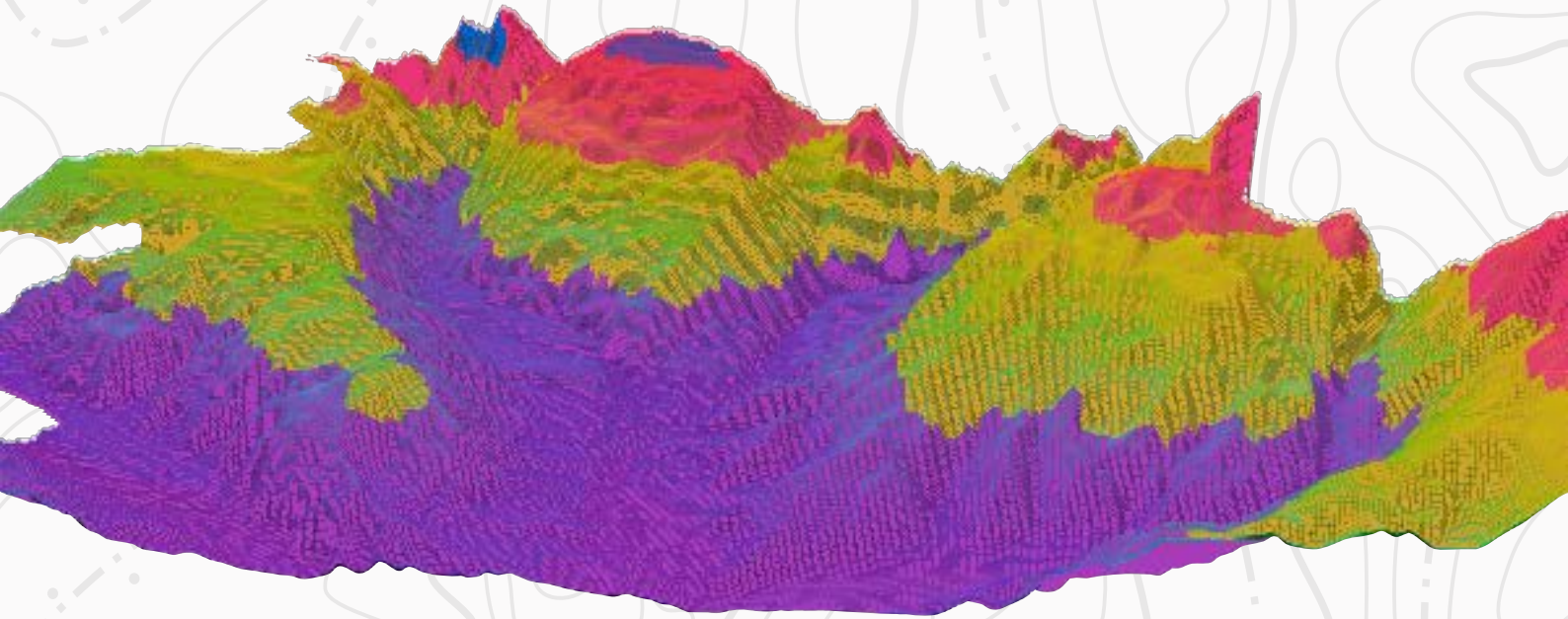
EUSeaMap:
A broad-scale seabed habitat map for European Seas



SEABED HABITATS

EMODnet

Spiny seahorse (*Hippocampus guttulatus*) sheltering in a *Zostera marina* seagrass meadow, Eastern English Channel.

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1 Introduction

EUSeaMap is a a broad-scale predictive map of physical habitats covering European waters in a consistent way[1]. EUSeaMap is a product of the Seabed Habitats theme of the European Marine Observation and Data Network (EMODnet). EMODnet is a long-term marine data initiative from the European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE) underpinning its Marine Knowledge 2020 strategy.

In the first phase (2009–12), over two million square kilometres of Europe's seabed was mapped, across four regions: the Baltic Sea, Greater North Sea, Celtic Seas and Western Mediterranean Sea (EUSeaMap 2012, *Cameron et al.*, 2012, **Figure 1**). In the second phase (2013–16), the existing EUSeaMap (EUSeaMap 2016, *Populus et al.*, 2017) was improved and its coverage extended to encompass all European basins from the Barents Sea to Macaronesia, the whole of the Mediterranean Sea, and the Black Sea. The third phase (2017–20) will see further improvement of EUSeaMap, with the most up-to-date input layers and the extension of EUSeaMap to cover the Barents Sea. Furthermore, EUSeaMap will move from a single broad-scale to multi-scale, making use of higher resolution data where it exists.

[1] Using the EUNIS classification system (European Nature Information System), **http://eunis.eea.europa.eu/habitats.jsp**

EMODnet

The main purpose of EMODnet is to unlock fragmented and hidden marine data resources and to make these available to individuals and organisations (public and private), and to facilitate investment in sustainable coastal and offshore activities through improved access to quality-assured, standardised and harmonised marine data.

