: Secchi disk depth ratio, Baltic Sea

The Secchi disk depth ratio was calculated from two separate variables: Secchi disk depth and depth to the seabed. The confidence in the ratio was therefore calculated by calculating the mean (rounded up) of two separate assessments:

- Depth to the seabed confidence (described in Section Depth to the seabed, all regions)
- Secchi disk depth confidence, described below

Secchi disk depth confidence was calculated using the density of in situ Secchi disk sample points per 0.3 x 0.3 degree grid in the Baltic Sea.

Considering the qualitative assessment described in **Table** , the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 10.1.8) and applied (Figure 10.1.8) for Secchi disk depth.

Table 10.1.7: Qualitative assessment of confidence in Secchi disk depth in the Baltic Sea.

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	The model was created from available Secchi depth data from ICES database and SYKE data. Only growing season data (March-October) mean value was used with a total of 5738 locations in the Baltic and North Sea.	A publication by ICES and Aarup publication 2002
Spatial resolution	The data sets have different resolution depending on the geographical location. The model resolution is of 250 m, so spatial resolution is considered good (Map resolution > Model resolution > True variability) in areas with dense sampling points to poor (True variability > Model resolution) in areas with low density of sampling points.	0.3x0.3 model resolution was taken to ensure as minimum as one data point in most cells.
Temporal resolution	Secchi samples were collected between 1980 and 1998 by ICES and SYKE data from 1999 to 2008.	There is an annual data acquisition at selected stations in the Baltic Sea.

Table 10.1.8: Criteria used for assessing confidence in Secchi disk depth in the Baltic Sea.

Confidence per cell	Criteria
High	50 ≤ in situ records per grid cell
Moderate	5 ≤ in situ records per grid cell < 50
Low	0 ≤ in situ records per grid cell < 5

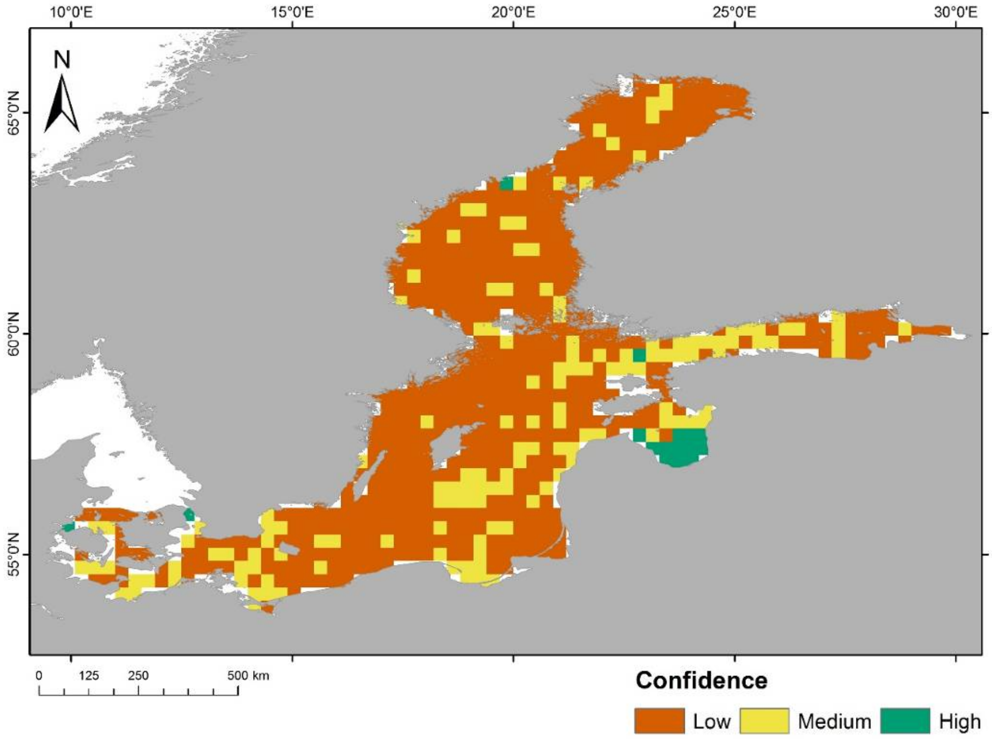

Figure 10.1.8: Confidence in Secchi disk depth in the Baltic Sea, based on number of Secchi disk samples per 0.3 x 0.3 degree grid square

Finally, the Secchi disk depth confidence (Figure 10.1.8) and the depth at the seabed confidence (Figure 10.1.1) were combined using the mean (rounded up) to produce the confidence in depth to seabed: Secchi disk depth ratio (Figure 10.1.9).

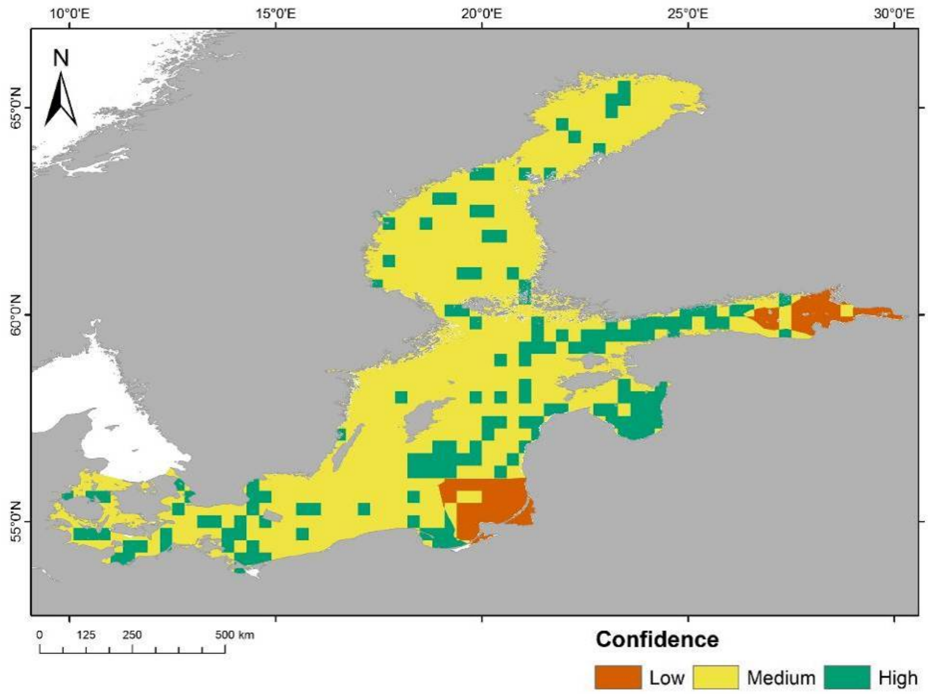

Figure 10.1.9: Confidence in depth to seabed: Secchi disk depth ratio in the Baltic Sea

10.1.4 Temperature at the seabed, Black Sea

Considering the qualitative assessment described in Table 10.1.9, the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 10.1.10) and applied (Figure 10.1.10).

Table 10.1.9: Qualitative assessment of confidence in temperature at the seabed in the Black Sea.

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	The reliability of the model was tested by comparison with observed data in the period 31/03/2005 – 26/09/2006 and was deemed to be good.	Demyshev S.G., 2012. “A numerical model of online forecasting Black sea currents”. Izvestiya, Atmospheric and oceanic physics, Vol. 48, N. 1, 2012.
Spatial resolution	The model resolution (4 km) is poor with respect to the true spatial variability. (True variability > Model resolution).	Model resolution: latitude:1/22 º longitude: 1/16 º 38 vertical levels
Temporal resolution	The model temporal resolution is adequate for reproducing the true temporal variability. (True variability < Model resolution).	Daily averages.

Table 10.1.10: Criteria used for assessing confidence in temperature at the seabed in the Black Sea.

Confidence per cell	Criteria
High	N/A
Moderate	N/A
Low	Spatial resolution = 4 km.

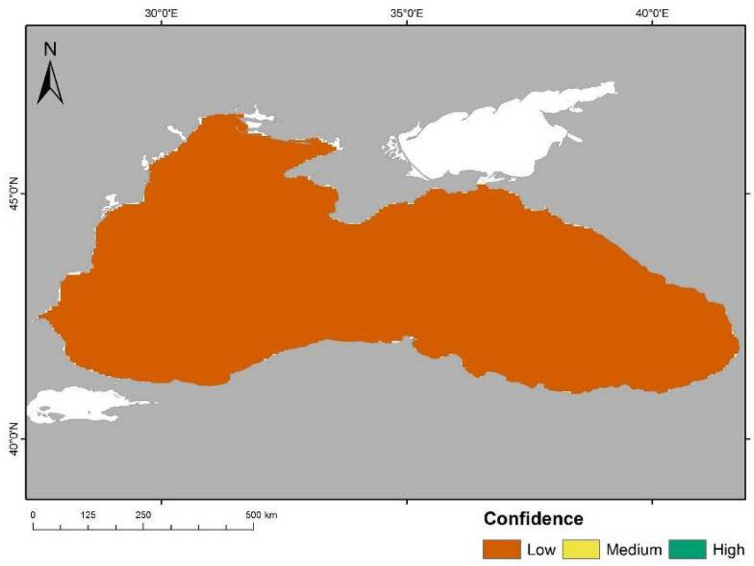

Figure 10.1.10: Confidence in temperature at the seabed in the Black Sea

10.1.5 Potential density anomaly (σθ) at the seabed, Black Sea

Considering the qualitative assessment described in Table 10.1.11, the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 10.1.12) and applied (Figure 10.1.11).

Table 10.1.11: Qualitative assessment of confidence in potential density anomaly (σθ) at the seabed in the Black Sea.

Factor influencing confidence	**Qualitative assessment**	**Information available for assessment**
Quality of training data and methods	The reanalysis data for 1993 were selected for calculation of density anomaly (σθ) levels at the seabed based on consultation with provider of MyOcean data products for Black Sea (MHI NASU at that time). The results were compared with calculations based on 1992, 2002 and 2012 reanalysis data and appeared to be consistent. The obtained σθ polylines were tested against Romanian groundtruth data on suboxic habitats and showed good correspondence.	MyOcean Black Sea products: BLACKSEA_REANALYSIS_PHYS_007_002 (service stopped in 2014)
Spatial resolution	With a model resolution of 5 km, it is poor (True variability > Model resolution).	Model resolution: latitude: 0.04445 º longitude: 0.06111º 38 vertical levels.
Temporal resolution	The model temporal resolution is adequate for reproducing the true temporal variability. (True variability ~= Model resolution).	Monthly averages

Table 10.1.12: Criteria used for assessing confidence in potential density anomaly (σθ) at the seabed in the Black Sea.

Confidence per cell	Criteria
High	N/A
Moderate	N/A
Low	Spatial resolution = 5 km

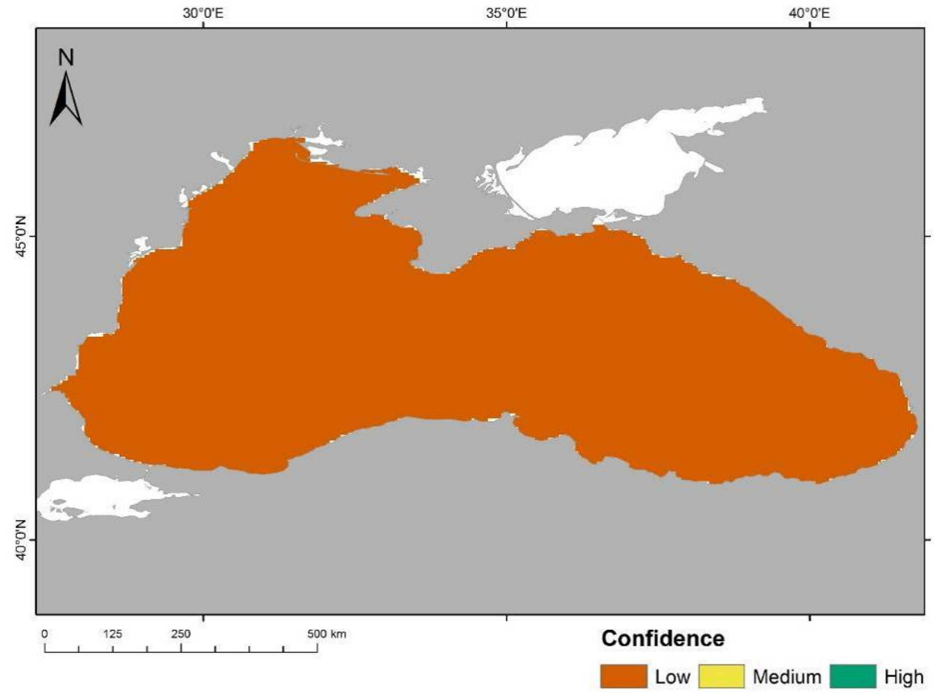

Figure 10.1.11: Confidence in potential density anomaly (σθ) at the seabed in the Black Sea.

10.1.6 Salinity at the seabed, Baltic Sea

Considering the qualitative assessment described in Table 10.1.13, the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 2.7.2) and applied (Figure 10.1.13).

Table 10.1.13: Qualitative assessment of confidence in the salinity at the seabed values in the Baltic Sea.

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	Data acquired from DHI hydrographic Model MIKE III It develops a dynamic time-dependant 3D baroclinic model for free surface flow. The wind, temperature, humidity and precipitation information was delivered by Vejr2 (2002-2008) and DMI (before 2002). Confidence based on 11 DHI	Report submitted by DHI that describes the input hydrodynamic and climate models.

	control points	
Spatial resolution	The salinity spatial resolution is 3nm. It is considered to be poor resolution given the habitat model resolution of 250m. However, the varied distribution of training data means that this varies over space.	Expert judgement about the true variability. Point locations of in situ training data.
Temporal resolution	The model uses Vejr2 (2002-2008) and DMI (before 2002).	The model produces 3D matrix of current, salinity and temperature with one hour resolution.

Table 10.1.14: Criteria used for assessing confidence in the salinity at the seabed values in the Baltic Sea.

Confidence per cell	**Criteria**
High	Distance between grid cell and nearest in situ control point < 45 km
Moderate	45 km < Distance between grid cell and nearest in situ control point < 55 kmxx m
Low	55 km < Distance between grid cell and nearest in situ control point

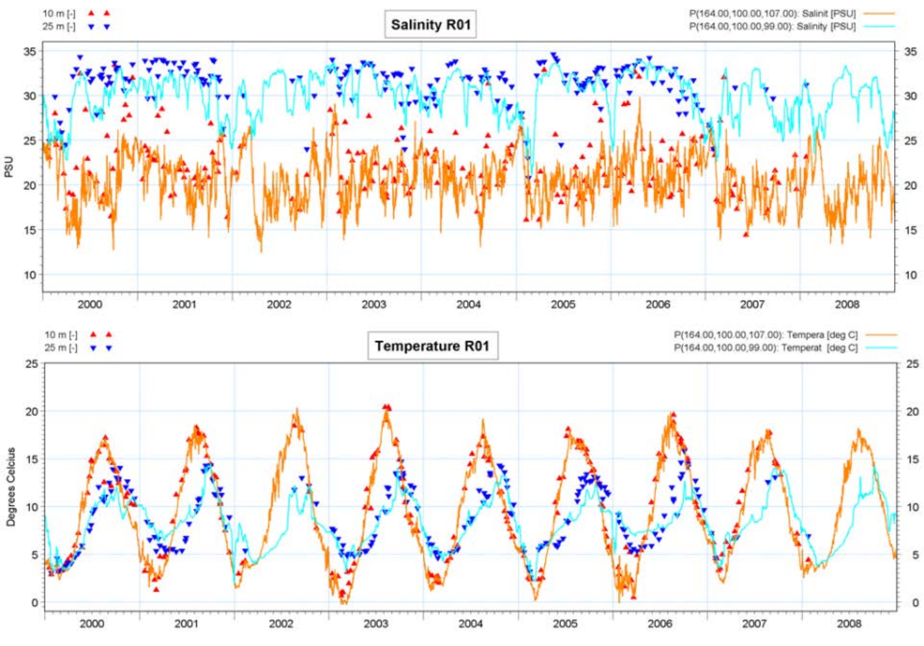

Figure 10.1.12: Comparison of measured and modelled salinity (upper) and temperature (lower) in Station R01. The two depths (10 m and 25 m) represent the surface layer and the bottom layer.

