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Centralisation Phase

EUSeaMap 2023

A European broad-scale seabed habitat map

Technical Report

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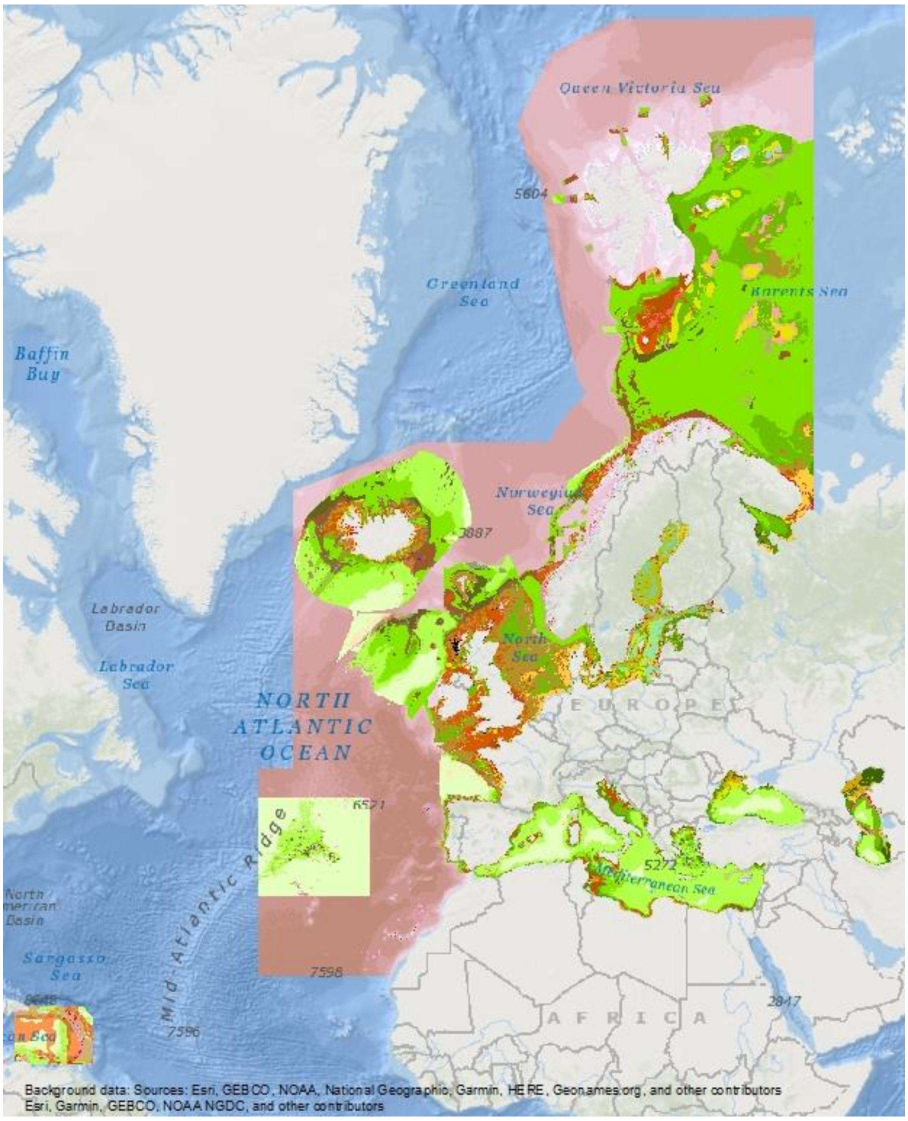
List of abbreviations and acronyms

DTM	Digital Terrain Model (i.e. gridded bathymetry)
EEA	European Environment Agency
ESH	EMODnet Seabed Habitats
EU	European Union
EUNIS	The EUNIS habitat classification is a pan-European system for habitat identification.
GIS	Geographic Information System
GTK	Geological Survey of Finland
HELCOM	The Baltic Marine Environment Protection Commission is an intergovernmental organization and a regional sea convention in the Baltic Sea area.
HUB	Helcom Underwater Biotope and Habitat Classification System
MSFD	Marine Strategy Framework Directive
MSFD TG	MSFD Technical Group
UK	United Kingdom
UNEP/MAP	United Nations Environment Programme/Mediterranean Action Plan

Executive summary

EUSeaMap 2023 is the sixth iteration of EUSeaMap. All versions have been produced as part of the EMODnet Seabed Habitats project, which is one of several thematic lots in EMODnet. The project has brought together a European consortium of specialists in benthic ecology and seabed habitat mapping. The partners first worked together in EMODnet Phase 1 (2009-2012) to develop a prototype predictive seabed habitat map in four test basins (Greater North Sea, Celtic Seas, Baltic Sea, Western Mediterranean). This predictive model was named EUSeaMap (Cameron and Askew, 2011). In EMODnet Phase 2 (2012-2016), the consortium extended the spatial coverage of EUSeaMap to all European regions (Populus el al., 2017). In Phase 3 (2017-2021), a first version (2019) extended the spatial coverage further north to include the Barents Sea, incorporated improved environmental data, and dramatically improved the spatial detail. In 2021 EUSeaMap was improved with new seabed substrate data and was published in new classifications, including the new version of the marine section of EUNIS, called EUNIS 2019. In this new version, called EUSeaMap 2023, EUSeaMap has been extended to the Caribbean Sea and the Caspian Sea. In Continental Europe, Macaronesia, Iceland and the Arctic, progress has been made in integrating new data on seabed substrate, bathymetry, wave energy and the probability of the occurrence of the halocline at the bottom of the Baltic Sea.



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1 Introduction

EUSeaMap 2023 is the sixth iteration of EUSeaMap. All versions have been produced as part of the EMODnet Seabed Habitats project, which is one of several thematic lots in EMODnet. The project has brought together a European consortium of specialists in benthic ecology and seabed habitat mapping. The partners first worked together in EMODnet Phase 1 (2009-2012) to develop a prototype predictive seabed habitat map in four test basins (Greater North Sea, Celtic Seas, Baltic Sea, Western Mediterranean). This predictive model was named EUSeaMap (Cameron and Askew, 2011). In EMODnet Phase 2 (2012-2016), the consortium extended the coverage of EUSeaMap to all European regions (Populus el al., 2017). In Phase 3 (2017-2021), a first release (2019) extended the spatial coverage further north to include the Barents Sea, incorporated improved environmental data, and dramatically improved the spatial detail. In 2021 EUSeaMap was improved with new seabed substrate data and was published in new classifications, including the new version of the marine section of EUNIS, called EUNIS 2019.

In this new release, called EUSeaMap 2023, EUSeaMap has been extended to two areas, the Caribbean Sea and the Caspian Sea. With respect to the Caribbean Sea, the spatial coverage achieved is the area known as the Lesser Antilles, which includes the EU Overseas Countries and Territories and the UK Overseas Territories. For ease of reading, this area, although only part of the Caribbean, is referred to in this report as the Caribbean Sea.

In Continental Europe, Macaronesia, Iceland and the Arctic, progress has been made in integrating new data on seabed substrate, bathymetry, wave energy and the probability of occurrence of the halocline at the bottom of Baltic Sea.

2 Material

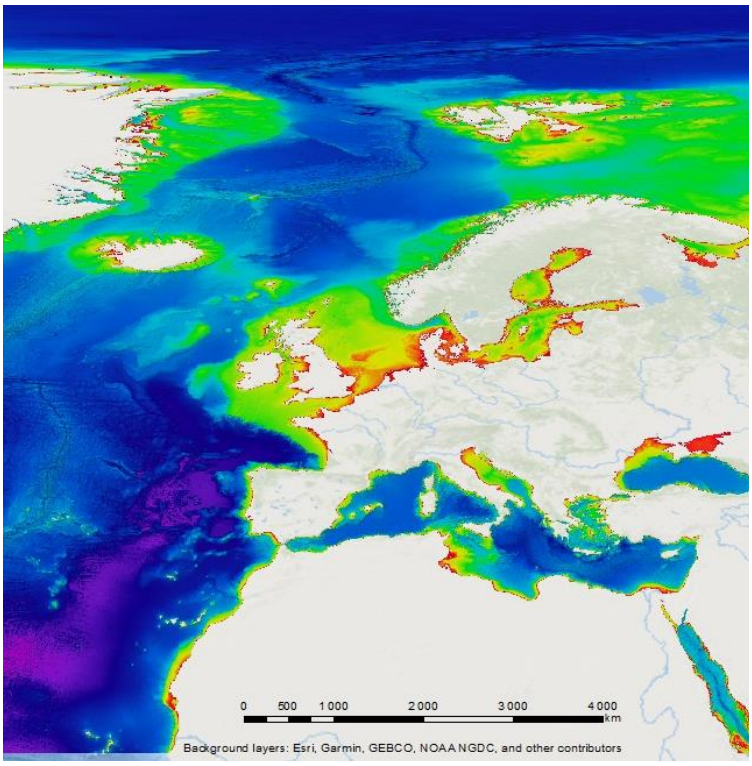
2.1 Bathymetry

Bathymetry is used to construct the Biological Zone dataset, which is one of the master layers of EUSeaMap along with the seabed substrate. In EUSeaMap 2023 the bathymetry has been updated using the DTM 2022 produced as part of EMODnet Bathymetry. This ~100m resolution DTM is based on observations (survey and satellite) and high resolution composite DTMs. In areas where neither observations nor high resolution composite DTMs are available, the EMODnet Bathymetry DTM uses GEBCO 2022 and IBCAO V4 DTMs. The EMODnet Bathymetry DTM does not cover the Caspian Sea. Therefore, for EUSeaMap 2023 the GEBCO_2021 DTM was used in this area.

In Continental Europe, Macaronesia, Iceland and the Arctic, the last update of the bathymetry in EUSeaMap was in 2019, using the EMODnet Bathymetry DTM 2018. In the meantime, the DTM has evolved significantly, integrating more survey-based datasets. The GEBCO DTM, which is one of the main components of the EMODnet DTM, has also evolved significantly.

EMODnet Bathymetry provides a confidence rating for the data used to construct the DTM. Each cell is assigned a confidence value in the interval 0-100 (0=lowest confidence, 100=highest confidence). As the EUSeaMap confidence rating uses a three-category confidence rating system (1: lowest score, 2: intermediate score and 3: highest score), the cut-off values of 40 and 70, recommended by the DTM authors, were used to classify continuous [0-100] values into the EUSeaMap confidence rating system (i.e. 1: value ≤ 40, 2: 40 < value ≤ 70, 3: value > 70). In the Caspian Sea, since GEBCO was used, all the DTM cells were assigned the lowest confidence value, i.e. 1.

Figures 1 to 3 show images of the bathymetry used for EUSeaMap 2023 together with a confidence map for Continental Europe, Macaronesia, the Arctic and Iceland (Figure 1), the Caribbean Sea (Figure 2) and the Caspian Sea (Figure 3).



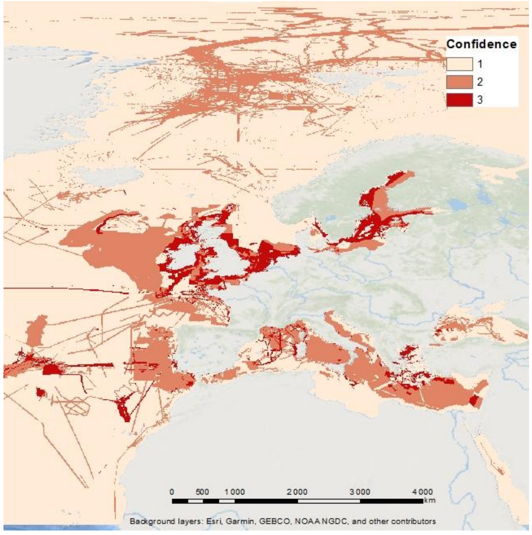
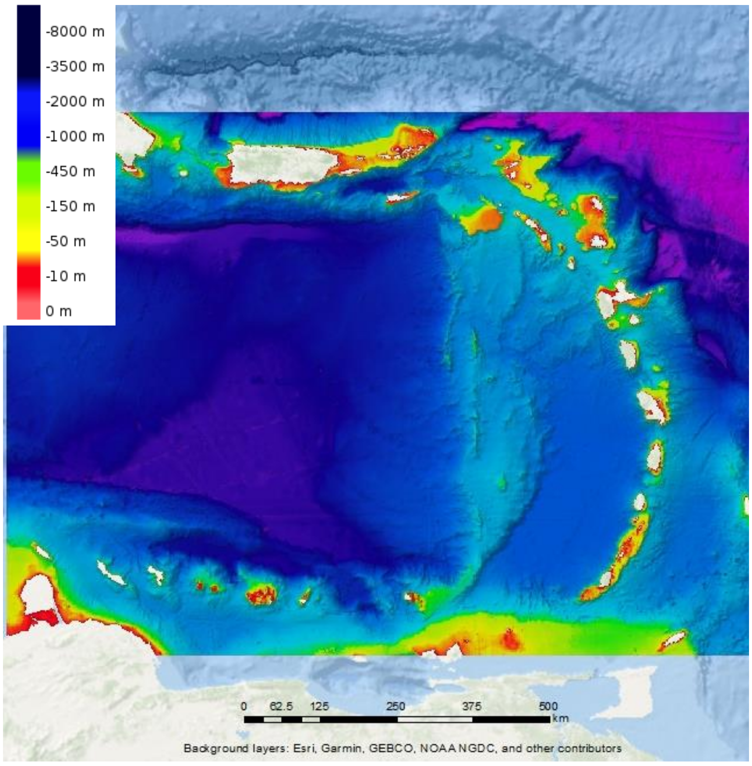


Fig. 1: (left panel) image of the bathymetry used for EUSeaMap 2023 in Continental Europe, Macaronesia, the Arctic and Iceland and (right panel) associated confidence expressed in the EUSeaMap three-category confidence scoring system (1=lowest score, 3=highest score).



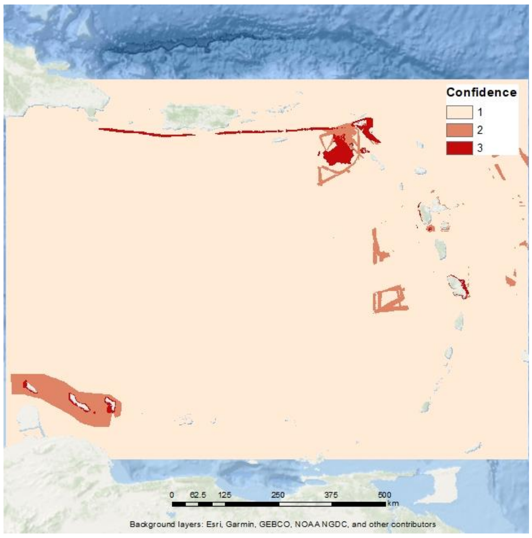
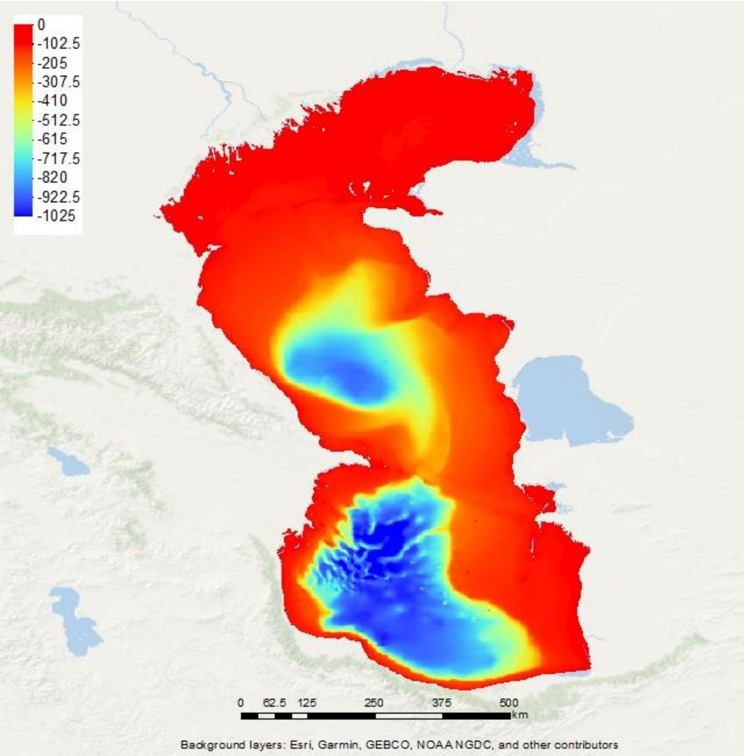


Fig. 2: (left panel) image of the bathymetry used for EUSeaMap 2023 in the Caribbean Sea and (right panel) associated confidence expressed in the EUSeaMap three-category confidence scoring system (1=lowest score, 3=highest score).



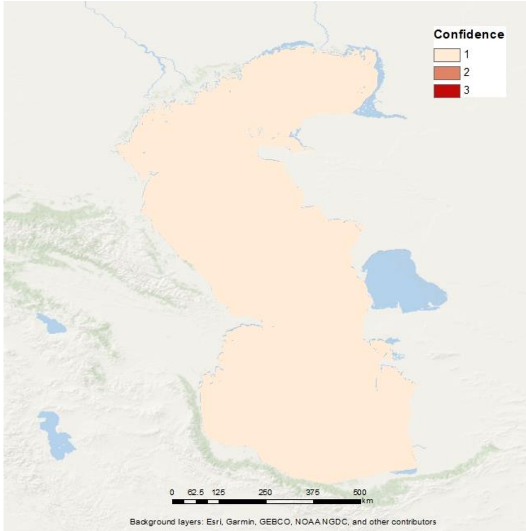


Fig. 3: (left panel) image of the bathymetry used for EUSeaMap 2023 in the Caspian Sea and (right panel) associated confidence expressed in the EUSeaMap three-category confidence scoring system (1=lowest score, 3=highest score).

2.2 Seabed substrate

Seabed substrate input is as important as bathymetry in the creation of EUSeaMap. The seabed substrate used as input to EUSeaMap is the result of combining multiple datasets at multiple scales into a single dataset containing the best scale available at each location. It is also the result of combining two types of input: sediment and rock substrate on the one hand, and biogenic substrate on the other.

2.2.1 Sediment and rock substrate

EUSeaMap requires seabed types to be classified according to a modified version of the Folk classification system with 7 classes (Rock, Coarse substrate, Mixed sediment, Sand, Muddy sand, Sandy mud, Mud).

For EUSeaMap 2023 the datasets were collated from the following archives:

- EMODnet Geology Seabed Substrate data product (scale 1:1,000,000 to 1:5,000)
- MeshAtlantic project map in the Azores (Mata Chacón el al., 2013).
- A map produced as part of ur-EMODnet Seabed Habitats in the Western Mediterranean Sea (Cameron and Askew, 2011).
- An unpublished map of hard seabed substrate in the Mediterranean.
- An unpublished map off Bulgaria, produced by EMODnet Seabed Habitats partner IO-BAS.
- A modelled rock layer in Norway (referred to as "Proxy for rock in Norway" in Populus el al., 2017).
- A layer of predicted rock outcrops or subcrops in the UK shelf seabed (JNCC, 2019).
- UK datasets not yet included in the EMODnet Geology Seabed Substrate data product.

The datasets produced by EMODnet Geology are by far the main source of seabed substrate input to EUSeaMap. The data product consists of several datasets, each representing a scale. The broader the scale, the higher the spatial coverage (e.g. the 1:1,000,000 dataset has full coverage), and the finer the scale, the lower the spatial coverage (e.g. the 1:5,000 dataset has quite low coverage).
In contrast to the 2021 version, which included new scale datasets but did not update the existing historical scale datasets (i.e. 1:1,000,000, 1:250,0000, 1:100,000), the 2023 version updated all scale datasets. New areas have also been added, namely the Caspian Sea and the Caribbean Sea.

2.2.2 Biogenic substrate

Biogenic substrates are hard substrates formed by animals or plants. Typical examples are mussel beds, coral reefs, coralligenous platforms and *Posidonia oceanica* meadows. In 2019, the marine section of the EUNIS classification was reformed. An important innovation in this new version was the inclusion of biogenic substrates at level 2 of the classification hierarchy, placing them on the same level as rock or grain size-based substrate types such as 'mud' and 'sand'.

To take this into account, the EMODnet Seabed Habitats consortium decided in 2017 to create a new data product for 'biogenic substrate'. The most complete polygon data sources for evidence of each biogenic substrate type in each biogeographic region were identified, assessed and compiled into a single data product. The first version of the product was published in 2021. The methodology and results are described in Lillis el al., 2021.

An update was published in 2023 (Monteiro el al., 2023). In the Caribbean, one biogenic substrate was included: tropical coral reefs. The main data source used was the UNEP Global Distribution of Coral Reefs[1]. Other fine-scale coral reef polygons from French maps from survey in the Guadeloupe and Martinique islands were included.

In the Caspian Sea, two seabed substrates formed by mussel species, *Mytilaster lineatus* and *Dreissena grimmi*, were included. Polygons were digitised from Karpinsky, 2003 and Karpinsky el al., 2005.

It is important to note that biogenic habitats have not been comprehensively mapped in any region. With the exception of *Posidonia oceanica* meadows, the spatial distribution of biogenic habitats in Europe is poorly mapped. It is therefore important to bear in mind that the polygons identified as biogenic habitats in EUSeaMap are not representative of their full distribution.

[1] https://data.unep-wcmc.org/datasets/1

2.2.3 The seabed substrate input to EUSeaMap as a result of a combination of sediment/rock substrate and biogenic substrate datasets

For EUSeaMap, the polygons of the EMODnet Seabed Habitats biogenic substrate product are combined with those of the sediment/rock substrate data product. The final seabed substrate dataset comprises several primary data sources at different scales (Figure 4).