www.emodnet.eu

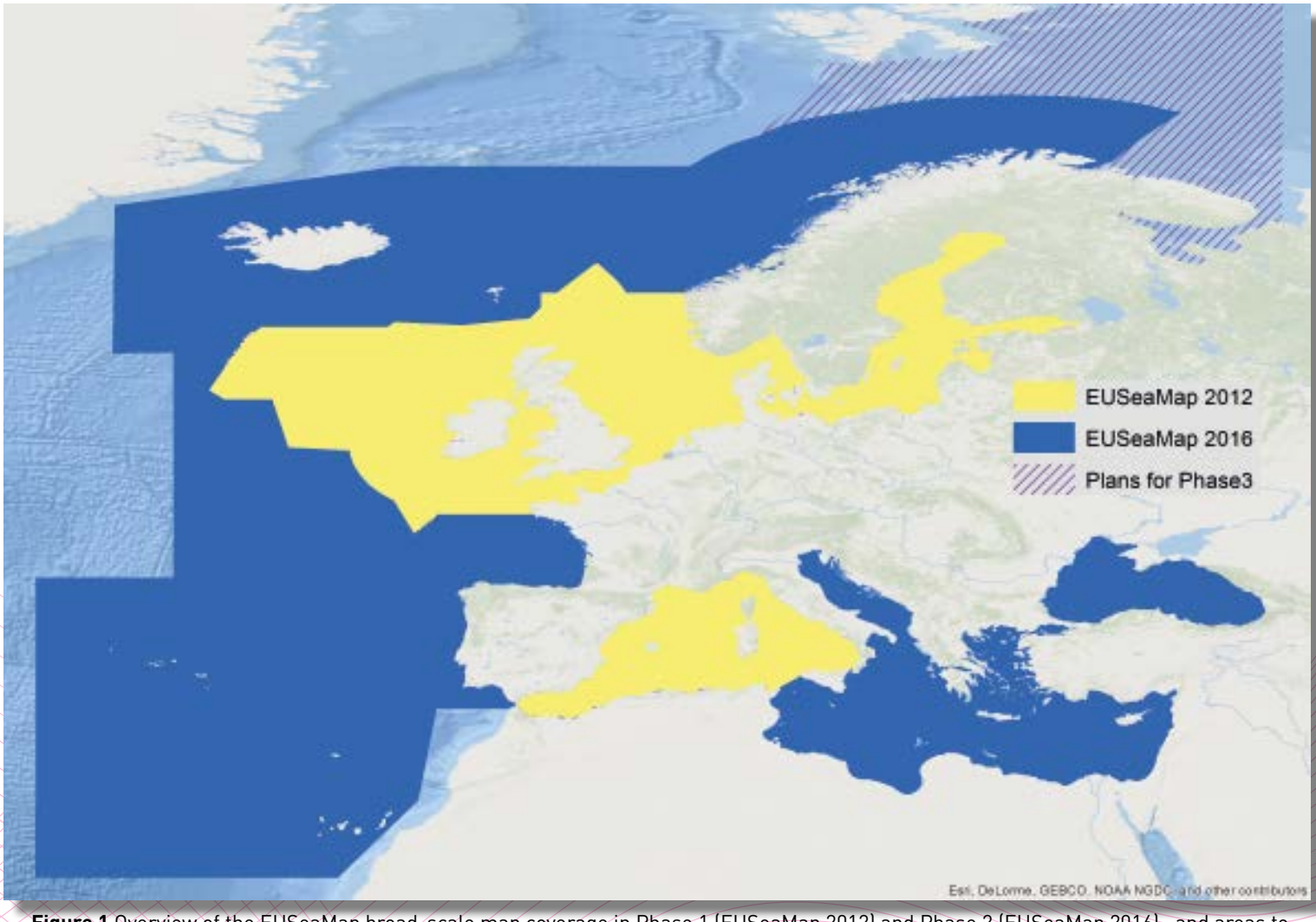

Figure 1 Overview of the EUSeaMap broad-scale map coverage in Phase 1 (EUSeaMap 2012) and Phase 2 (EUSeaMap 2016), and areas to be covered in Phase 3 (2017–20).

EMODnet provides access to data and mapping products from the following themes: bathymetry, geology, physics, chemistry, biology, human activities and seabed habitats. EUSeaMap is a product of the seabed habitat theme and is a primary user of many of the harmonised data layers produced by other EMODnet partners, such as the seabed substrata, bathymetry and seabed biology datasets.

2 Benefits of a European broad-scale seabed habitat map

In order to most benefit from the potential offered by the European marine basins in terms of growth and employment, and to protect the marine environment, we need to know more about the seafloor. European Directives, such as the Marine Strategy Framework Directive (MSFD), call for a full-coverage seabed habitat map of all European seas. In general, habitat maps are very costly and time consuming to produce from survey. The creation of a detailed habitat map involves first surveying the seafloor with sonar equipment and collecting samples or photos of the seabed. These data are then analysed and integrated to generate a map. It can take several years from planning a survey to completing a detailed map. By contrast, a more time- and cost-efficient way to meet the need for a full-coverage habitat map is to use low-resolution maps and models to predict seafloor habitat types.

EUSeaMap provides the community with a comprehensive, free and ready-to-use map, harmonising mapping procedures and fostering a common understanding among seabed mappers in Europe. The EUSeaMap methods are repeatable and ensure that the predictive maps can continue to be improved in the future.

Europe's marine habitat classification EUNIS

EUSeaMap 2016 is classified according EUNIS version 2007–11 (Davies et al., 2004). The European Nature Information System (EUNIS) classifies habitats on a seven-tier hierarchical scale developed by the European Environment Agency. The upper levels of the marine classification of EUNIS are primarily defined using abiotic variables (substrate, depth, etc.) which are categorised in a way that is relevant to the biological communities they support. Having separated marine habitats at Level 1 from terrestrial habitats, Level 2 identifies eight broad marine habitats based primarily on biological zone, substrate type and characteristics of the pelagic water column. Differentiations between habitats based on the components of the biological communities begin to appear at Level 4 in rocky environments (e.g. kelp with cushion fauna and foliose red seaweeds, **Figure 2**).

The MSFD Benthic Broad Habitat Types classification

EUSeaMap 2016 is also available in the Benthic Broad Habitat Types classification, which provides habitat categories that are more simple than the EUNIS classification, and facilitates harmonisation at EU scale. The classification is based on the EU MSFD 2017 revision – Commission Decision (2017/848/EU)[2] – that was previously known as the 'MSFD predominant habitats classification'.

Substrate type and biological zone are the only information required for benthic broad habitat types. Littoral, upper bathyal and lower bathyal zone habitats are differentiated into two classes, based on substrate: sediment or rock and biogenic reef. For continental shelf habitats (infralittoral, circalittoral and offshore), sediment types are further distinguished into coarse, sand, mixed and mud. The abyssal zone is not divided based on substrate type.

[2] Commision Decision (2017/848/EU): **http://mcc.jrc.ec.europa.eu/documents/ComDec/Com_dec_GES_2017_848_EU.pdf**

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A common hermit crab (*Pagurus bernhardus*) on a bed of Maerl (*Lithothamnion glaciale*) in a Scottish sea loch.

Figure 2 Examples from the EUNIS hierarchy. Using continuous physical data, habitats can be modelled to EUNIS Level 3 (version 2007–11) for rocky environments (right) and EUNIS Level 4 (version 2007–11) for sedimentary environments (left). Predicting higher levels (5 and 6) for all of Europe would require large amounts of biological community data from sampling.