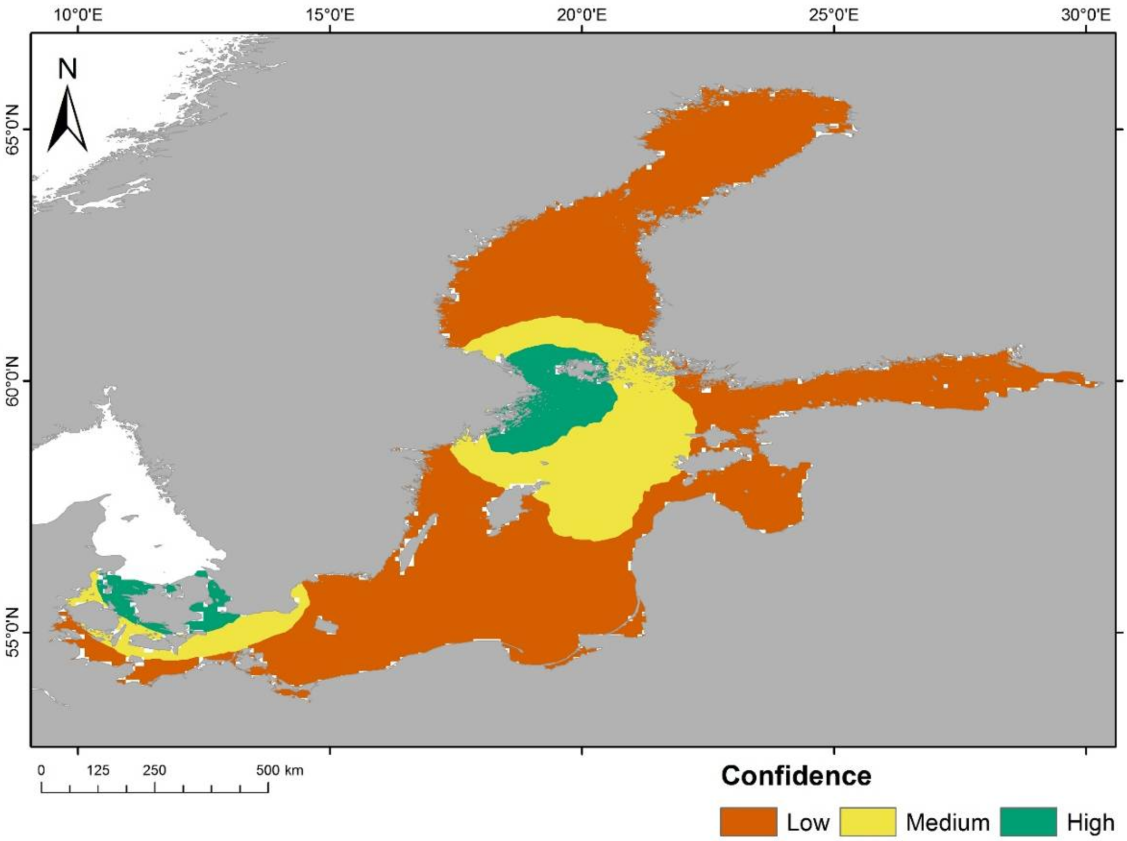

Figure 10.1.13: Confidence in salinity at the seabed values in the Baltic Sea.

10.1.7 Kinetic energy due to currents, Arctic and Atlantic

Considering the qualitative assessment described in Table 10.1.15, the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 10.1.16) and applied (Figure 10.1.14).

Table 10.1.15: Qualitative assessment of confidence in Kinetic energy due to currents in Arctic and Atlantic.

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	The models were created using sound methods overall. In the Norwegian and Arctic Seas, the Norwegian current speed model NorKyst800 (with a horizontal resolution of 800 m) was applied. This means that narrow sounds and shallow areas were poorly represented. For the Greater North Sea & Celtic Seas area current energy layer was produced with model data from the National Oceanography Centre (NOC). A combination of three current energy	Albretsen et al (2011) for the Norwegian and Arctic Seas. For the Greater North Sea & Celtic Seas Reports from contractors detailing the methods used and information about the NOC models is available (ABPmer,

	models was use. The high resolution continental shelf model (CS20), fine resolution continental shelf model (CS3), and the North East Atlantic model (NEA). For the Iberia, Biscay, and Azores model area current-induced energy layers were produced with model data from Ifremer in the Bay of Biscay from Maretec in the Iberia and Azores	2010b). Caillaud et al, 2016 for Bay of Biscay Vasquez et al, 2015 for Iberia and Azores
Spatial resolution	Overall, it is moderate (Model resolution > True variability > Map resolution) to poor (True variability > Model resolution). For the Greater North Sea & Celtic Seas area model resolution was different for each of the three models CS20 = 1.8km, CS3 = 16km, and NEA = 35km. Resolution is higher close to the coast to reflect the fact that there is more variability in shallower waters. In the Bay of Biscay, Iberia and Azores the resolution is 500m in the Bay of Biscay and 4km in the Iberia and Azores	Expert judgement about the true variability. Actual spatial resolution of the models (ABPmer, 2010b).
Temporal resolution	For the Greater North Sea & Celtic Seas the kinetic energy time series was based on 30 minute output from tidal models run for 2001, considered to be a typical year (ABPmer 2010a and ABPmer 2010 Arctic: 2 years Bay of Biscay: 6 years Iberia and Azores: 3 years In all cases the top 10 % of values were excluded to account for extreme weather. These ranges of years are deemed appropriate.	Expert judgement

Table 10.1.16: Criteria used for assessing confidence in Kinetic energy due to currents in Arctic and Atlantic.

Confidence per cell	**Criteria**
High	0 m ≤ spatial resolution < 3,000 m
Moderate	3,000 m ≤ spatial resolution < 35,000 m
Low	35,000 m ≤ spatial resolution

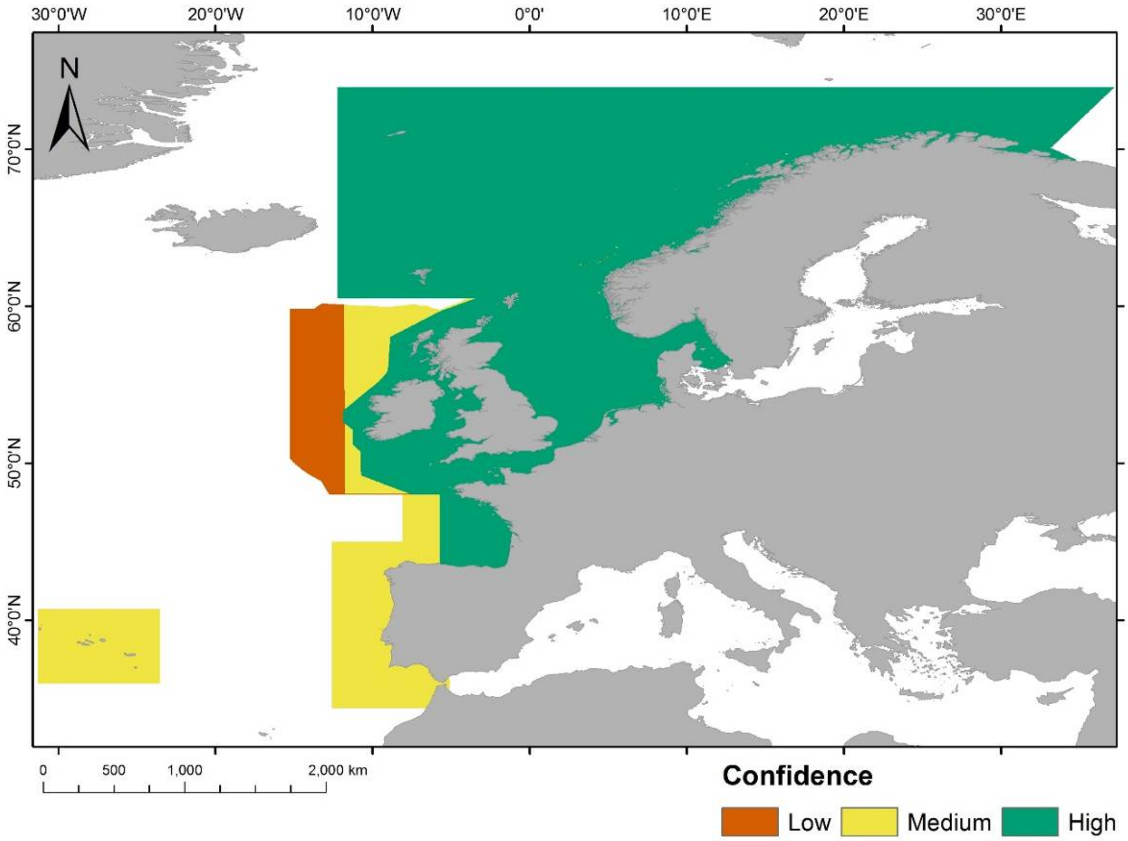

Figure 10.1.14: Confidence in kinetic energy due to currents in Arctic and Atlantic

10.1.8 Kinetic energy due to waves, Atlantic and Mediterranean (Adriatic only), and Wave exposure index, Arctic and Baltic

Considering the qualitative assessment described in Table 10.1.17, the criteria for determining "high", "moderate" and "low" categories that vary spatially were derived (Table 10.1.18) and applied (Figure 10.1.15).

Table 10.1.17: Qualitative assessment of confidence in Kinetic energy due to waves in Atlantic and Mediterranean (Adriatic only), and Wave exposure index in Arctic and Baltic.

Factor influencing confidence	Qualitative assessment	Information available for assessment
Quality of training data and methods	The models were created using sound methods. In the Baltic Sea the wave exposure index relates to the surface rather than the seabed, meaning depth is not taken into account. In the Arctic Seas model area a wave exposure index is used. The models were created using sound methods. Modelled wave exposure index (corrected for bathymetry, i.e. it is a seabed model) was applied with a horizontal resolution of 25	Reports from contractors detailing the methods used (ABPmer, 2010b).

	m. Wave exposure was divided into classes by the “National program for mapping biodiversity – coast” (Norway) For the Greater North Sea & Celtic Seas area the wave energy layer was produced with model data from the National Oceanography Centre (NOC), primarily the ProWAM wave model however a series of 24 bespoke wave models were used for coastal areas. For the Iberia, Biscay, and Azores model area energy layers were produced with model data • from HOMERE hindcast archive in the Bay of Biscay along French coast to Santander westward • from a coarse wave model from Santander to La Coruña • from Maretec in the Iberia • from University in the Azores In the masked area of riverine inputs in the Adriatic …	Bay of Biscay along French coast to Santander westward: Boudiere et al, 2013 Azores and Iberia: Vasquez et al, 2015
Spatial resolution	Overall, it is moderate (Model resolution > True variability > Map resolution) to poor (True variability > Model resolution). For the Greater North Sea & Celtic Seas, coastal areas (up to ~6km from coastline) use higher resolution models (~300m). The NOC ProWAM wave model has a resolution of ~12km. Resolution is higher close to the coast to reflect the fact that this is where waves have the highest impact on the seabed. In the bay of Biscay along French coast to Santander westward the resolution is 300m at the coast and 3km offshore. From Santander to La Coruña it is 20km. In the Iberian Peninsula and the Azores it is 4km	Expert judgement about the true variability. Actual spatial resolution of the models.
Temporal resolution	The models all used data from multiple years (North Sea and Celtic Seas: average 5 years of ProWAM data 2000 - 2005; Baltic Sea: 5 years from 2002-2007). Model data was integrated over 5 years (2000-2005) in the Bay of Biscay and 3	Expert judgement

	years in the Iberia and Azores In all cases the top 10 % of values were excluded to account for extreme weather. These ranges of years are deemed appropriate.	

Table 10.1.18: Criteria used for assessing confidence in Kinetic energy due to waves in Atlantic and Mediterranean (Adriatic only), and Wave exposure index in Arctic and Baltic.

Confidence per cell	Criteria
High	0 m ≤ spatial resolution < 301 m
Moderate	301 m ≤ spatial resolution < 12,001 m
Low	12,001 m ≤ spatial resolution

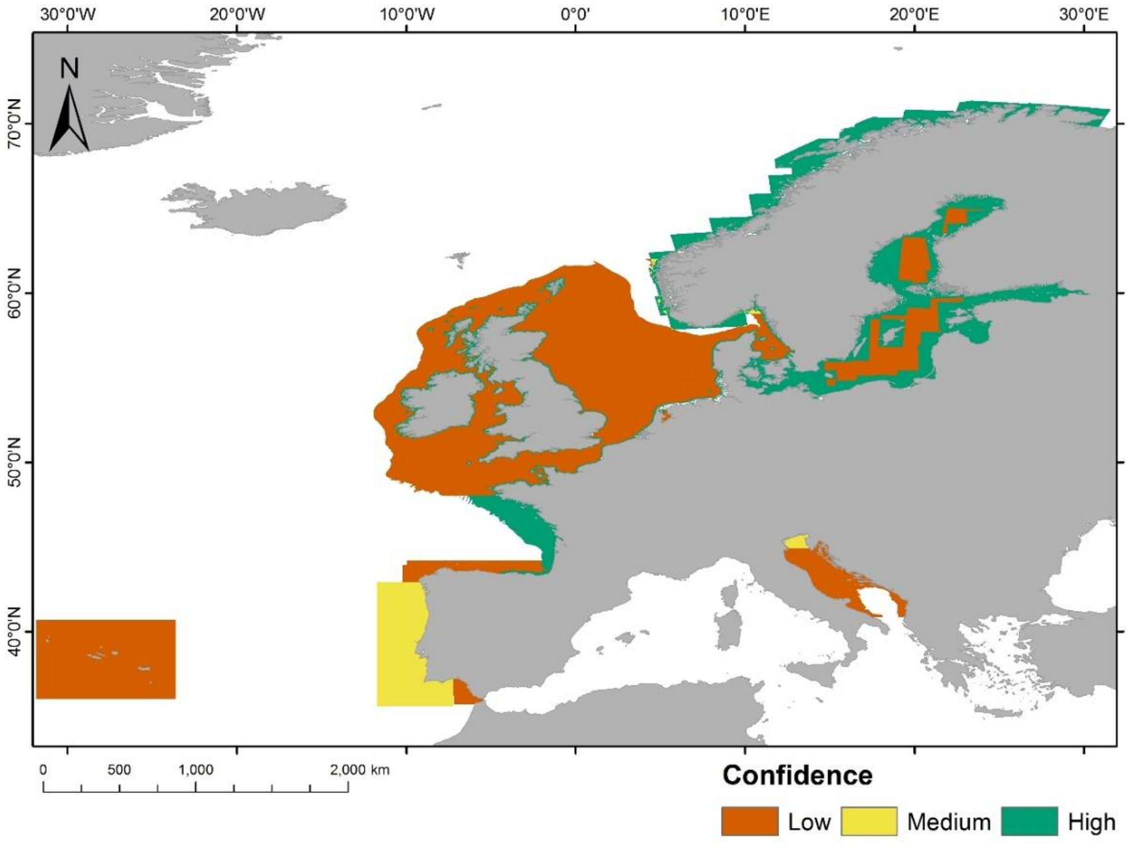

Figure 10.1.15: Confidence in Kinetic energy due to waves in Atlantic and Mediterranean (Adriatic only), and Wave exposure index in Arctic and Baltic

10.1.9 Wave base ratio, Atlantic (Greater North Sea and Celtic Seas, Bay of Biscay and Iberian coast only)

For the areas where wavelength information is also available from the wave models, wavelength was used along with depth to the seabed in order to calculate the wave base ratio (see section 9.1 in main report). Confidence scores for wave base ratio were calculated by taking the mean of the confidence in depth to seabed and the confidence in kinetic energy due to waves then rounding up. The results are shown in Figure 10.1.16.

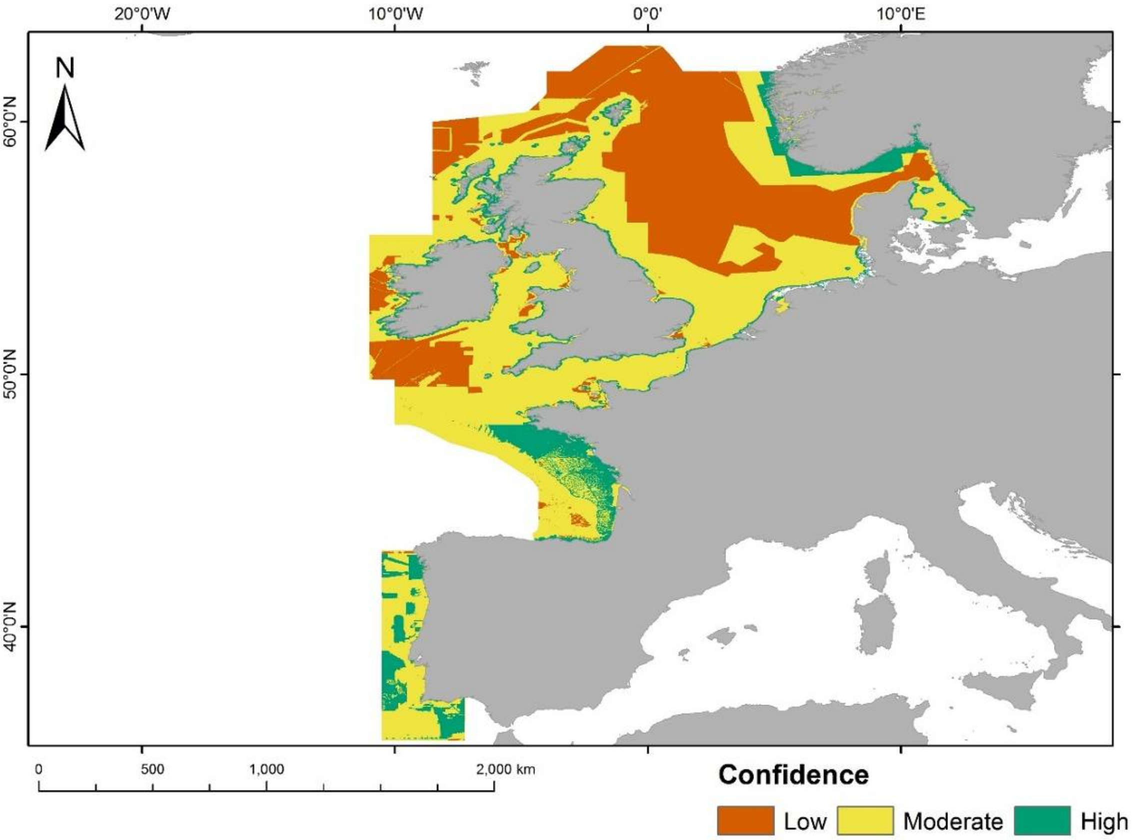

Figure 10.1.16: Confidence in wave base ratio in the Atlantic

10.2 Confidence in classification of habitat descriptors based only on threshold uncertainty for continuous physical variables – special cases for manually-drawn boundaries

While the creation of these confidence layers is quite straightforward for classification based on a single threshold of a single continuous physical variable (see Section 2.6.2a of the main report), a bespoke approach was needed for the two sets of boundaries that were drawn manually (see Section 2.6.2b of main report). The methods used to create these confidence layers are described here.

