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Mapping seabed habitats over large areas: prospects and limits

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List of abbreviations and acronyms

CMEMS	Copernicus Marine Service
DTM	Digital Terrain Model
ESH	EMODnet Seabed Habitats
EU	European Union
FAO	The Food and Agriculture Organization
GAM	Generalized Additive Models
GLM	Generalised Linear Model
HELCOM	The Baltic Marine Environment Protection Commission is an intergovernmental organization and a regional sea convention in the Baltic Sea area
ICES	International Council for the Exploration of the Sea
JNCC	A partner of the EMODnet Seabed Habitat consortium
KdPAR	Attenuation coefficient of the PAR
MSFD	Marine Strategy Framework Directive
OSPAR	The mechanism by which 15 Governments and the EU cooperate to protect the marine environment of the North-East Atlantic.
PAR	Photosynthetically Available Radiation
SDM	Species Dictribution Modeling
WGDEC	ICES Working Group on Deep-water Ecology
WGMHM	ICES Working Group on Marine Habitat Mapping

Contents

Abstract

Since its inception, in 2009, EMODnet Seabed Habitats has brought together a European consortium of specialists in benthic ecology and seabed habitat mapping to develop a transnational broad-scale seabed habitat map, named EUSeaMap. EUSeaMap is the only pan-European cartographic product that provides a standardised trans-boundary overview of the spatial distribution of seabed habitats across Europe. As such, it has been extensively used in various applications such as Marine Protected Area evaluation or cumulative impact of stressors on habitats, and it is likely to be used again in the future in various marine ecosystem assessments. It is therefore important to continue to update it regularly when significant improvements to the data products that constitute its basis, i.e. the seabed substrate, bathymetry or environmental variables, are published.

In addition to EUSeaMap, it would be desirable to provide stakeholders with products on the spatial distribution of targeted habitats/biotopes such as those of conservation interest (e.g. kelp forest, seagrass meadows, coral reefs). Some techniques, hereafter referred to as "SDMs", are acknowledged to be effective in mapping these habitats.

We argue that a program that would use these techniques to map these key habitats/biotopes in European waters would be invaluable, but such a program can only be achieved if there is a significant improvement in the spatial resolution of environmental variables. An important message of this report is therefore that the EU should consider funding a project that would develop spatially explicit high-resolution (at least 500 m) data products on key variables (light availability, hydrodynamics, wave exposure, temperature, oxygenation, chlorophyll-a, phosphate, nitrate, etc.) that would spatially cover all European waters.

1 Introduction

Since its inception, in 2009, EMODnet Seabed Habitats has brought together a European consortium of specialists in benthic ecology and seabed habitat mapping to develop a transnational broad-scale seabed habitat map.

The partners first collaborated in EMODnet Phase 1 (2009-2012) to deliver a prototype predictive seabed habitat map in four trial basins (Greater North Sea, Celtic Seas, Baltic, Western Mediterranean). This predictive model was named **EUSeaMap** (Cameron and Askew, 2011). In EMODnet Phase 2 (2012-2016), the consortium extended EUSeaMap's coverage to all European regions and worked on improving the method, particularly for the calculation of thresholds that best reflect the communities that occupy the habitats (Populus et al, 2017). During the first two years of EMODnet Phase 3 (2017-2021), the spatial coverage was extended further north to include the Barents Sea, and the spatial detail was substantially improved. This was made possible by the improvements of input predictor variables created by other EMODnet thematic lots or other initiatives such as CMEMS (Vasquez et al, 2020).

In the chapters below, we attempt to examine areas where progress is possible, and also where it is not. We also discuss what other types of complementary spatially explicit seabed habitat products may further be of use to stakeholders.

2 Improving EUSeaMap

2.1 Method

In simple terms, the method combines individual habitat descriptor[1] maps to create a map of seabed habitats that can then be translated into different habitat classifications such as EUNIS or the MSFD broad habitat types. For example, in Figure 1.1 the habitat map in the EUNIS classification is the result of the combination of three habitat descriptors, namely seabed substrate, biological zones (also referred to as biozones) and levels of energy at the seabed.