2.1 Examples of application of EUSeaMap

Broad-scale habitat maps, such as EUSeaMap, are widely used for multiple purposes, for example:

- **MSFD assessments:** These assessments must be undertaken in all regions of Europe, i.e. the Baltic Sea, Black Sea, Mediterranean Sea and north-east Atlantic including the North Sea (*Andersen et al.*, 2018). For example, in Italian national waters EUSeaMap was used in the 2012 MSFD Initial Assessment to outline where the MSFD predominant habitats occur, where detailed information was previously lacking.
- **Natura 2000 Marine Protected Areas (MPA) network assessments:** EUSeaMap has also been used in UK waters in reviewing the developing MPA network, where it was used to provide the predicted area of each broad-scale habitat within a given biogeographic region.
- **Impacts assessments:** In undertaking cumulative impact assessments for MSFD, EUSeaMap 2016 and EMODnet Seabed Habitats data from survey, were used in conjunction with pressure data, to map potential disturbance to benthic habitats due to fishing in the north-east Atlantic. The assessment was part of the wider OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) Intermediate Assessment 2017[3].
- **Benthic ecosystem services:** Harmonised broad-scale habitats maps of seabed habitats, including EUSeaMap, were used in a first assessment of the benthic ecosystem services on the Atlantic-European scale, in the context of the Mapping and Assessment of Ecosystems and their Services (MAES) programme, the European Biodiversity Strategy and the implementation of the MSFD, by *Galparsoro et al.* (2014).
- **Marine planning:** EUSeaMap outputs were used as data sources during the creation of the UK's first marine plans[4] – for the South of England and East of England inshore and offshore area. Similar to the plans developed on land, the marine plans inform and guide marine users and regulators across England, managing the sustainable development of marine industries alongside the need to conserve and protect marine species and habitats.

For more information about the use of broad-scale habitat maps in the context of ecosystem-based management, see *Anderson et al.* (2018).

[3] OSPAR Intermediate Assessment 2017: **https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017**
[4] England Marine Plans: **www.gov.uk/topic/planning-development/marine-planning**

EUSeaMap products have been used for assessing and reporting the status of European seas and potential cumulative impacts, designing ecologically coherent MPA networks, for regional mapping of ecosystem services and informing marine planning.

Brittle stars and crustose communities on rock, Solan Bank, Scottish Continental Shelf.

3 Principles behind making broad-scale seabed habitat maps

Due to to the practical problems and high costs associated with *direct* mapping of the seabed, particularly in deep areas, coupled with the vastness of the area being mapped, a fundamental principle in the creation of such an ambitious map is that of Connor et al. (2006):

> [it is] *recognised* [that there is] *strong correlation between environmental parameters and ecological character, such that mapping* ***environmental parameters*** *in an* ***integrated manner*** *can successfully be used to produce ecologically relevant maps.*

In other words, it is possible to produce a 'predictive map' of expected seabed habitat types by combining a series of proxy measurements, such as water depth and light levels, and using statistical analysis and a set of rules for combining spatial information in a geographical information system (GIS).

Principal drivers for seabed habitat distributions depend on the biogeographic region, but can include the type of seabed substrate (rock, mud, mixed sediment, etc.), depth, light availability, oxygen, salinity and the energy of water movements, among others. To describe the variation in environmental conditions with depth, EUNIS divides subtidal habitats into zones: infralittoral, shallow circalittoral (or circalittoral), deep circalittoral, and deep sea (**Figure 3**). In EUSeaMap, it was decided to further subdivide the deep sea zone into bathyal and abyssal zones (in the Atlantic and Arctic, bathyal is further divided into upper, mid and lower bathyal and upper, mid, lower abyssal zones), following scientific literature and recognising the diversity of these huge areas.

Another factor that can be fundamental in driving habitat types is the degree of exposure to wave and water-current energy (**Figure 5**). For some basins that are more enclosed, other parameters, such as salinity, presence of large rivers, oxygen levels and temperature of water at the seabed, are also considered to be fundamental for habitat mapping. For example, the salinity regime is considered in the EUSeaMap habitat model of the Baltic Sea.

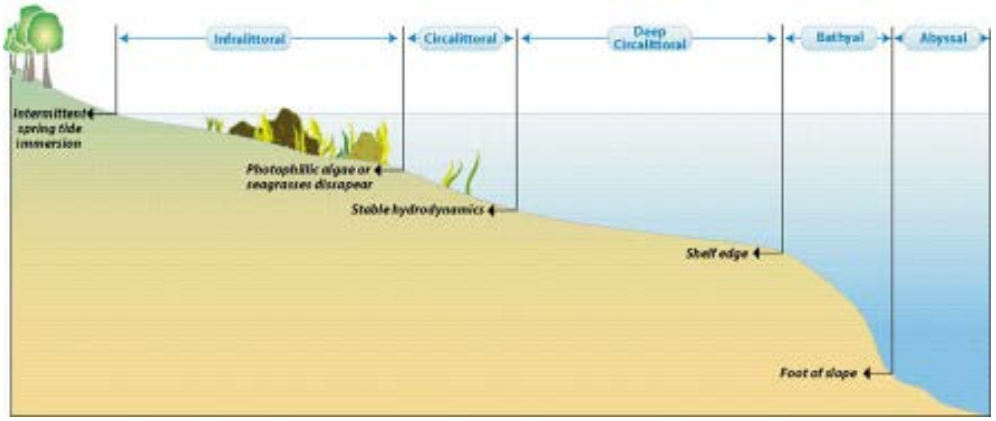


Figure 3 The division of marine sublittoral habitats into biological zones. ©MESH Atlantic Blue Box, 2013.

Figure 4 Deep sea rocky habitats from the north-east Atlantic: Antohn Dohrn SeaMount. ©JNCC.

Figure 5 Examples of an exposed rocky habitat and a more sheltered muddy habitat from the north-east Atlantic.

4 Generating the maps

EUSeaMap is based on a consistent method that takes into account the diverse range of seabed habitats found in different regions.

The first step is to acquire the best of the available spatial data for several environmental variables. This includes data provided by EMODnet Geology and Bathymetry thematic portals (see EMODnet box). The continuous data are organised, manipulated and classified into biologically-meaningful classes (**Figures 6** and **7**). These classified data layers can be combined by 'layering' the data in GIS to create a combined output describing the habitat (**Figure 6**). The principal input layers are the type of seabed substrate and the biological zones. Depending on the basin, layers of hydrodynamic energy levels, oxygen regime, salinity and/or temperature are also produced. For example, the hydrodynamic energy layer is divided into 'low', 'medium' and 'high' classes.

Angelshark *(Squatina squatina)* resting camouflaged on the seabed. Canary Islands, East Atlantic Ocean.