10.2.1 Circalittoral/ bathyal/ abyssal biozone boundaries, Mediterranean and Black Sea

In the Mediterranean and Black Sea, the boundaries between the circalittoral and bathyal biozones and the bathyal and abyssal biozones are based on depth and slope values (See section 3.3 and 3.4).

To assess the confidence in these boundaries a slope analysis was undertaken. The concept is as follows: the faster the slope value increases from the circalittoral to the bathyal zone (i.e. a more pronounced shelf break), the higher the confidence of the respective boundary. Similarly, the faster the slope value decreases from the bathyal to the abyssal zone, the higher the confidence of the respective boundary. The confidence of the boundary is low when the slope value changes gently from the one zone to the other.

In order to assign low, medium, and high confidence to the biozones boundaries, the following slope variability method was applied.

Slope variability is the difference between the maximum and the minimum slope (SV = Smax – Smin). It is the measure of the “relief of slope” of a landscape (Ruszkiczay-Rudiger et al., 2009).

First the Slope raster was calculated, using the bathymetry raster (250x250m). The inclination of slope was calculated as percent rise, also referred to as the percent slope.

Each cell of the slope raster was treated using a focal statistics analysis. This analysis provides a value for a cell based on the values of the surrounding cells in a 3x3 grid. In this way a maximum and minimum value was calculated for each cell based on the percentage slope raster. Figure 10. shows an example of how this analysis works. In this way two additional slope raster files were created, maximum and minimum slope. By subtracting the minimum slope value raster (Smin) from the maximum slope value raster (Smax), the slope variability raster (SV) was calculated (i.e. SV = Smax – Smin). Slope variability values were then extracted from all the raster cells that intersect one of the relevant biozone boundaries.

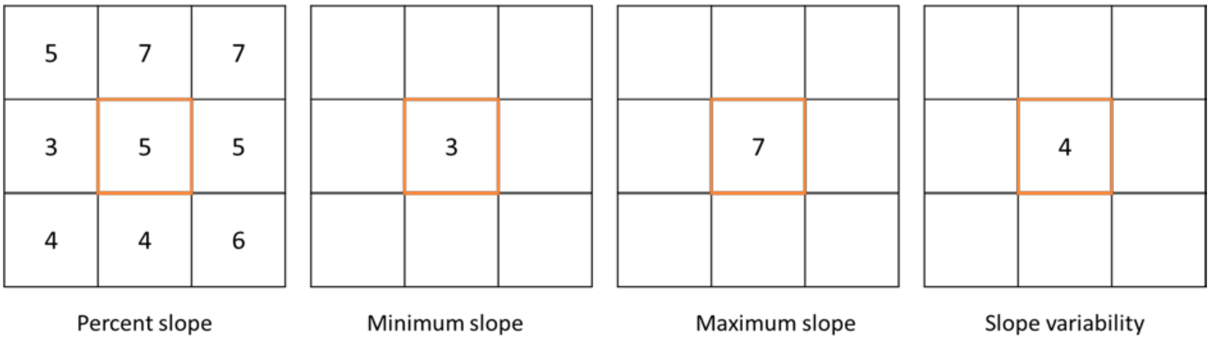

Figure 10.2.1: Diagram to demonstrate how each grid cell of the percentage slope raster is assigned a minimum and maximum value based on the surrounding cells in a 3x3 grid. The minimum slope is then subtracted from the maximum slope to give the slope variability. This process is repeated for each cell in the raster.

Slope variability values near zero indicate slow slope changes between the circalittoral and the bathyal zone, implying low confidence in the definition of the boundary between biozones. High slope variability values indicate rapid slope changes implying high confidence in the definition of the biozones boundary. The slope variability values were classified into high, medium and low confidence based on expert judgement (Table 10.2.1).

Table 10.2.1: Criteria used for assessing confidence in slope variability along the boundaries of the circalittoral/ bathyal/ abyssal biozones in the Mediterranean and Black Sea.

Confidence per cell	Criteria
High	slope variability > 10%
Moderate	3% < slope variability ≤ 10%
Low	3% ≥ slope variability

In order to show the areas of confidence around the biozone boundaries, two buffers were applied to the boundary line, one buffer to show the area of low confidence and the other one to show the area of moderate confidence. Areas outside of these two buffers are considered high confidence.

The width of the buffers is based on expert judgement and is dependent on the confidence in the slope variability. So where confidence in the slope variability is low, the buffers are wider to reflect the greater uncertainty in the true location of the boundary. Conversely, where the confidence in the slope variability is high, the buffers are narrower (Table 10.2.2 and Figure 10.2.2).

Table 10.2.2: Width of low and moderate confidence buffer to either side of the biozone boundary line for the three levels of slope variability confidence. Areas beyond the buffer distances below are considered high confidence

Confidence in boundary	Low confidence buffer distance (m)	Moderate confidence buffer distance (m)
Low	3000	6000
Moderate	2000	4000
High	1000	2000

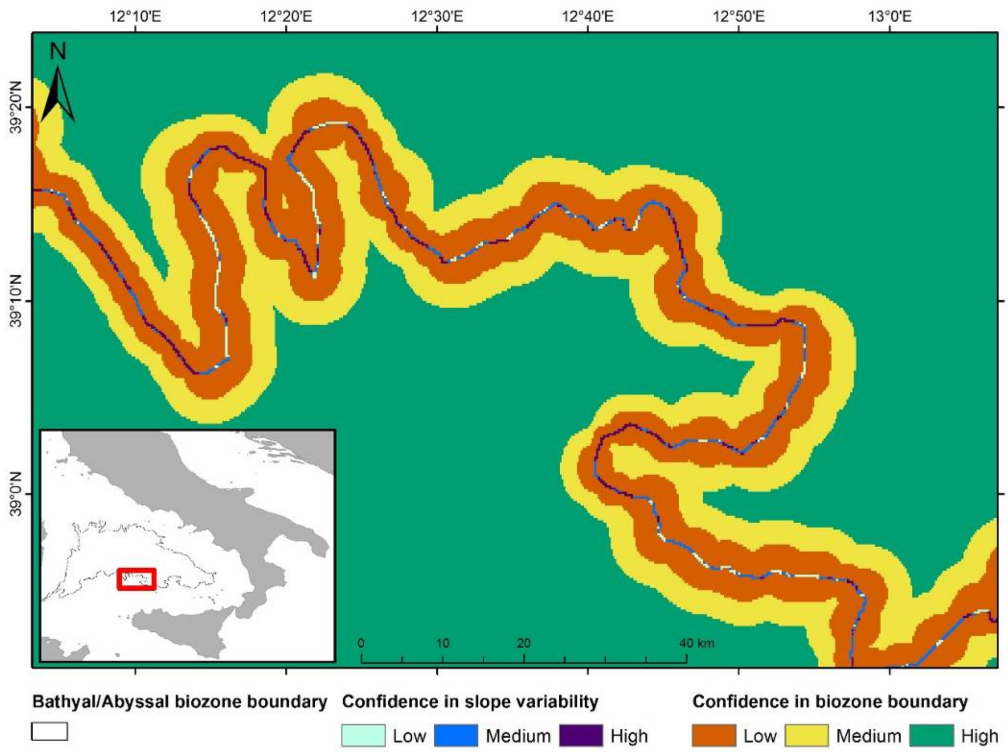

Figure 10.2.2: Example of confidence buffers applied to the bathyal/abyssal biozone boundary in the Mediterranean Sea. Note how the areas of low and medium confidence in the biozone boundary are broader where the confidence in slope variability is low, and narrower where it is high.

10.2.2 Deep circalittoral/ upper bathyal biozones boundary in the Bay of Biscay

In the Iberia, Biscay and Macaronesia model area a manually drawn shelf break is used to separate the deep circalittoral and upper bathyal bozones. This manually drawn shelf break extends from the Bay of Biscay and around the Iberian Peninsula.

In order to create boundaries of uncertainty around the manually drawn shelf break two buffers were applied to the line, one at 0.1 degrees and one at 0.3 degrees.

10.3 Confidence in classification of habitat descriptors

The overall method for this assessment, whereby confidence in physical variables is combined with confidence in threshold values, is described in Section 2.7 of the main report.

The method used to combine the confidence in physical variables and threshold values is different depending on the number of physical variables used to produce a habitat descriptor. In the simplest cases, one physical variable is used to describe all classes of a habitat descriptor. In other cases, multiple physical variables used to describe all classes of one habitat descriptor.

The following sections describe the confidence assessment method applied for each data layer described in Table 2.2 except seabed substrate type.

10.3.1 Upper and lower boundaries classified from the same continuous physical variable – oxygen regime, salinity regime, energy class (Baltic, Arctic only), biozone (deep sea only)

Some habitat descriptors are based on a single continuous physical variable

In this situation the confidence based on boundary uncertainty was combined for all boundaries of the habitat descriptor before being combined with the relevant continuous physical variable confidence according to logic shown in table 2.7.6.

In the Black Sea model area, the oxygen density habitat descriptor is modelled based on the continuous physical variable, potential density anomaly at the seabed (Section Potential density anomaly (σθ) at the seabed, Black Sea). The confidence in this physical variable and the confidence in the thresholds used to separate the habitat descriptor classes are combined according to the logic shown in table 2.7.6. The results are shown in Figure 10.3.1.

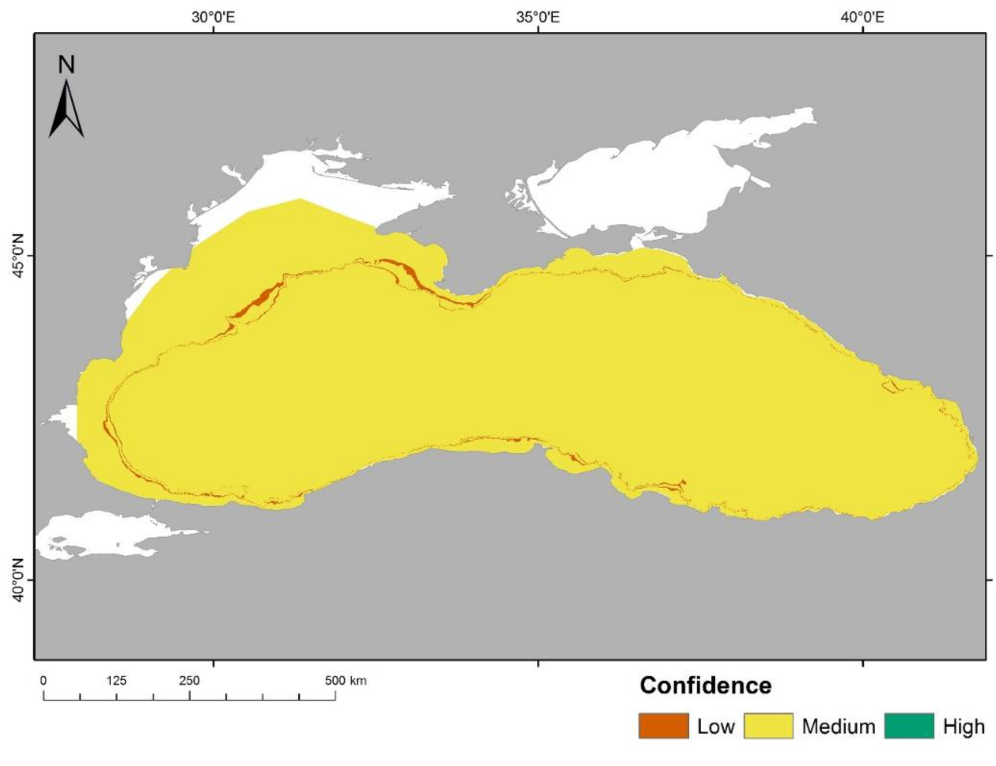

Figure 10.3.1: Confidence in classification of habitat descriptor: oxygen regime in the Black Sea.

In the Baltic Sea model area, the salinity regime habitat descriptor is modelled based on the continuous physical variable, salinity at the seabed (Section Salinity at the seabed, Baltic Sea). The confidence in this physical variable and the confidence in the thresholds used to separate the habitat descriptor classes are combined according to the logic shown in table 2.7.6. The results are shown in Figure 10.3.2.

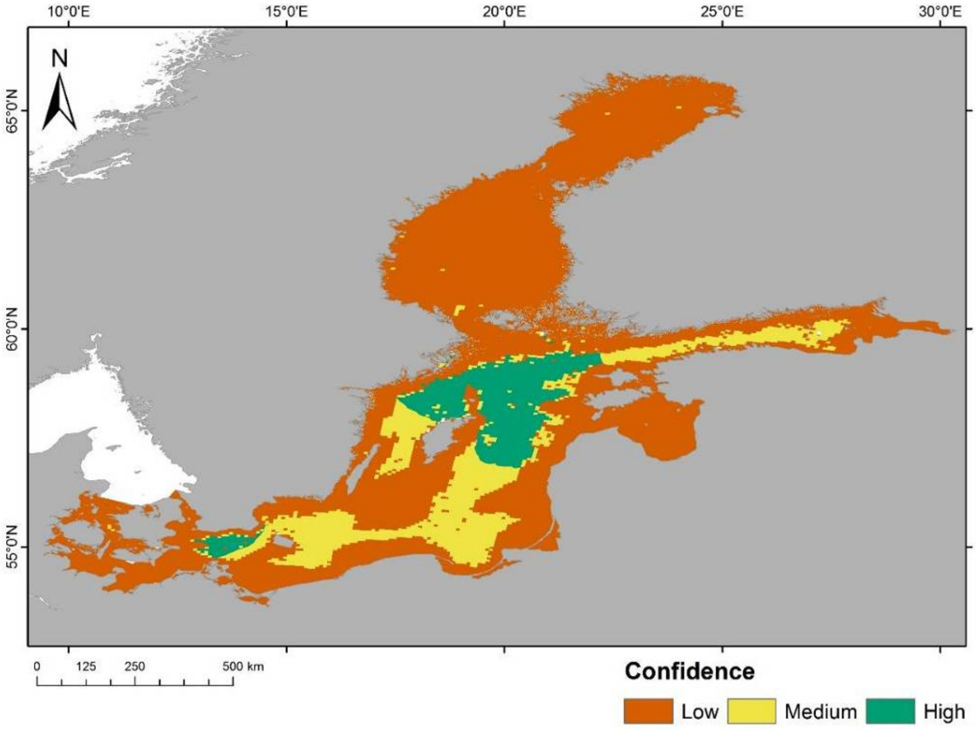

Figure 10.3.2: Confidence in classification of habitat descriptor: salinity regime in the Baltic Sea.

In the Arctic and Baltic Sea model area, the energy level habitat descriptor is modelled based on the continuous physical variable, wave index (Section Kinetic energy due to waves, Atlantic and Mediterranean (Adriatic only), and Wave exposure index, Arctic and Baltic). The confidence in this physical variable and the confidence in the thresholds used to separate the habitat descriptor classes are combined according to the logic shown in table 2.7.6. The results are shown in Figure 10.3.3.

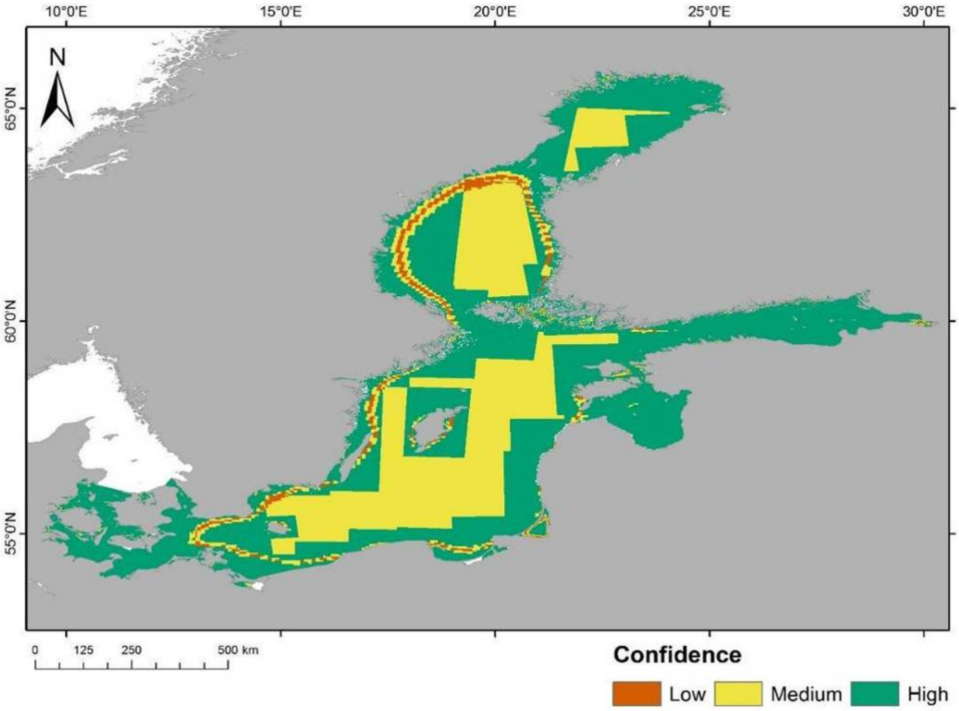

Figure 10.3.3: Confidence in classification of habitat descriptor: energy class in the Baltic Sea.