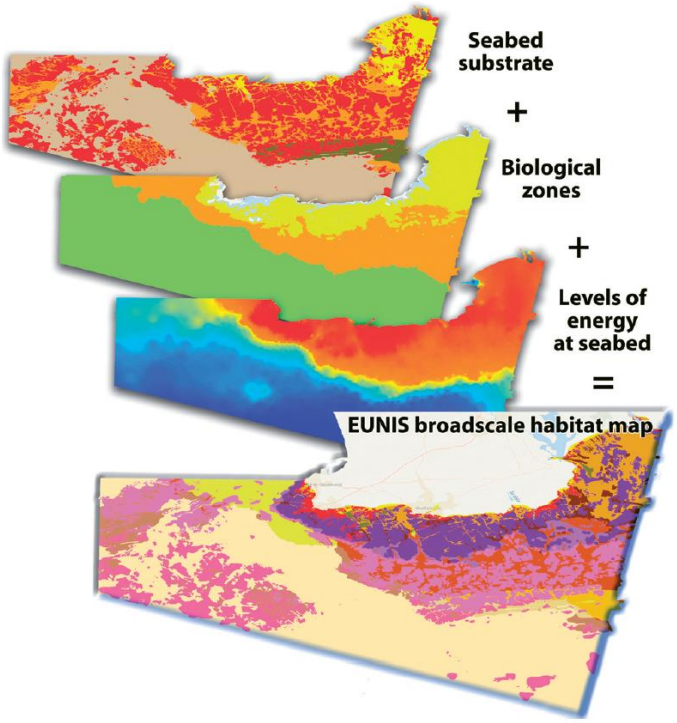

Figure 1.1: The broad-scale seabed habitat map approach comprises combining habitat descriptor maps (in Vasquez et al, 2015)

The seabed substrate input dataset is a compendium of historical maps from a variety of sources harmonised in the Folk sediment classification (Folk, 1954). It mainly includes the EMODnet Geology product referred to as "Seabed Substrate".

The biological zone data products have been fully developed by EMODnet Seabed Habitats. In EUNIS, the seabed is divided into five main biological zones: Infralittoral, shallow Circalittoral, deep Circalittoral, Bathyal and Abyssal. The role of EMODnet Seabed Habitats has been to i) agree on a clear definition of the individual biozones, with the challenge that the definition may vary from one European region to another, ii) develop spatially-explicit gridded datasets describing the seabed environmental characteristics that drive the spatial

[1] A habitat descriptor is e.g. seabed substrate types or biological zones

distribution of biological zones (e.g. light at the seabed for the infralittoral), and iii) define the thresholds that enable the classification of the environmental gridded datasets into biological zones.

Other habitat descriptor data products such as energy levels in the Atlantic or oxygenation in the Black Sea have also been developed as part of EMODnet Seabed Habitats.

2.2 Areas for improvement

2.2.1 Classification

The marine section of the EUNIS habitat hierarchical classification, developed and maintained by the European Environment Agency (EEA), has been significantly transformed. The detailed parts of the new classification were released in March 2020 under the name "EUNIS marine habitat classification 2019" (referred to as "EUNIS 2019" hereafter). In this version, Levels 1-3 of EUNIS marine section have been restructured to improve consistency in the structure and accross regions (Evans et al, 2016).

For all regions, Level 2 is divided by biological zone and seabed substrate. As opposed to the previous version, the bathyal zone is subdivided (namely into upper bathyal and lower bathyal). Soft sediment classes are defined by the relative proportions of mud, sand and gravel, based on the Folk classification (Folk, 1954). Level 2 also incorporates biogenic habitats, i.e. habitats where the seabed substrate is constructed by living organisms (e.g. coral reefs, Posidonia beds).

Regarding EUSeaMap, it is important to raise the following issues:

- In the Mediterranean, the bathyal will need to be subdivided to upper and lower bathyal. This is not the case for the other regions (the subdivision already exists in EUSeaMap for the Atlantic, there is no bathyal in the Baltic, and the bathyal is anoxic in the Black Sea)
- Biogenic habitat polygons from survey maps will have to be incorporated into EUSeaMap, as has been done so far in the Mediterranean Sea for the Posidonia beds.
- In the Black Sea, the communities that have been identified as part of EMODnet Seabed Habitats (Populus et al, 2017; Vasquez et al, 2020) have not been included at the biotope[2] level of EUNIS 2019. The purpose of EUSeaMap is to provide users with a cartographic representation of the habitats decribed at Level 1-3, which are surrogates for the communities that occupy them. For the users to use the maps appropriately, it is therefore essential that key communities are present in the classifications.
- In contrast with the previous version (EUNIS 2007-11), EUNIS 2019 does not dedicate a hierarchical level to the description of wave- and current-induced energy at the seabed for rocky habitats.