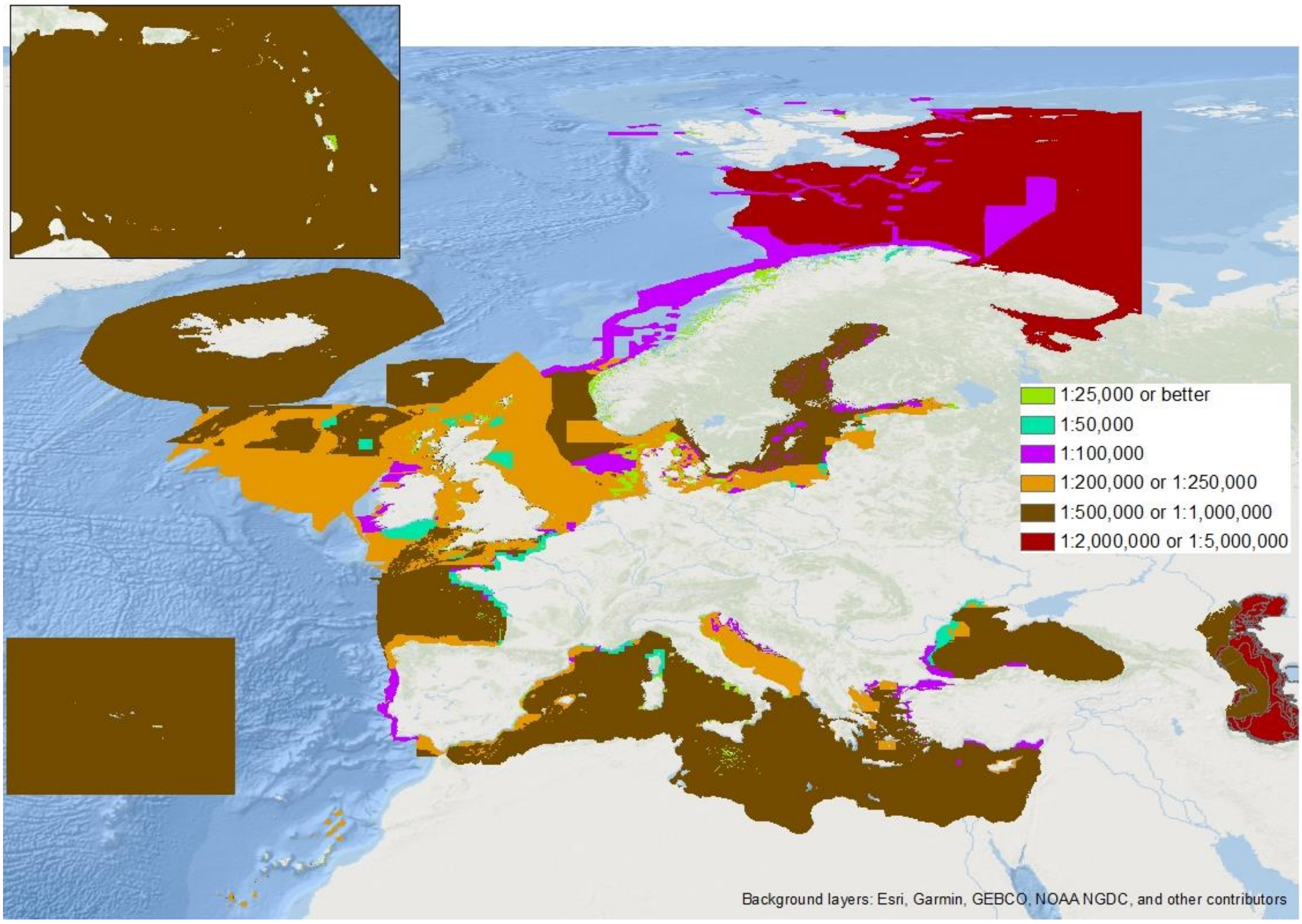


Fig. 4: scales available in the seabed substrate dataset used as input for EUSeaMap 2023. Top left: scales available in the Caribbean Sea.

Confidence was obtained by reclassifying the confidence scores associated with each primary dataset into the EUSeaMap three-category confidence rating system. The reclassification logic used for each primary dataset is shown in Table 1.

Table 1: seabed substrate confidence - Translation of the different confidence ratings associated with the substrate datasets used in EUSeaMap into the EUSeaMap three-category confidence rating system.

EUSeaMap score	EMODnet Geology Confidence score	Map compiled as part of ur-EMODnet Seabed Habitats in the western Mediterranean	MeshAtlantic Project map in the Azores	Non-published map of hard substratum in the Mediterranean	Non-published map off Bulgaria	EMODnet Seabed habitats biogenic substrate product	Modelled Rock substrate Norway
1	0						Presence
2	2 ,1	≤55	Presence		Presence		
3	3, 4	>55		Presence		Presence	

Figure 5 shows the final seabed substrate map together with the associated confidence map. When comparing the 2023 version of the EMODnet Geology Seabed Substrate with the 2021 version it is worth noting that:

- Version 2023 contains major updates. At all scales, many areas have been updated (e.g. France, Ireland, Italy, Lithuania and Norway) and in many areas new data have been added (e.g. in Norway, Ireland, Italy, Lithuania, Azerbaijan, Belgium and Spain).
- In Sweden and Finland some 1:100,000 and 1:20,000 datasets have become non-public and been replaced by coarser (1:1,000,000) datasets.
- In northern Norway some polygons have been removed and not replaced.

It is also noticeable that in the new areas (Caribbean and Caspian Sea) the scale is quite broad. This is especially true for the Caribbean Sea, with the exception of the island of Martinique.

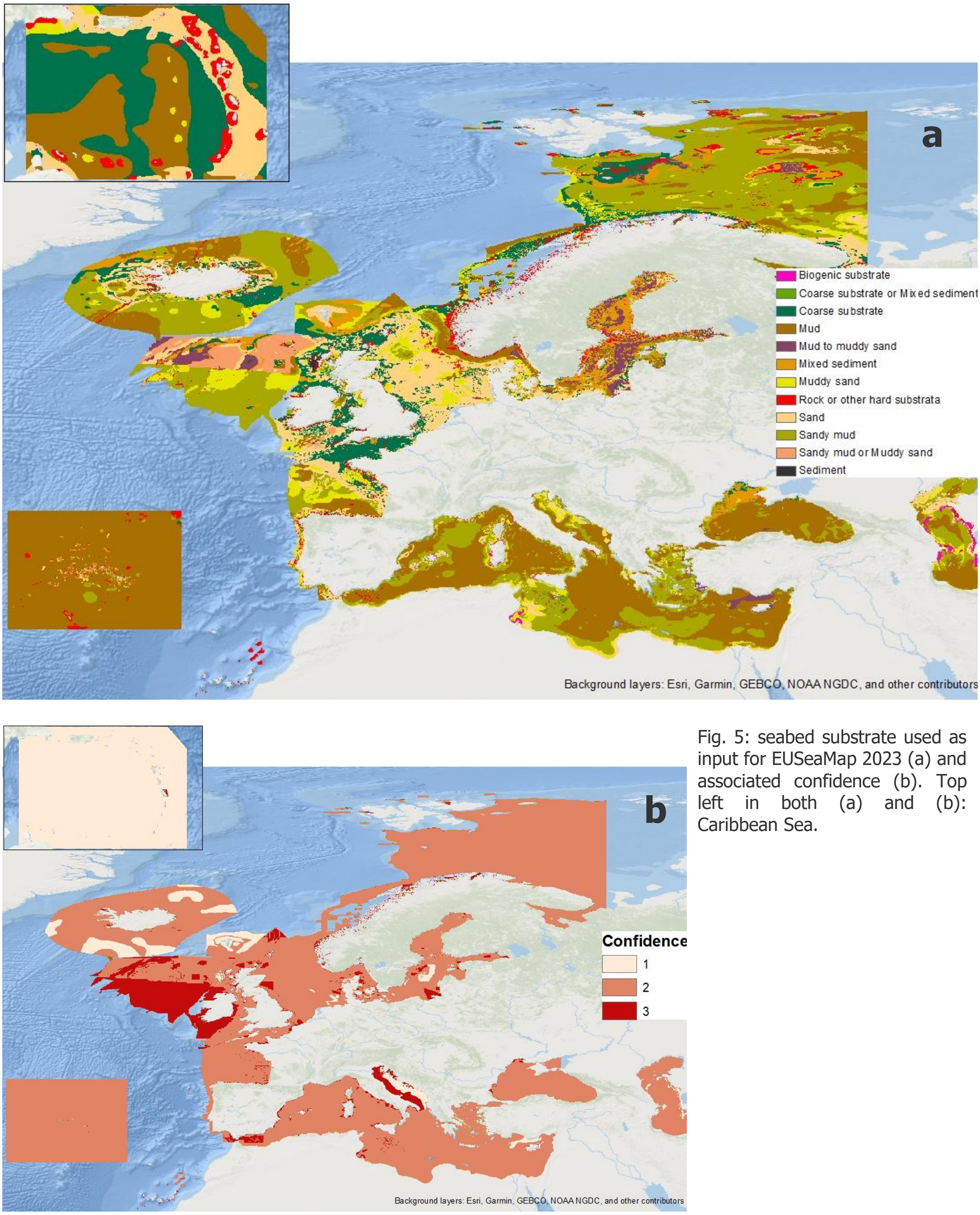


Fig. 5: seabed substrate used as input for EUSeaMap 2023 (a) and associated confidence (b). Top left in both (a) and (b): Caribbean Sea.

2.3 Environmental variable datasets

There are several environmental datasets in use in EUSeaMap, most of which are used to construct the Biological Zone dataset. For EUSeaMap 2023 new datasets have been produced for the following variables:

- Amount of light available at the seabed (Caribbean and Caspian Sea)
- Wave-induced energy at the seabed and wave wavelength (Northwest Europe)
- Probability that the seafloor is below the halocline (Baltic Sea)
- Seabed salinity (Baltic Sea)

2.3.1 Amount of light available at the seabed in the Caribbean and Caspian Sea

The amount of light on the seabed is a parameter used in EUSeaMap to construct the Biological Zone habitat descriptor dataset, specifically for the boundary between the infralittoral and circalittoral zones.

The variable used to approximate the amount of light on the seabed is the seabed PAR (photosynthetically available radiation), which is calculated by intersecting a grid of 5-year mean atmospheric PAR, a grid of 5-year mean KdPAR (diffuse attenuation coefficient of photosynthetic active radiation, i.e. a proxy for light attenuation in the water column) and a grid of bathymetry using the formula $PAR_{Seabed} = PAR_{Surface} \times e^{(-KdPAR \times bathymetry)}$.

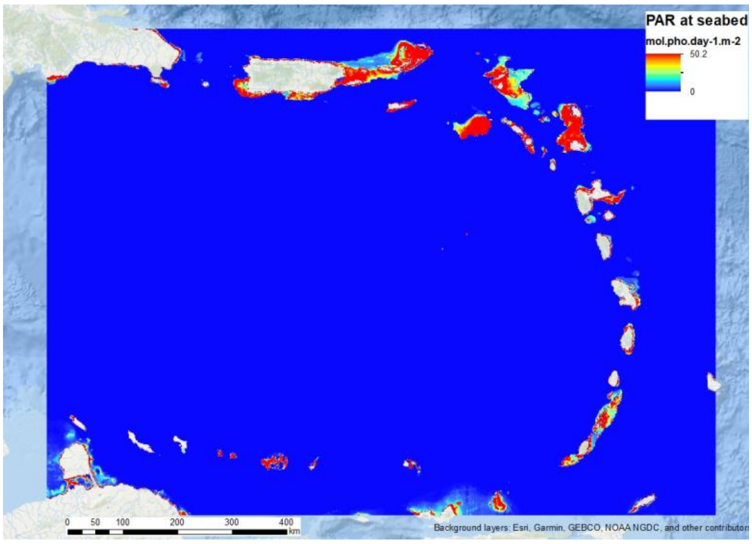
In the Caspian Sea, as in other regions, data was compiled from the MERIS Full Resolution (250m) image archive for the period 2005-2009. In the Caribbean Sea, the number of available MERIS Full Resolution images was insufficient. As a result, KdPAR was estimated using SENTINEL-3 OLCI A and B images (300m). In both the Caspian Sea and the Caribbean Sea, KdPAR was estimated using the method developed by Saulquin el al. (2013). Atmospheric PAR grids were estimated at 4 km resolution using the same archives as for KdPAR (MERIS for the Caspian, SENTINEL OLCI for the Caribbean) and for the same time periods as for KdPAR (2005-2009 for the Caspian, 2018-2022 for the Caribbean).

The confidence in the seabed PAR was calculated by averaging two separate confidence assessments: the bathymetry confidence (see section 2.1) and the KdPAR confidence, the latter estimated for each cell of the grid based on the number of satellite images used to calculate the 5-year mean of the kdPAR (see Table 2).

Table 2: rules used to estimate the confidence in KdPAR datasets.

Confidence per cell	Rule
1 (lowest)	number of images < 29
2	29 ≤ number of images < 39
3 (highest)	number of images ≤ 39

Figures 6 and 7 show a picture of the seabed PAR in the two regions and the associated confidence assessment.



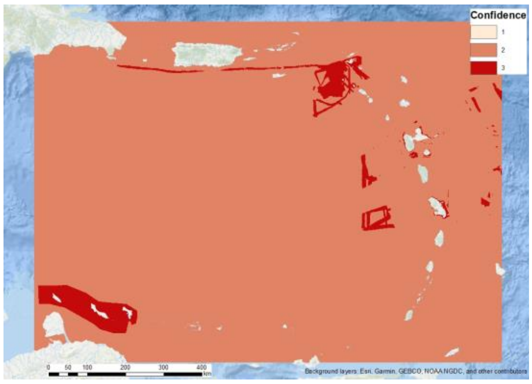
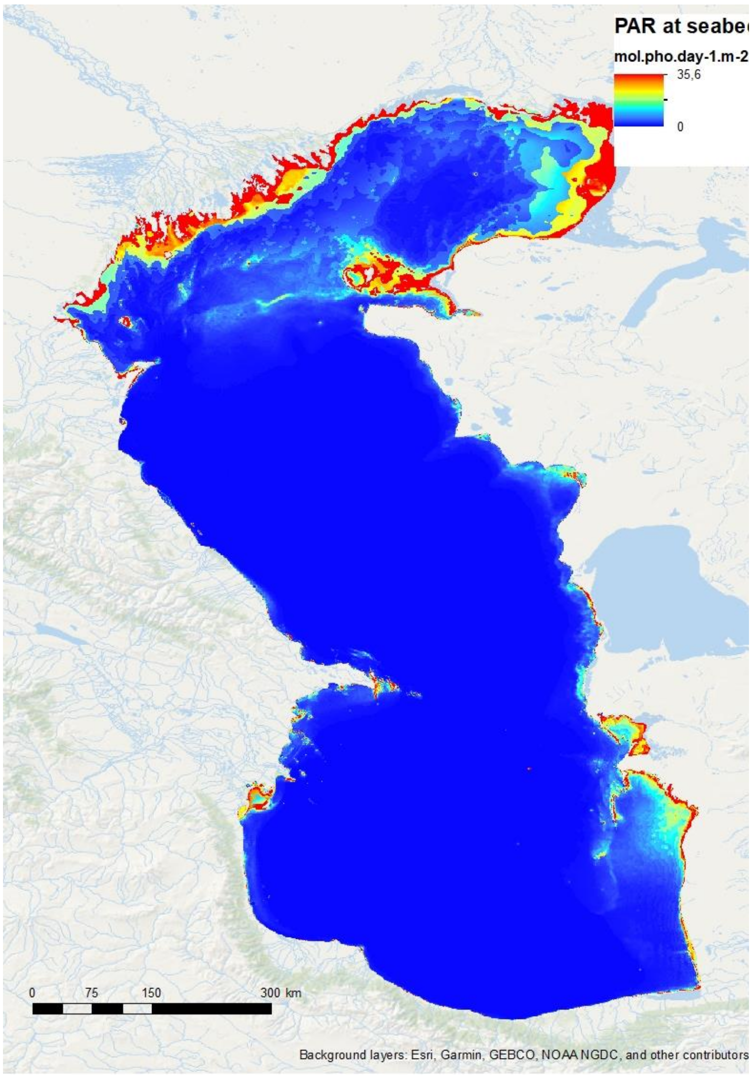


Fig. 6: PAR at seabed (left) and associated confidence (right) in the Caribbean Sea.



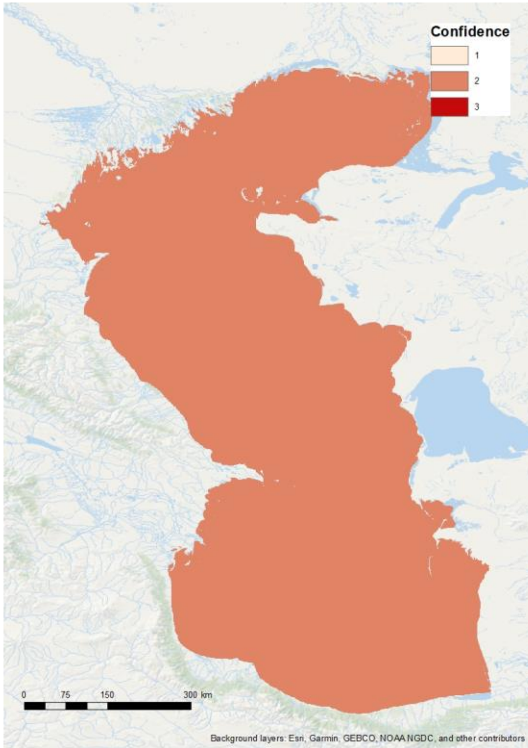


Fig. 7: PAR at seabed (left) and associated confidence (right) in the Caspian Sea.

2.3.2 Wave-induced energy at the seabed and wave wavelength in Northwest Europe

In 2022, the RESOURCECODE project released a hindcast database[2] of high-resolution ocean energy resource parameters for European waters (extending from the north of Scotland to the Bay of Biscay), validated against industrial test site datasets and satellite data (Accensi el al., 2022). The data are organised according to a triangular irregular network of nodes, where the minimum node distance is ~300m at coastlines and refined areas, while the largest triangle side can reach ~20km in deep waters.

This was seen by EMODnet Seabed Habitats as an opportunity to improve on the wave data previously used in EUSeaMap for the Iberian Peninsula, the Bay of Biscay, the Celtic Sea, the English Channel and North Sea, which was a patchwork of datasets with inconsistent spatial resolution and temporal coverage, resulting in datasets with values that were not comparable from one region to another.

Data for the period 2000-2005 were downloaded from the RESOURCECODE archive and a 90th percentile ~100m resolution grid was calculated for two variables of the database: ubr (rms bottom velocity amplitude) and lm (mean wavelength). A seabed kinetic energy grid was calculated from ubr (Seabed kinetic energy = 0.5 x 1027 x ubr^2, where 1027 is water density in kg.m^{-3}) and a wave base ratio grid was calculated from lm and bathymetry (wave base ratio = lm / bathymetry). These two grids were used as input to EUSeaMap, the former as input to the construction of the Wave Energy Level habitat descriptor dataset and the latter as input to the construction of the Biological Zone habitat descriptor dataset, specifically to mark the boundary between the circalittoral and the offshore circalittoral.

Confidence was estimated using the EUSeaMap three-category confidence rating system based on the number of model nodes per cell of the 100m grid according to the logic given in Table 3.

Table 3: rules used to estimate the confidence in ubr and lm datasets.

Confidence per cell	Rule for variable ubr	Rule for variable lm
1 (lowest)	number of nodes < 11	number of nodes < 2
2	11 ≤ number of nodes < 21	2 ≤ number of nodes < 5
3 (highest)	number of nodes ≤ 21	number of nodes ≤ 5

Figures 8 and 9 show a picture of kinetic energy and wavelength, respectively, and the associated confidence assessment.

[2] https://doi.org/10.12770/d089a801-c853-49bd-9064-dde5808ff8d8

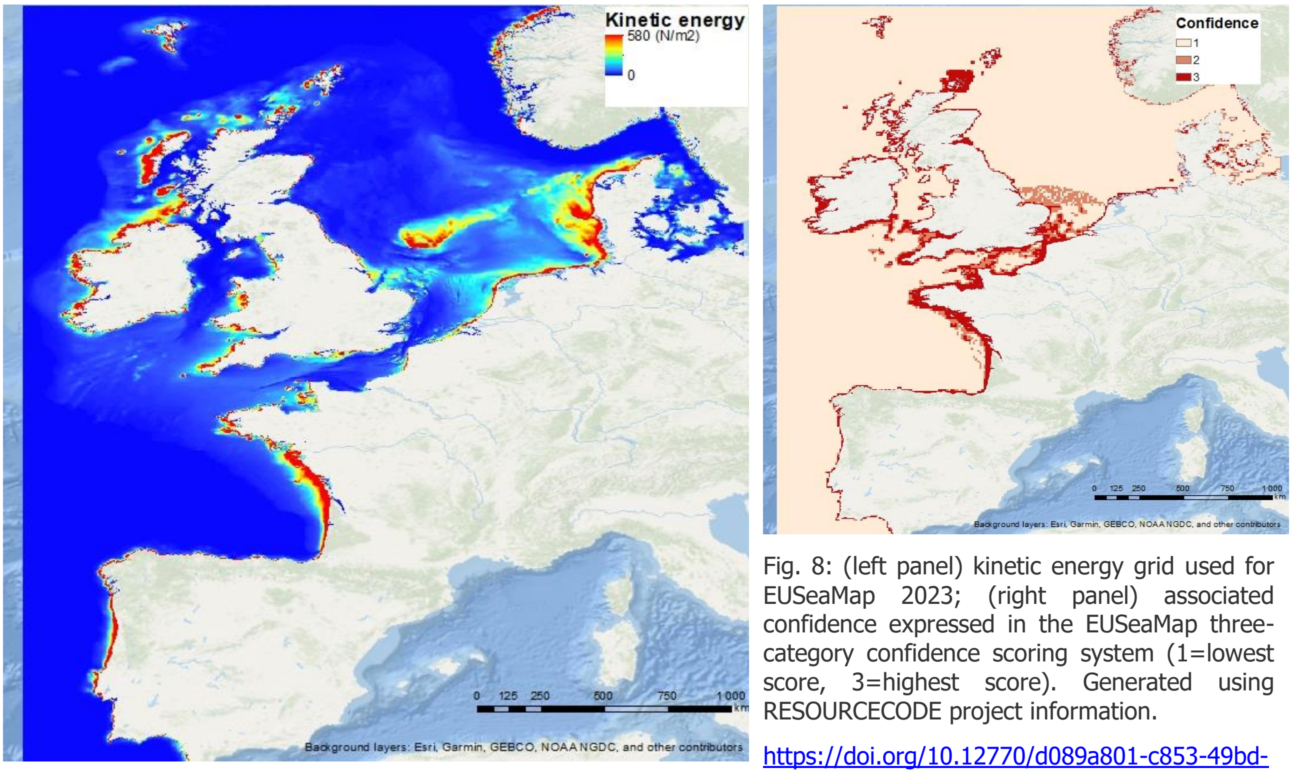


Fig. 8: (left panel) kinetic energy grid used for EUSeaMap 2023; (right panel) associated confidence expressed in the EUSeaMap three-category confidence scoring system (1=lowest score, 3=highest score). Generated using RESOURCECODE project information.

https://doi.org/10.12770/d089a801-c853-49bd-9064-dde5808ff8d8

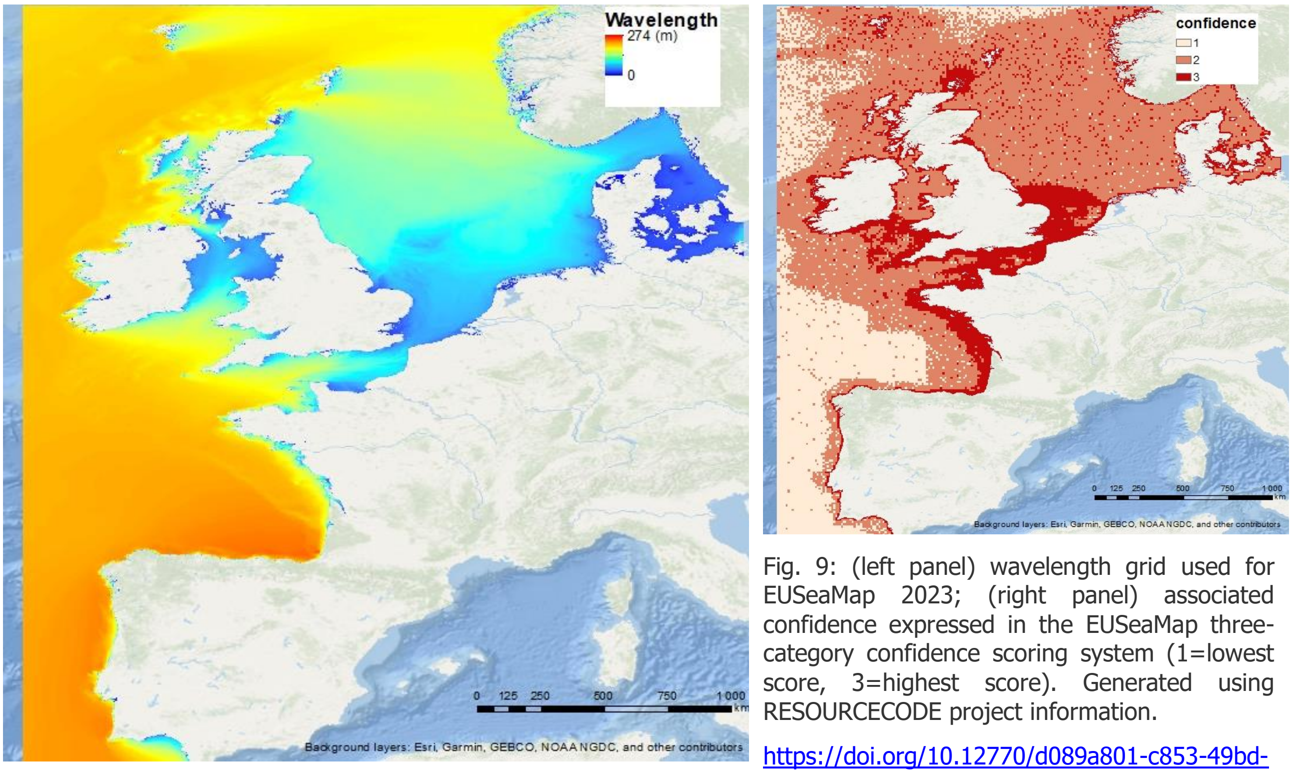


Fig. 9: (left panel) wavelength grid used for EUSeaMap 2023; (right panel) associated confidence expressed in the EUSeaMap three-category confidence scoring system (1=lowest score, 3=highest score). Generated using RESOURCECODE project information.

https://doi.org/10.12770/d089a801-c853-49bd-9064-dde5808ff8d8

2.3.3 Probability that the seafloor is below the halocline in the Baltic Sea

A probability grid of the seafloor being below the halocline is required as input to EUSeaMap to construct the Biological Zone habitat descriptor dataset in the Baltic Sea, specifically for the boundary between the circalittoral and the offshore circalittoral. According to the EUNIS habitat classification, in the Baltic Sea the circalittoral is above the halocline while the offshore circalittoral is below the halocline. The previous version of the grid was developed in 2010 for the very first version of EUSeaMap. For the 2023 version it was decided to update the dataset. Based on the results of runs of the DHI hydrographic model MIKE III (3D baroclinic model for free surface flow), a point dataset was generated describing for each year the probability of a given seabed location in the Baltic Sea being below the halocline. The spatial resolution was 5km, and the temporal coverage was 20 years (2001-2020). From the point dataset a grid representing 20-year probability averages was calculated (Figure 10).