10.3.2 Intermediate habitat descriptor layers used (upper and lower boundaries for intermediate layers classified from the same continuous physical variable) – energy class (Atlantic only)

In Atlantic Seas, the above process was followed for each of two intermediate habitat descriptor layers: wave energy class and current energy class. For each grid cell the highest of the two energy classes was chosen as the final energy class.

To obtain a single confidence layer for the energy class habitat descriptor in Atlantic seas, the two intermediate confidence layers were combined. Although it would have been possible to do something more complicated involving using the confidence of the source of the chosen class, a simpler option was applied whereby for all grid cells the confidence in final energy class is the mean of intermediate classes, rounded up.

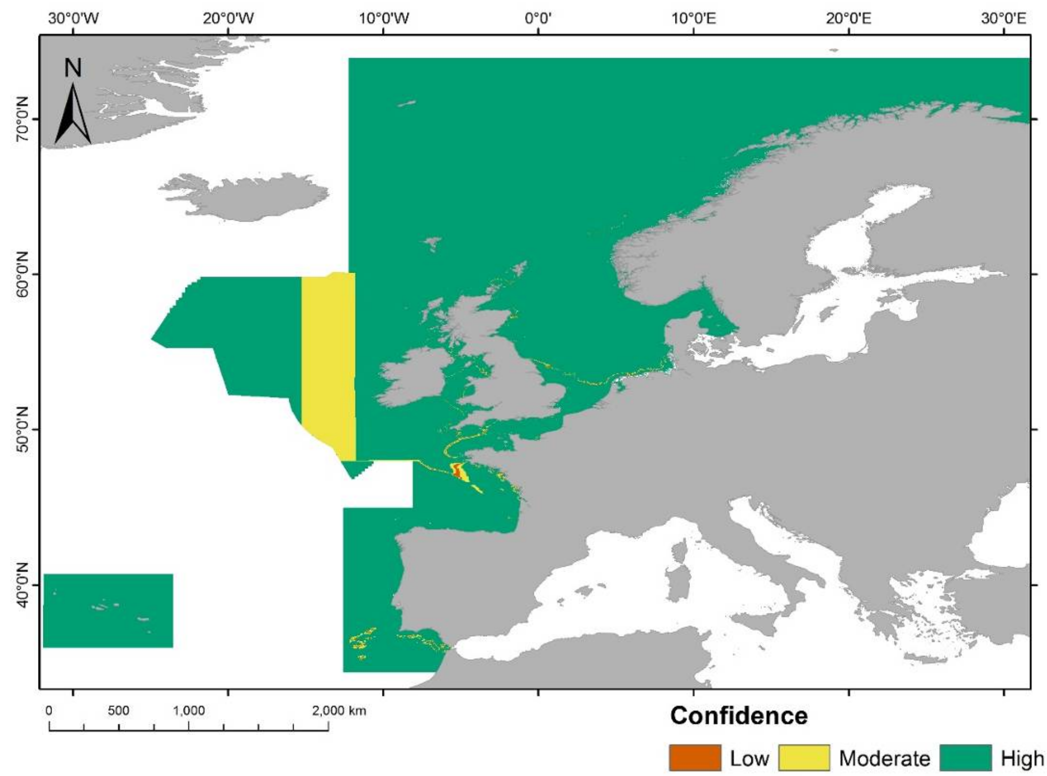

Figure 10.3.4: Confidence in classification of intermediate habitat descriptors: current energy class in Atlantic Seas

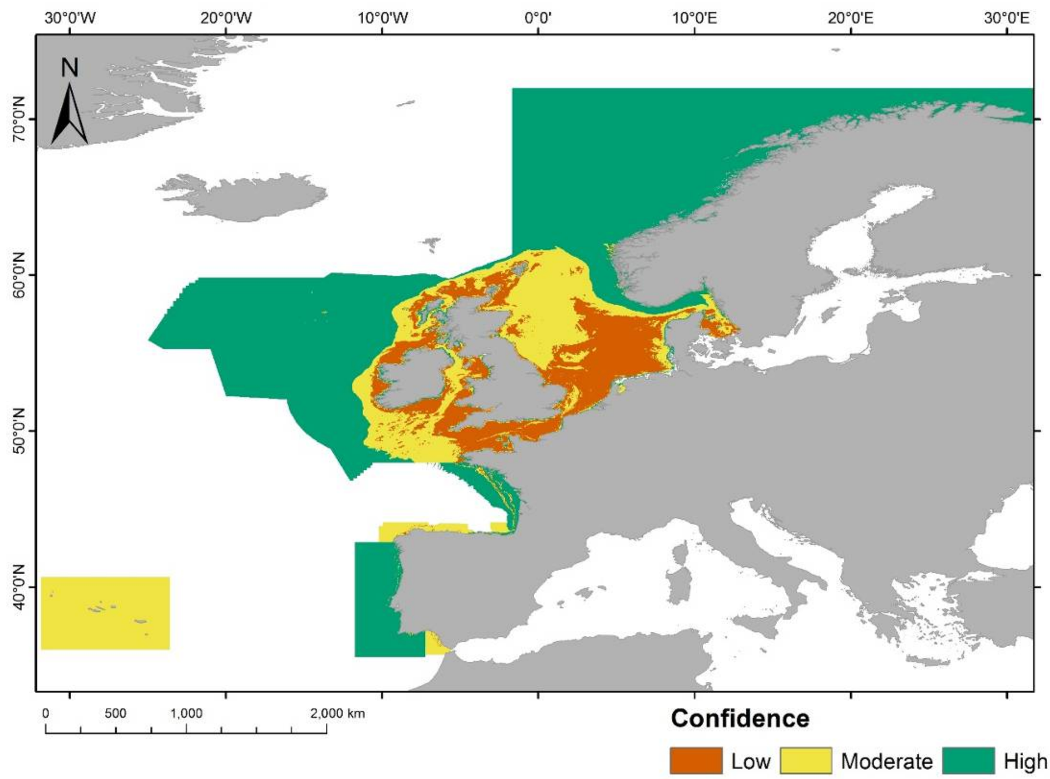

Figure 10.3.5: Confidence in classification of intermediate habitat descriptors: wave energy class in Atlantic Seas.

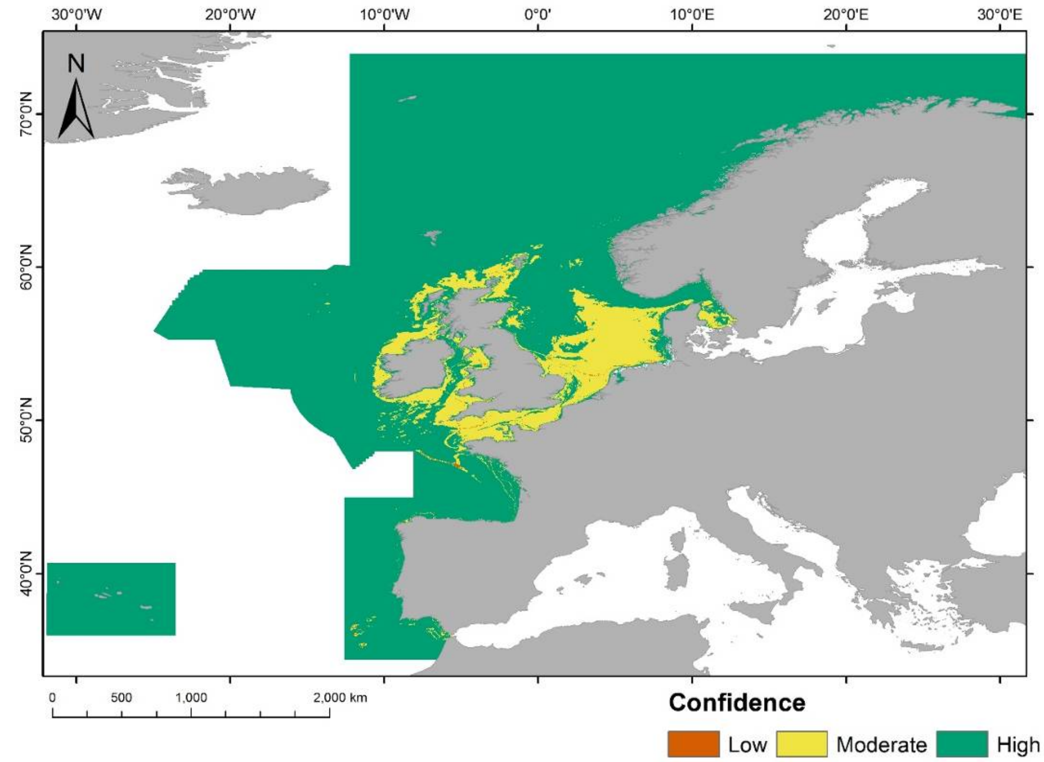

Figure 10.3.6: Confidence in classification of habitat descriptor: energy class in Atlantic Seas.

10.3.3 Upper and lower boundaries classified from different continuous physical variables

The biozone classes are separated based on a variety of different physical variables. In the cases of circalittoral biozones the upper and lower boundary of the biozone are classified based on different physical variables. Other biozone classes are not affected by this as deep-sea biozones are all defined by depth and the infralittoral biozone only has a lower boundary, in these cases the process for producing confidence in the habitat descriptor is the same as described in section Upper and lower boundaries classified from the same continuous physical variable – oxygen regime, salinity regime, energy class (Baltic, Arctic only), biozone (deep sea only). Table 10.3.1 shows the circalittoral biozone classes and the physical variables used to identify their upper and lower boundaries.

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Table 10.3.1: Biozone classes with different physical variables used to define the upper and lower boundary.

Region	Biozone class	Upper boundary	Lower boundary
Atlantic	Deep circalittoral	Wave base ratio	Depth to seabed
Atlantic	Shallow circalittoral	PAR at the seabed	Wave base ratio
Mediterranean Sea	Circalittoral	PAR at the seabed	Depth to seabed
Mediterranean Sea (Adriatic only)	Circalittoral	Wave base ratio	Depth to seabed
Black Sea	Shallow circalittoral	Depth to seabed	Temperature
Baltic Sea	Shallow circalittoral	Depth to seabed : Secchi disk depth ratio	Depth to halocline

Confidence in these classes is then calculated by taking the mean of the confidence in the habitat descriptor of the upper and lower boundary. To produce a confidence in habitat descriptors for all biozones, the confidence for each of the individual biozones (both those using the same physical variables for all boundaries and those using different physical variables for each boundary) are merged into one layer (figures 10.7.7 to 10.7.12).

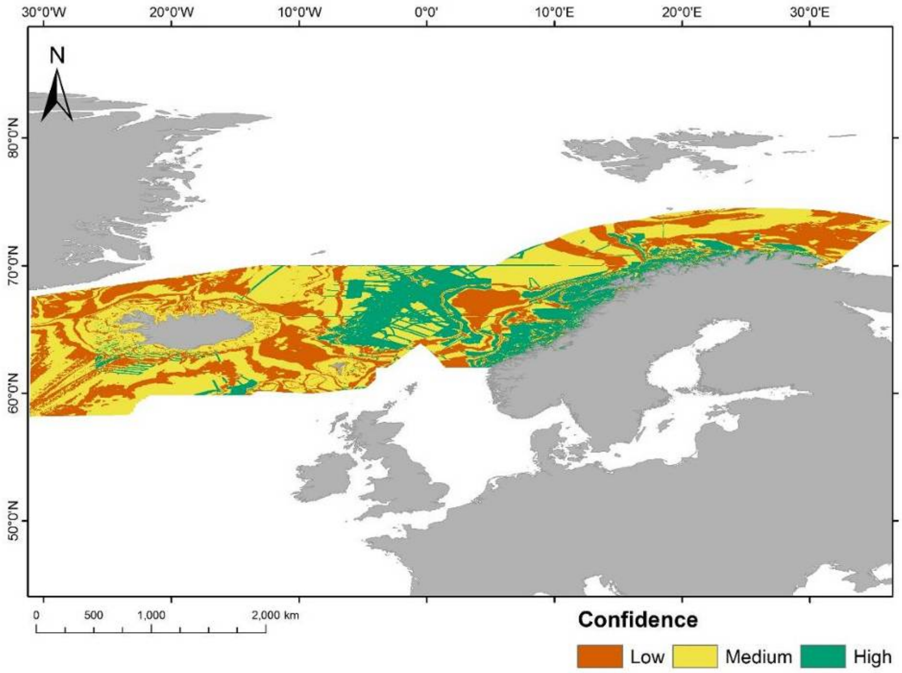

Figure 10.3.7: Confidence in classification of biozones habitat descriptor in Arctic Seas model area

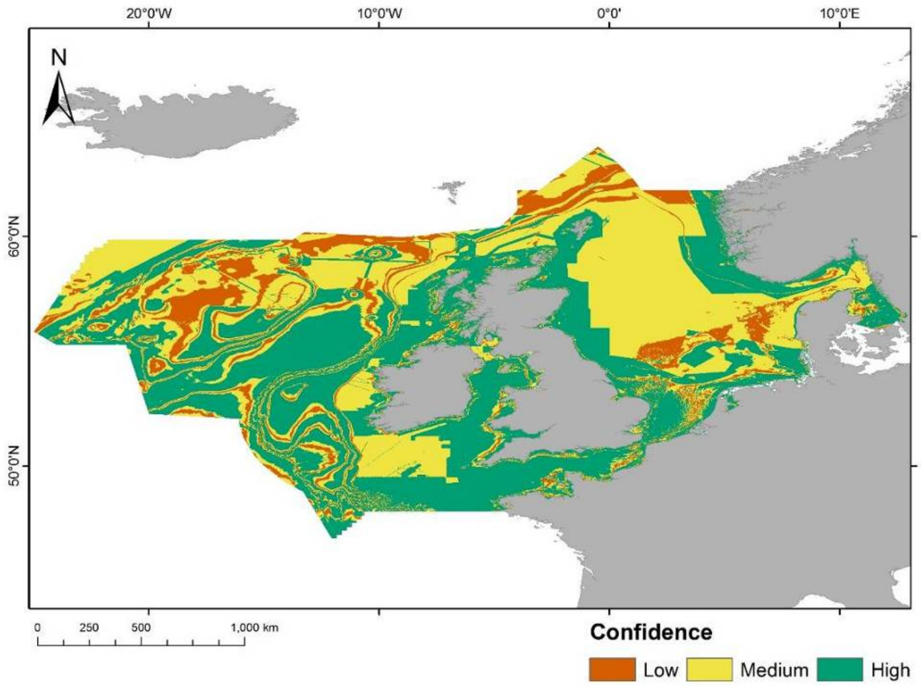

Figure 10.3.8: Confidence in classification of biozones habitat descriptor in Greater North Sea and Celtic Seas model area

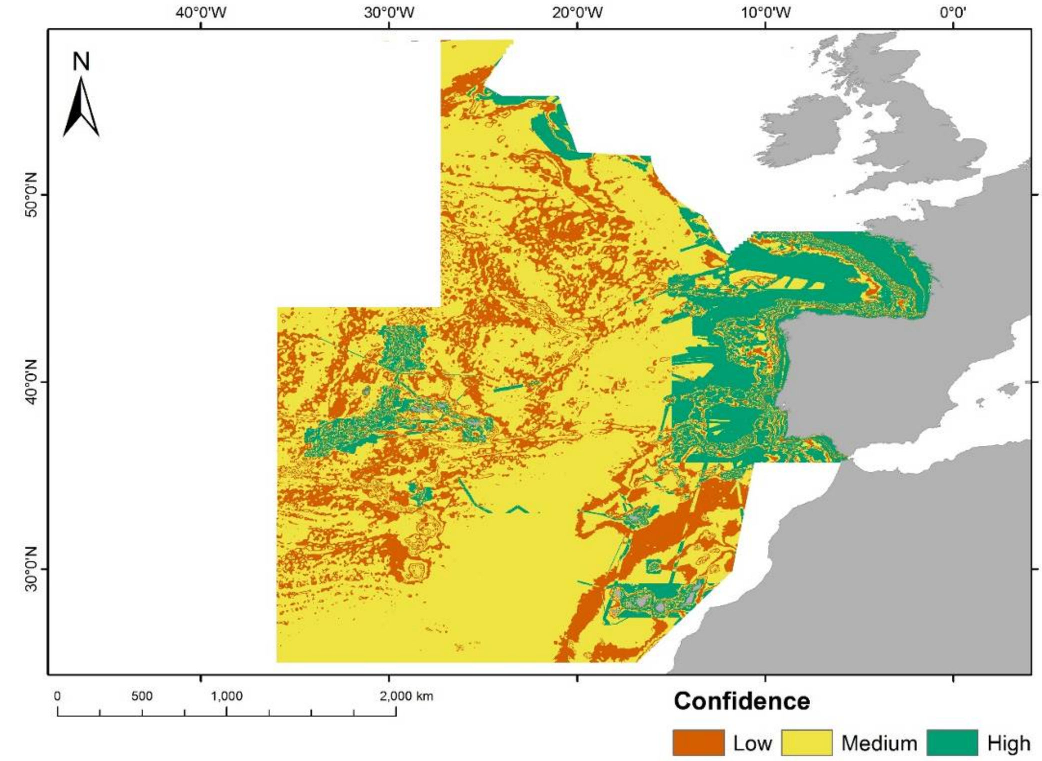

Figure 10.3.9: Confidence in classification of biozones habitat descriptor in Iberia, Biscay, and Macaronesia model area