2.2.2 Seabed substrate

Integration of new fine-scale, survey-level maps

It is expected that more seabed substrate data will become available in the future. Therefore, EUSeaMap will have to be updated on a regular basis, possibly every two years. At some point, a decision will have to be made on the required level of detail of the seabed substrate maps that are to be integrated into EUSeaMap, e.g. is it appropriate to include a detailed survey-level map, covering a small area, into a broad-scale map?

[2] Biotope: a habitat and its associated species community, described in Levels 4-6 of the EUNIS classification

Integration of inovative products

A significant part of EUSeaMap's variance lies in the seabed substrate data products that are used as input. These data products are compilations of harmonised historical maps, the features of which have been delineated using heads-up digitising. In the best case, manual delineation has been performed in sonar and/or bathymetry images but, in some locations, delineation has been carried out without the aid of visual support. In addition, some of the original data sources were not in the Folk classification, and the translation into Folk of the original classification may not have been straightforward, leading to some uncertainty, particularly where the original class emcompasses multiple classes in the Folk classification.

EMODnet Geology has been working on a more objective approach to seabed substrate mapping. They have been testing machine learning approaches in creating seabed sediment maps from descriptive and numerical predictors such as terrain metrics, exposure, or sedimentation rates. As a result, they may be able to create data products describing probability for each sediment type along with uncertainty metrics.

We believe that this type of continuous gridded data product (as opposed to manually delineated polygons in the current EMODnet geology seabed substrate product) has the potential to substantially improve EUSeaMap by providing more spatial detail and enabling the use of ecologically-relevant thresholds to classify the data product in the different sediment types. To assess the appropriateness of this product for EUSeaMap, benthos observations from surveys would be used to determine ecologically relevant thresholds to categorise the continuous layer of seabed substrate in each of the seabed substrate types considered in the EUNIS classification.

2.2.3 Biozones

Black Sea

In the Black Sea the main issue is the quality of the bathymetry data. In most parts of the Sea, the quality index provided by EMODnet Bathymetry for their high-resolution DTM is low to moderate. The low quality is particularly true in coastal waters, with the exceptions of Burgas Bay (south of Bulgarian coast) and a narrow strip along the Romanian coast. As bathymetry is key to appropriately discriminate individual biozones, EUSeaMap will have to be regularly updated as, and when, EMODnet Bathymetry's DTM has significant progress in the region.

Mediterranean Sea

So far, in the Mediterranean the circalittoral zone has not been formally divided into "shallow" and "offshore" sub-zones. However, within a same substrate a specific threshold value was used to differentiate between circalittoral bicoenosis. This threshold can be applied to subdivide the circalittoral zone. In order to comply with EUNIS 2019, the bathyal zone will also need to be subdivided in upper and lower bathyal. A depth threshold will need to be determined either from statistical analyses (should appropriate data on biotope occurrence be available) or from the literature.

Baltic Sea

In the Baltic Sea, the gridded data product on halocline occurrence probability, which has been used to differentiate between circalittoral and offshore circalittoral, was developed in 2010 as part of EMODnet Phase 1 and is coarse resolution (approximately 10km). Increasing the resolution would facilitate the delineation for the boundary between the two biozones with greater accuracy.

North-East Atlantic and Arctic

The delineation between shallow circalittoral and offshore circalittoral has the potential to be improved. By definition, this boundary is where the temperature of the seabed becomes stable. The concept of the wave base (depth at which the seabed is no longer affected by wave action) has been used, so far, as a proxy to thermal stability. The rationale for using wave data rather than seabed temperature data is that wave data products are more accurate and easier to find than seabed temperature data products. Should more accurate seabed temperature products become available for the entire area of interest, an opportunity may arise to improve the delineation of this boundary.

2.2.4 Other habitat descriptors

The nature of other habitat descriptors depends on the European region. In the North-East Atlantic, the energy induced by water movement has been considered for rocky habitats; in the Baltic Sea, salinity is acknowledged to be a key factor; In the Black Sea, oxygen availability at the seabed is an important issue.