Based on the spatial resolution of the dataset (5km), each grid cell was assigned a confidence value of 2.

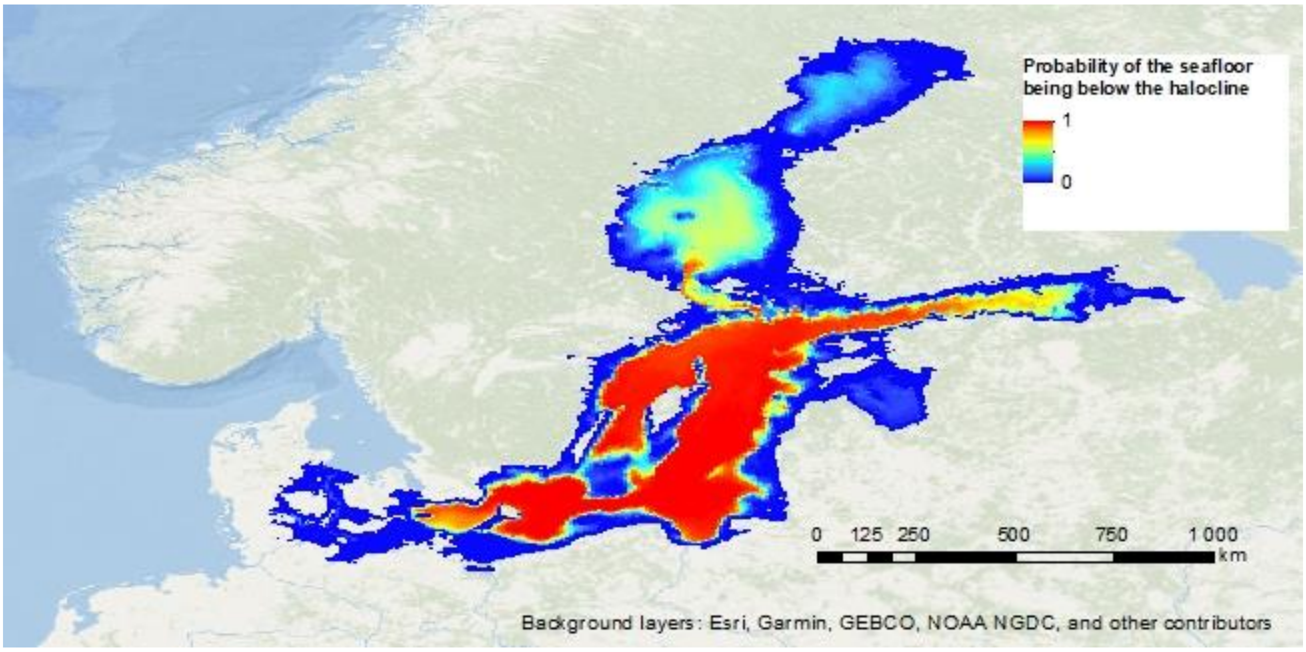


Fig. 10: probability of the seafloor being below the halocline used for EUSeaMap 2023.

2.3.4 Seabed salinity in the Baltic Sea

Seabed salinity is an important input for EUSeaMap in the Baltic Sea, as seabed salinity levels (euhaline, polyhaline, mesohaline, and oligohaline) are a habitat descriptor in this region and determine the variable and the thresholds used to model the biological zones. There had been no update since the first version of EUSeaMap was created in 2010.

To create a new, fresher dataset, data were downloaded from the Copernicus portal. The Copernicus product used was the Baltic Sea Physical Reanalysis[3] (BALTICSEA_MULTIYEAR_ PHY_003_011). Annual mean values of

[3] https://doi.org/10.48670/moi-00013

the variable 'Bottom Salinity' for the period 2017-2021 were downloaded and averaged (Figure 11). Based on the spatial resolution of the dataset (~2km), each grid cell was assigned a confidence value of 2.

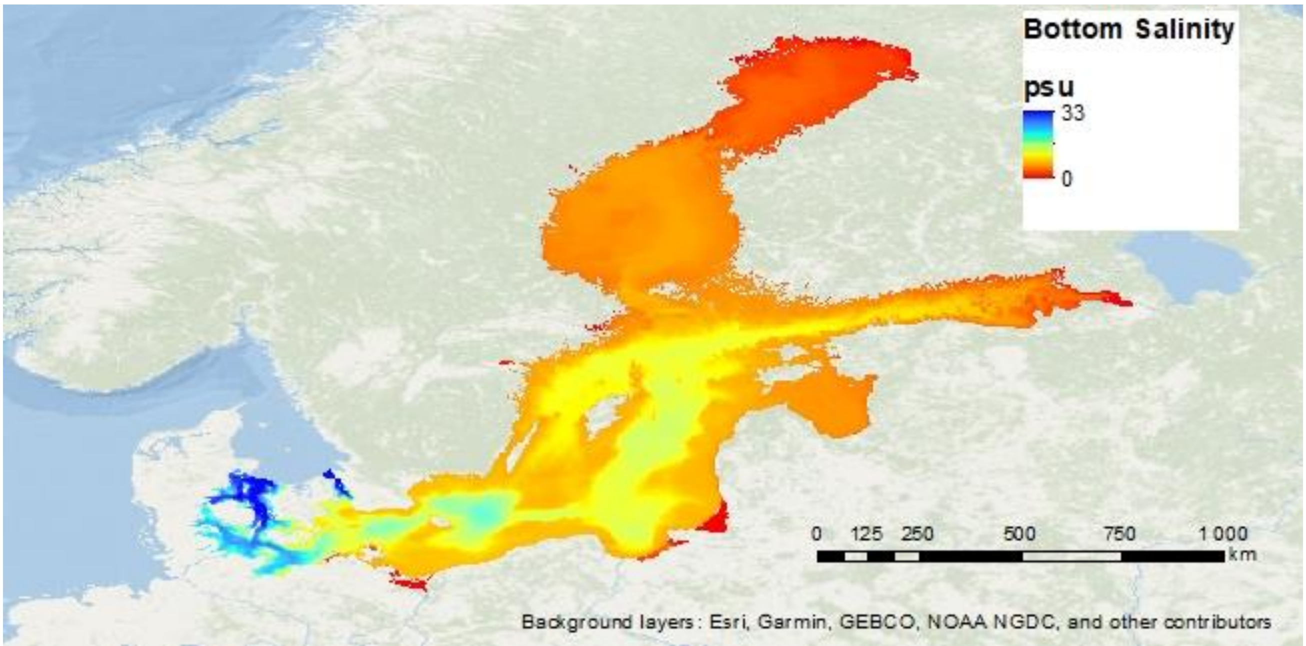


Fig. 11: seabed salinity used for EUSeaMap 2023. Generated using E.U. Copernicus Marine Service Information; https://doi.org/10.48670/moi-00013.

2.4 Seabed Habitat Classifications used

EUSeaMap describes habitats according to European classifications (EUNIS and MSFD broad habitat types) and regional classifications (Helcom Hub in the Baltic and Mediterranean habitat types). In the new areas, the Caribbean Sea and the Caspian Sea, habitats to be included in EUSeaMap were defined, and crosswalks between these habitats and the European classifications were established.

2.4.1 Arctic, Atlantic, Baltic Sea, Mediterranean Sea and Black Sea

Since its launch in 2010, EUSeaMap has been published in various classifications, including the marine part of the EUNIS classification developed and maintained by the European Environment Agency (EEA).The EUNIS classification underwent a major restructuring in 2019, the foundations of which were established in 2016 (Evans et al., 2016), and the detailed part of which was published in March 2020 in the form of an Excel file under the name 'EUNIS marine habitat classification 2019'. In this version, the abiotic levels (i.e. 1 to 3) of EUNIS marine were restructured to improve consistency between marine regions. An update to this version, which mainly concerns the Atlantic Regional Sea, has been available since March 2022. This update (hereafter referred to as "EUNIS 2022") did not change the abiotic levels.

In addition to the previous EUNIS version (2007-2011), EUNIS 202 and the MSFD Broad Benthic Habitat Types, EUSeaMap also includes the regional HELCOM HUB classification (HELCOM, 2013) and the regional revised classification of Mediterranean habitat types (UNEP/MAP, 2019. See decision IG.24/7, annex VI).

2.4.2 Caribbean Sea

The classification used for EUSeaMap 2023 is largely based on that published in June 2022 by the MNHN (French Museum of Natural History) for the island of Martinique (Andres et al., 2022).

In Andres et al. (2022) the infralittoral is home to seagrass beds, algae and shallow coral reefs. In contrast to EUNIS, the circalittoral is not subdivided into circalittoral and offshore circalittoral due to a lack of knowledge on community changes within the circalittoral. The bathyal and the abyssal zones are included, but the authors note that there is a lack of knowledge and data on the communities that occupy these zones. Seabed substrates include rock, sand, muddy sand, mud, coarse substrate, and the biogenic substrate coral reef. Annex 1 shows the crosswalks between the EUSeaMap classification, the Andres et al. (2022) classification, EUNIS 2022, and the MSFD broad habitat types.

2.4.3 Caspian Sea

Defining habitats in the Caspian Sea was challenging. In contrast to the Caribbean, no existing seabed habitat classification based on the same principles as EUNIS was found in the literature. Habitats were defined during two workshops in which Ifremer and GeoEcomar participated. Using the limited data found in the literature, a cluster analysis was carried out to define preliminary communities of species occurring in similar seabed substrate types and environmental conditions. These were then assigned to a EUNIS-like broad habitat type (i.e. a broad habitat type defined by a diptic biological zone/seabed substrate type). In this EUSeaMap classification of broad habitat types, biological zones include infralittoral, circalittoral, offshore circalittoral, bathyal and abyssal (interestingly, despite the shallow nature of the Caspian Sea -maximum depth is 1025m-, the existence of two abyssal plains is widely accepted - e.g. Kosarev, 2005). Seabed substrate types include rock, sand, mud, coarse substrate and mixed sediment. Two mussel species were identified as biogenic substrate builders: *Mytilaster lineatus*, which occurs in the infralittoral, and *Dreissena grimmi*, which occurs in the circalittoral. The preliminary habitat classification is presented in Annex 3. Crosswalks between the EUSeaMap classification, EUNIS 2022, and the MSFD broad habitat types are shown in Annex 2.

2.5 Habitat descriptor class boundaries

In the EUSeaMap methods, the boundaries between two adjacent habitat descriptor classes (e.g. between infralittoral and circalittoral or between high and moderate energy) are mostly defined by thresholds used to classify a continuous grid of a given variable into one habitat descriptor class or its adjacent class (e.g. a threshold value is used to classify a seabed PAR grid as infralittoral or circalittoral). In some cases, the boundaries are defined manually. This is the case, for example, for the bathyal/abyssal boundary, which in EUSeaMap is defined in many regions as a slope change. In this particular case, the boundary is delineated by heads-up digitisation or semi-automatic approaches using grids such as slope and hillshade.

In EUSeaMap 2023, boundaries have been defined in the new regions (Caribbean Sea and Caspian Sea) and some boundaries have been defined or revised in the other regions.

2.5.1 Atlantic – Boundaries updated due to more recent wave data

In the Atlantic, new grid datasets have been used for the wave-induced energy (used to define the boundary between the wave energy levels) and for the wave base ratio (used to define the circalittoral/offshore circalittoral boundary) - see Section 2.3.2. As a result, the boundaries between the wave energy levels (Figure 12) and the circalittoral/offshore circalittoral boundary (Figure 13) have been updated in the area covered by the new grids. The thresholds have been chosen to maintain similar boundaries to the previous version.

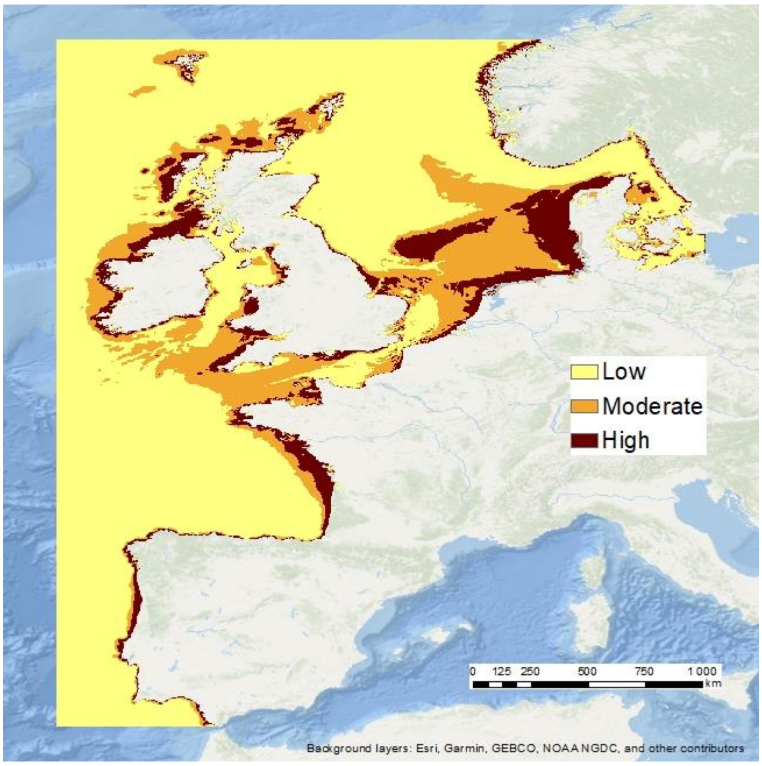


Fig. 12: updated boundaries for the wave energy levels.

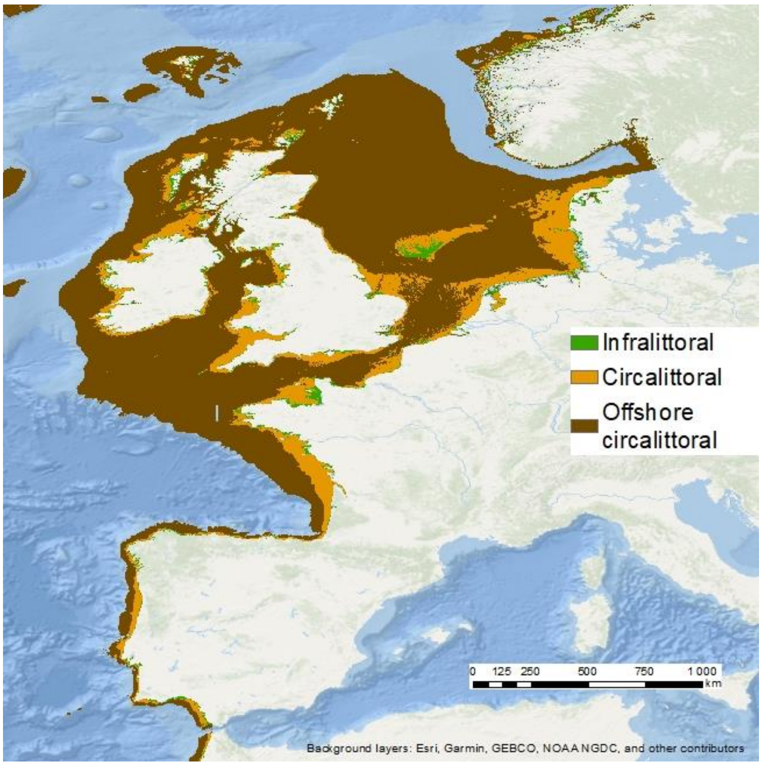
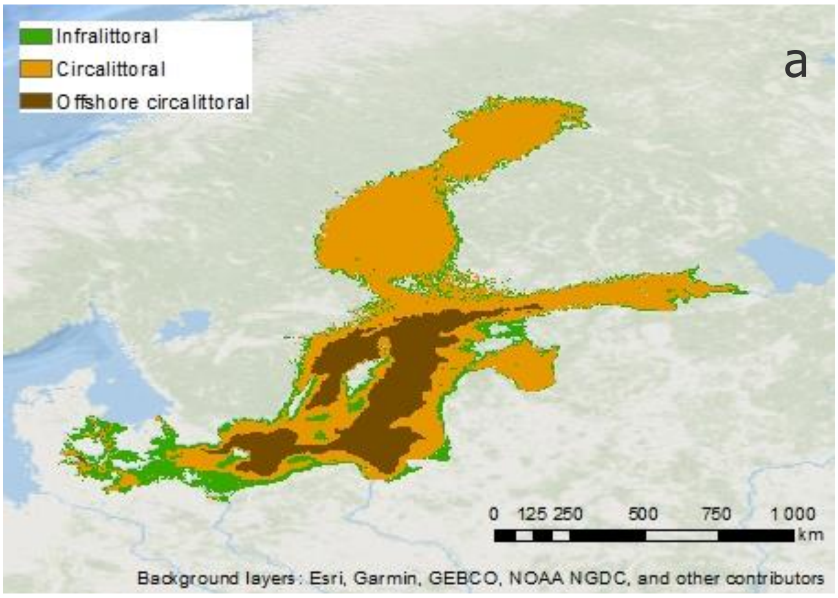


Fig. 13: updated circalittoral/offshore circalittoral boundary.

2.5.2 Baltic Sea – Circalittoral/offshore circalittoral boundary updated due to improved halocline data

In the Baltic Sea the grid dataset on the probability of the seafloor being below the halocline has been updated (see Section 2.3.3). Therefore, the threshold defining the boundary was re-examined. The analysis was carried out using existing benthic fauna biomass data from 2001-2019, corresponding to the temporal coverage of the halocline grid. The data consist of benthic samples collected in the Baltic Sea proper and the Gulf of Finland, from two data sources: samples from the HERTTA database collected by SYKE, and data from the Swedish national database for marine data (SHARKWEB). The occurrence and biomass of the four species *Macoma balthica*, *Monoporeia affinis*, *Pontoporeia femorata* and *Saduria entomon* were used to define the threshold. These species characterise the community above the halocline, according to a recent Baltic Sea scale inventory of benthic faunal communities (Gogina et al. 2016). The results suggested that the optimal probability threshold was 0.95, with a fuzzy interval between 0.9 and 1. The revised boundary is shown in Figure 14.



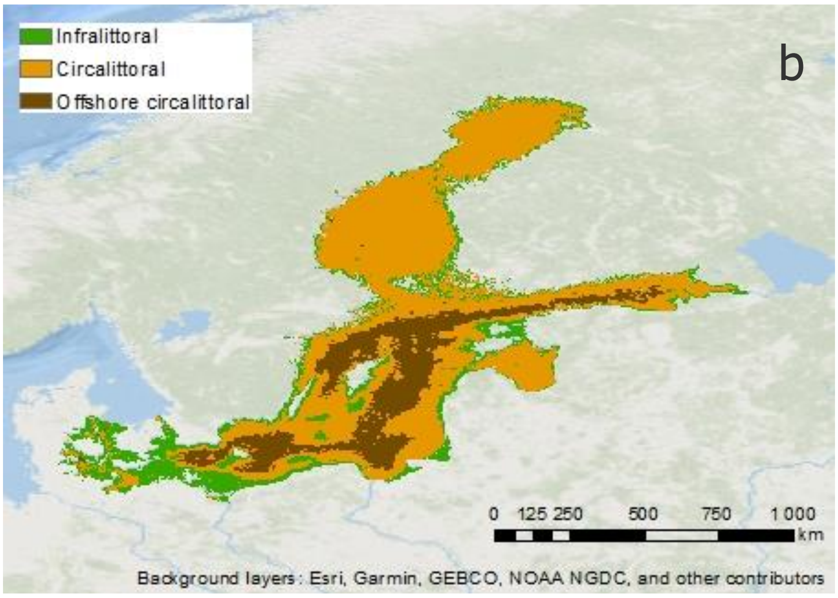


Fig. 14: revised circalittoral/offshore circalittoral boundary (a) versus boundary in previous version (b).