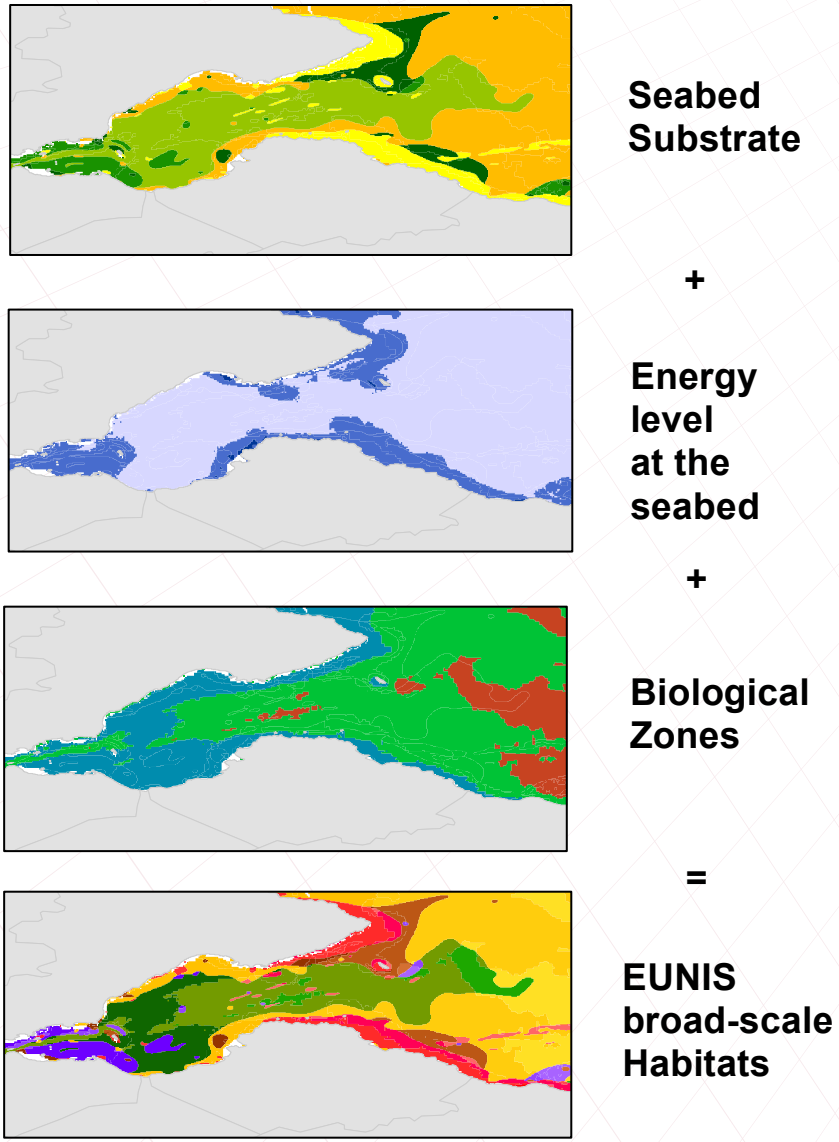


Figure 6 Illustration of how a predictive habitat map can be created by 'layering' data in GIS.

Blue mussel (*Mytilus edulis*) banks in Norwegian waters

The EUSeaMap model was developed in ESRI™ ArcGIS ModelBuilder, and can be saved and executed multiple times, which ensures the systems are repeatable and easily updated when new layers or methodologies are available.

As well as careful evaluation of contributing data and refining statistical methods for its interpretation, it is necessary to define meaningful *thresholds for likely changes in habitats*: in each input layer these are used to define the boundaries between classes, where the change in the physical conditions reaches a critical point that defines an expected change in habitat type (at the map-scale adopted in EUSeaMap, 250m x 250m blocks). For example, the infralittoral zone is generally defined as the area of the seabed where photosynthetic algae is able to grow (**Figures 8a, 8b** and **Figures 9a, 9b**). In most basins in EUSeaMap, a threshold amount of light reaching the seabed was used to define the lower boundary of the infralittoral zone.

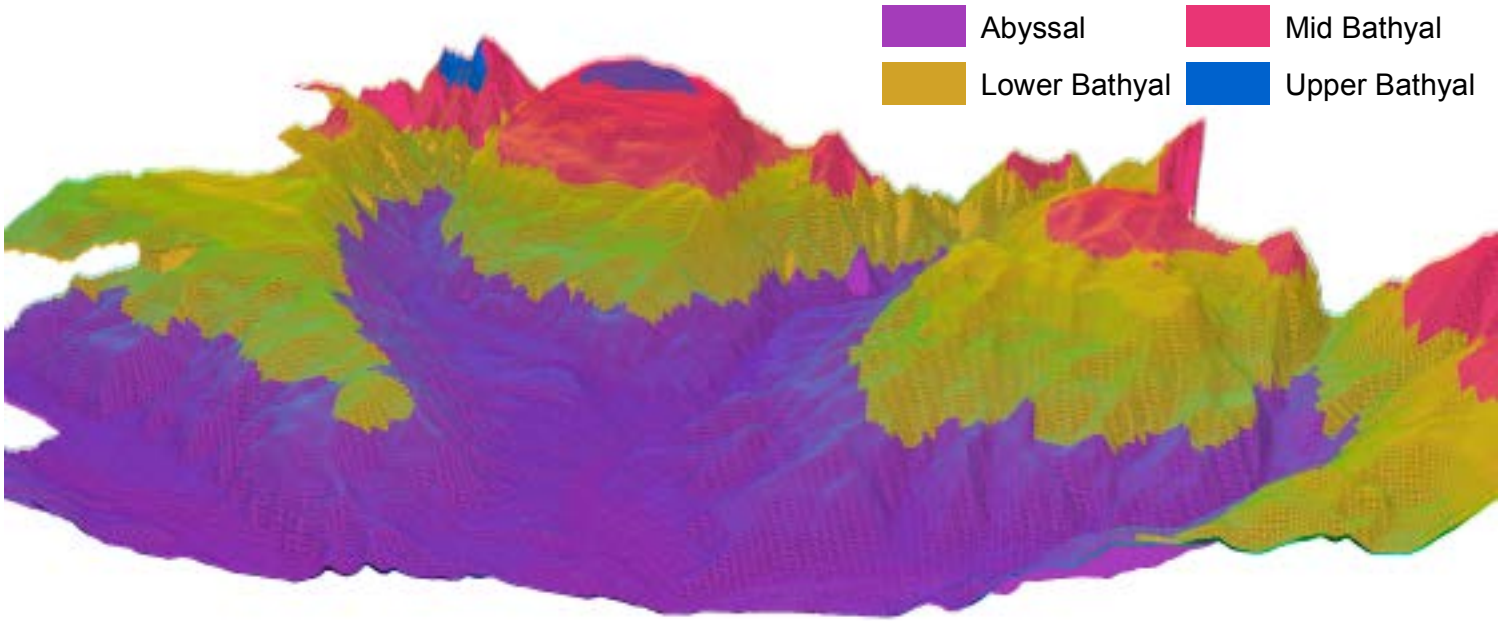


Figure 7 Example of an input layer: The modelled biological zones layer used in EUSeaMap to predict seabed habitats. Input layers are also useful per se and are available online through the EUSeaMap web portal.