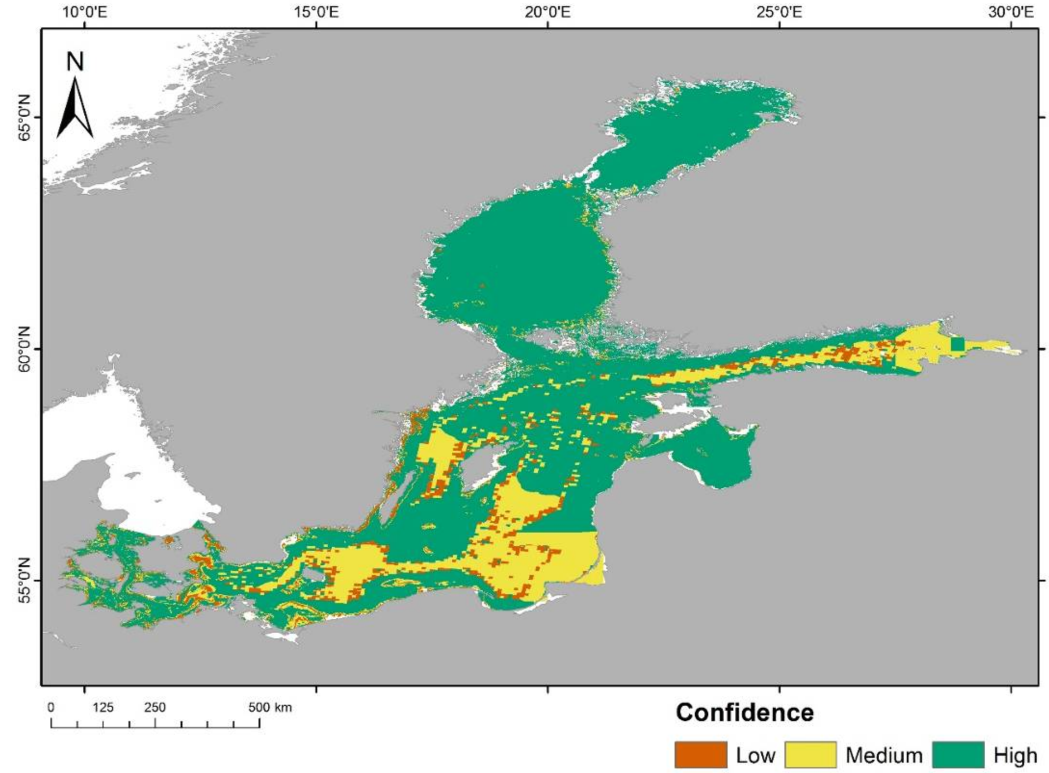

Figure 10.3.10: Confidence in classification of biozones habitat descriptor in Baltic Sea model area

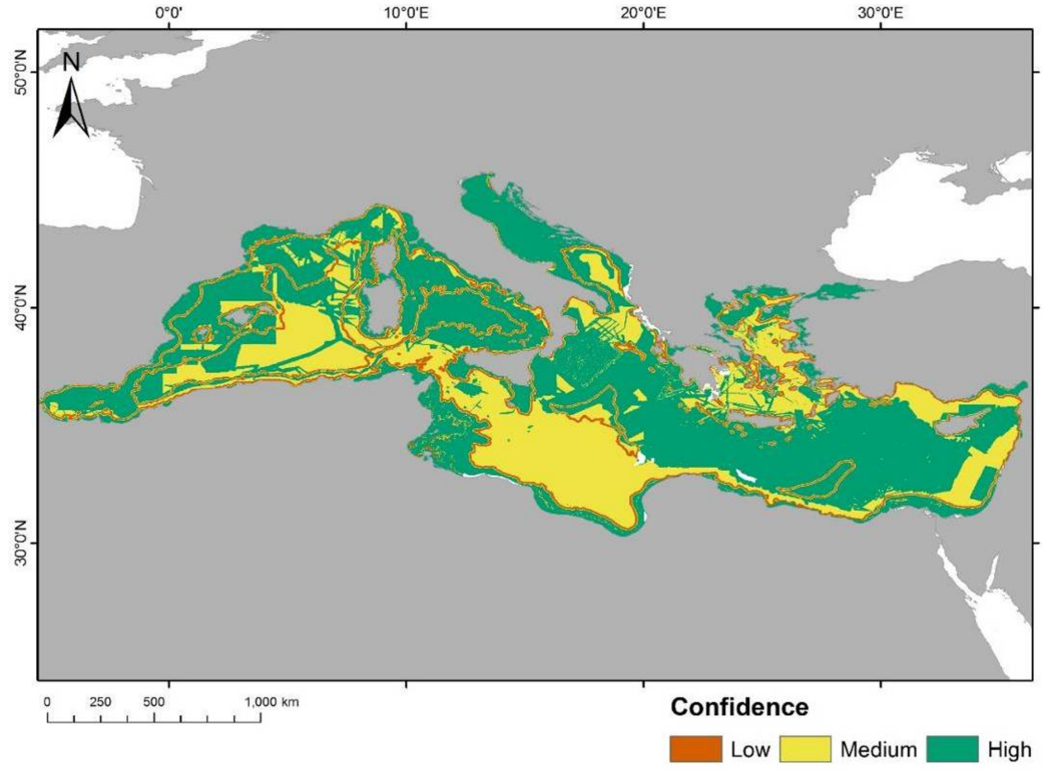

Figure 10.3.11: Confidence in classification of biozones habitat descriptor in Mediterranean Sea model area

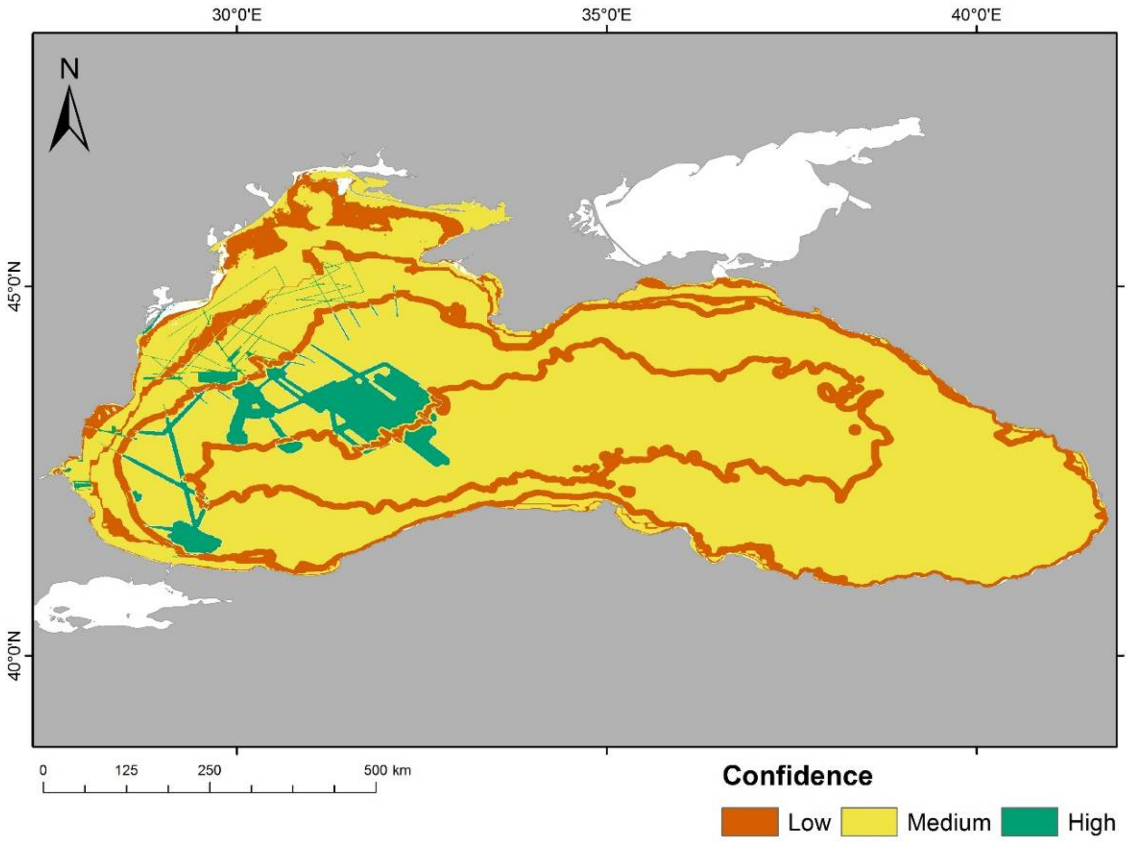

Figure 10.3.12: Confidence in classification of biozones habitat descriptor in Black Sea model area

10.4 Confidence in habitat type

Confidence in the final habitat type is calculated as the minimum confidence of all habitat descriptors used for any given pixel. Table 10.4.1 shows which habitat descriptors have been used to describe habitat types.

Table 10.4.1: Habitat descriptors used in the determination of habitat types. A shaded box indicates that a habitat descriptor was used for determining the habitat types; the minimum confidence out of the relevant habitat descriptor was taken to be the confidence in the habitat type.

Habitat type	Region	Substrate type	Biozone	Energy class	Oxygen regime	Salinity regime	Mask of riverine sediment input
all infra, circa (outside of mask) deep circa, bathyal & abyssal	Med. Sea	■	■				
all infra & circa (in mask)	Med. Sea	■	■				■
all infra, circa (outside of mask) & abyssal	Black Sea	■	■				
all deep circa & bathyal	Black Sea	■	■		■		
all infra & circa (in mask)	Black Sea	■	■				■
infra, circa & deep circa rock	Iberia, Biscay, Macaronesia	■	■	■			
infra, circa & deep circa sediment	Iberia, Biscay, Macaronesia	■	■				
all deep sea	Iberia, Biscay, Macaronesia	■	■				
infra, circa & deep circa rock	Greater North Sea and Celtic Seas	■	■	■			
infra, circa & deep circa sediment	Greater North Sea and Celtic Seas	■	■				
all deep sea	Greater North Sea and Celtic Seas	■	■				
infra, circa & deep circa rock	Arctic Seas	■	■	■			

infra, circa & deep circa sediment	Arctic Seas						
all deep sea	Arctic Seas						
infra, circa & deep circa rock	Baltic Sea					~	
infra, circa & deep circa sediment	Baltic Sea					~	

10.5 References

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Demyshev S.G., 2012. "A numerical model of online forecasting Black sea currents". Izvestiya, Atmospheric and oceanic physics, Vol. 48, N. 1, 2012.

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10.6 Appendix: mean (rounded up)

The mean (rounded up) of categorical values was obtained by treating the categories as integers; i.e. high confidence = 2, moderate confidence = 1 and low confidence = 0, then rounding up any half-values to the next integer and converting the integers back to the confidence category (Table).

Table 10.6: Illustration of the effect of treating confidence categories as integers, calculating the mean and rounding up.

		Confidence in first layer		
		H (2)	**M (1)**	**L (0)**
Confidence in second layer	**H (2)**	H (2)	H (1.5)	M (1)
	M (1)	H (1.5)	M (1)	M (0.5)
	L (0)	M (1)	M (0.5)	L (0)

11 Appendix: Manual modifications made to the maps

Whilst running the models required to produce EUSeaMap, visual quality checks of the model outputs were carried out. These quality checks looked for unlikely predictions made by the model and were corrected manually often by changing raster values within masked off areas. This appendix lists and describes manual modifications that were made and provides maps showing what the affected areas looked like before and after the modifications.

11.1 Atlantic and Arctic

Model area	Affected layer	Description of issue	Description of correction	Location Description	Bounding box latitude and longitude (decimal degrees)		Figure
					NE	SW	
Atlantic	Biozone	The bathyal zone changes from "Atlantic mid bathyal" to "Atlanto-Mediterranean mid bathyal" at 52.5 degrees North. A small area of the "Atlanto-Mediterranean mid bathyal" crosses back over this line of latitude where it is unlikely to represent a different water mass.	A mask was created to cover the area that needed changing. Areas of "Atlantic mid bathyal" within the mask were converted to "Atlanto-Mediterranean mid bathyal",	Porcupine Bight	52.55 -12.87	52.40 -12.66	**Figure 11.**1
Atlantic	Biozone	The threshold between the Deep Circalittoral and upper bathyal biozones is defined as 200m deep. On the continental shelf around the UK and Ireland, there are some areas that are deeper than 200m. However, the upper bathyal zone should represent a change from shelf to slope seas. These small areas would not be considered part of the continental slope or the upper bathyal biozone.	A mask was created manually to roughly cover the shelf seas around the UK and Ireland, as predicted by the 200m depth contour. Areas of upper bathyal biozones within this mask were then converted to deep circalittoral.	UK and Ireland continental shelf	62.00 -11.58	47.10 12.70	**Figure 11.**2
Atlantic	Biozone	Seamounts with peaks shallower than	A mask was created to cover	Seamounts	30.16	29.83	**Figure 11.3**

Model area	Affected layer	Description of issue	Description of correction	Location Description	Bounding box latitude and longitude (decimal degrees)		Figure
					NE	SW	
		200m deep, but no information available to assign shelf biozones (i.e. PAR at the seabed, and wave base ratio), create patches of no data in the biozones layer.	the areas of no data. As these areas are small and clearly not part of the continental shelf, they were converted to upper bathyal	south of the Azores	-28.73	-28.54	
Atlantic	Biozone	The lower boundary of the "Deep circalittoral" zone is limited to the extent of the wave base ratio input dataset. This results in a gap of no data between the deep circalittoral zone and the manualy drawn shelf break used in the Bay of Biscay.	The wave base ratio input raster was extended to overlap the upper bathyal zone, but with values that will produce a membership value of 0. This results in the no data area being defined as deep circalittoral	Bay of Biscay	48.04 -8.00	43.38 -1.82	**Figure 11.4**
Atlantic	Biozone	At the border where upper bathyal delineation changes from a depth proxy to manual delineation, a small area of >200m offshore was classified as upper bathyal.	A mask was created and used to convert the patch of upper bathyal to deep circalittoral.	West of Brittany	48.16 -7.90	47.95 -7.53	**Figure 11.**5
Atlantic	Biozone	An area of shallow circumlittoral and an area of no data are present on the North Spanish coast. This biozones type appears to be a result of values in the wave base layer and is unlikely to be correct due to the depth in the area (~120 - ~190m).	A mask was created and used to convert the specified area of shallow circalittoral, and the patch of no data to deep circalittoral.	North Spanish coast	44.15 -7.42	43.83 -6.70	**Figure 11.**6
Atlantic	Biozone	Along the Atlantic coast of the Iberian Peninsula, there are a number of deep-sea canyons which extend relatively close to shore. Due to the coarseness of the wave model and closeness of the	In the MESH Atlantic model area, the biozone layers were stacked so that the deep-sea biozones had priority over the shallow circalittoral biozone.	Portuguese canyons	44.86 -10.05	35.62 -0.30	**Figure 11.**7

Model area	**Affected layer**	**Description of issue**	**Description of correction**	**Location Description**	**Bounding box latitude and longitude (decimal degrees)**		**Figure**
					NE	SW	
		canyon to the coast, the shallow circalitorral zone overlaps some of these deep-sea canyons.					
Atlantic	Biozone	The Scottish island of St Kilda is partly outside the coverage of the PAR at seabed layer. This has resulted in no shallow circalittoral or infralittoral biozones being predicted in the area.	A mask was created around St Kilda and used to fill areas of no data with the biozones predictions made in the 2015 draft biozones raster.	St Kilda, Scotland	57.95 -8.76	57.72 -8.48	**Figure 11.**7
Atlantic	Biozone	An isolated patch of mid bathyal biozones was present within the upper bathyal zone north of Iceland.	A mask was created and used to convert the specified area to upper bathyal biozone	North of Iceland	66.89 -18.94	66.62 -18.58	**Figure 11.**

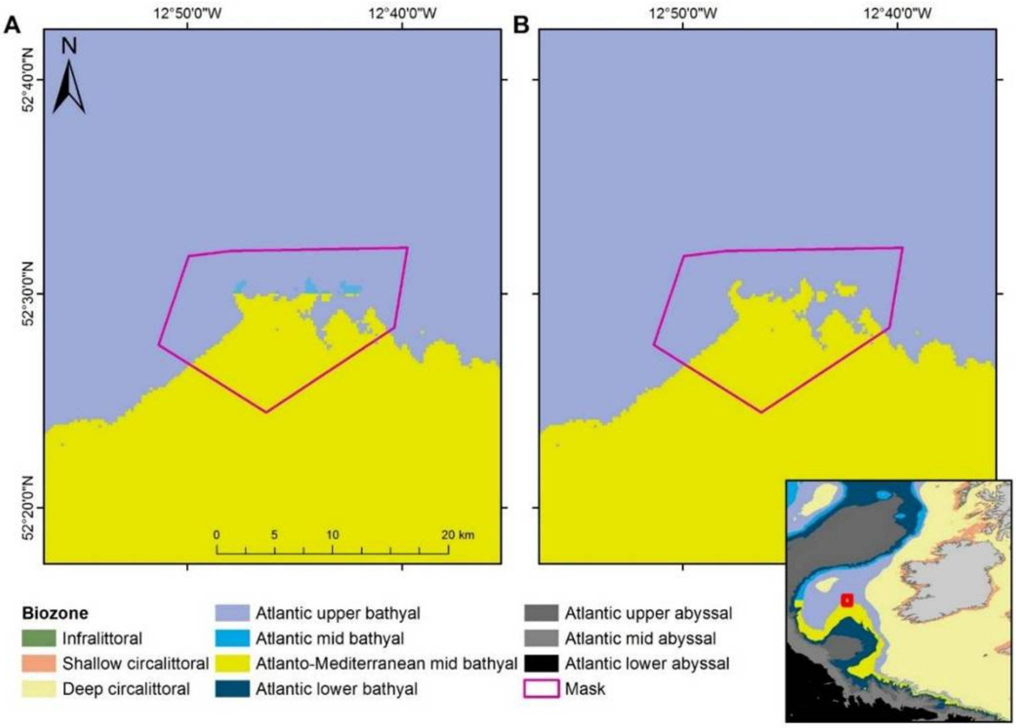

Figure 11.1: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The mask was used to convert "Atlantic mid bathyal" to "Atlanto-Mediterranean mid bathyal". The inset map shows the location of maps A and B (red box) in relation to Ireland.