2.5.3 Mediterranean and Black Seas – Subdivision of bathyal into upper and lower bathyal

The subdivision of the bathyal zone into upper and lower bathyal zones was a new feature of EUNIS 2019 for all regions. However, there is no indication of how the boundary is defined in the different regions, in particular which depth threshold should be used.

In the Mediterranean Sea, a literature review was carried out to determine a depth threshold. The draft interpretation manual for marine habitats, initiated by the Regional Activity Centre for Specially Protected Areas (SPA/RAC), and presented at the Fifteenth Meeting of SPA/BD Focal Points in 2021 (UNEP/MAP SPA/RAC, 2021), uses a threshold of 500m to divide the upper and lower bathyal, but no reference is provided to support this value. Similarly, Montefalcone et al. (2021) mention 500m but no references are given. Two older publications (Emig, 1997; Emig and Geistdoerfer, 2004), divide the bathyal zone into several subzones with boundaries corresponding to changes in faunal composition. One of these boundaries is between 470m and 510m depth. Finally, in a paper analysing the study of trawled bottom populations in the Gulf of Genoa (Relini el al., 1986), epi- and meso- bathyal zones were described, the boundary of which is at about 450 m depth, in relation to a change in the fauna detectable by trawling. As a result of the literature review, it was decided to use a threshold of 500m, with a fuzzy interval between 450m and 550m.

In the Black Sea, where the bathyal zone is anoxic, it was not considered relevant to divide the bathyal into upper and lower bathyal. It was therefore decided not to follow EUNIS 2022 and to consider the bathyal as an indivisible whole.

2.5.4 The Arctic/Atlantic boundary

Since the 2019 version, EUNIS includes the Arctic as a new area, but there is no mention of the spatial extent of this marine region. For EUSeaMap 2021, it was decided that the spatial extent used would be based on changes in the dominant fauna based on water mass characteristics rather than administrative considerations. Since 2016, EUSeaMap has included Arctic and Atlantic biological zones in the bathyal and abyssal zone (Populus el al., 2017). It was decided to use these to separate the EUNIS Arctic region from the EUNIS Atlantic region in the bathyal and abyssal. For the sublittoral zones (i.e. infralittoral, circalittoral or offshore circalittoral), a mask was created based on both the polar front as described in Buhl-Mortensen el al. (2020) and the ice cover as described in Vasquez el al. (2019). Within the mask, any sublittoral zone north of the polar front or within the ice cover was referred to as the Arctic, and any sublittoral zone south of the polar front or outside the ice-cover was referred to as the Atlantic. Figure 15 shows the spatial extent of the Arctic and the Atlantic.

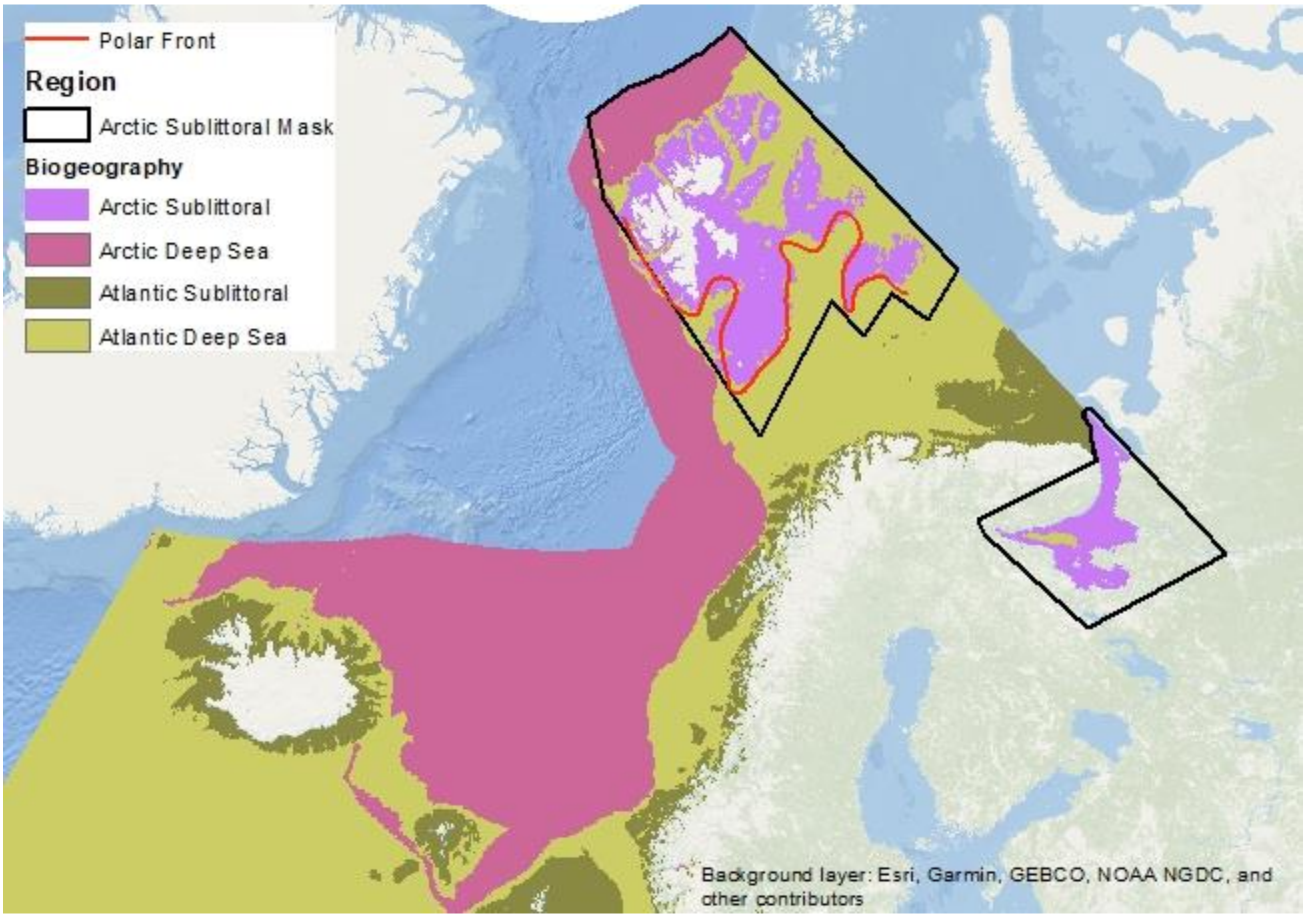


Fig. 15: Arctic waters vs Atlantic waters used for EUSeaMap. In the deep sea, the separation was defined based on Populus el al. (2017). In the sublittoral, the separation was defined based on the polar front (delineation proposed in Buhl-Mortensen el al., 2020) and the ice cover (Vasquez el al., 2019): within a mask (referred to as Arctic Sublittoral Mask in the figure), any sublittoral zone north of the polar front or within the ice cover was referred to as the Arctic, and any sublittoral zone south of the polar front or outside the ice cover was referred to as the Atlantic.

2.5.5 Caribbean Sea

2.5.5.1 Infralittoral/circalittoral boundary

In the Caribbean Sea, the infralittoral is home to seagrass beds, algae and shallow coral reefs. It is generally accepted that shallow coral reefs occur down to 30m and then give way to mesophotic coral ecosystems. However, recent research suggests that most shallow corals, sponges, fish and other species extend into the upper mesophotic zone (Bridge et al., 2013; Laverick et al., 2018), which would then place the boundary between the infralittoral and circalittoral at a depth of 50-60m. To reflect this, a seabed PAR value of 1.8 mol.pho.day^{-1}.m^{-2} was chosen as the threshold for the separation between infralittoral and circalittoral, with a fuzzy interval between 1.4 and 2.2 mol.pho.day^{-1}.m^{-2}. As shown in Figure 16b and 16c, the value of 1.8 mol.pho.day^{-1}.m^{-2} corresponds to the 50 m depth where the water is clear, while in turbid areas there are patches of shallower circalittoral areas.

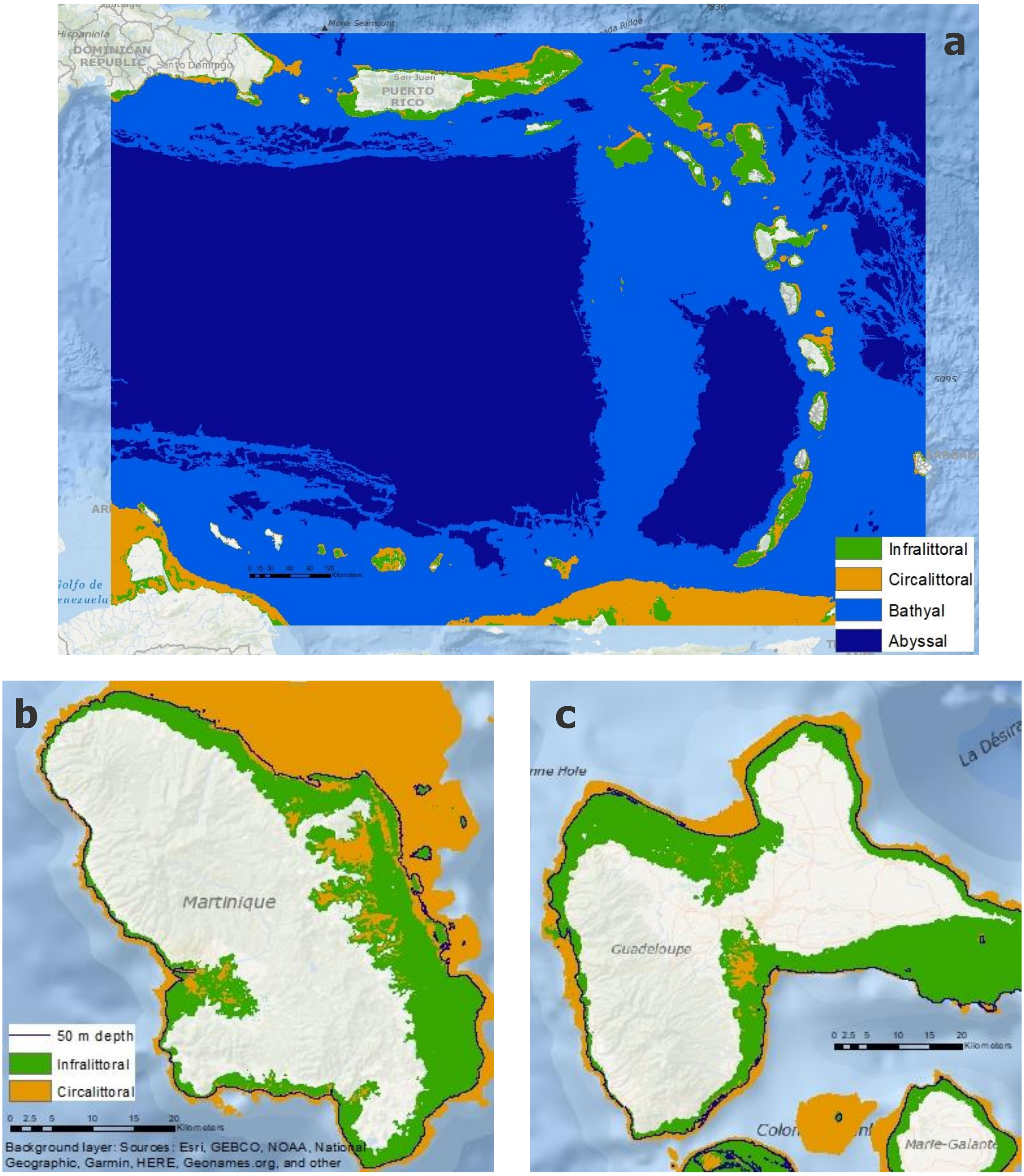


Fig. 16: (a) biological zones in the Caribbean Sea. (b) and (c) examples of the infralittoral/circalittoral in the Caribbean Sea. A seabed PAR threshold of 1.8 mol.pho.day^{-1}.m^{-2} was used to classify into infralittoral or circalittoral. The boundary matches the 50 m depth contour where the water is clear. Where the water is turbid (e.g. in bays), there are patches of circalittoral.

2.5.5.2 Circalittoral/bathyal and bathyal/abyssal boundaries

For the circalittoral/bathyal boundary it was decided to use a threshold of 200m, with a fuzzy interval between 180m and 220m. The bathyal/abyssal boundary was defined by a change in slope, with the bathyal zone having a steep slope and the abyssal zone having a gentle slope. A semi-automatic approach was used to roughly delineate between bathyal and abyssal, where the abyssal was defined as areas with slope < 5% and depth > 2500m. The classification was then fine-tuned manually (Figure 16a).

2.5.6 Caspian Sea

2.5.6.1 Infralittoral/circalittoral boundary

The infralittoral was defined in the Caspian Sea as where macrophytobenthos occur. A threshold of seabed PAR 0.15 mol.pho.day^{-1}.m^{-2} with a fuzzy interval between 0.1 and 0.2 mol.pho.day^{-1}.m^{-2} was identified using historical maps of the spatial distribution of macrophytobenthos in the North Caspian. The seabed PAR value of 0.15 mol.pho.day^{-1}.m^{-2} corresponds to an average depth value of 19.5m across the basin.

2.5.6.2 Circalittoral/ offshore circalittoral boundary

Based on the limited biological data available in the literature it was decided to use a threshold of 50m depth with a fuzzy interval between 40m and 60m to separate the circalittoral from the offshore circalittoral.

2.5.6.3 Offshore circalittoral/bathyal and bathyal/abyssal boundaries

The circalittoral/bathyal and bathyal/abyssal boundaries were defined by changes in slope, with the bathyal zone having a steep slope, while the circalittoral and abyssal zones have a gentle slope. A semi-automatic approach was used to roughly delineate between offshore circalittoral and bathyal, and between bathyal and abyssal. Areas with slope < 3% and depth < 220 m were classified as offshore circalittoral. Areas with slope < ~ 3-5% and depth > ~ 600-800m were classified as abyssal. The classification was then fine-tuned manually (Figure 17).

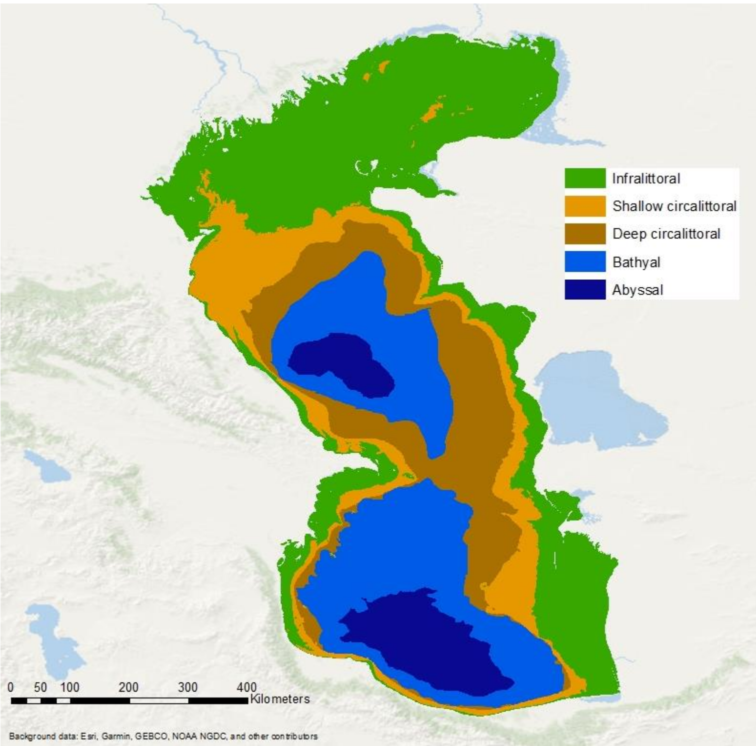


Fig. 17: biological zones in the Caspian Sea.

3 Results

The EUSeaMap product consists of a polygon dataset and a series of confidence raster datasets, where each cell value is the confidence in the EUSeaMap habitat type. The structure of the polygon dataset table is described in Table 4. The polygon dataset attribute table consists of one field per habitat descriptor (biological zone, seabed substrate, energy, etc.) and per habitat classification (i.e. EUNIS 2007-2011, EUNIS 2022, MSFD benthic broad habitat types, regional classifications, etc.). Confidence was assessed using the method developed by the EMODnet Seabed Habitats Consortium and described in Populus el al. (2017). There is one confidence grid dataset for each classification used.

3.1 Attribute table structure

Table 4: attribute table format. Field names are 10 characters or less for compatibility with ESRI Shapefile format

Field Name	Description
Oxygen	Oxygenation level at the seabed. Used in the Black Sea only. Possible values: • Oxic • Suboxic • Anoxic
Salinity	Salinity level at the seabed. Used in the Baltic Sea only. Possible values: • Euhaline • Polyhaline • Mesohaline • Oligohaline
Energy	Combined current-and wave-induced energy at the seabed. Possible values: • High energy • Moderate energy • Low energy
Biozone	Biological zones. Possible values: • Infralittoral • Shallow circalittoral • Deep circalittoral • Bathyal • Abyssal • Atlanto-Mediterranean mid bathyal • Atlantic upper bathyal • Atlantic mid bathyal • Atlantic lower bathyal • Atlantic upper abyssal • Atlantic mid abyssal • Atlantic lower abyssal • Atlanto-Arctic upper bathyal • Arctic mid bathyal • Arctic lower bathyal • Arctic upper abyssal
Substrate	Seabed substrate type. Possible values: • Seabed (when the seabed substrate is not known) • Fine mud

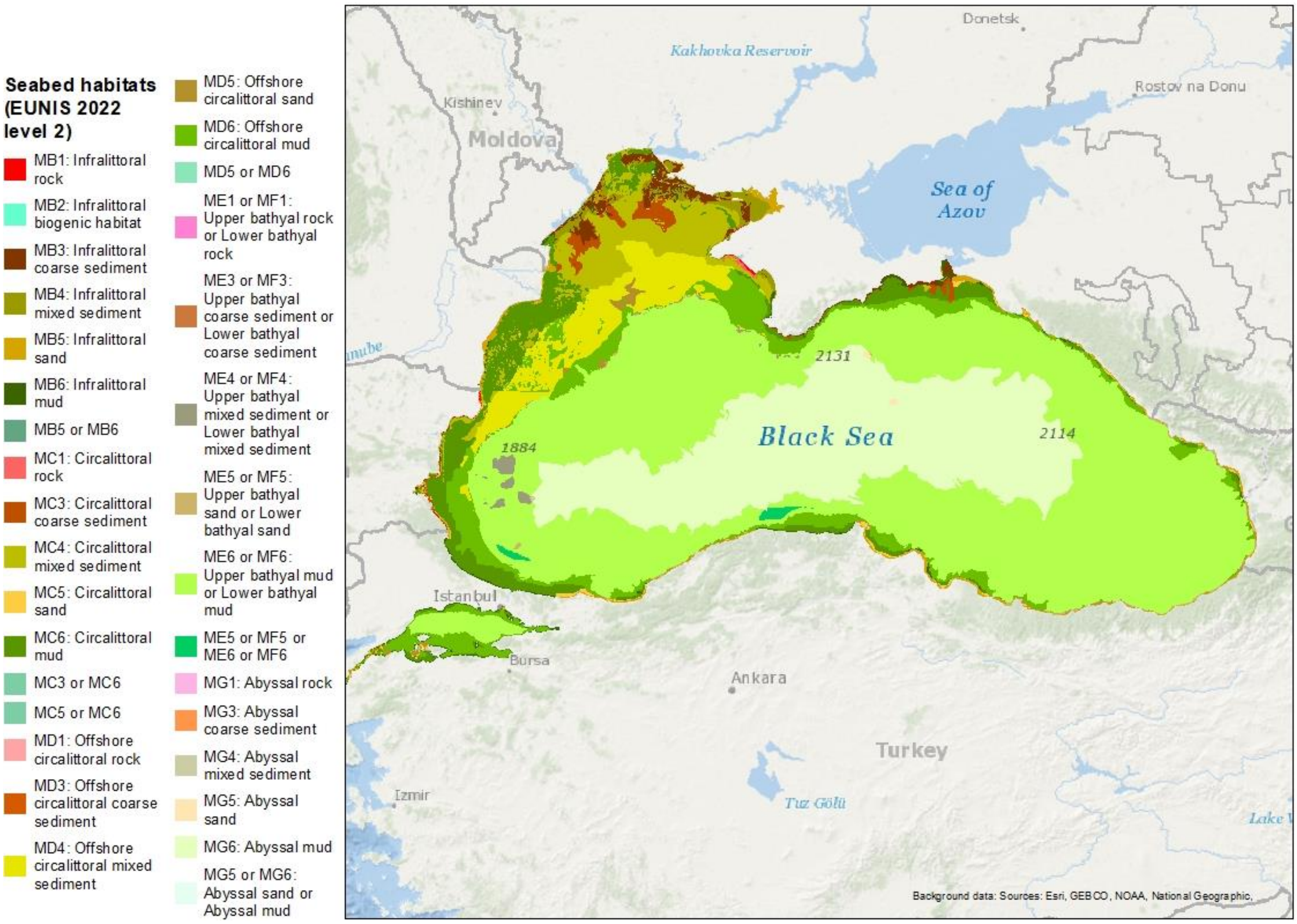
	• Sand • Coarse sediment • Mixed sediment • Sandy mud • Muddy sand • Rock • Sediment • Sandy mud or Muddy sand • Fine mud or sandy mud or muddy sand • Biogenic substrate • Worm reefs • Bivalve reefs • Mussel beds • Cold water coral reefs • Tropical coral reefs • [Posidonia oceanica] meadows • [Posidonia oceanica] "Barrier-reef" • Dead mattes of [Posidonia oceanica] • Coralligenous platforms • Facies with [Vermetus] spp. of the infralittoral algae biocenosis • Facies with [Ficopomatus enigmaticus] of the euryhaline and/or eurythermal lagoon biocenosis • [Sabellaria alveolata] reefs • [Sabellaria spinulosa] reefs • [Serpula vermicularis] reefs • [Limaria hians] beds • [Ostrea edulis] beds • [Mytilus edulis] beds • [Modiolus modiolus] beds • dominated by zebra mussel • dominated by valve snails • [Hiatella arctica] beds • [Lophelia pertusa] reefs • [Solenosmilia variabilis] reefs • dominated by [Dreissena grimmi] and corophiids • dominated by [Mytilaster lineatus] and [Amphibalanus improvises] • Shell gravel • Peat bottoms • Biogenic detritic bottoms
EUNIScomb	Habitat description using EUNIS 2007-2011 code (e.g. 'A5.35'). Na where EUNIS 2007-2011 is not applicable.
EUNIScombD	EUNIS 2007-2011 full description (e.g. 'A5.35: Circalittoral sandy mud'). Na where EUNIS 2007-2011 is not applicable.
Allcomb	Habitat description using EUNIS 2007-2011 code (e.g. 'A5.35') where EUNIS 2007-2011 is applicable, or other unpublished classification where 2007-2011 is not applicable.
AllcombD	Habitat description using EUNIS 2007-2011 full description (e.g. A5.35: Circalittoral sandy mud) where EUNIS 2007-2011 is applicable. Description using other unpublished classification (e.g. 'Low energy infralittoral seabed') where 2007-2011 is not applicable.
SalcombD	Used in the Baltic Sea only. Habitat description using an unpublished habitat classification that describes salinity level (e.g. 'Deep circalittoral mixed sediments in Oligohaline').
MSFD_BBHT	Habitat description using the MSFD Benthic Broad Habitat types (as defined in COMMISSION DECISION (EU) 2017/848). Na where the classification is not applicable.