Figure 8a The amount of light reaching the seabed affects the distribution of life in the Norwegian sea. Example of a habitat of the infralittoral zone, dominated by photosynthetic organisms.

Figure 8b Habitat of the circalittoral zone, where light is scarce and animal life (rather than plant life) dominates.

Figure 9a Biogeographic differences: similar light conditions to those in **Figure 8a and 8b** in a different basin. Mediterranean Sea habitats.

Posidonia oceanica seagrass beds support a rich habitat in the infralittoral zone of Mediterranean Sea organisms.

Figure 9b Mediterranean coralligenous communities in the circalittoral zone.

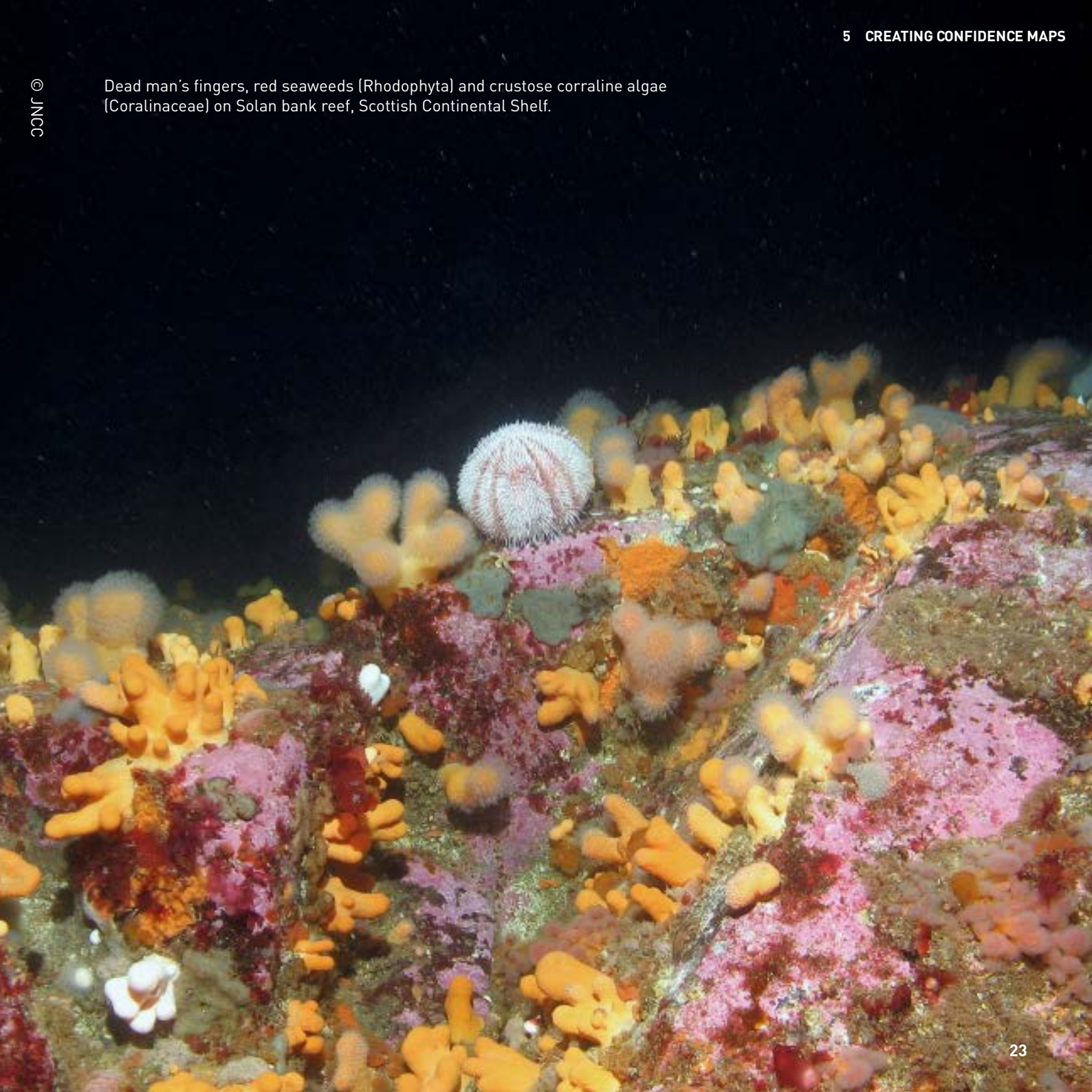
5 Creating confidence maps

EUSeaMap is based on a consistent method that takes into account the diverse range of seabed habitats found in different regions.

The confidence assessment method follows a consistent structure and method for all regions. The assessment consists of a hierarchy of confidence assessments that cover confidence in the quality of the input layers and uncertainties associated with threshold values used to categorise these layers.

Each assessment is given as a rating of high (H), moderate (M) or low (L) confidence to ensure consistency across data types and regions, and, in most cases, reflect the lack of detail available to produce a more detailed assessment. These are combined into a single final value of confidence in the habitat type.

The confidence assessment method is simple and flexible enough to be applied to the multitude of different data types and methods used to create the primary and secondary data layers that make-up EUSeaMap.



Dead man's fingers, red seaweeds (Rhodophyta) and crustose corraline algae (Coralinaceae) on Solan bank reef, Scottish Continental Shelf.

6 Products

EUNIS EUSeaMap – EUSeaMap broad-scale maps classified according to the EUNIS habitats classification are available to end users at 250m resolution (**Figure 10**), which roughly correspond to a 1:500,000 scale. The EUNIS EUSeaMap maps are region-specific and more detailed than the MSFD broad habitat types map, due to the specific conditions relevant to each region.