As mentioned in section 2.2.1, in contrast with the former version EUNIS 2019 does not dedicate a hierarchical level to the description of wave- and current-induced energy at the seabed for rocky habitats. It is noteworthy that the MSFD broad habitat types[3] classification does not consider energy either. It is therefore quite likely that EMODnet Seabed Habitats will stop developing a data product on these energy levels (i.e. a data product classifying energy in "low", "moderate" and "high").

In the Black Sea, in EUNIS 2019 no reference is made to oxygenation levels (i.e. oxic, suboxic, anoxic). Given its particular ecological significance in the Black Sea, it would however be appropriate to maintain and further develop a data product on this habitat descriptor, for which knowledge of the spatial distribution is crucial. Indeed, seabed habitats in the anoxic zone have been identified by Member States as exceptions under Article 14 of MSFD because good environmental status cannot be achieved through politicy measures due to natural causes.

In the Baltic Sea, a seabed habitat classification that describes salinity levels was proposed for EUSeaMap within the framework of ur-EMODnet (with classes such as "Deep circalittoral sand in Euhaline", or "Deep circalittoral sand in Polyhaline"). This proposal was not retained by the experts who developed HELCOM HUB and EUNIS 2019. As a result, in the future it may be not relevant to continue publishing EUSeaMap in that bespoke classification. However, as salinity levels are also used in the rules used to differentiate between the individual biozones, the data product on salinity levels will have to be maintained and further developed.

[3] defined in COMMISSION DECISION (EU) 2017/848

3 Mapping the biotopes - The SDM approach

The EUSeaMap technique (classification, using thresholds, of gridded continuous environmental data into categorical data products) is appropriate for mapping the abiotic categories that are a combination of the seabed substrate types and the other habitat descriptor classes that are indicative of the overall nature of a place on the seabed. Despite its abiotic character, EUSeaMap has ecological relevance as individual broad habitat types support a characteristic suite of plant and/or animal communities, i.e. reflects the species or communities of species that occupy them. For example, where "Infralittoral rock" habitat occurs, there is no certainty that photophilic algae occur, but it reflects that all conditions required for photophilic algae to exist are present.

However, it is recognised that some stakeholders would be better informed with biotope[4] maps rather than with maps on the habitats that the communities occupy.

It would not be realistic, nor relevant, to produce maps of all biotopes considered in the EUNIS classification. A selection would inevitably have to be made, e.g. those that have conservation interest because they are threatened (see OSPAR List of Threatened and/or Declining Habitats or FAO's Vulnerable Marine Ecosystems – VMEs -), and/or are carbon sinks (e.g. seagrass) and/or are biodiversity spots (e.g. kelp forests, coral reefs).

Species Distributions Models (SDMs), also known as Habitat Suitability Models (HSMs), Ecological Niche Models (ENMs), and Predictive Habitat Models (PHMs), are widely used to infer the ecological requirements of species and to predict their spatial distribution. Such models have been applied for decades in the terrestrial realm to a variety of questions in ecology, including spatial conservation prioritisation and forecasting the effects of climate change on species distributions. In the marine realm, applications are more recent but it has also been extensively used (for a review of European initiatives see Virtanen et al, 2019). In a way, the principle is the same as for EUSeaMap: a joint use of point observations and full-coverage environmental data products to predict a spatial distribution (figure 3.1). The technique, however, is quite different:

1) The environmental variables are not limited to those considered in habitat classifications.

2) Several methods (e.g. regression methods such as GLM / GAM, machine learning methods such as random forest and boosted regression trees) can be used in the same sequence and their results can be ensembled in one single map.

3) It is applicable to infer biotopes.

So, if these techniques are so effective, why aren't they being used more widely?

A possible answer to this question may be the reluctance of stakeholders to use them because they may question their ability to produce results that can inform them appropriately, or they may be expecting standards to use them appropriately. This issue was raised as part of the 2020 ICES WGMHM and WGDEC meetings and, as a result, a workshop on the "Use of Predictive Habitat Models in ICES Advice" will occur in early February 2021[5], which is aimed at providing benchmark standards for the use of such models in ICES advice related to the distribution of Vulnerable Marine Ecosystems (VMEs), with a view to avoid misuse or misinterpretation of model outputs and give greater credibility to SDM model-based advice.