EUNIS2019C	Habitat description using EUNIS 2022 code (e.g. 'MB23'). Na where EUNIS 2022 is not applicable.
EUNIS2019D	Habitat description using EUNIS 2022 full description (e.g. 'MB23: Baltic infralittoral biogenic habitat'). Na where EUNIS 2022 is not applicable.
All2019D	Habitat description using EUNIS 2022 full description (e.g. 'MB23: Baltic infralittoral biogenic habitat') where EUNIS 2022 is applicable, or other unpublished classification (e.g. 'Baltic infralittoral seabed') where EUNIS 2022 is not applicable.
All2019DL2	Habitat description using EUNIS 2022 description at level 2 (e.g. 'MB5: Infralittoral sand'), or other unpublished classification (e.g. 'Infralittoral seabed') where EUNIS 2022 is not applicable.
RegionalD	Habitat description using a published regional classification. Used in the Baltic (HELCOM HUB classification) and the Mediterranean Sea (revised classification of Mediterranean habitat types). Na when the classification is not applicable.
Val_comm	Comment.

3.2 Example of maps

For consistency between marine regions, the maps presented in Figures 18 to 22 are classified according to the EUNIS 2022 Level 2 classification. It should be noted that EUSeaMap is also classified according to EUNIS 2022 Level 3 (or more detailed levels where applicable), EUNIS 2007-2011, the MSFD benthic broad habitat types, the HELCOM HUB classification in the Baltic Sea and the recently revised habitat classification in the Mediterranean Sea. In the Black Sea, EUNIS 2007-2011 is not used (due to inapplicability) but is classified according to an EUSeaMap classification (Populus et al., 2017, and for a revised version Vasquez et al., 2020). In the Caspian Sea and the Caribbean Sea, habitats are classified according to an EUSeaMap classification (see section 2.4) and translated into MSFD BBHT and EUNIS 2022 Level 2. The classification used in Figures 23 (Caribbean Sea) and 24 (Caspian Sea) is the EUSeaMap classification.

3.2.1 Black Sea



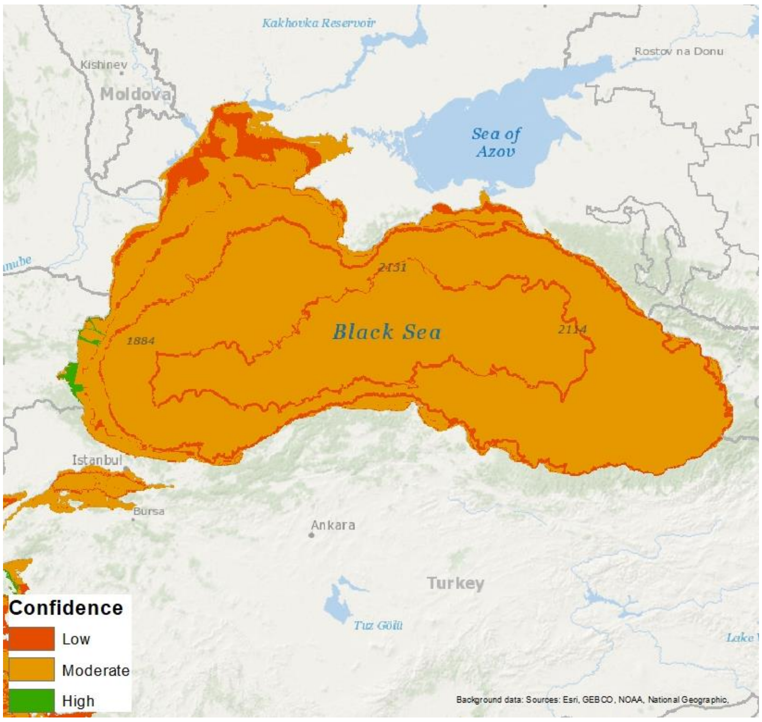
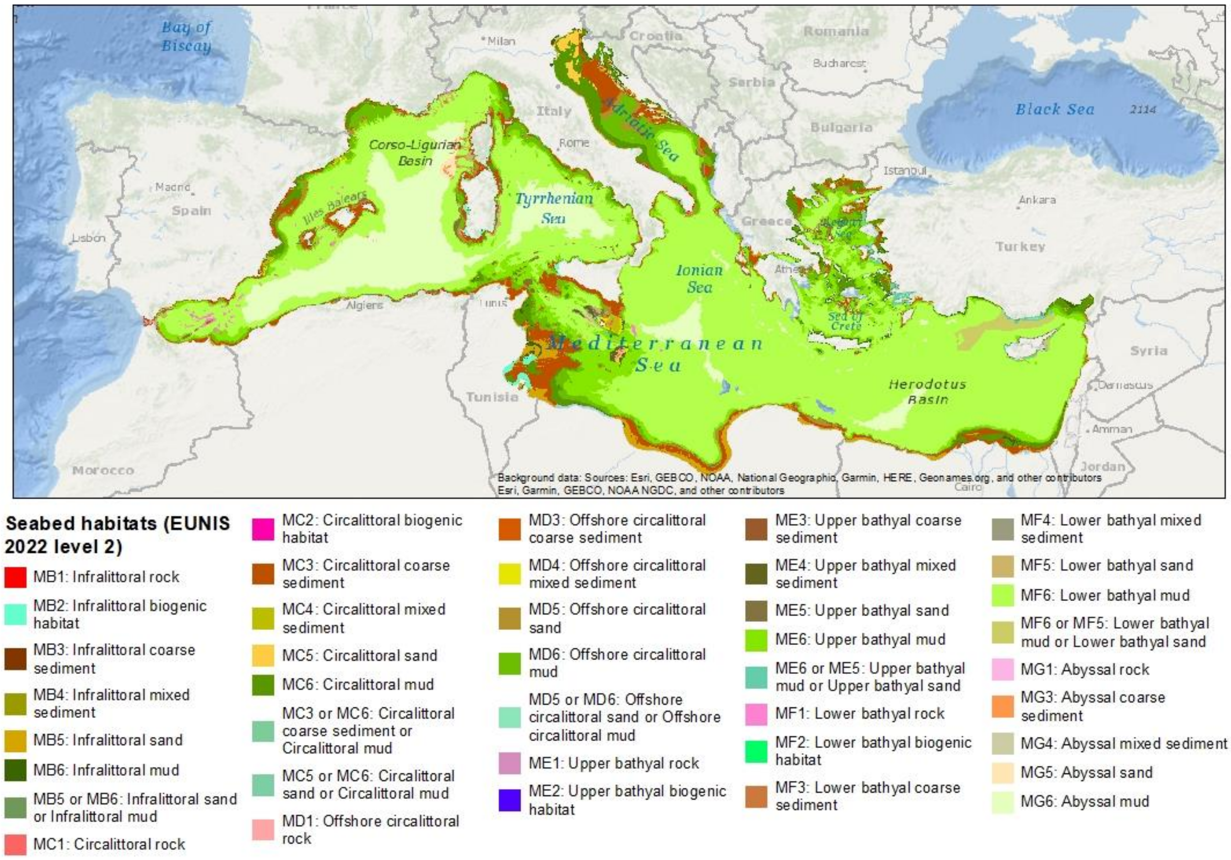


Figure 18: Black Sea - Habitat map in EUNIS 2022 (level 2) and associated confidence map. The statement 'or' is used (e.g. 'MC5 or MC6') when classes cannot be distinguished due to undifferentiated seabed substrate (e.g. polygons with seabed substrate 'fine mud or sandy mud or muddy sand') and/or undifferentiated biological zone (e.g. polygons with biological zone 'upper bathyal or lower bathyal'). It is noteworthy that in EUNIS 2022 the Marmara Sea habitats, which are known to be similar to Mediterranean habitats, are included in the Black Sea.

3.2.2 Mediterranean Sea



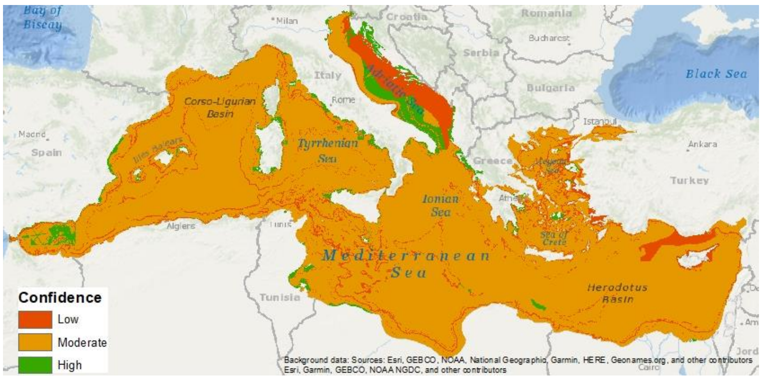
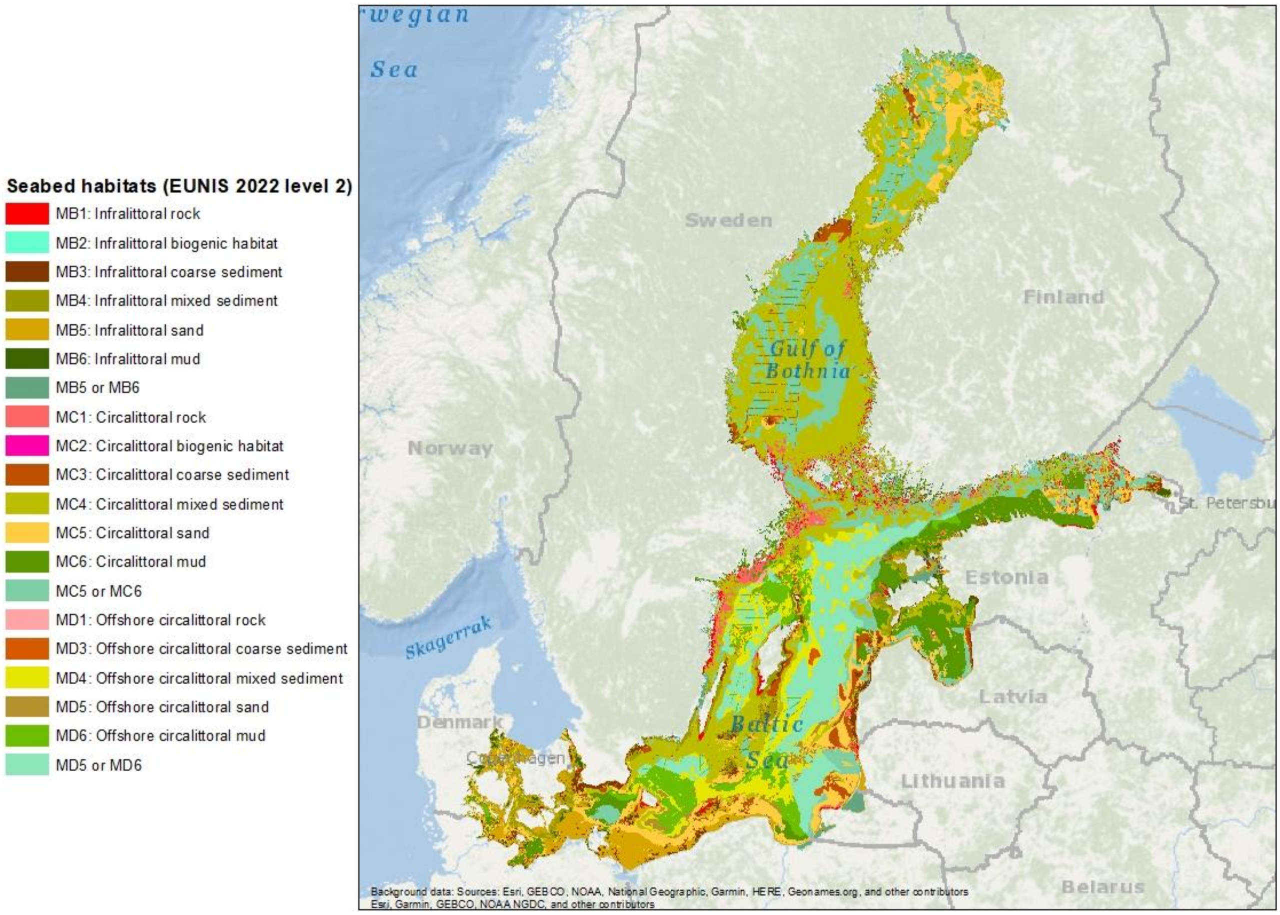


Figure 19: Mediterranean Sea - Habitat map in EUNIS 2022 (level 2) and associated confidence map. The statement 'or' is used (e.g. 'MC5 or MC6') when classes cannot be distinguished due to undifferentiated seabed substrate (e.g. polygons with seabed substrate 'fine mud or sandy mud or muddy sand').

3.2.3 Baltic Sea



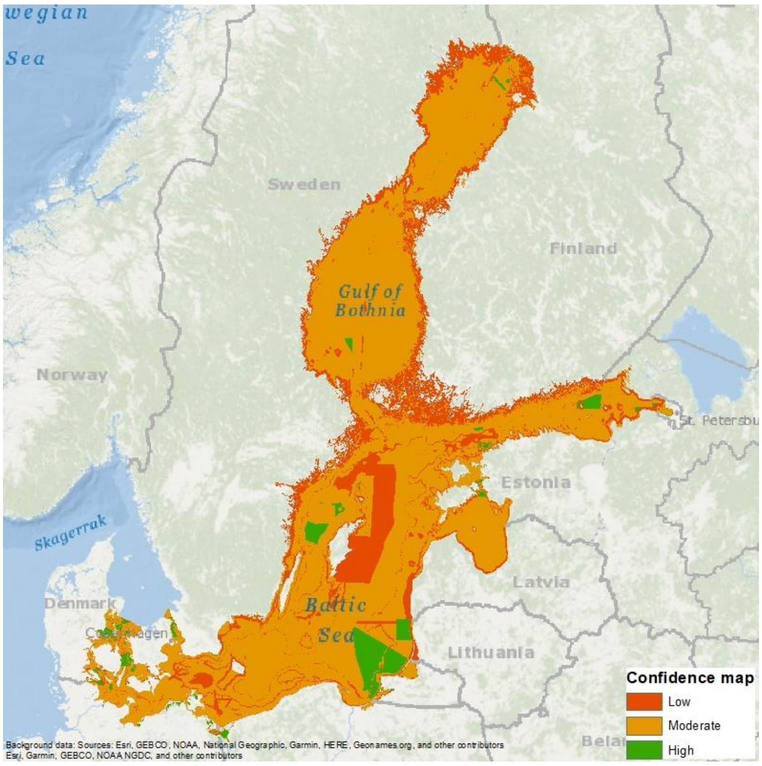
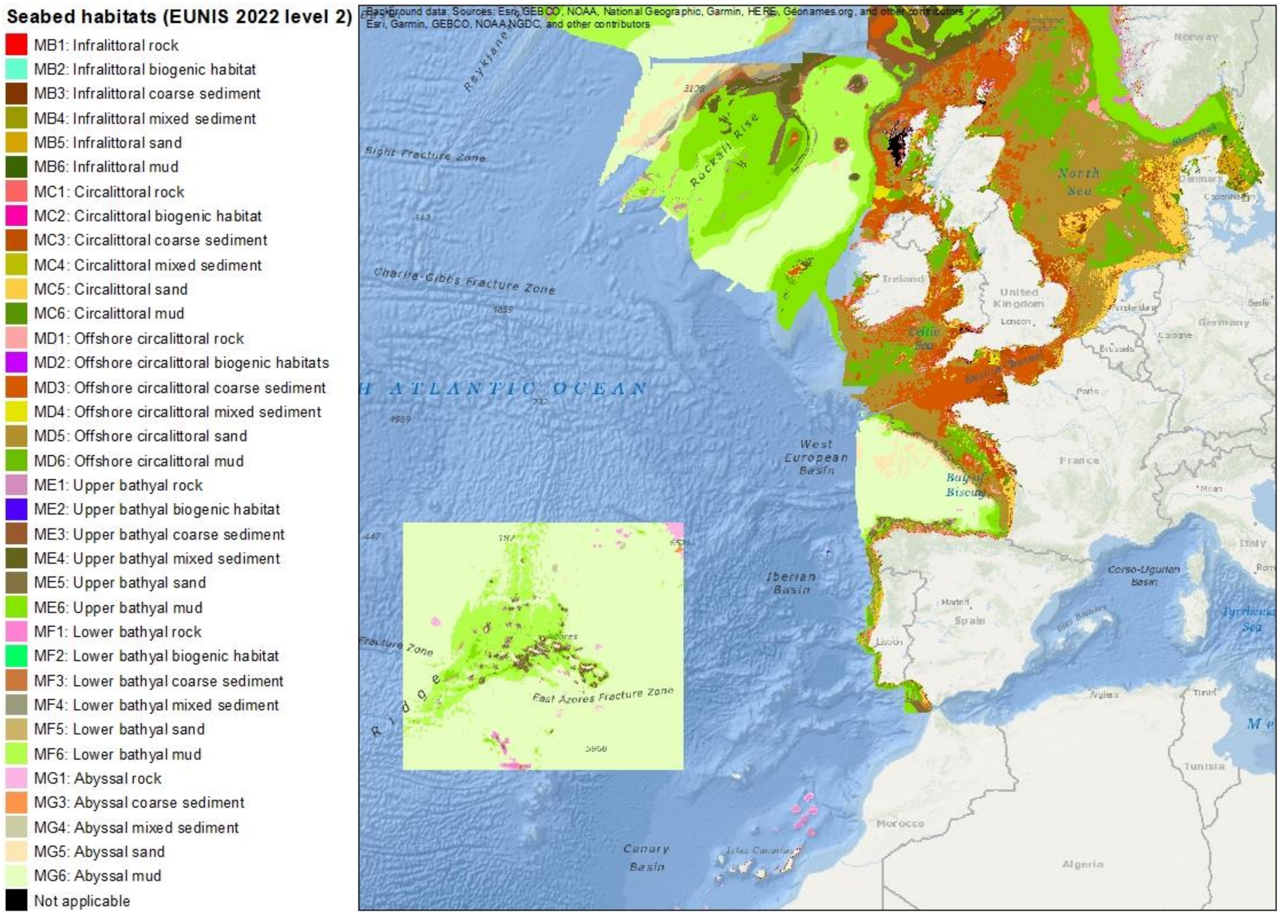


Figure 20: Baltic Sea - Habitat map in EUNIS 2022 (level 2) and associated confidence map. The statement 'or' is used (e.g. 'MC5 or MC6') when classes cannot be distinguished due to undifferentiated seabed substrate (e.g. polygons with seabed substrate 'fine mud or sandy mud or muddy sand').

3.2.4 Northeast Atlantic, including Arctic



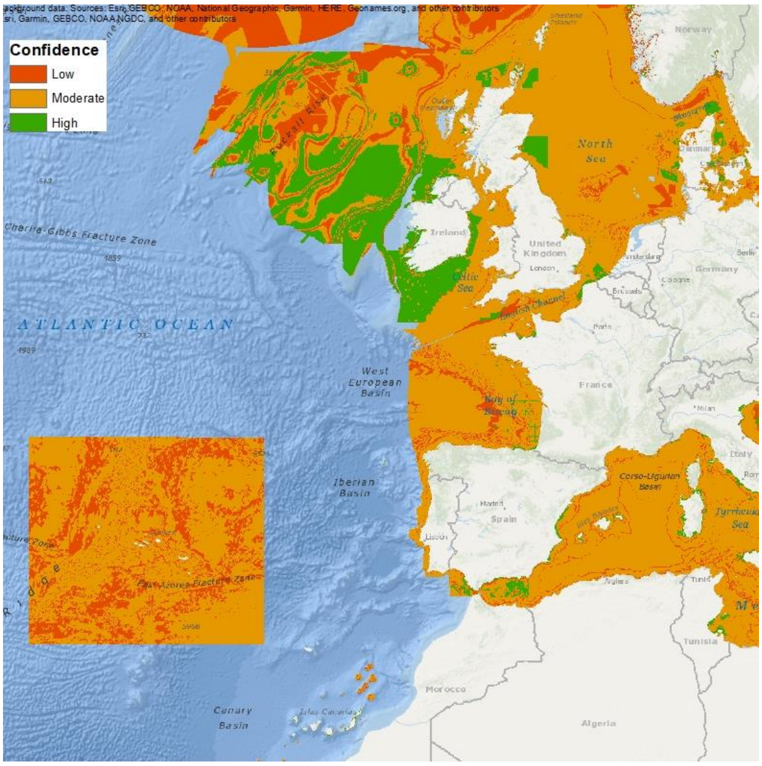
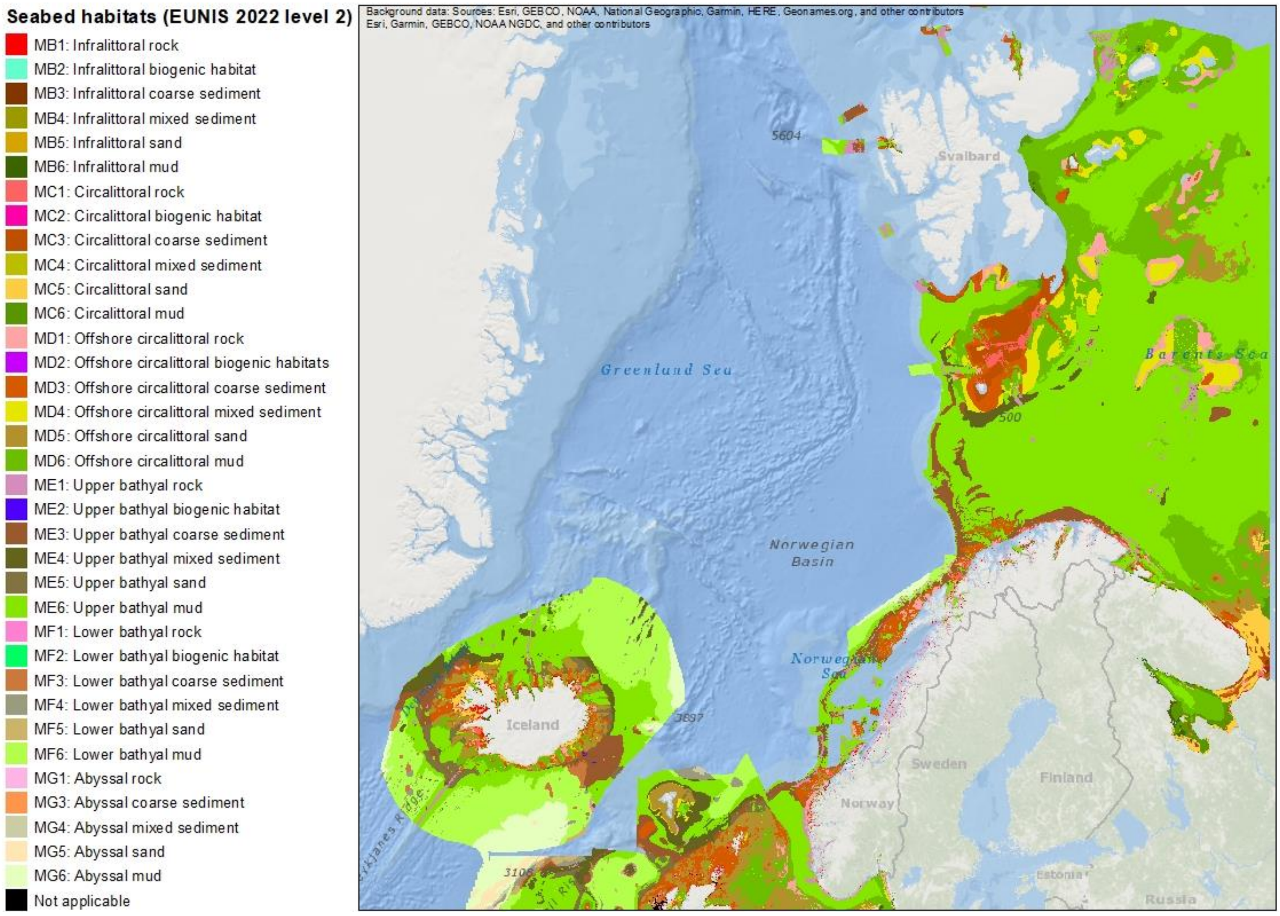


Figure 21: Macaronesia, Iberian Peninsula, Bay of Biscay, Channel Sea, Celtic seas, Greater North Sea and Kattegat - Habitat map in EUNIS 2022 (level 2) and associated confidence map.