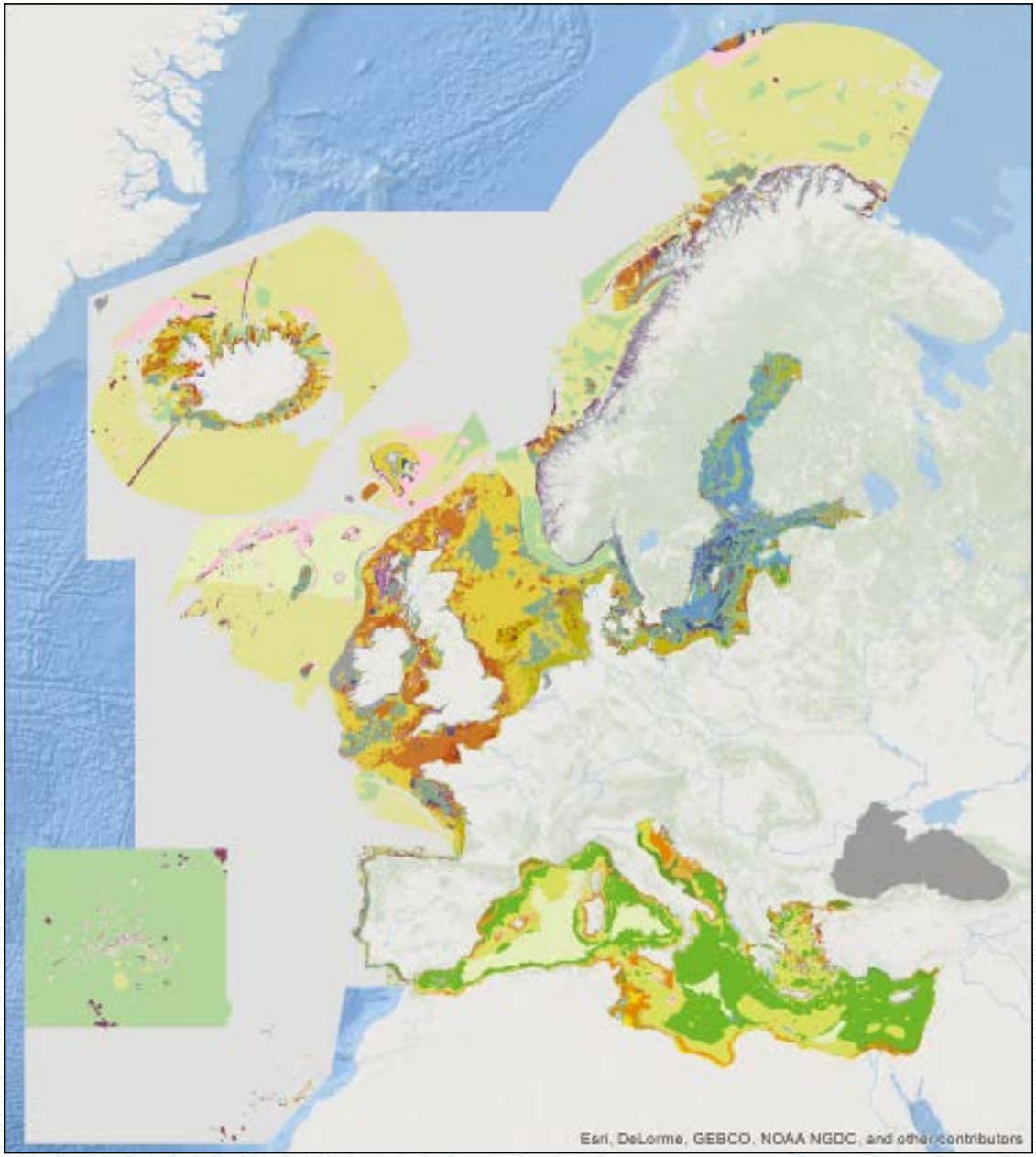


Figure 10 The EUNIS EUSeaMap (Version 2016).

EMODnet Seabed Habitats MSFD Broad Habitat Types 2017 – A single harmonised broad-scale habitat map is available for all **European seas** (**Figure 11**). Its coverage will be further extended by 2020. The habitats in this map are consistent between basins and correspond to the MSFD 'Benthic Broad Habitats Types', as defined in May 2017.

MSFD Benthic Broad Habitat Types

- Infralittoral coarse sediment
- Infralittoral mixed sediment
- Infralittoral mud
- Infralittoral rock and biogenic reef
- Infralittoral sand
- Circalittoral coarse sediment
- Circalittoral mixed sediment
- Circalittoral mud
- Circalittoral rock and biogenic reef
- Circalittoral sand
- Offshore circalittoral coarse sediment
- Offshore circalittoral mixed sediment
- Offshore circalittoral mud
- Offshore circalittoral rock and biogenic reef
- Offshore circalittoral sand
- Circalittoral mud or Offshore circalittoral mud
- Upper bathyal sediment
- Upper bathyal rock and biogenic reef
- Upper bathyal sediment or Upper bathyal rock and biogenic reef
- Lower bathyal sediment
- Lower bathyal rock and biogenic reef
- Lower bathyal sediment or Lower bathyal rock and biogenic reef
- Upper bathyal sediment or Lower bathyal sediment
- Upper bathyal rock and biogenic reef or Lower bathyal rock and biogenic reef
- Abyssal
- Not applicable