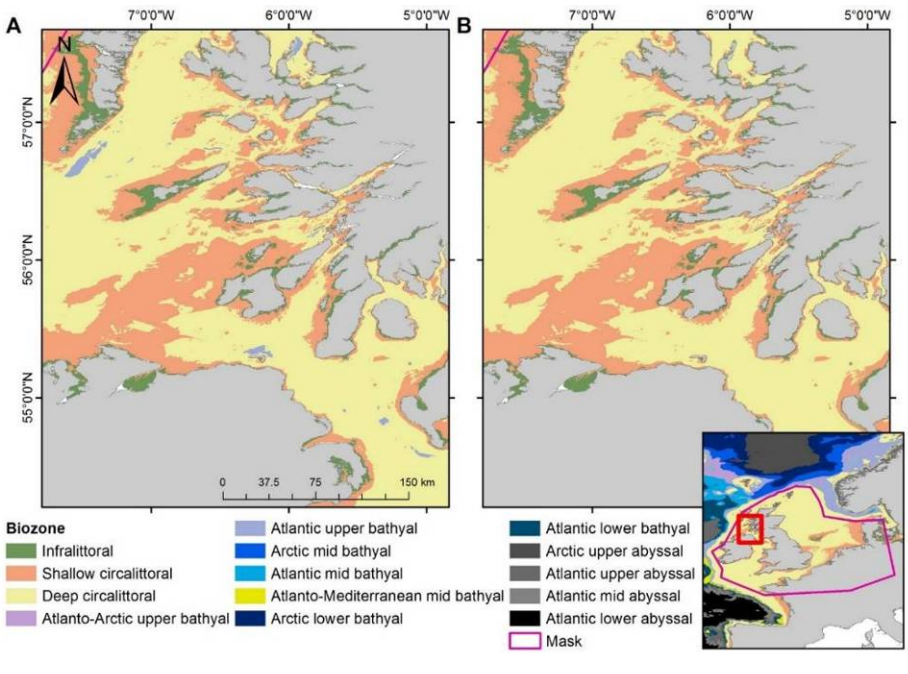

Figure 11.2: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The mask was used to convert "Atlantic upper bathyal" to "Deep circalittoral" biozones. The inset map shows the location of maps A and B (red box) in relation to the UK and Ireland, note that maps A and B represent only a few examples of the multiple cases where the "Atlantic upper bathyal" biozones was present within the masked area.

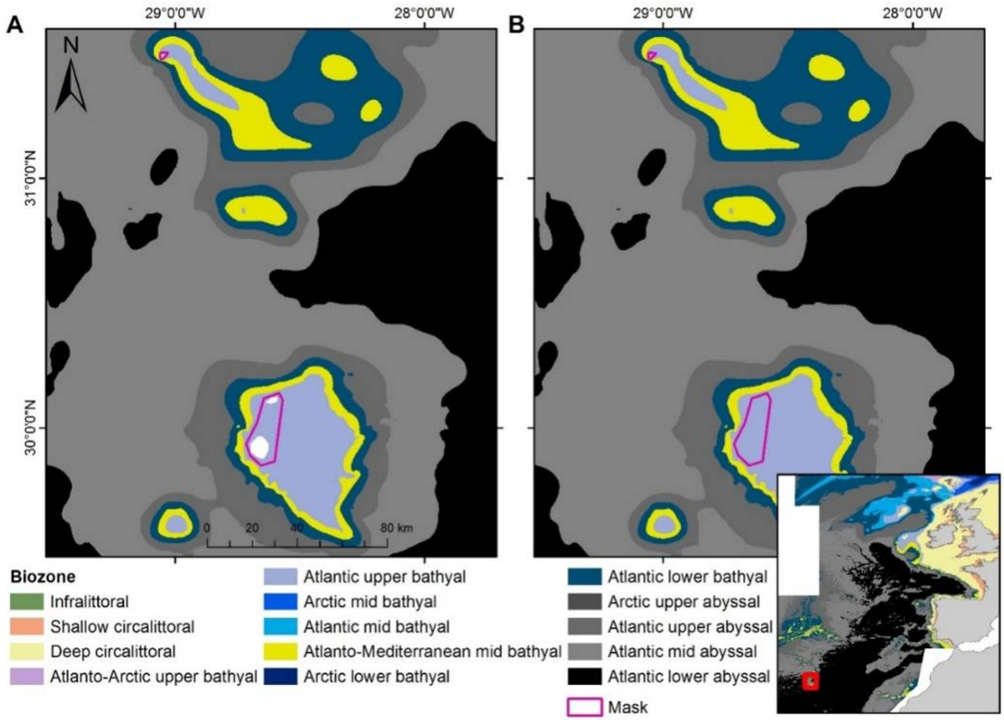

Figure 11.3: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The mask was used to convert "no data" to "Atlantic upper bathyal". The inset map shows the location of maps A and B (red box) in relation to Western Europe and North Africa.

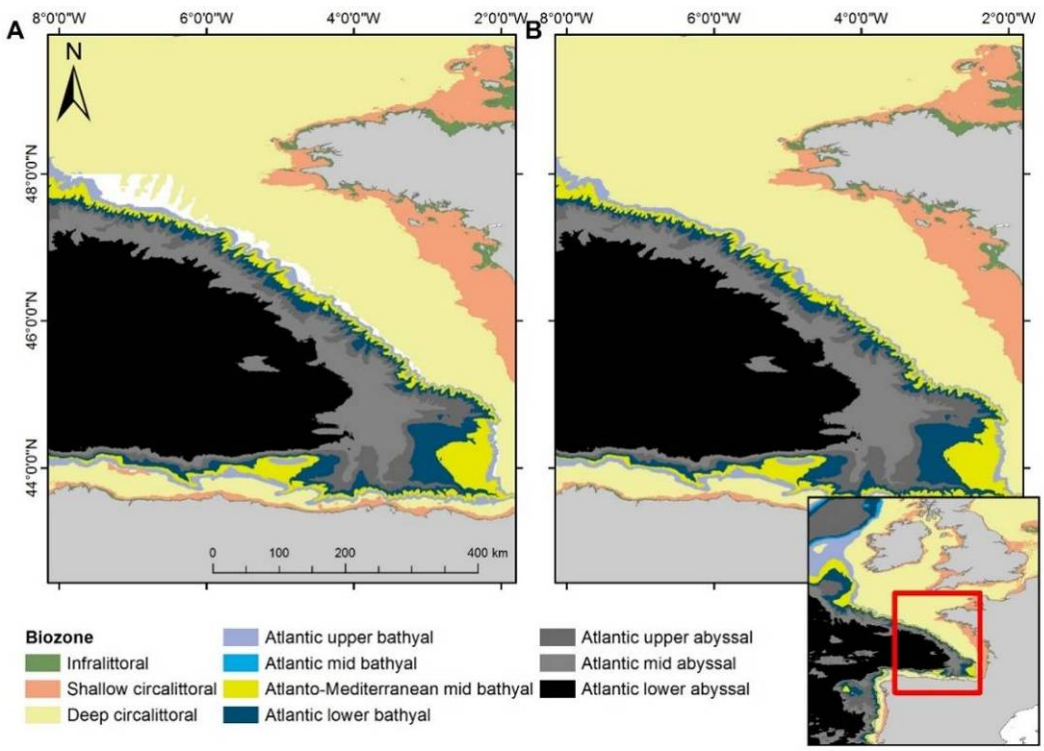

Figure 11.4: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. Area of no data between the "Deep circalittoral" and "Atlantic upper bathyal" biozones is removed by altering the input dataset. The inset map shows the location of maps A and B (red box) in relation to Western Europe.

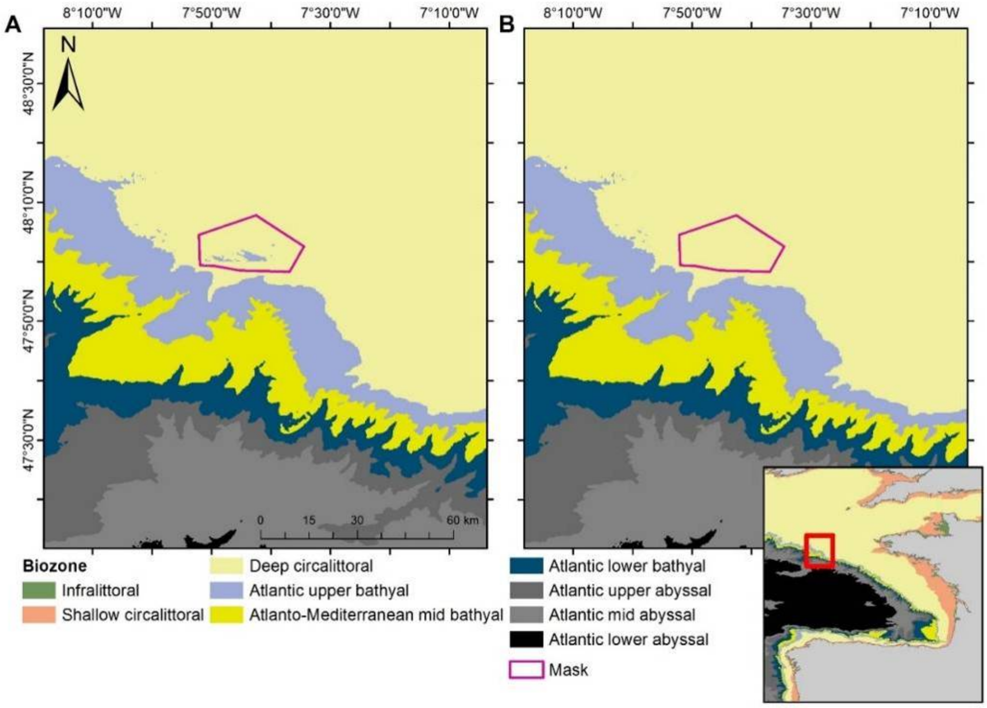

Figure 11.5: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The mask was used to convert "Atlantic upper bathyal" to "Deep circalittoral". The inset map shows the location of maps A and B (red box) in relation to Western Europe and North Africa.

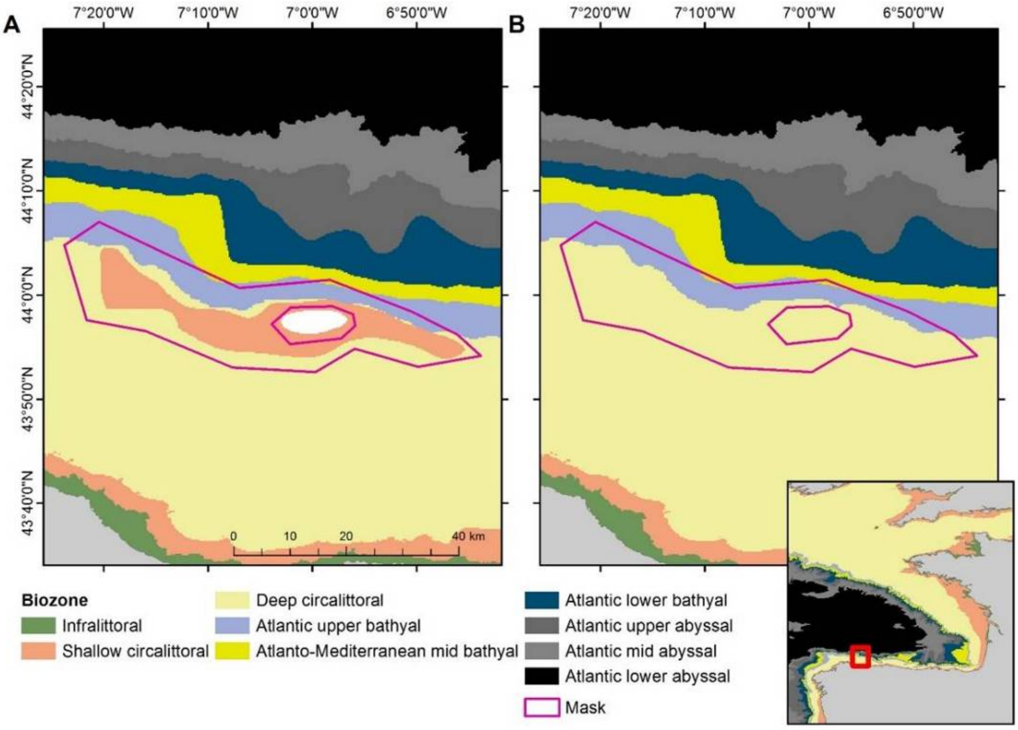

Figure 11.6: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The mask was used to convert "Shallow circalittoral" and "no data" areas to "Deep circalittoral". The inset map shows the location of maps A and B (red box) in relation to the Bay of Biscay.

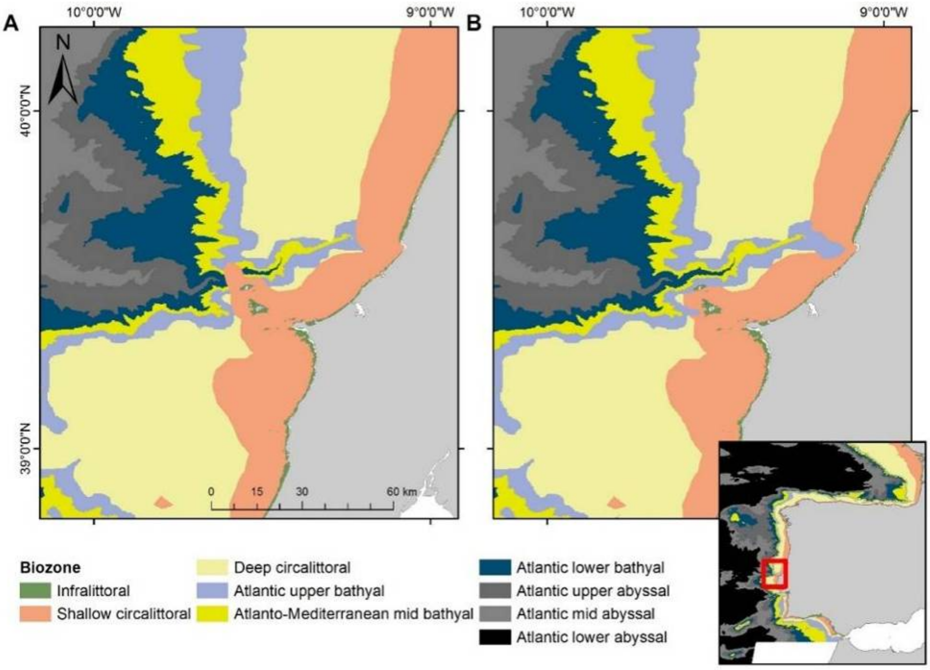

Figure 11.7: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The biozones are layered so that deep-sea biozones are given priority over the shallow circalittoral. The inset map shows the location of maps A and B (red box) in relation to the Iberian Peninsula. Please note that maps A and B represent only a few examples of the multiple cases where deep-sea canyons are overlapped by the shallow circalittoral biozones along the Portuguese coast.

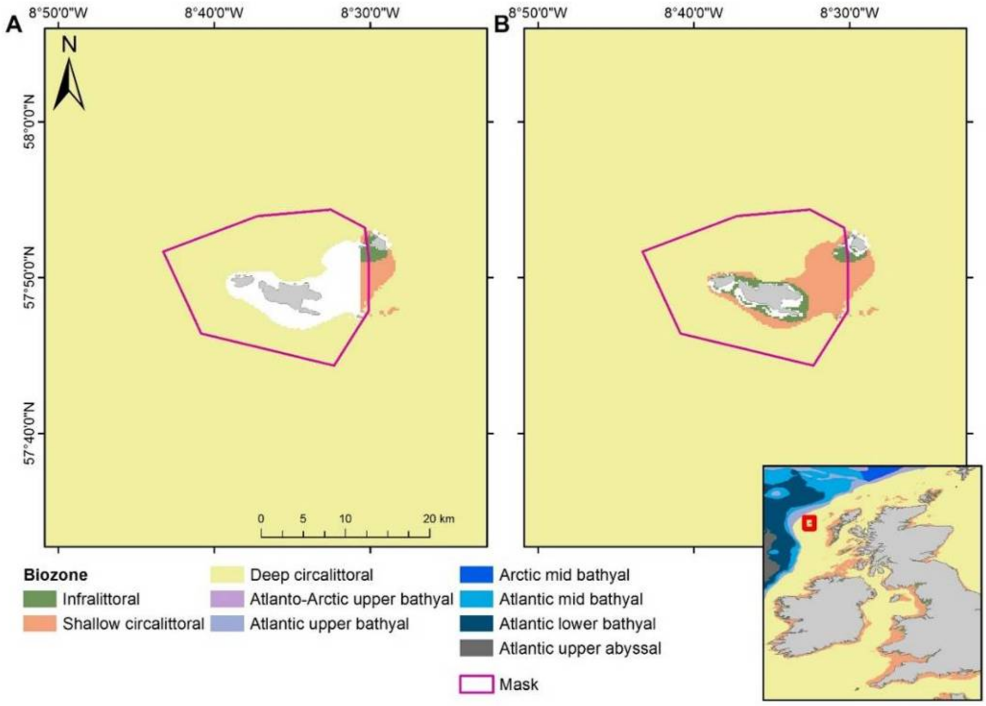

Figure 11.8: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The mask was used to infill "no data" areas with biozone outputs from the 2015 draft of EUSeaMap. The inset map shows the location of maps A and B (red box) in relation to the UK and Ireland.