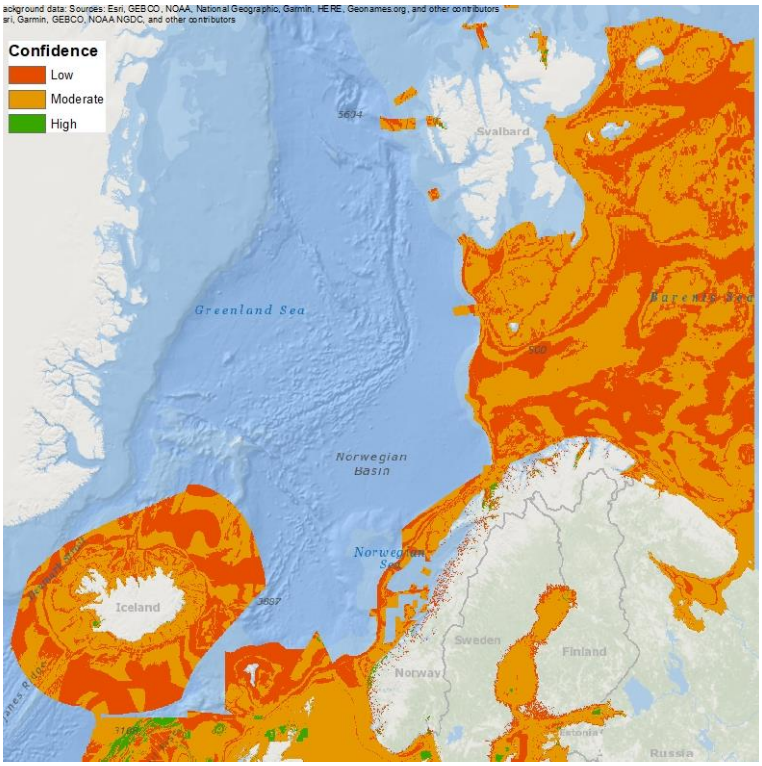
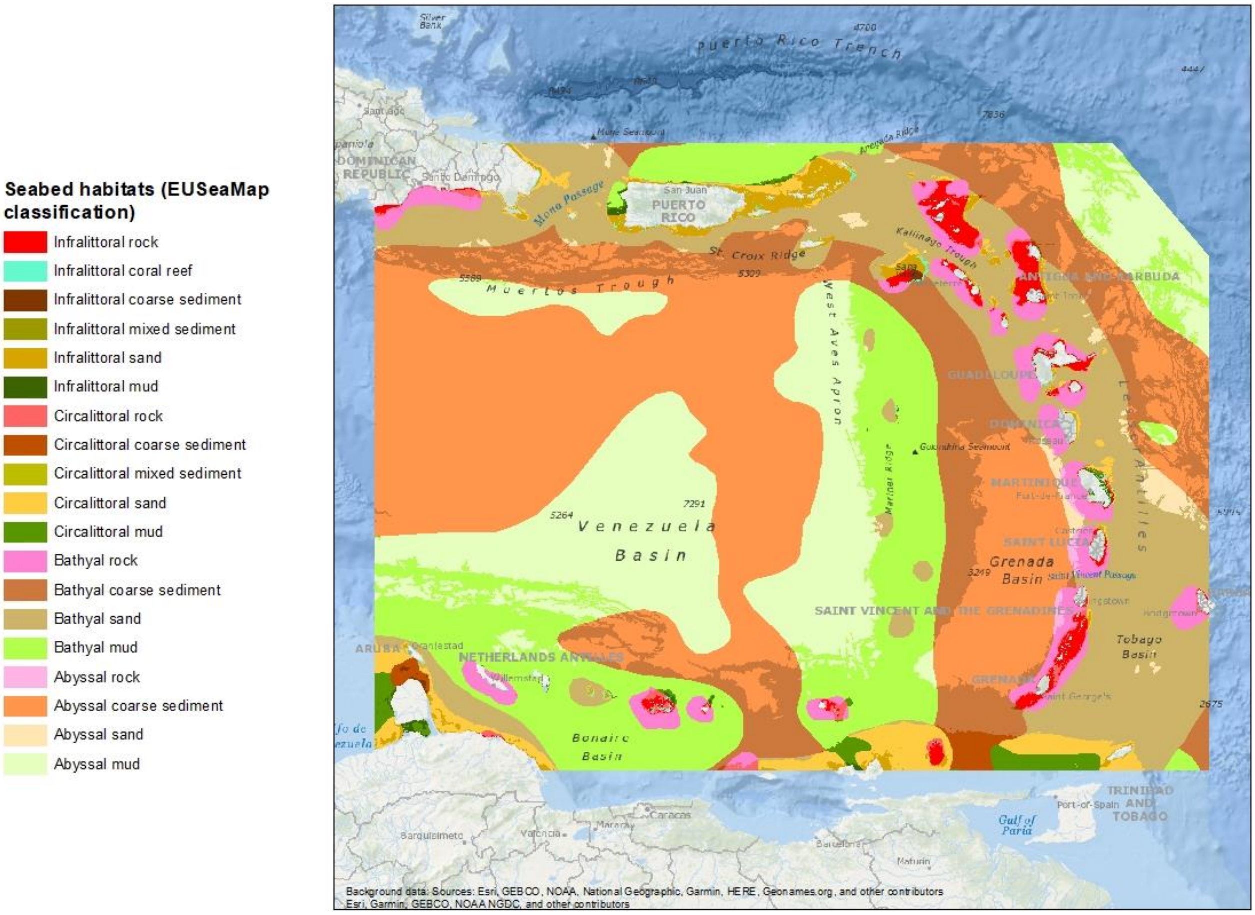


Figure 22: Iceland Sea, Norwegian Sea, Barents Sea and White Sea - Habitat map in EUNIS 2022 (level 2) and associated confidence map. The gap north of Norway, not present in EUSeaMap 2021, is due to polygons removed in the 2023 version of the EMODnet Geogoly Seabed Substrate data product (see section 2.2.3).

3.2.5 Caribbean Sea



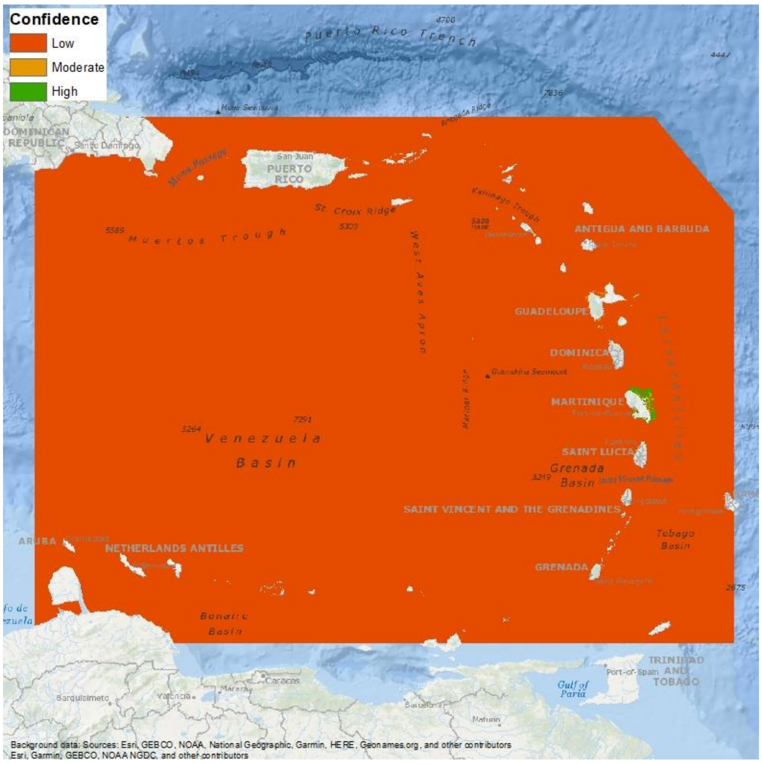
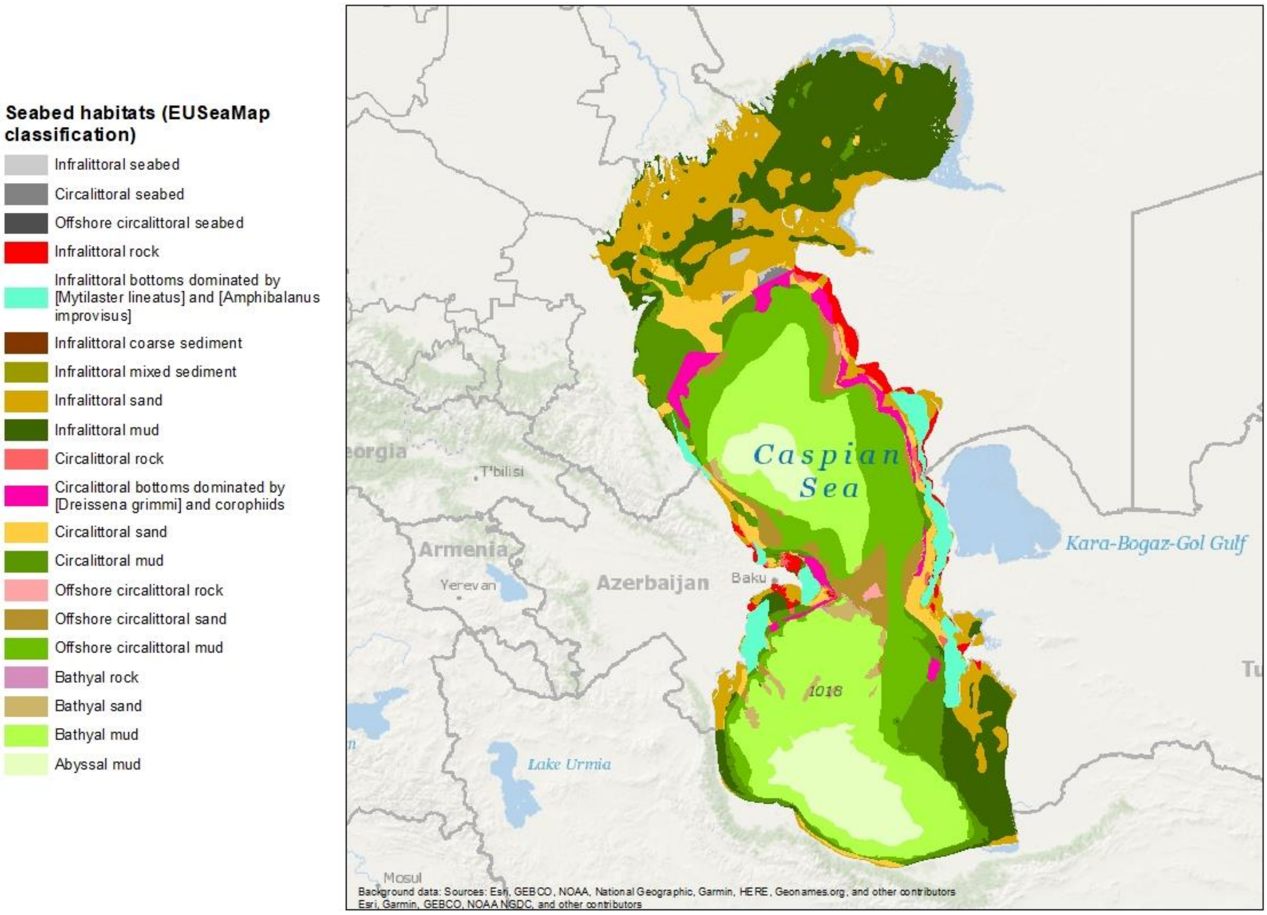


Figure 23: Caribbean Sea - Habitat map in the EUSeaMap classification and associated confidence map. The gap in the upper right corner is due to the fact that the EMODnet Geogoly Seabed Substrate data product does not cover this area (see figure 5).

3.2.6 Caspian Sea



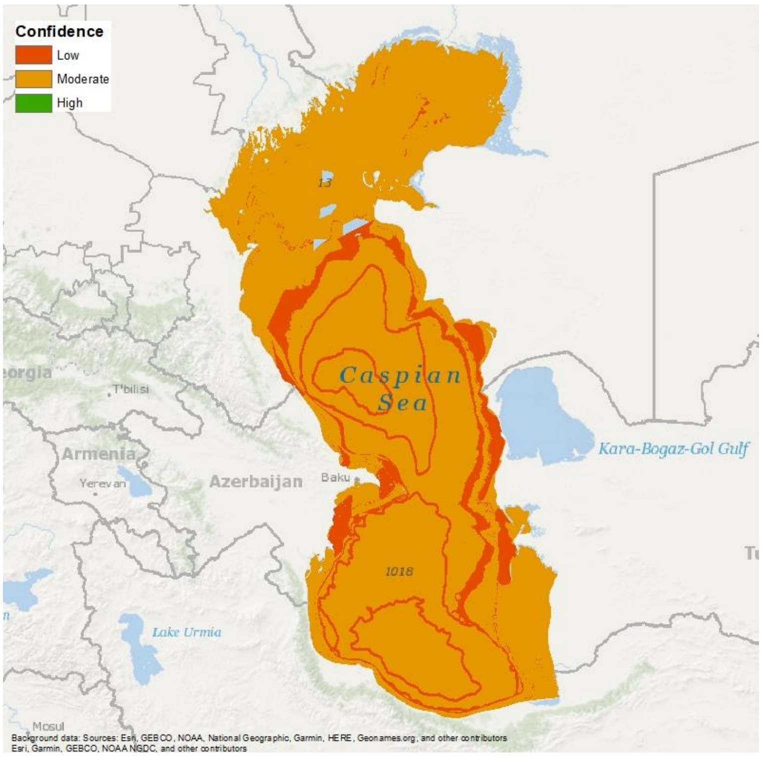


Figure 24: Caspian Sea - Habitat map in the EUSeaMap classification and associated confidence map.

4 Conclusion, perspectives, and recommendations to the EU

EUSeaMap 2023 is a major update, with new regions included and significant updates to regions already covered. The extension of the map to the Caribbean and the Caspian Sea was challenging for several reasons, as discussed below. However, using the available data and knowledge, the project was able to develop a data product that provides, for the first time in these regions, a full-coverage picture of the benthic broad habitat types. In other regions, EUSeaMap has been significantly improved in terms of seabed substrate and, thanks to the integration of new bathymetry and other physical variables, in terms of biological zone.

New regions covered

One component requiring improvement in the Caribbean is the seabed substrate. Currently, the EMODnet Geology Caribbean Seabed Substrate data product is based on fine-scale data for Martinique island and a large-scale data source elsewhere. During the current phase, EMODnet Seabed Habitats has sourced a number of fine-scale seabed habitat datasets in the region, which often include substrate information. It would be beneficial for the EMODnet Geology group to assess these existing datasets to determine if relevant data might be included in the next seabed substrate update. In the Caspian Sea, one component requiring improvement is the bathymetry, which for this first version was based solely on GEBCO. It would be desirable for the next update, as for the other regions, to be provided by a DTM developed by EMODnet Bathymetry.

The classification of seabed habitats was an issue in both regions. In the Caspian Sea, the project started from scratch with no local expertise due to the geopolitical situation and lack of publicly available data. In the Caribbean, the classification used for this first version of EUSeaMap is based on an existing classification developed for the island of Martinique. The existence of this classification, based on the same principles as EUNIS but tailored to the region of focus, has been of inestimable value. However, it is focused on Martinique and therefore does not represent the diversity of communities that occupy the Caribbean Sea (e.g. mesophotic coral ecosystems). A standardised EUNIS-like classification system for all Caribbean benthic habitats would certainly be beneficial to EUSeaMap. Such a classification doesn't exist, and it is currently unlikely that a Caribbean initiative will emerge to develop one. One of the main habitat descriptors used in EUNIS, the biological zones, is a concept developed and well used in Europe but not used elsewhere, including in the Caribbean countries. Therefore, although it is not the role of EMODnet Seabed Habitats to develop seabed habitat classifications, it is likely that the project will need to take the lead in further improving the classification used for this first version of EUSeaMap in the Caribbean. If the longer-term goal of EMODnet is to produce a more comprehensive map that is meaningful for the entire region, we would recommend that the EU consider the creation of a EUNIS regional working group that would include experts from the EU Overseas Countries and Territories, the UK Overseas Territories, existing holders or users of seabed habitat data (e.g. NOAA) and CARICOM (Caribbean Community). This would increase the chances that a standardised system such as EUNIS would be widely adopted by stakeholders in the region.

EUSeaMap update frequency

Since 2017, EUSeaMap has been updated every two years at the request of the Contracting Parties, and next update will be in two years. We recommend reducing the update frequency, which should have no impact on users. An update frequency modelled on the update frequency of the MSFD assessments, i.e. every 6 years, would be more appropriate. This would allow EMODnet Seabed Habitats to devote more effort to methodologies and the production of improved inputs to EUSeaMap.

Issues with the EUNIS classification

In Europe, the transformation of the EUNIS classification in 2019 led to standardised naming across regions of broad habitat types (i.e. those described at hierarchical levels 1-3 of the classification scheme), which was widely welcomed and seen as a significant improvement. However, the classification scheme still has major issues.

A recent user feedback from the MSFD TG Seabed illustrates one of the main issues, which is the lack of specific, quantitative definitions of the broad seabed habitat types. As part of their MSFD assessments, some users noticed significant discrepancies in the German North Sea between EUSeaMap and German local habitat maps with respect to sediment characterisation. In many places EUSeaMap exhibited muddy habitats while the local maps exhibited sandy habitats. Both maps however used the same sediment maps as source, which were all originally classified in the same sediment classification scheme, namely Folk (1954), which uses metrics of sand:mud ratio and proportion of gravels to classify into the various sediment types, including 'mud', 'sandy mud', 'muddy sand', 'sand', etc. In reality, this region contains high proportions of what the Folk classification calls 'sandy mud', which is a class that has been variously interpreted by habitat mappers over the years when deriving a habitat type from sediment information.

In this example, the German local maps placed the boundary between EUNIS mud and sand categories at the sand:mud ratio of 4:1 (i.e. 80% sand) while EUSeaMap 2021 uses a ratio of 9:1 (i.e. 90% sand). This adds to other examples of inconsistent sediment categorisations in the habitat mapping initiatives over the past 20 years. For example, the boundary between EUNIS sand and mud categories was placed by Connor el al. (2006) (UKSeaMap) and Cameron and Askew (2011) (EUSeaMap 2010) at ratio 4:1, while James el al. (2010) and Tappin el al. (2011) (local UK-based studies) placed it at 6:1 (approx. 85% sand). For the version 2016 of EUSeaMap (Populus el al., 2017), a further analysis in northwest Europe concluded that there is no clear evidence for a hard, ecologically-relevant boundary between sand and mud, whether it be at ratio 7:1 (i.e. 87.5% sand) or 9:1. From a practical point of view, it was decided to place it at 9:1 for EUSeaMap, seeing as though it aligned with an existing Folk boundary - the classification in the sediment map used as a source for EUSeaMap and used universally in sediment mapping.

The last published manual for the EUNIS classification was released in 2004 (Davies el al., 2004). We have been informed that the manual to accompany the latest version of EUNIS is still not close to publication. As a result, the new version of EUNIS is little more than a set of terms, each with a brief description, without any quantitative definition. The 2004 guidance itself is also not helpful in resolving the matter as it refers to a ratio of 30% mud, 70% sand – a boundary that predates all the European scale broad-scale mapping studies and that is not currently used.

Commission Decision (EU) 2017/848 (laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment) lists the habitat types that Member States must refer to for the purposes of the MSFD – the Benthic Broad Habitat Types. This list does not include definitions but appears to assume that the (new version of) EUNIS classification scheme would include standard consistent definitions that reflect the standard, consistent terminology.

Further discrepancies between maps are likely to occur until EUNIS sediment types are clearly defined in terms of Folk classification metrics. But this is just an example. There are other compartments of the EUNIS classification that are not defined, or their definition is so unspecific that it may lead to confusion or misinterpretation. Considering how fundamental it is to MSFD implementation, precise definitions of broad habitat types are imperative for all Europe.

Therefore, we would recommend that the EU considers the creation of EUNIS regional working groups, the terms of reference of which would be to 1) define precisely the broad habitat types in all marine regions, and 2) review and update the EUNIS classification at biotope levels, i.e. levels 4-6. This would be needed in all regions, but more particularly in the Black Sea, where there is no consensus. There are also substantial gaps in the Arctic section, which currently only comprises these biotopes from the Atlantic section that are acknowledged to occur in the Arctic. This could lead to consistency within regions at least, if not between regions. These should be accompanied by a timely update mechanism for all changes to be published by the European Environment Agency.

5 Data access

EUSeaMap 2023 can be viewed and downloaded from the EMODnet portal.

Table 5 lists the EMODnet metadata records in the EMODnet Data Product Catalogue. The metadata pages contain the download links, WMF/WFS links and the link to the viewer.