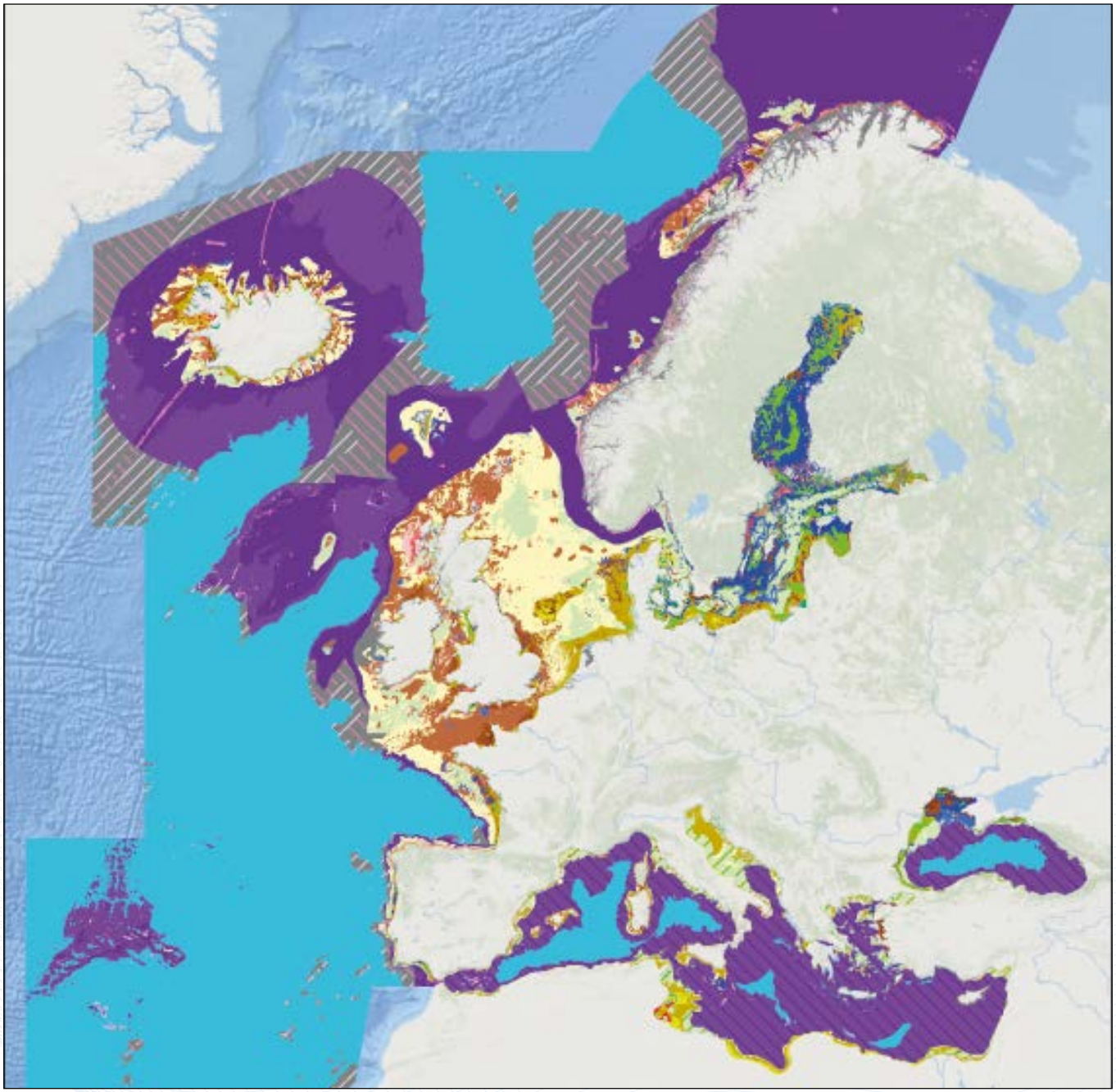


Figure 11 The MSFD benthic broad habitat types EUSeaMap (Version 2016).

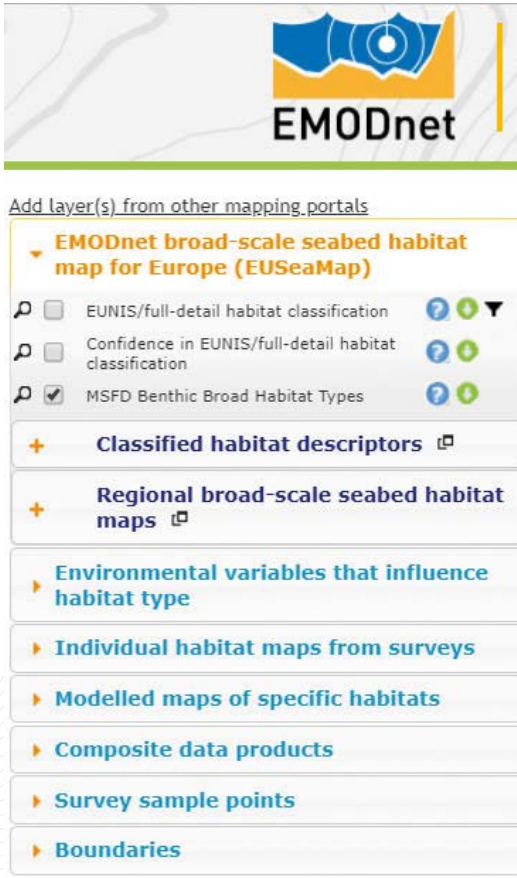
7 Making data available: the web portal

EUSeaMap products and reports are all available through the EMODnet Seabed Habitats interactive online mapping portal: **www.emodnet-seabedhabitats.eu**

The EMODnet Seabed Habitats interactive mapping portal is a free resource for viewing and downloading not only the EUSeaMap modelled broad-scale maps but also the EUSeaMap confidence layers and the input data layers used in EUSeaMap (such as depth, kinetic wave energy, light penetration or halocline layer, among others).

All layers can be downloaded in GIS format to be easily overlaid with users' datasets or exported using the Web Map Service (WMS) or the Web Feature Service (WFS) to personal desktop GIS applications or to other web mapping portals.

Metadata describing the file content is provided with the files following INSPIRE Directive[5] standards.



[5] INSPIRE: European Directive 2007/2/EC.