Another answer to this question may be that in order to get the most out of these techniques, significant progress is required in the spatial resolution of environmental data used as input to the models. The better the resolution the better the result, but we estimate that a resolution of around 500m would provide appropriate results in many cases for regional to transnational assessments. Currently the CMEMS platform provides data products for environmental variables at the resolution of 4km, and is aiming 1km in the future for hydrodynamics

[4] Biotope: a habitat and its associated species community, described in Levels 4-6 of the EUNIS classification

[5] http://ices.dk/community/groups/Pages/WKPHM.aspx

products. This resolution is not fit-for-purpose. An alternative to operational platforms may be to fund a project that would run high resolution models in order to produce high resolution data products covering a limited time window (e.g. climatologies over 5 years) for a set of ecology-relevant environmental variables (e.g. hydrodynamics, waves, biogeochemical variables).

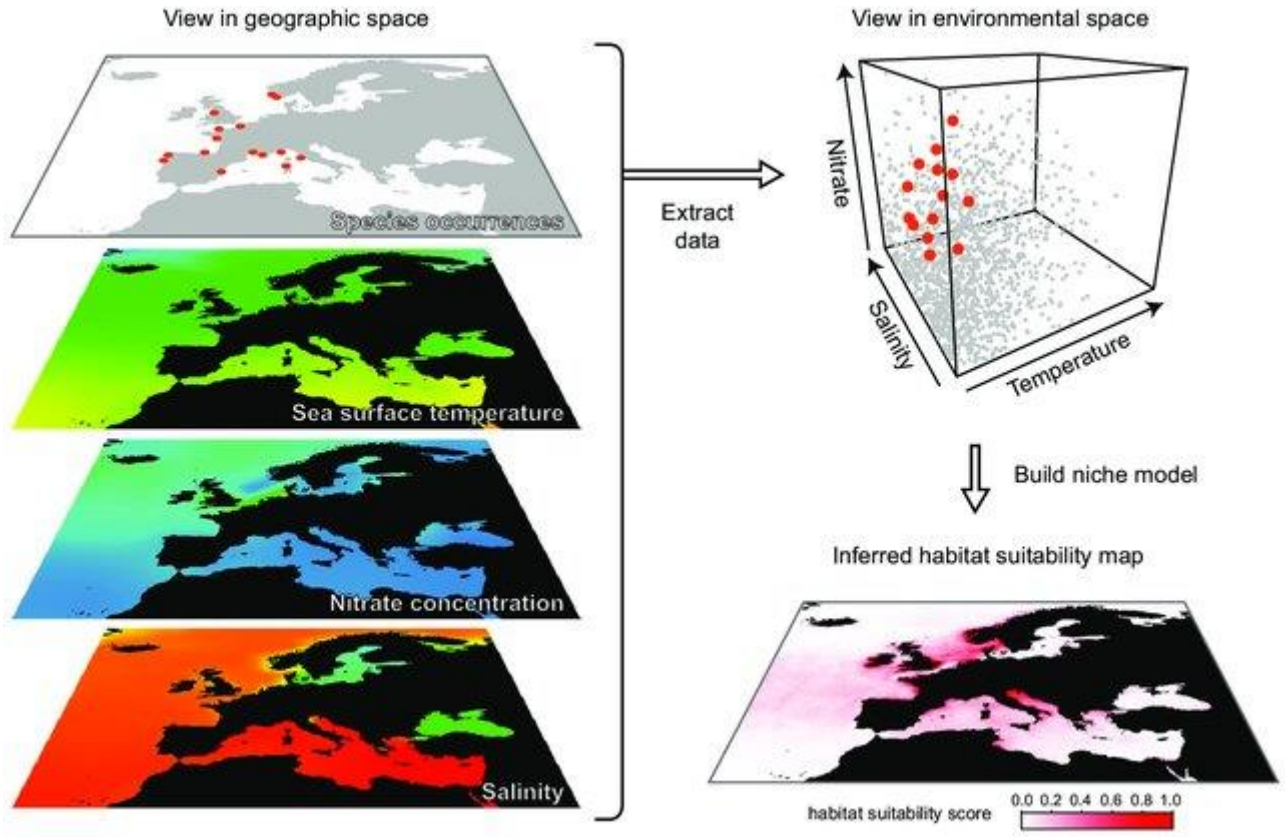

Figure 3.1: the SDM approach (in Marcelino & Verbruggen, 2015). A model is fitted based on the information about the species' environmental preferences. The model and the environmental data products are then used to predict full-coverage habitat suitability.