Table 5: links to EUSeaMap metadata records in the EMODnet data product catalogue

Region	Link to the EMODnet catalog
Continental Europe, Macaronesia, Iceland and Arctic	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/0a1cb988-22de-48b2-8cda-d90947ef77d1
Caribbean Sea	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/f6c4606d-049c-4bf0-b26b-61cb7499c030
Caspian Sea	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/e6078619-6c5b-48c2-8892-30fd34ad840a

6 Tools

In 2021, EMODnet Seabed Habitat developed an EUSeaMap GIS workflow that is repeatable and transferable across marine regions (Vasquez, 2021) and implemented this workflow in tools mainly based on R software. The scripts have been updated to use the terra package instead of the raster package. The R scripts are available on GitHub. (https://github.com/emodnetseabedhabitats/EUSeaMap_creation).

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8 References

Accensi, M., Alday Gonzalez, M.F., Maisondieu, C., 2022. RESOURCECODE - Resource Characterization to Reduce the Cost of Energy through Coordinated Data Enterprise. Database user manual. WP3| Database development. https://doi.org/10.13155/86306

Andres S., Ferry R., Gaudillat V., Dirberg G., 2022. Typologie des habitats benthiques de la Martinique. Patrinat (OFB-CNRS MNHN). 207 pp. https://inpn.mnhn.fr/docs-web/docs/download/408199

Bridge, T., Hughes, T., Guinotte, J. et al. Call to protect all coral reefs. Nature Clim Change 3, 528–530 (2013). https://doi.org/10.1038/nclimate1879

Buhl-Mortensen, P., Dolan, M.F.J., Ross, R.E., Gonzalez-Mirelis, G., Buhl-Mortensen, L., Bjarnadóttir, L.R., Albretsen, J., 2020. Classification and Mapping of Benthic Biotopes in Arctic and Sub-Arctic Norwegian Waters. Frontiers in Marine Science 7.

Cameron, A. and Askew, N. (eds.), 2011. EUSeaMap - Preparatory Action for development and assessment of a European broad-scale seabed habitat map final report. https://www.emodnet-seabedhabitats.eu/media/1593/20110228_finalreport_euseamap_v28.pdf

Coltman, N., Golding, N., Verling, E., 2008. Developing a broadscale predictive EUNIS habitat map for the MESH study area. 16 pp. Available online at http://www.searchmesh.net/pdf/MESH%20EUNIS%20model.pdf

Connor, D. W., Gilliland, P. M., Golding, N., Robinson, P.,Todd, D., and Verloing, E., 2006. UKSeaMap: the mapping of seabed and water column features of UK seas. Joint Nature Conservation Committee, Peterborough.

Davies, C., Moss, D. and Hill, M. (2004). EUNIS Habitat Classification Revised 2004. Report to European Environment Agency, October 2004.

Emig, C.C., and Geistdoerfer, P., 2004. The Mediterranean deep-sea fauna: historical evolution, bathymetric variations and geographical changes. Carnets de Géologie / Notebooks on Geology, Maintenon, Article 2004/01 (CG2004_A01_CCE-PG)

Emig, C.C., 1997. Bathyal zones of the Mediterranean continental slope: An attempt, Publ. Espec.Inst.Esp.Oceanogr. 23, 23-33

Evans, D., Aish, A., Boon, A., Condé, S., Connor, D., Gelabert, E. Michez, N., Parry, M., Richard, D., Salvati, E. & Tunesi, L. 2016. Revising the marine section of the EUNIS Habitat classification, 2016 - Report of a workshop held at the European Topic Centre on Biological Diversity, 12 & 13 May 2016. ETC/BD report to the EEA. https://www.eionet.europa.eu/etcs/etc-bd/products/etc-bd-reports/revising_marine_section_eunis_hab_classification

Gogina, M., Nygård, H., Blomqvist, M., Daunys, D., Josefson, A.B., Kotta, J., Maximov, A., Warzocha, J., Yermakov, V., Gräwe, U., Zettler, M.L., 2016. The Baltic Sea scale inventory of benthic faunal communities. ICES Journal of Marine Science. https://doi.org/10.1093/icesjms/fsv265

HELCOM, 2013. HELCOM HUB – Technical Report on the HELCOM Underwater Biotope and habitat classification, Baltic Sea Environment Proceedings. N° 139. www.helcom.fi/Lists/Publications/BSEP139.pdf

James, J. W. C., Pearce, B., Coggan, R. A., Arnott, S. H. L., Clark, R., Plim, J. F., Pinnion, J., Barrio Frójan, C., Gardiner, J. P., Morando, A., Baggaley, P. A., Scott, G., and Bigourdan, N., 2010. The South Coast Regional Environmental Characterisation. British Geological Survey Open Report OR/09/51. 249 pp

JNCC, 2019. Prediction of outcrops or subcrops of rock in UK shelf seabed. https://doi.org/10.25603/840424.1.0.0 available at: https://data.gov.uk/dataset/fee92896-76a9-4718-a576-cd0d42224751/prediction-of-outcrops-or-subcrops-of-rock-in-uk-shelf-seabed-public

Karpinsky, M.G., 2003. "Benthos biocoenoses in the Middle and South Caspian Sea," Oceanology (Engl. Transl.) 43(3), 376–386.

Karpinsky, M.G., Shiganova, T.A., and Katunin, D.N., 2005. Introduced species, in Kostianoy, A.G., and Kosarev, A.N., eds., The Caspian Sea Environment: The Handbook of Environmental Chemistry, Part 5P: Berlin, Springer-Verlag, p. 175–90, https://doi.org/10.1007/698_5_009.

Kosarev, A.N., 2005. Physico-Geographical Conditions of the Caspian Sea. In: Kostianoy, A.G., Kosarev, A.N. (eds) The Caspian Sea Environment. The Handbook of Environmental Chemistry, vol 5P. Springer, Berlin, Heidelberg . https://doi.org/10.1007/698_5_002

Laverick, J.H., Piango, S., Andradi-Brown, D.A. et al. To what extent do mesophotic coral ecosystems and shallow reefs share species of conservation interest? A systematic review. Environ Evid 7, 15 (2018). https://doi.org/10.1186/s13750-018-0127-1

Lillis, H., Allen, H., Annunziatellis, A., Vasquez, M., 2021. A combined, harmonized data product showing the best evidence for the extent of biogenic substrate in Europe. EMODnet report.

Mata Chacón, D., Sanz Alonso, J.L., Gonçalves, J.M.S., Monteiro, P., Bentes, L., McGrath, F., Henriques, V., Freitas, R., Amorim, P., Tempera, F., Fossecave, P., Alonso, C., Galparsoro, I., Vasquez, M., Populus, J., 2013. Report on collation of historic maps. Bathymetry, substrate and habitats - MeshAtlantic Report. Spanish Institute of Oceanography. 98 pp.

Montefalcone, M., Tunesi, L., Ouerghi, A., 2021. A review of the classification systems for marine benthic habitats and the new updated Barcelona Convention classification for the Mediterranean, Marine Environmental Research, Volume 169, 105387, ISSN 0141136, https://doi.org/10.1016/j.marenvres.2021.105387.

Monteiro, P., Bentes, L., O'Keeffe, E., Woods, H., Vasquez, M., Ségeat, B., Gonçalves, J., 2023. Report detailing the construction of the biogenic habitat data product (updated). D3.10. EASME/EMFF/2020/1.3.1.11/Lot3/SI2.843624. – EMODnet Thematic Lot n° 3 – Seabed Habitats.

Populus, J., Vasquez, M., Albrecht, J., Manca, E., Agnesi, S., Al Hamdani, Z., Andersen, J., Annunziatellis, A., Bekkby, T., Bruschi, A., Doncheva, V., Drakopoulou, V., Duncan, G., Inghilesi, R., Kyriakidou, C., Lalli, F., Lillis, H., Mo, G., Muresan, M., Salomidi, M., Sakellariou, D., Simboura, M., Teaca, A., Tezcan, D., Todorova, V., Tunesi, L., 2017. EUSeaMap. A European broad-scale seabed habitat map. https://doi.org/10.13155/49975

Relini, G., Peirano, A., Tunesi, L., 1986. Osservazioni sulle comunità dei fondi strascicabili del Mar Ligure Centro-Orientale, Bol. Mus. Ist. Biol. Univ. Genova 52 suppl., 139-161

Saulquin, B., Hamdi, A., Gohin, F., Populus, J., Mangin, A., d' Andon, O.F., 2013. Estimation of the diffuse attenuation coefficient KdPAR using MERIS and application to seabed habitat mapping. Remote Sensing of Environment 128, 224–233. doi: 10.1016/j.rse.2012.10.002.

Tappin,D. R., Pearce, B., Fitch, S., Dove, D., Geary, B., Hill, J. M., Chambers, C., Bates, R., Pinnion, J., Green, M., Gallyot, J., Georgiou, L., Brutto, D., Marzialetti, S., Hopla, E., Ramsay, E., Fielding, H., 2011. The Humber Regional Environmental Characterisation Marine Aggregate Levy Sustainability Fund (MALSF), British Geological Survey Open Report OR/10/54. 317 pp.

UNEP/MAP, 2019. Report of the 21st Meeting of the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols. 821 pp. https://wedocs.unep.org/bitstream/handle/20.500.11822/30095/19ig24_22_eng.pdf

UNEP/MAP SPA/RAC - Tunis, 2021. Interpretation Manual of Marine Habitat Types in the Mediterranean Sea. Fifteenth Meeting of SPA/BD Focal Points, Videoconference, 23-25 June 2021. UNEP/MED WG.502/Inf.4, 426 pp. https://www.rac-spa.org/meetings/nfp15/nfp_docs/inf/21wg502_inf04_en.pdf

Vasquez, M., Manca, E., Inghilesi, R., Martin, S., Agnesi, S., Al Hamdani, Z., Annunziatellis, A., Bekkby, T., Pesch, R., Askew, N., Bentes, L., Castle, L., Doncheva, V., Drakopoulou, V., Gonçalves, J., Laamanen, L., Lillis, H., Loukaidi, V., McGrath, F., Mo, G., Monteiro, P., Muresan, M., O'Keeffe, E., Populus, J., Pinder, J., Ridgeway, A., Sakellariou, D., Simboura, M., Teaca, A., Tempera, F., Todorova, V., Tunesi, L. and Virtanen, E., 2020. EUSeaMap 2019, A European broad-scale seabed habitat map, Technical Report. https://doi.org/10.13155/74782

Vasquez, M., 2021. Constructing EUSeaMap - User Guide. D1.14. EASME/EMFF/2018/1.3.1.8/Lot2/SI2.810241– EMODnet Thematic Lot n° 2 – Seabed Habitats. https://archimer.ifremer.fr/doc/00718/82999/

Vasquez, M., Agnesi, S., Al Hamdani, Z., Annunziatellis, A., Askew, N., Bekkby, T., Bentes, L., Castle, L., Doncheva, V., Duncan, G., Gonçalves, J., Inghilesi, R., Laamanen, L., Lillis, H., Manca, E., McGrath, F., Mo, G., Monteiro, P., Muresan, M., O'Keeffe, E., Pesch, R., Pinder, J., Teaca, A., Todorova, V., Tunesi, L., Virtanen, E., 2021. Mapping seabed habitats over large areas: prospects and limits. EMODnet Thematic Lot n° 2 – Seabed Habitats. D1.15. EASME/EMFF/2018/1.3.1.8/Lot2/SI2.810241. https://doi.org/10.13155/78021

Annex 1 – Crosswalks between the EUSeaMap classification for the Caribbean Sea, Andres el al. (2002), EUNIS 2022 and the MSFD broad habitat types

Biological zone	Seabed substrate	EUSeaMap classification	EUNIS 2022 level 2	MSFD broad habitat types	Andres el al. (2022) level 2 (rock) or 3 (sediment)
Infralittoral	Rock	Infralittoral rock	MB1: Infralittoral rock	Infralittoral rock and biogenic reef	C1 SUBSTRATS DURS VOLCANIQUES INFRALITTORAUX
Infralittoral	Coral reef	Infralittoral coral reef	MB2: Infralittoral biogenic habitat	Infralittoral rock and biogenic reef	C2 SUBSTRATS DURS BIOGÈNES INFRALITTORAUX
Infralittoral	Coarse substrate	Infralittoral coarse sediment	MB3: Infralittoral coarse sediment	Infralittoral coarse sediment	C4-4 SÉDIMENTS GROSSIERS
Infralittoral	Mixed sediment	Infralittoral mixed sediment	MB4: Infralittoral mixed sediment	Infralittoral mixed sediment	No mention
Infralittoral	Sand	Infralittoral sand	MB5: Infralittoral sand	Infralittoral sand	C4-2 SABLES VASEUX or C4-3 SABLES
Infralittoral	Mud	Infralittoral mud	MB6: Infralittoral mud	Infralittoral mud	C4-1 VASES

The European Marine Observation and Data Network (EMODnet) is financed by the European Union under Regulation (EU) No 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund.

Circalittoral	Rock	Circalittoral rock	MC1 or MD1: Circalittoral rock or Offshore circalittoral rock	Circalittoral rock and biogenic reef or Offshore circalittoral rock and biogenic reef	D1 SUBSTRATS DURS
Circalittoral	Coarse substrate	Circalittoral coarse sediment	MC3 or MD3: Circalittoral coarse sediment or Offshore circalittoral coarse sediment	Circalittoral coarse sediment or Offshore circalittoral coarse sediment	D2-4 SÉDIMENTS GROSSIERS
Circalittoral	Mixed sediment	Circalittoral mixed sediment	MC4 or MD4: Circalittoral mixed sediment or Offshore circalittoral mixed sediment	Circalittoral mixed sediment or Offshore circalittoral mixed sediment	No mention
Circalittoral	Sand	Circalittoral sand	MC5 or MD5: Circalittoral sand or Offshore circalittoral sand	Circalittoral sand or Offshore circalittoral sand	D2-3 SABLES or D2-2 SABLES VASEUX
Circalittoral	Mud	Circalittoral mud	MC6 or MD6: Circalittoral mud or Offshore circalittoral mud	Circalittoral mud or Offshore circalittoral mud	D2-1 VASES
Bathyal	Rock	Bathyal rock	ME1 or MF1: Upper bathyal rock or Lower bathyal rock	Upper bathyal rock and biogenic reef or Lower bathyal rock and biogenic reef	E1 SUBSTRATS DURS
Bathyal	Coarse substrate	Bathyal coarse sediment	ME3 or MF3: Upper bathyal coarse sediment or Lower bathyal coarse sediment	Upper bathyal sediment or Lower bathyal sediment	E2 SUBSTRATS MEUBLES
Bathyal	Mixed sediment	Bathyal mixed sediment	ME4 or MF4: Upper bathyal mixed sediment or Lower bathyal mixed sediment	Upper bathyal sediment or Lower bathyal sediment	E2 SUBSTRATS MEUBLES
Bathyal	Sand	Bathyal sand	ME5 or MF5: Upper bathyal sand or Lower bathyal sand	Upper bathyal sediment or Lower bathyal sediment	E2 SUBSTRATS MEUBLES
Bathyal	Mud	Bathyal mud	ME6 or MF6: Upper bathyal mud or Lower bathyal mud	Upper bathyal sediment or Lower bathyal sediment	E2 SUBSTRATS MEUBLES

Abyssal	Rock	Abyssal rock	MG1: Abyssal rock	Abyssal	F1 SUBSTRATS DURS
Abyssal	Coarse substrate	Abyssal coarse sediment	MG3: Abyssal coarse sediment	Abyssal	F2 SUBSTRATS MEUBLES
Abyssal	Mixed sediment	Abyssal mixed sediment	MG4: Abyssal mixed sediment	Abyssal	F2 SUBSTRATS MEUBLES
Abyssal	Sand	Abyssal sand	MG5: Abyssal sand	Abyssal	F2 SUBSTRATS MEUBLES
Abyssal	Mud	Abyssal mud	MG6: Abyssal mud	Abyssal	F2 SUBSTRATS MEUBLES

Annex 2 – Crosswalks between the EUSeaMap classification for the Caspian Sea, EUNIS 2022 and the MSFD broad habitat types

Biological zone	Seabed substrate	EUSeaMap classification	EUNIS 2022 level 2	MSFD broad habitat types
Infralittoral	Rock	Infralittoral rock	MB1: Infralittoral rock	Infralittoral rock and biogenic reef
Infralittoral	Dominated by *Mytilaster lineatus* and *Amphibalanus improvisus*	Infralittoral bottoms dominated by *Mytilaster lineatus* and *Amphibalanus improvisus*	MB2: Infralittoral biogenic habitat	Infralittoral rock and biogenic reef
Infralittoral	Coarse substrate	Infralittoral coarse sediment	MB3: Infralittoral coarse sediment	Infralittoral coarse sediment
Infralittoral	Mixed sediment	Infralittoral mixed sediment	MB4: Infralittoral mixed sediment	Infralittoral mixed sediment
Infralittoral	Sand	Infralittoral sand	MB5: Infralittoral sand	Infralittoral sand
Infralittoral	Mud	Infralittoral mud	MB6: Infralittoral mud	Infralittoral mud
Circalittoral	Rock	Circalittoral rock	MC1: Circalittoral rock	Circalittoral rock and biogenic reef
Circalittoral	dominated by *Dreissena grimmi* and corophiids	Circalittoral bottoms dominated by *Dreissena grimmi* and corophiids	MC2: Circalittoral biogenic habitat	Circalittoral rock and biogenic reef

Circalittoral	Coarse substrate	Circalittoral coarse sediment	MC3: Circalittoral coarse sediment	Circalittoral coarse sediment
Circalittoral	Mixed sediment	Circalittoral mixed sediment	MC4: Circalittoral mixed sediment	Circalittoral mixed sediment
Circalittoral	Sand	Circalittoral sand	MC5: Circalittoral sand	Circalittoral sand
Circalittoral	Mud	Circalittoral mud	MC6: Circalittoral mud	Circalittoral mud
Offshore circalittoral	Rock	Offshore circalittoral rock	MD1: Circalittoral rock or Offshore circalittoral rock	Offshore circalittoral rock and biogenic reef
Offshore circalittoral	Coarse substrate	Offshore circalittoral coarse sediment	MD3: Offshore circalittoral coarse sediment	Offshore circalittoral coarse sediment
Offshore circalittoral	Mixed sediment	Offshore circalittoral mixed sediment	MD4: Offshore circalittoral mixed sediment	Offshore circalittoral mixed sediment
Offshore circalittoral	Sand	Offshore circalittoral sand	MD5: Offshore circalittoral sand	Offshore circalittoral sand
Offshore circalittoral	Mud	Offshore circalittoral mud	MD6: Offshore circalittoral mud	Offshore circalittoral mud
Bathyal	Rock	Bathyal rock	ME1 or MF1: Upper bathyal rock or Lower bathyal rock	Upper bathyal rock and biogenic reef or Lower bathyal rock and biogenic reef
Bathyal	Coarse substrate	Bathyal coarse sediment	ME3 or MF3: Upper bathyal coarse sediment or Lower bathyal coarse sediment	Upper bathyal sediment or Lower bathyal sediment
Bathyal	Mixed sediment	Bathyal mixed sediment	ME4 or MF4: Upper bathyal mixed sediment or Lower bathyal mixed sediment	Upper bathyal sediment or Lower bathyal sediment

Bathyal	Sand	Bathyal sand	ME5 or MF5: Upper bathyal sand or Lower bathyal sand	Upper bathyal sediment or Lower bathyal sediment
Bathyal	Mud	Bathyal mud	ME6 or MF6: Upper bathyal mud or Lower bathyal mud	Upper bathyal sediment or Lower bathyal sediment
Abyssal	Rock	Abyssal rock	MG1: Abyssal rock	Abyssal
Abyssal	Coarse substrate	Abyssal coarse sediment	MG3: Abyssal coarse sediment	Abyssal
Abyssal	Mixed sediment	Abyssal mixed sediment	MG4: Abyssal mixed sediment	Abyssal
Abyssal	Sand	Abyssal sand	MG5: Abyssal sand	Abyssal
Abyssal	Mud	Abyssal mud	MG6: Abyssal mud	Abyssal

Annex 3 – Preliminary habitat classification for the Caspian Sea

EUSeaMap broad habitat types	Communities
Infralittoral rock	Not found in literature
Infralittoral bottoms dominated by *Mytilaster lineatus* and *Amphibalanus improvisus*	Infralittoral bottoms dominated by *Mytilaster lineatus* and *Amphibalanus improvisus*
Infralittoral coarse sediment	North-Caspian marine water complex of benthic fauna on coarse substrata
Infralittoral mixed sediment	North-Caspian marine macrophytes phytocoenosis of Polisiphonieta and Laurencieta, Ulveta, Cladophoreta and Ceramium on mixed sediment
Infralittoral sand	North-Caspian freshwater complex of benthic fauna on sandy substrata with high input of vegetal detritus North-Caspian infralittoral slightly brackish water complex of benthic fauna on sand substrata Infralittoral sand dominated by *Abra segmentum* North-Caspian Brackish water phanerogam phytocoenosis of Zostereta North-Caspian Freshwater phanerogam phytocoenosis of Potameta, Ceratophylleta, Vallisnerieta, and Myriophylleta on sand
Infralittoral mud	North-Caspian brackish water complex of benthic fauna on mud substrata Infralittroral mud with Oligochaetes and chironomids Infralittroral mud with *Hediste diversicolor*, *Alitta succinea* and *Cerastoderma glaucum*
Circalittoral rock	Not found in literature

Circalittoral bottoms dominated by *Dreissena grimmi* and corophiids	Circalittoral bottoms dominated by *Dreissena grimmi* and corophiids
Circalittoral coarse sediment	Not found in literature
Circalittoral mixed sediment	Not found in literature
Circalittoral sand	Circalittoral sand with Ponto-caspian complex of Gammaridea and Cumacea (*Chaetogammarus pauxillus*, *Chaetogammarus ischnus* - *Schizorhynchus eudorelloides*, *Stenocuma diastyloides*, *Stenocuma gracilis*, *Pterocuma spp.*)
Circalittoral mud	Lots of species live on circalittoral mud, but no specific communities were identified.
Offshore circalittoral rock	Not found in literature
Offshore circalittoral coarse sediment	Not found in literature
Offshore circalittoral mixed sediment	Not found in literature
Offshore circalittoral sand	Not found in literature
Offshore circalittoral mud	Offshore circalittoral mud with Oligochaeta (*Psamoryctides deserticola*, *Isochaetides michaelsenii*, *Stylodrilus cernosvitovi*), *Corophium spinulosum*, *Corophium chelicorne* and *Saduria entomon* Offshore circalittoral mud with Pontoporeia affinis microphthalma
Bathyal rock	Not found in literature
Bathyal coarse sediment	Not found in literature
Bathyal mixed sediment	Not found in literature
Bathyal sand	Not found in literature
Bathyal mud	Bathyal mud with *Hypania invalida*, *Psamoryctides deserticola*, *Didacna profundicola*

Abyssal rock	Not found in literature
Abyssal coarse sediment	Not found in literature
Abyssal mixed sediment	Not found in literature
Abyssal sand	Not found in literature
Abyssal mud	Not found in literature

Annex 4 – Habitat descriptor class boundary parameters

This annex summarises, for each boundary and descriptor class, the classification method used, the slope and intercept of the GLM or fuzzy equation, and the probability threshold. These 3 figures, namely slope, intercept and probability threshold, are those that feed the GIS modelling workflow. Other figures are provided here for information, as they are more meaningful than the slope, intercept and probability threshold, namely the threshold in the unit of the explanatory variable (variable threshold column) and, if the classification method is a fuzzy rule, the X1 and X0 values, i.e. the values at which the probability starts to be 1 and 0 respectively. We recall that for the fuzzy classification method, slope = 1/(X1-X0); intercept = -X0/(X1-X0). Further details on GLM and fuzzy classification can be found in Populus et al. (2017), section "Modelling habitat descriptor classes and setting boundaries".