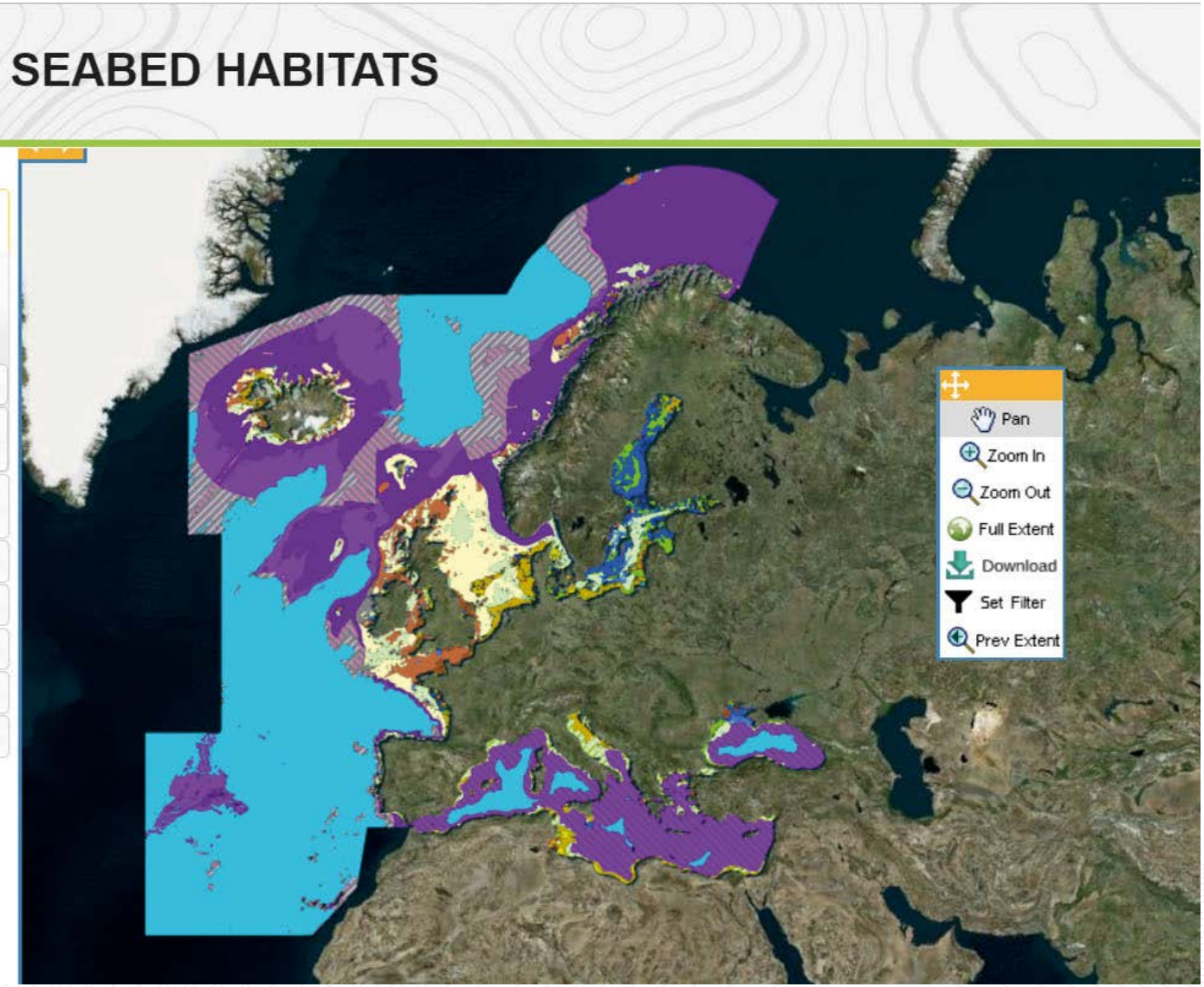


Figure 12 A screen grab from the web portal showing the interactive map that can be used to view and download the EUSeaMap layers.

8 The future of EUSeaMap

In the framework of **Marine Knowledge 2020**, EMODnet in Phase 3 (2017–20) works towards "providing a seamless multi-resolution digital map of the entire seabed of European waters providing highest resolution possible in areas that have been surveyed, including topography, geology, habitats and ecosystems; accompanied by timely information on physical, chemical and biological state of the overlying water column as well as oceanographic forecasts"[6].

During Phase 3 of EMODnet Seabed Habitats, EUSeaMap will be further improved:

- **Increasing spatial coverage** – this time the spatial coverage will be extended to include more of the Barents Sea and anywhere else in Europe where there is seabed substrate data.
- **Updating input data and thresholds** – EUSeaMap will make use of available improved dataset as they become available (substrate and bathymetry, for example), form modelling and threhsodl calculation.
- **A multi-scale map** – EUSeaMap will move from being at a single broad-scale to a multi-scale map making use of higher resolution data where it exists.

[6] EMODnet: www.emodnet.eu

Yellow sun star (Solaster endeca) surrounded by brittlestars (Ophiothrix fragilis), Shetland, Scotland, September.

9 The EMODnet Seabed Habitats Partnership

The Partnership comprises government agencies, research institutions and private companies with proven national and international expertise in benthic ecology, spatial habitat modelling, data collation and management, web delivery, geology, oceanography and marine policy.

In EMODnet Phase 1 (2009–12), a consortium of seven partners from five countries, led by the UK government's nature conservation advisor (JNCC), came together to deliver the Seabed Habitats theme. In 2013–16 a consortium of nine partners worked together to deliver EMODnet Seabed Habitats (Phase 2), under the leadership of French research institute Ifremer.

Centre of Marine Sciences, Portugal
(Phase 3)

Danish Ministry of the Environment, Agency for Spatial and Environmental planning
(Phase 1)

DHI (International consulting and research organisation, former Danish Hydraulic Institute)
(Phase 1)

GeoEcoMar (Romanian national research and development institute for marine geology and geoecology)
(Phase 2 and 3)

Geological Survey of Denmark and Greenland
(Phase 3)

Hellenic Centre for Marine Research (National laboratory of Greece on oceanography and marine research)
(Phase 2 and 3)

In Phase 3, JNCC is the leader once again, with a consortium of 12 partners covering the full geographic scope of the project area.

IEO (Spanish national oceanographic institute)
(Phase 1 and 2)

Ifremer (French national institute for marine research)
(Phase 1, 2 [lead] and 3)

IOBAS (Institute of Oceanology, Bulgarian Academy of Sciences)
(Phase 2 and 3)

ISPRA (Italian institute for environmental protection and research)
(Phase 1, 2 and 3)

JNCC (UK government's nature conservation advisor)
(Phase 1 [lead], 2 and 3 [lead])

Marine Institute, Ireland
(Phase 3)

Natur Vårds Verket (Swedish Environmental Protection Agency)
(Phase 1)

NIVA (Norwegian Institute for water research)
(Phase 2 and 3)

NIVA denmark.The Norwegian Institute for Water Research, in Denmark)
(Phase 2 and 3)

Finnish Environment Institute
(Phase 3)

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A rocky reef teeming with life in the Tyrrhenian Sea, West Mediterranean.

11 Acknowledgements

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- Phase 1: MARE/2008/07/ EC
- Phase 2: MARE/2012/10
- Phase 3: EASME/EMFF/2016/1.3.1.2

Grey seal (*Halichoerus grypus*) swimming amongst kelp, Northern North Sea.

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SEABED HABITATS

Unlocking seabed habitat data in Europe