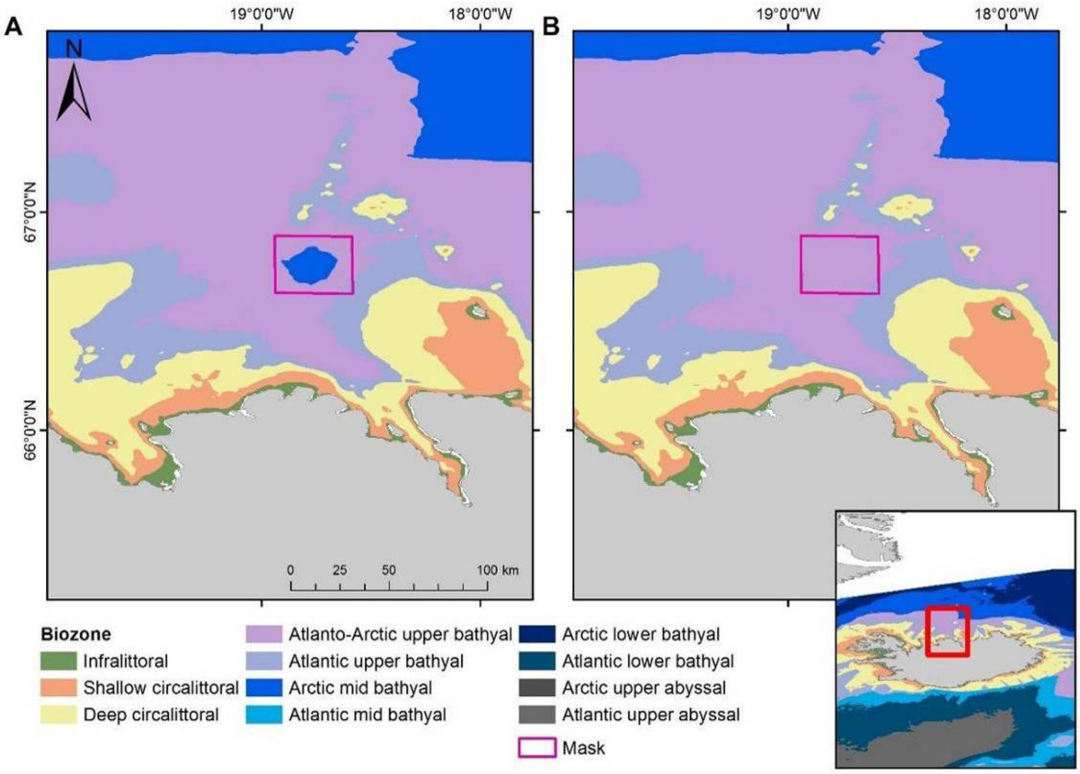

Figure 11.9: Original output (A) and the corrected output (B) of the biozones layer used in the Atlantic model area of EUSeaMap. The mask was used to convert "Arctic mid bathyal" to "Atlanto-Arctic upper bathyal". The inset map shows the location of maps A and B (red box) in relation to the UK and Ireland.

12 Appendix: Making the Broadscale Map

12.1 Introduction

The implementation of the modelling process in a GIS was performed in a raster-based context by using ESRI® ArcGIS ™ 10.2 with the Spatial Analyst extension. The processing workflows were designed under the ArcGIS™ Model Builder tool. The overall workflow is the following suite of sequential processes.

1. From the raster input data layers of key environmental variables, continuous layers of each habitat descriptor class presence probability are computed according to a set of defined GLM or fuzzy equations.
2. Probability layers' pixels are assigned a binary presence/absence value according to a defined cut-off value.
3. From those presence/absence binary rasters, the thematic categorical raster layer that are e.g. biozones or oxygen regimes are assembled.
4. A combination of the layers produced in step 3 is eventually performed, the result of which is the final habitat map.

The inputs to the model are i) the raster primary environmental data layers, e.g. light penetration or wave-induced energy, ii) the slope and intercept values for the GLM or fuzzy equations and iii) the probability cut-off values. The outputs are i) continuous raster layers of presence probability for each habitat descriptor class, ii) categorical layers such as biozones or oxygen regimes in the Black Sea, and iii) the habitat map.

In the following we will focus on processes 1 to 3. For those 3 steps that produce probability and binary presence rasters from continuous environmental input datasets, we had to develop a method that adresses the spatial heterogeneity of

- the input environmetal datasets
- the modelling method (in some places we used GLMs, in others fuzzy equations)
- the GLM/fuzzy equation slope and intercepts
- the cut-off values

Below we further explain this spatial heterogeneity, and we present how this was addressed in the GIS.

12.2 Spatial variation of model inputs

12.2.1 The source and nature of the input variables vary spatially

With the EUSeaMap approach for producing broad-scale seabed habitat maps, habitat descriptor classes such as "Infralittoral" or "High energy" are mapped across the European basins using oceanography variables as proxies. Ideally a dataset for a variable used as a proxy for a given habitat descriptor class would be produced for all Europe waters using consistent methods, spatial resolution, and averaged over a same time period. In reality, initiatives for producing full-coverage oceanography data across European waters are rare. Moreover when such initiatives exist (e.g. Copernicus), their outputs rarely fit the spatial resolution that is required by EUSeaMap, i.e. around 250m, so where a local dataset with better spatial resolution exists it is used instead of the coarser full-coverage dataset. It also may happen that no data is locally available, and therefore an alternative variable has to be used as a proxy in some places.

As a result the oceanography data that comes as inputs of EUSeaMap usually is a compendium of bits of datasets that are produced here and there, that have different spatial resolution, are averaged over different time windows, and that have values that are calculated with different methods (e.g. different wave modeling approach). Figure 12.1a illustrates this with the example of the lower boundary of the shallow circalittoral. This boundary is defined as where the seafloor is no longer disturbed by wave action, thus wave data is typically used as a proxy to model the lower boundary of the shallow circalittoral and the upper boundary of deep circalittoral. For the Channel Sea, Celtic Sea and the Bay of Biscay data produced by a high resolution French wave model was collated, while for the Iberian Peninsula data provided by a coarser wave model was available. Elsewhere no wave data is available, thus bathymetry data is used as a proxy.

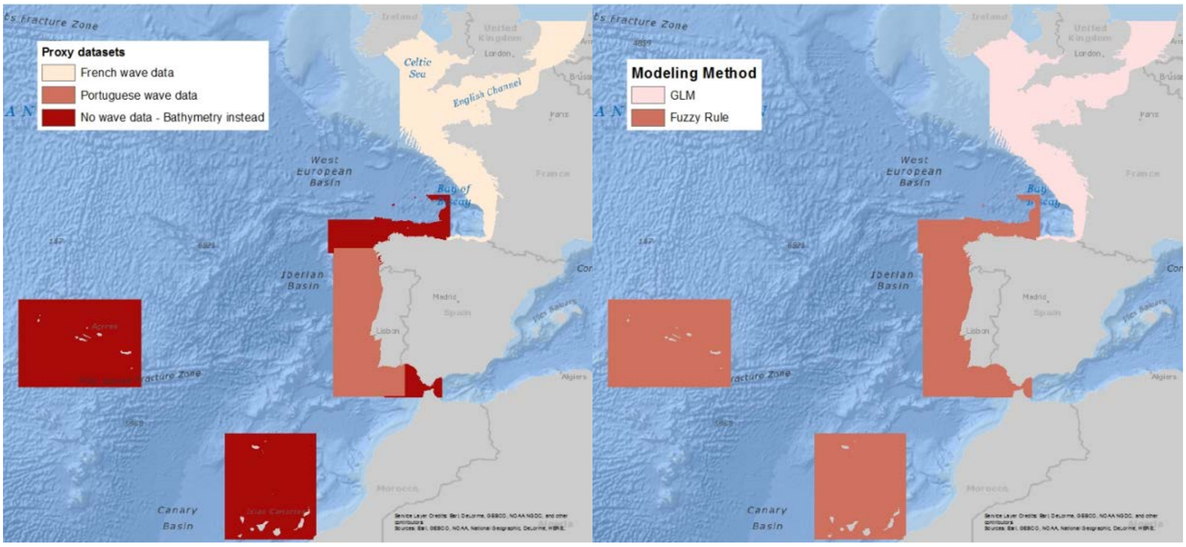

Figure 12.1: example showing how the inputs and the methods used for modeling a EUNIS category (here the shallow circalittoral lower boundary) can vary spatially; a) the source of the variable used as proxy (France vs Portugal) vary, and so does the nature of the variable (wave vs bathymetry); b) the method used (GLM vs Fuzzy rules) vary

12.2.2 The modeling method used varies spatially

The EUSeaMap approach for seabed habitat mapping uses either GLM (Generalised Linear Model) or fuzzy equations to model the spatial distribution of EUNIS habitat descriptor classes. GLM is used where a GLM model could be fitted because sample point data of biology was available. Fuzzy rules are used where such data was not available. This inconsistency of the modeling method used is illustrated in figure 12.1b with the example of the lower boundary of the shallow circalittoral. In the bay of Biscay there is some historical sample point data of benthic communities occurrences that are indicator of the either the coastal or the deep circalittoral. Therefore a GLM could be fitted there with wave data as a predictor input. This GLM equation is not applicable in all places because, as stated above, i) in the Iberian peninsula the wave data is not consistent with that of the Bay of Biscay (coarser spatial resolution, different time window) and ii) elsewhere no wave data is available and bathymetry is used as an alternative proxy. No sample point data was available for those places, hence it was not possible to fit a GLM there, and fuzzy rules are used instead. Figure 14.2b is another example, the infralittoral lower boundary. A GLM with light fraction reaching the seabed as a predictor variable of the infralittoral occurence was fitted with groundtruth point data. The GLM unfortunately cannot be applied in every place because the light dataset is not consistent: in the Azores and the Canaries, the light values were not computed in the same way as it was elsewhere. As there were not sample point data there, fuzzy arbitrary rules had to be worked out.

12.2.3 The slope and intercept of the modeling equations vary spatially

Basically a fuzzy equation is a simple y = ax+b linear equation, while a GLM equation is of the form $y = e^{ax+b}/1+e^{ax+b}$. y is the probability of occurrence of a habitat descriptor class (e.g. infralittoral), and x is the predictor variable (e.g. surface light fraction reaching the seabed). Both for a fuzzy rule and a GLM the equation has 2 coefficients, a and b, namely the slope and the intercept. Due to the inconsistency of the input datasets stated above those constants have to vary spatially. This is illustrated in figure 12.2 with the example of the lower infralittoral boundary.

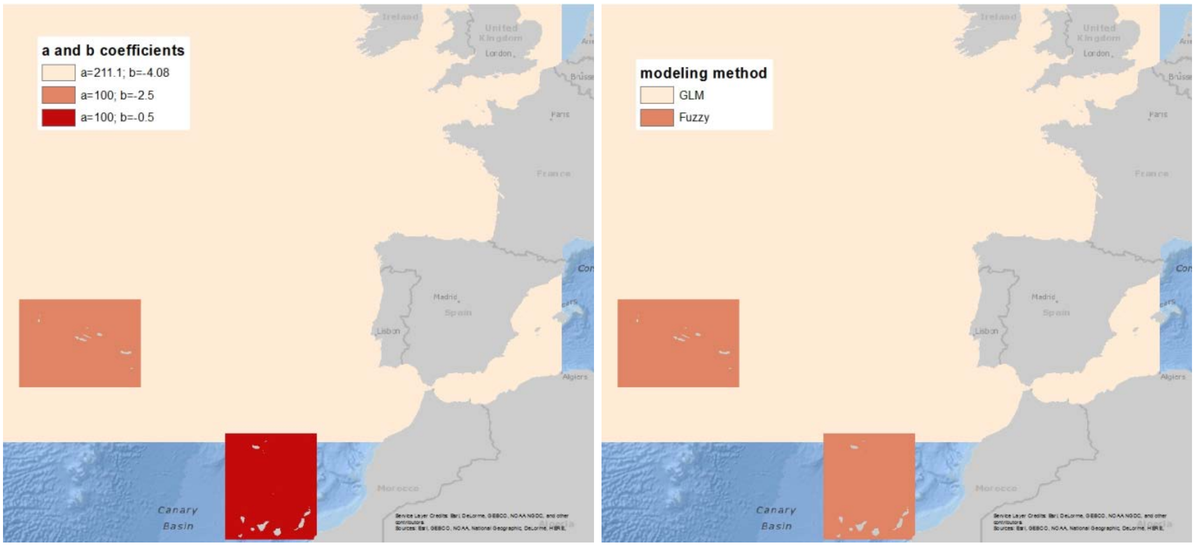

Figure 12.2: example of how the equations and the methods used for modeling a EUNIS category (here the infralittoral lower boundary) can vary spatially; a) the coefficient a and b (slope and intercept) of the equations vary; b) the method used (GLM vs Fuzzy rules) vary

12.2.4 The cut-off value varies spatially

When applied on a proxy data layer, GLM and fuzzy rules produce a quantitative probability layer of occurrence of a habitat descriptor class, i.e. each pixel of the layer has a value between 0 and 1 that is the probability of occurrence of the habitat descriptor class at the location of the pixel. In order to obtain from that probability layer a binary layer of presence/absence of the habitat descriptor class, a cut-off value of probability has to be used. One may think that this value has to be systematically 0.5, but it is not. Two examples of this are illustrated in figure 12.3.

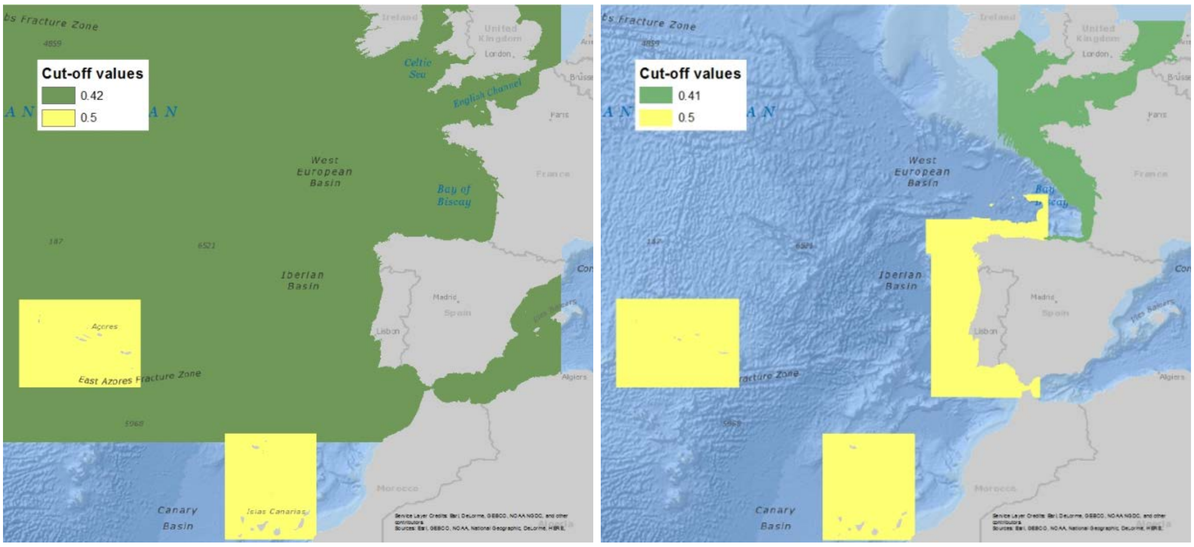

Figure 12.3: example of how the cut-off values vary spatially; a) cut-off values for the infralittoral lower boundary; b) cut-off values for the circalittoral lower boundary

12.3 Implementation in ArcGIS

Since the input parameters that come into play in the GIS model that produces a seabed habitat map are not spatially constant over a given basin due to heterogeneity in the spatial data inputs and in the modeling methods used (GLM or fuzzy rules), the EUSeamap GIS models cannot be fed by constant values that would be valid for the entire basin. The solution to this is to feed the GIS models with rasters, i.e. a raster for:

- the method used (2 possible values: 1 if fuzzy rule, 2 if GLM)
- the slope
- the intercept
- the probability cut-off value

A set of those 4 rasters has to be produced for each boundary between 2 habitat descriptor classes, and given as inputs to the GIS model which, as illustrated in figure 12.4,

1) produces the probability layers for each EUNIS category boundary: this is done by a sub-model that basically applies a linear function where the method raster has the value 1 (i.e. fuzzy) and a GLM equation where the method raster has the value 2 (i.e. GLM);

2) produces the presence layer for each habitat descriptor class, taking into account the values of the cut-off rasters

3) merges all the presence layer in order to produce a unique raster layer for each habitat descriptor (i.e. in the Atlantic a layer for biological zones and a layer for energy levels).