1 Atlantic and Arctic - Sublittoral biological zones

Table A4.1 – Sublittoral biological zone boundary parameters for Atlantic and Arctic.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Infralittoral/Circalittoral	Seabed PAR ($mol.pho.m^{-2}.d^{-1}$)	GLM	Infralittoral lower boundary	NA	NA	0.685	1.076	-0.777	0.49
			Circalittoral upper boundary	NA	NA	0.685	-1.076	0.777	0.51
Infralittoral/Circalittoral Kattegat	Seabed PAR ($mol.pho.m^{-2}.d^{-1}$)	Fuzzy	Infralittoral lower boundary	0.1	0.04	0.07	16.6666667	-0.6666667	0.5
			Circalittoral upper boundary	0.04	0.1	0.07	-16.6666667	1.6666667	0.5
Circalittoral/Offshore circalittoral	Wavelength/depth	Fuzzy	Circalittoral lower boundary	3	2.5	2.75	2	-5	0.5
			Offshore circalittoral upper boundary	2.5	3	2.75	-2	6	0.5

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Within RESOURCECODE[4] data spatial extent									
Circalittoral/Offshore circalittoral Kattegat	Depth (m)	Fuzzy	Circalittoral lower boundary	-25	-35	-30	0.1	3.5	0.5
			Offshore circalittoral upper boundary	-35	-25	-30	-0.1	-2.5	0.5
Circalittoral/Offshore circalittoral Norway	Wave exposure index	Fuzzy	Circalittoral lower boundary	10200	8800	9500	0.000714	-6.286	0.5
			Offshore circalittoral upper boundary	8800	10200	9500	-0.000714	7.286	0.5
Circalittoral/Offshore circalittoral Macaronesia, Iceland and Arctic	Depth (m)	Fuzzy	Circalittoral lower boundary	-60	-80	-70	0.05	4	0.5
			Offshore circalittoral upper boundary	-80	-60	-70	-0.05	-3	0.5
Offshore circalittoral/Upper bathyal	Depth (m)	Fuzzy	Offshore circalittoral lower boundary	-180	-220	-200	0.025	5.5	0.5
			Upper bathyal upper boundary	-220	-180	-200	-0.025	-4.5	0.5

[4] See section 2.3.2

2 Atlantic and Arctic – Deep sea biological zones

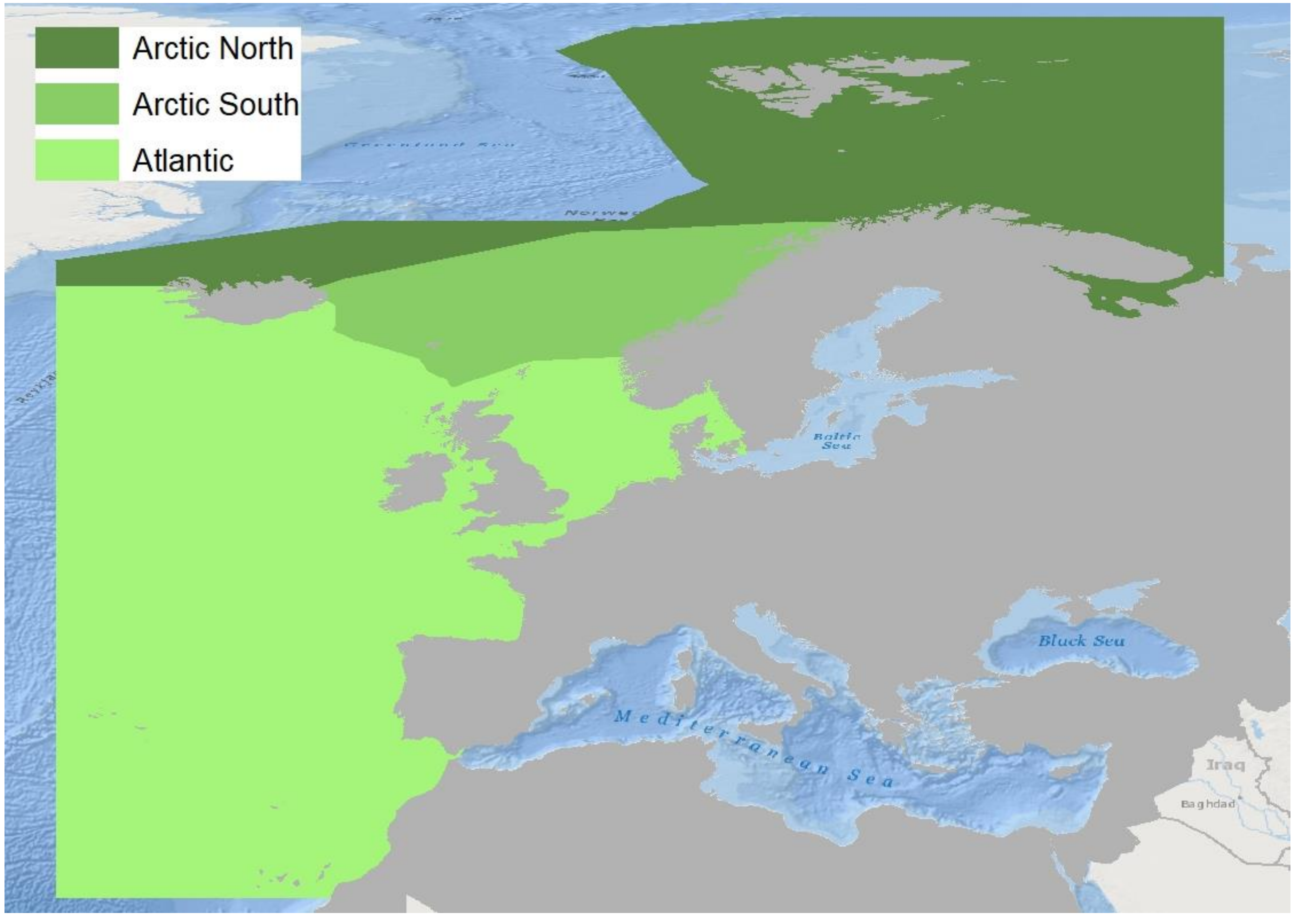

Figure A4.1: in the Northeast Atlantic (including the Greater North Sea and the British Isles) and the Arctic, deep-sea biological zones were defined in 2016 based on an unpublished study that identified potential biogeographical zones at the seabed (Populus et al., 2017). To facilitate the integration of this into the EUSeamap GIS workflow, the seabed is divided into three zones (i.e. North Arctic, South Arctic and Atlantic), each with its own set of deep-sea biological zones and associated boundary parameters. These are described in tables A4.2, A4.3 and A4.4.

Table A4.2 – Deep sea biological zone boundary parameters for Atlantic and Arctic - Arctic North[5] area.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Atlantic upper bathyal North/Atlanto Arctic upper bathyal North	Depth (m)	Fuzzy	Atlantic upper bathyal North lower boundary	-226	-374	-300	0.006756757	2.52702727	0.5
			Atlanto Arctic upper bathyal North upper boundary	-374	-226	-300	-0.006756757	-1.52702727	0.5
Atlanto Arctic upper bathyal North/Arctic mid bathyal	Depth (m)	Fuzzy	Atlanto Arctic upper bathyal North lower boundary	-352	-848	-600	0.002016129	1.709677419	0.5
			Arctic mid bathyal upper boundary	-848	-352	-600	-0.002016129	-0.709677419	0.5
Arctic mid bathyal/Arctic lower bathyal	Depth (m)	Fuzzy	Arctic mid bathyal lower boundary	-923	-1677	-1300	0.00132626	2.224137931	0.5
			Arctic lower bathyal upper boundary	-1677	-923	-1300	-0.00132626	-1.224137931	0.5
Arctic lower bathyal/Arctic upper abyssal	Depth (m)	Fuzzy	Arctic lower bathyal lower boundary	-2090	-2710	-2400	0.001612903	4.370967742	0.5

[5] See figure A4.1

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
			Arctic upper abyssal upper boundary	-2710	-2090	-2400	-0.001612903	-3.370967742	0.5

Table A4.3 - Deep sea biological zone boundary parameters for Atlantic and Arctic - Arctic South[6] area.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Atlantic upper bathyal South/Atlanto Arctic upper bathyal South	Depth (m)	Fuzzy	Atlantic upper bathyal South lower boundary	-343	-457	-400	-0.00877193	4.00877193	0.5
			Atlanto Arctic upper bathyal South upper boundary	-457	-343	-400	0.00877193	-3.00877193	0.5
Atlanto Arctic upper bathyal South/Arctic mid bathyal	Depth (m)	Fuzzy	Atlanto Arctic upper bathyal South lower boundary	-352	-848	-600	0.002016129	1.709677419	0.5
			Arctic mid bathyal upper boundary	-848	-352	-600	-0.002016129	-0.709677419	0.5
Arctic mid bathyal/Arctic lower bathyal	Depth (m)	Fuzzy	Arctic mid bathyal lower boundary	-923	-1677	-1300	0.00132626	2.224137931	0.5

[6] See figure A4.1

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
			Arctic lower bathyal upper boundary	-1677	-923	-1300	-0.00132626	-1.224137931	0.5
Arctic lower bathyal/Arctic upper abyssal	Depth (m)	Fuzzy	Arctic lower bathyal lower boundary	-2090	-2710	-2400	0.001612903	4.370967742	0.5
			Arctic upper abyssal upper boundary	-2710	-2090	-2400	-0.001612903	-3.370967742	0.5

Table A4.4 - Deep sea biological zone boundary parameters for Atlantic and Arctic - Atlantic[7] area.

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

[7] See figure A4.1

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

3 Atlantic and Arctic – Wave-induced energy levels

Table A4.5 – Wave-induced energy level boundary parameters for Atlantic and Arctic.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
High/Moderate Within RESOURCECODE[8] data spatial extent	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	High lower boundary	15	12.5	13.75	0.4	-5	0.5
			Moderate upper boundary	12.5	15	13.75	-0.4	6	0.5
High/Moderate Azores	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	High lower boundary	48.7	38.7	43.7	0.1	-3.87	0.5
			Moderate upper boundary	38.7	48.7	43.7	-0.1	4.87	0.5
High/Moderate Norway	Wave exposure index	Fuzzy	High lower boundary	550000	450000	500000	0.00001	-4.5	0.5
			Moderate upper boundary	450000	550000	500000	-0.00001	5.5	0.5
Moderate/Low Within RESOURCECODE data spatial extent	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	Moderate lower boundary	4.2	3.4	3.8	1.25	-4.25	0.5
			Low upper boundary	3.4	4.2	3.8	-1.25	5.25	0.5
Moderate/Low	Kinetic energy at the seabottom	Fuzzy	Moderate lower boundary	4	2	3	0.5	-1	0.5

[8] See section 2.3.2

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Azores	($N.m^{-2}$)		Low upper boundary	2	4	3	-0.5	2	0.5
Moderate/Low Norway	Wave exposure index	Fuzzy	Moderate lower boundary	110000	90000	100000	0.00005	-4.5	0.5
			Low upper boundary	90000	110000	100000	-0.00005	5.5	0.5

4 Atlantic and Arctic – Current-induced energy levels

Note: for Macaronesia and Kattegat, the current-induced energy is assumed to be low everywhere.

Table A4.6 – Current-induced energy level boundary parameters for Atlantic and Arctic.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
High/Moderate Greater North Sea, Celtic Sea, British Isles, Norway and Barents Sea	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	High lower boundary	1170	1150	1160	0.05	-57.5	0.5
			Moderate upper boundary	1150	1170	1160	-0.05	58.5	0.5
High/Moderate Bay of Biscay	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	High lower boundary	450	350	400	0.01	-3.5	0.5
			Moderate upper boundary	350	450	400	-0.01	4.5	0.5

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
High/Moderate Iberian Peninsula	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	High lower boundary	1000	800	900	0.005	-4	0.5
			Moderate upper boundary	800	1000	900	-0.005	5	0.5
Moderate/Low Barents Sea	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	High lower boundary	140	120	130	0.05	-6	0.5
			Moderate upper boundary	120	140	130	-0.05	7	0.5
Moderate/Low Greater North Sea, Celtic Sea, British Isles and Norway	Kinetic energy at the seabottom ($N.m^{-2}$)	Fuzzy	Moderate lower boundary	970	830	900	0.0071	-5.9286	0.5
			Low upper boundary	830	970	900	-0.0071	6.9286	0.5
Moderate/Low Bay of Biscay	Seabottom Kinetic energy ($N.m^{-2}$)	Fuzzy	Moderate lower boundary	100	60	80	0.025	-1.5	0.5
			Low upper boundary	60	100	80	-0.025	2.5	0.5
Moderate/Low Iberian Peninsula	Seabottom Kinetic energy ($N.m^{-2}$)	Fuzzy	Moderate lower boundary	120	80	100	0.025	-2	0.5
			Low upper boundary	80	120	100	-0.025	3	0.5

5 Baltic Sea – Biological zones

Table A4.7 – Biological zone boundary parameters for Baltic Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Infralittoral/Circalittoral Polyhaline or euhaline waters	Seabed PAR (mol.pho.m^{-2}.d^{-1})	Fuzzy	Infralittoral lower boundary	0.1	0.04	0.07	16.6666667	-0.6666667	0.5
			Circalittoral upper boundary	0.04	0.1	0.07	-16.6666667	1.6666667	0.5
Infralittoral/Circalittoral Oligohaline or mesohaline waters	A layer on the spatial distribution of the photic zone, derived from fine-scale national studies (Hammar et al., 2018[9]; Lappalainen et al., 2019[10]), is directly incorporated into the EUSeaMap biological zone layer.								
Circalittoral/Offshore circalittoral Polyhaline or euhaline waters	Depth (m)	Fuzzy	Circalittoral lower boundary	-25	-35	-30	0.1	3.5	0.5
			Offshore circalittoral upper boundary	-35	-25	-30	-0.1	-2.5	0.5
Circalittoral/Offshore circalittoral		Fuzzy	Circalittoral lower boundary	0.9	1	0.95	-10	10	0.5

[9] Hammar L., Schmidtbauer Crona, J., Kågesten, G., Hume, D., Pålsson, J., Aarsrud, M., Mattsson, D., Åberg, F., Hallberg, M., Johansson, T., 2018. Symphony, Integrerat planeringsstöd för statlig havsplanering utifrån en ekosystemansats. Havs- och vattenmyndighetens rapport

[10] Lappalainen, J., Virtanen, E.A., Kallio, K., Junttila, S., Viitasalo, M., 2019. Substrate limitation of a habitatforming genus Fucus under different water clarity scenarios in the northern Baltic Sea. Estuarine, Coastal and Shelf Science 218, 31–38. https://doi.org/10.1016/j.ecss.2018.11.010

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Oligohaline or mesohaline waters	Probability that the seafloor is below the halocline		Offshore circalittoral upper boundary	1	0.9	0.95	10	-9	0.5

6 Baltic Sea – Salinity regimes

Table A4.8 – Salinity regime boundary parameters for Baltic Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Oligohaline/Mesohaline	Salinity at the seabottom (psu)	Fuzzy	Oligohaline lower boundary	4	4.8	4.4	-1.25	6	0.5
			Mesohaline upper boundary	4.8	4	4.4	1.25	-5	0.5
Mesohaline/Polyhaline	Salinity at the seabottom (psu)	Fuzzy	Mesohaline lower boundary	16	20	18	-0.25	5	0.5
			Polyhaline upper boundary	20	16	18	0.25	-4	0.5
Polyhaline/Euhaline	Salinity at the seabottom (psu)	Fuzzy	Polyhaline lower boundary	28	32	30	-0.25	8	0.5
			Euhaline upper boundary	32	28	30	0.25	-7	0.5

6 Baltic Sea – Wave-induced energy levels

Table A4.9 – Wave-induced energy level boundary parameters for Baltic Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
High/Moderate	Wave exposure index	Fuzzy	High lower boundary	680000	520000	600000	0.00000625	-3.25	0.5
			Moderate upper boundary	520000	680000	600000	-0.00000625	4.25	0.5
Moderate/Low	Wave exposure index	Fuzzy	Moderate lower boundary	80000	40000	60000	0.000025	-1	0.5
			Low upper boundary	40000	80000	60000	-0.000025	2	0.5

8 Black Sea – Biological zones

Table A4.10 – Biological zone boundary parameters for Black Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Infralittoral/Circalittoral Hard bottoms	Depth (m)	Fuzzy	Infralittoral lower boundary	-12	-16	-14	0.25	4	0.5
			Circalittoral upper boundary	-16	-12	-14	-0.25	-3	0.5
Infralittoral/Circalittoral Soft bottoms	Depth (m)	Fuzzy	Infralittoral lower boundary	-10	-30	-20	0.05	1.5	0.5
			Circalittoral upper boundary	-30	-10	-20	-0.05	-0.5	0.5
Infralittoral/Circalittoral Soft bottoms – Bulgarian coast	Depth (m)	Fuzzy	Infralittoral lower boundary	-11	-15	-13	0.25	3.75	0.5
			Circalittoral upper boundary	-15	-11	-13	-0.25	-2.75	0.5
Circalittoral/Offshore circalittoral	Seabottom temperature (°C)	GLM	Circalittoral lower boundary	NA	NA	9	3.74	-34.59	0.27
			Offshore circalittoral upper boundary	NA	NA	9	-3.74	34.59	0.73

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Offshore circalittoral/Bathyal	Manually drawn. The boundary marks the end of the continental shelf and the beginning of the bathyal zone, which corresponds to the continental slope. The criteria used for pre-processing are as follows: Offshore circalittoral: 220m < depth < 140m Bathyal: depth > 140m, slope > 3%								
Bathyal/Abyssal	Manually drawn. The abyssal zones are the deepest flat plains in the region and are surrounded by shallower, steeper seafloor. The criteria used for pre-processing are as follows: Bathyal: depth < 2000m, slope > 5% Abyssal: depth > 2000m, slope < 5%								

9 Black Sea – Oxygenation regimes

Table A4.11 – Oxygenation regime boundary parameters for Black Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Oxic/Suboxic	Potential density at the seabottom ($kg.m^{-3}$)	Fuzzy	Oxic lower boundary	15.7	16.1	15.9	-2.5	40.25	0.5
			Suboxic upper boundary	16.1	15.7	15.9	2.5	-39.25	0.5
Suboxic/Anoxic	Potential density at the seabottom ($kg.m^{-3}$)	Fuzzy	Suboxic lower boundary	16.2	16.6	16.4	-2.5	41.5	0.5
			Anoxic upper boundary	16.6	16.2	16.4	2.5	-40.5	0.5

8 Mediterranean Sea – Biological zones

Table A4.12 – Biological zone boundary parameters for Mediterranean Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Infralittoral/Circalittoral	Seabed PAR ($mol.pho.m^{-2}.d^{-1}$)	Fuzzy	Infralittoral lower boundary	2.27	1.19	1.82	0.92593	-1.10185	0.58
			Circalittoral upper boundary	1.19	2.27	1.82	-0.92593	2.10185	0.42
Circalittoral/Offshore circalittoral	Fraction of incident light reaching the seabed	Fuzzy	Circalittoral lower boundary	0.00075	0.00025	0.0005	2000	-0.5	0.5
			Offshore circalittoral upper boundary	0.00025	0.00075	0.0005	-2000	1.5	0.5
Offshore circalittoral/Upper bathyal	Manually drawn. The boundary marks the end of the continental shelf and the beginning of the bathyal zone, which corresponds to the continental slope. The criteria used for pre-processing are as follows: Offshore circalittoral: 220m < depth < 140m Bathyal: depth > 140m, slope > 3%								
Upper bathyal/Lower bathyal	Depth (m)	Fuzzy	Upper bathyal lower boundary	-450	-550	-500	0.01	5.5	0.5
			Lower bathyal upper boundary	-550	-450	-500	-0.01	-4.5	0.5

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Lower bathyal/Abyssal	Manually drawn. The abyssal zones are the deepest flat plains in the region and are surrounded by shallower, steeper seafloor. The criteria used for pre-processing are as follows: Bathyal: depth < 3000m, slope > 5% Abyssal: depth > 3000m, slope < 5%								

8 Caribbean Sea – Biological zones

Table A4.13 – Biological zone boundary parameters for Caribbean Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Infralittoral/Circalittoral	Seabed PAR ($mol.pho.m^{-2}.d^{-1}$)	Fuzzy	Infralittoral lower boundary	2.2	1.4	1.8	1.25	-1.75	0.5
			Circalittoral upper boundary	1.4	2.2	1.8	-1.25	2.75	0.5
Circalittoral/Bathyal	Depth (m)	Fuzzy	Circalittoral lower boundary	-180	-220	-200	0.025	5.5	0.5
			Bathyal upper boundary	-220	-180	-200	-0.025	-4.5	0.5
Bathyal/Abyssal	Manually drawn. The abyssal zones are the deepest flat plains in the region and are surrounded by shallower, steeper seafloor. The criteria used for pre-processing are as follows: Bathyal: depth < 2500m, slope > 5% Abyssal: depth > 2500m, slope < 5%								

9 Caspian Sea – Biological zones

Table A4.14 – Biological zone boundary parameters for Caspian Sea.

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
Infralittoral/Circalittoral	Seabed PAR ($mol.pho.m^{-2}.d^{-1}$)	Fuzzy	Infralittoral lower boundary	0.2	0.1	0.15	10	-1	0.5
			Circalittoral upper boundary	0.1	0.2	0.15	-10	2	0.5
Circalittoral/Offshore circalittoral	Depth (m)	Fuzzy	Circalittoral lower boundary	-40	-60	-50	0.05	3	0.5
			Offshore circalittoral upper boundary	-60	-40	-50	-0.05	-2	0.5
Offshore circalittoral/Bathyal	Manually drawn. The boundary marks the end of the continental shelf and the beginning of the bathyal zone, which corresponds to the continental slope. The criteria used for pre-processing are as follows: Offshore circalittoral: 220m < depth < 140m Bathyal: depth > 140m, slope > 3%								
Bathyal/Abyssal	Manually drawn. The abyssal zones are the deepest flat plains in the region and are surrounded by shallower, steeper seafloor. The criteria used for pre-processing are as follows: Middle Caspian abyssal plain ("Derbent basin") Bathyal: depth < 600m, slope > 5% Abyssal: depth > 600m, slope < 5% Southern abyssal plain ("South Caspian Basin") Bathyal: depth < 700m, slope > 5%								

Boundary	Explanatory variable	Classification method	Habitat descriptor class	Fuzzy X1	Fuzzy X0	Variable threshold	Slope	Intercept	Probability threshold
	Abyssal: depth > 700m, slope < 5%								