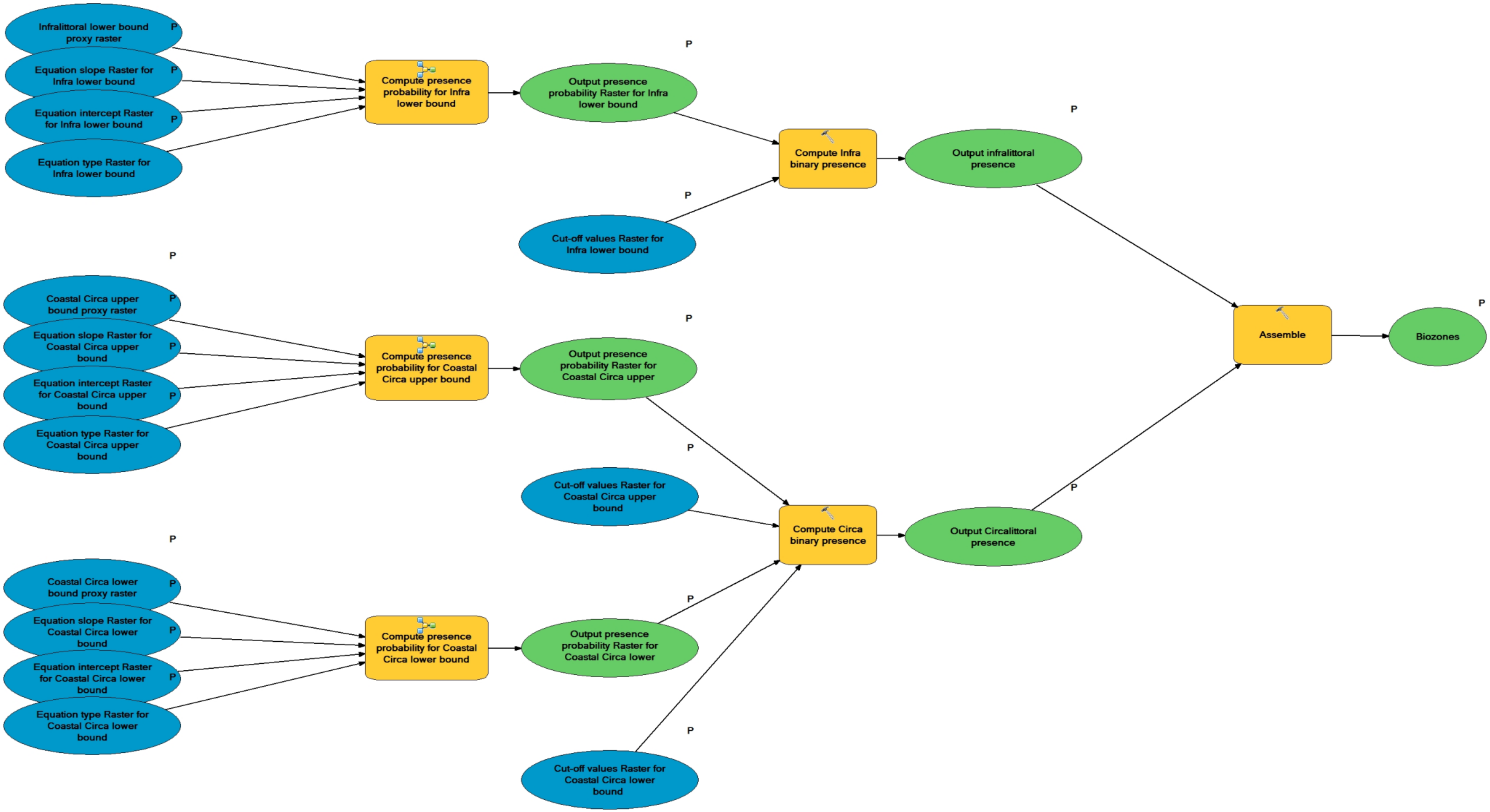

Fig. 12.4: the GIS worklow for the production of a habitat descriptor layer, namely biological zones. For simplification only 2 biological zones are considered (infralittoral and shallow circalittoral);

1: calculation of the probability layer for each habitat descriptor class boundary (infralittoral lower boundary, shallow circalittoral upper boundary, shallow circalittoral lower boundary);

2: calculation of the presence layer for each habitat descriptor class;

3: combination of all presence layers into an single categorical layer

13 Appendix: List of the Posidonia oceanica, Cymodocea nodosa and hard bottom cartographies used as integrative substrate layer

The data collection process for the selection of P. oceanica for validation of light threshold was conducted in parallel with the collection of P.oceanica and C. nodosa cartographies to be used as additional substrate layer. Any spatial information on hard bottom assemblages found in the cartographies through this process was also integrated into the basic substrate layer. Cartographies of seagrass meadows were censused and collected as follows:

- EUSEAMAP project partners searched in house and through national research networks for available P. oceanica and C. nodosa cartographic data;
- All Barcelona Convention National Focal Points for the SPA/BIO protocol were contacted to census for available cartographic data and any national contact known to have been involved in Water Framework Directive monitoring on Posidonia lower limits
- A literature review of UNEP - RAC/SPA technical documents pertaining to seagrasses and proceedings of the five Mediterranean Workshops on Marine Vegetation was conducted so as to identify potential scientific data owners with cartographic data and information on the Posidonia selection criteria described above.
- Requests were sent to all identified data owners so as to collect cartographies

Table 13.1 - Sources of cartographic and georeferenced datasets used to integrate into the EMODNET substrate layer polygon and point data referring to *Posidonia oceanica*, *Cymodocea nodosa* and hard bottoms. Bibliographic references are indicated for documents that were made available for consultation.

Country	Direct cartographic data source	*Posidonia oceanica*	*Cymodocea nodosa*	Hard bottoms	Bibliographic reference codes
ALBANIA	International School for Scientific Diving, Lucca, Italy	•	•		1
CROATIA	International Marine Center, Oristano, Italy	•			
	University of Zagreb, Faculty of Science, Division of Biology , Croatia	•			
	Institute for oceanography and fisheries , Split, Croatia	•			
	State Institute for Nature Protection, Croatia	•			25, 27, 28, 29, 30, 31, 39, 54, 65,
CYPRUS	Department of Fisheries and Marine Research (DFMR), Cyprus	•			49
FRANCE	Ifremer, Bureau d'Etude Géologique - Brest	•	•		5

Country	Direct cartographic data source	*Posidonia oceanica*	*Cymodocea nodosa*	Hard bottoms	Bibliographic reference codes
	Communauté d'Agglomération Nice Côte d'Azur, Conseil Général des Alpes-Maritimes, Région PACA, Agence de l'Eau Rhône Méditerranée & Corse, Andromède Environnement	•	•		24
	Ville de Cannes, Conseil Général des Alpes-Maritimes, Région PACA, Agence de l'Eau Rhône Méditerranée & Corse, Andromède Océanologie	•	•		22
	SIVOM du Littoral des Maures, Agence de l'Eau Rhône Méditerranée & Corse, SAFEGE CETIIS	•	•		15
	Parc national de Port-Cros, DIREN PACA, GIS Posidonie, Ifremer	•	•		56
	Parc national Port-Cros, DIREN PACA, Ifremer, Bureau d'étude géologique (Brest), Centre d'océanologie de Marseille	•	•		42
	Parc national de Port-Cros, DIREN PACA, GIS Posidonie, Ifremer	•	•		55
	Région PACA, Agence de l'Eau Rhône Méditerranée & Corse, Ifremer, GIS Posidonie	•	•		41
	Toulon Provence Métropole, Région PACA, DIREN PACA, Conseil Général du Var, Agence de l'Eau Rhône Méditerranée & Corse, GIS Posidonie, Ifremer	•	•		6
	Conseil général des Bouches du Rhône, Ifremer, GIS Posidonie, Philippe Clabaut Consultant	•	•		14
	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	•	•		67
	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	•	•		12
	Centre d'Océanologie de Marseille, CNEXO	•	•		8
	DIREN Languedoc-Roussillon, Andromede Environnnement	•	•		23
	ADENA, DIREN Languedoc-Roussillon, Agence de l'Eau Rhône Méditerranée & Corse, Conseil	•	•		18

Country	Direct cartographic data source	*Posidonia oceanica*	*Cymodocea nodosa*	Hard bottoms	Bibliographic reference codes
	Régional du Languedoc-Roussillon, Université de Nice, CNRS-EPHE Université de Perpignan, GIS Posidonie, Ville d'Agde				
	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	•	•		32
	Equipe Ecosystèmes Littoraux - Université de Corse	•	•		43
	Mairie de Sartène, GIS Posidonie, Université de Corse	•	•		20
	Equipe Ecosystèmes Littoraux - Université de Corse, IFREMER	•	•		47
	Office de l’Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse	•	•		66
	Office de l’Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse	•	•		44
	Equipe Ecosystèmes Littoraux - Université de Corse, Office de l’Environnement de la Corse	•	•		48
	Office de l’Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse	•	•		45
	Office de l’Environnement de la Corse, GIS Posidonie, Equipe Ecosystèmes Littoraux - Université de Corse	•	•		46
	Ifremer, reseau MEDBENTH		•		
GREECE	Greek Ministry of the Environment	•			37
	HCMR	•			
ITALY	see reference document	•	•	•	52
	see reference document	•	•		63
	Agenzia Regionale per la Prevenzione e la Protezione dell'Ambiente, Puglia, Italy	•	•	•	53
	see reference document		•	•	57, 16

Country	Direct cartographic data source	*Posidonia oceanica*	*Cymodocea nodosa*	Hard bottoms	Bibliographic reference codes
	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale	•	•	•	
	see reference document	•	•		61
	see reference document	•	•	•	36
	see reference document	•	•	•	7
	see reference document		•	•	35
	see reference document			•	58
	Prof. Russo, Parthenope Un. of Naples			•	64
	see reference document	•		•	13
	see reference document			•	26
	see reference document	•		•	17
	Italian MSFD reporting on habitats			•	
	Italian MSFD reporting on habitats			•	
	see reference document	•		•	51
	Ente gestore Area Marina Protetta Secche di Tor Paterno	•		•	
	ISPRA, Chioggia			•	
LIBYA	UNEP/MAP - RAC/SPA, Tunis, Tunisia	•			62
MALTA	Malta Environment and Planning Authority, Malta	•	•		2,3,9,10,11,21
SLOVENIA	Institute of the Republic of Slovenia for Nature Conservation, Slovenia	•	•		33
SPAIN	Instituto Español de Oceanografía (IEO) / Secretaría General de Pesca Marítima (MAPA)	•			59
	Dirección General de Costas. Ministerio de Obras Públicas	•			50
	Instituto Español de Oceanografía (IEO)	•			60
TUNISIA	Andromède Océanologie, France	•	•	•	4
	UNEP/MAP - RAC/SPA, Tunis, Tunisia	•			62
TURKEY	see reference document	•			19, 34, 38, 40

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14 Appendix: MSFD Benthic Broad Habitat types map

EUSeaMap 2016 outputs were harmonised into a single pan European map of broad marine habitats (See Figure 14.1 below) classified according to the Marine Strategy Framework Directive Benthic Broad Habitat Types list (COMMISSION DECISION (EU) 2017/848 of 17 May 2017).

In the Mediterranean Sea the biozones "Circalittoral" and "Offshore circalittoral" are not distinguished when the substrate is of "Mud" type, as explained in Section 3.3.3.

In the Black Sea and the Mediterranean Sea, the Bathyal zone was not subdivided into "upper" or "lower" therefore the classes "Upper bathyal sediment" and "Lower bathyal sediment" could not be distinguished. Similarly, "Upper bathyal rock and biogenic reef" could not be separated from "Lower bathyal rock and biogenic reef" in those basins.

In the Atlantic and Arctic, the Bathyal zone was subdivided into "upper", "mid" and "lower", which needed to be grouped to match the MSFD broad habitat zones upper bathyal and lower bathyal. For this we chose to group the EUSeaMap mid bathyal biozone with EUSeaMap upper bathyal biozone. This is for two main reasons:

1) In general there are more similarities in the communities living in the Mid bathyal and Upper bathyal than in the Lower bathyal (Parry et al., 2015). For example the shift from Lophelia to Solenosomillia coral communities occurs at about 1,300 m depth (which corresponds to the depth proxy threshold between EUSeaMap mid and lower bathyal zones in Arctic and Atlantic); or, as an example in soft sediments, the dense aggregations of sea pens of the genus *Kophobelemnon* occur both in upper and mid bathyal muds, but not in lower bathyal muds.
2) For a more even depth distribution of the classes, as the upper bathyal and mid bathyal together cover about 1,100 m depth, and the lower bathyal alone covers 1,100 m depth.

In all regions, "Na" indicates that an MSFD broad habitat type could not be assigned due to a lack of substrate information (except the 'Abyssal' type which does not require substrate information) or the habitat could not be assigned (e.g. Non-valid habitats in the Black Sea).

Regarding the substrate classification, the Mediterranean and Black Sea slightly different from the rest of the basins, as explained in more detail in Section 2.2.1 of this report. This means that in the conversion to MSFD Benthic Broad Habitat Types the Mediterranean and Black Sea polygons where the Folk (1954) classes muddy sand are classified as a Sand MSFD Broad Habitat Type as a Mud MSFD Broad Habitat Type in other sea regions.

All the rules used to convert the EUSeaMap 2016 full-detail habitats into MSFD Broad Habitat Types are reported, for each region (Black Sea, Mediterranean Sea, Baltic, Arctic and Atlantic), in the tables contained in the Excel file that accompanies this report.

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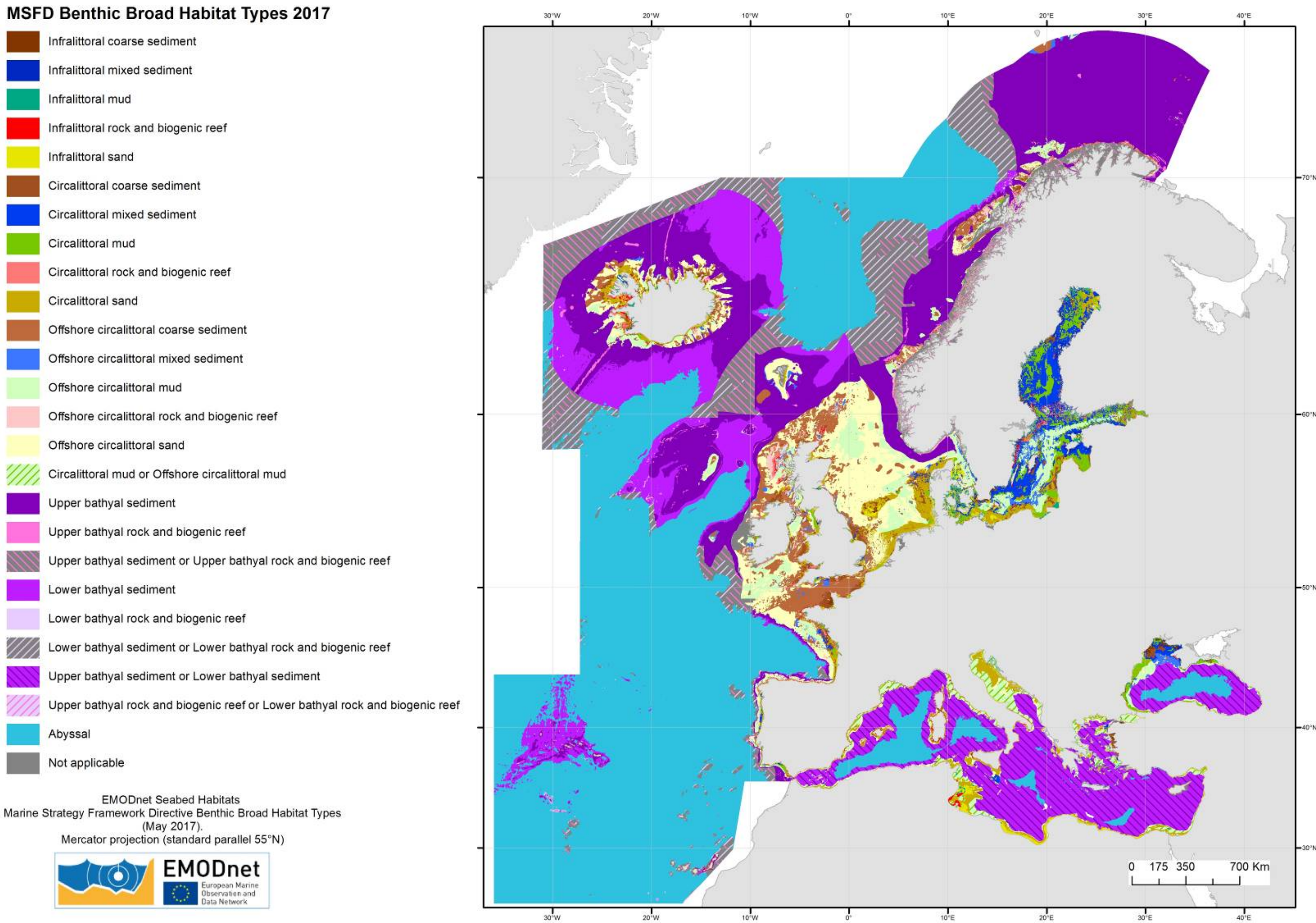

Figure 14.1: EMODnet Seabed Habitats MSFD Benthic Broad Habitat Types