4 Hybrid products: combining EUSeaMap with other sources

In 2021, EMODnet Seabed Habitat will prepare for OSPAR a composite data product showing the best evidence for extent of seabed habitats in the NE Atlantic, classified to level 3 of EUNIS version 2007-11. This product, needed for the assessment of the OSPAR common indicator named "Extent of Physical Damage to Predominant and Special Habitats", will be a combination of EUSeaMap 2019 and EUNIS broad habitat type polygons from survey maps.

Similarly, for the cumulative impact assessments in the 3rd holistic assessment of the Baltic Sea (HOLAS III), which will start in 2022, there is a process ongoing in HELCOM to find where there might be more detailed maps on broad habitat types in view of combining these maps with EUSeaMap 2021.

It is expected that the requirement for products combining EUSeaMap and any better available evidence from survey will grow in the future. However, is it within EMODnet Seabed Habitat's remit to make that kind of composite product? In "any better available evidence from survey", "better" is quite subjective, i.e. will always depend on the user's purpose. Some users, as in the above-mentioned examples, may require to combine EUSeaMap with broad habitat type polygons from finer-scale data products; some others may like to combine EUSeaMap with fine-scale data on some habitats of conservation interest (e.g. seagrass beds, kelp forests); some may want a product that combines EUSeaMap with polygons of both broad habitat types and habitats of conservation interest etc. In other words, various adaptations of such hybrid products would have to be created in order to satisfy every user and, as a result, there would be a high risk of users being confused by the availability of a series of EUSeaMap-based products which would be only subtly different from each other.

Therefore, EMODnet Seabed Habitats should continue to concentrate efforts on making sound base products such as EUSeaMap or the composite products made from survey maps. Making bespoke products from these base products would be left to the users, depending on their purpose. It is important that users are provided with good tools to retrieve the best habitat dataset available at any location. This is what EMODnet Seabed Habitats has been working towards, and the future integrated EMODnet portal, planned for mid-2022, will undoubtedly offer this capability.

5 Conclusion

EUSeaMap is the only pan-European cartographic product that provides a standardised trans-boundary overview of the spatial distribution of seabed habitats across Europe. As such, it has been extensively used in various applications such as Marine Protected Area evaluation or cumulative impact of stressors on habitats (for a review, see Andersen et al, 2018; for recent use cases see the web portal[6]), and it is likely to be used again in the future in various marine ecosystem assessments, some of which are already in preparation (cumulative impact assessments as part of HOLAS III in the Baltic Sea, OSPAR assessment of physical damage to habitats). It is therefore important to continue to improve it by regular integration of significant improvements in data products on seabed substrate, bathymetry or environmental variables.

Stakeholders would also need to be informed on the spatial distribution of habitats/biotopes that have conservation interest, such as those which provide ecosystem services (e.g. breeding and nursery, shoreline stabilisation and erosion control, carbon sequestration), typically kelp forests, coral reefs, seagrass beds or mangroves. There are techniques based on statistical modeling, above referred to as "SDMs", for mapping

[6] https://www.emodnet.eu/en/use-cases

these habitats. A program that would use these techniques to map these habitats in European waters would be invaluable, but a strong condition for the success of this program would be a major improvement in the spatial resolution of the environmental variables that are necessary for these techniques.

6 Recommendations for follow-up actions by the EU

The EU is invited to:

1) Consider enhancing the collaboration at Regional Conventions level to review and update the EUNIS classification at biotope level, i.e. Levels 4-6. This would be required in all regions, with the highest priority in the Black Sea.
2) Consider funding a project that would develop high-resolution spatially-explicit data products on key variables (light availability, hydrodynamics, wave exposure, temperature, oxygenation, chlorophyll-a, phosphate, nitrate, etc). These variables would ideally:
   - Be averaged over relevant time periods (to be defined)
   - Spatially cover Europe
   - Be at the resolution of 500m at least for most of them, 100m for light availability
   - With values at the seabed
3) Highly dependent on (2) (i.e. not relevant if there is no prior provision of appropriate data products on key environmental variables), consider funding a project using SDMs to develop maps for a selection of key habitats, e.g. those that have conservation interest because they are threatened (see OSPAR List of threatened and declining habitats or FAO vulnerable marine ecosystems -VMEs-), and/or are carbon sinks (e.g. seagrass) and/or are biodiversity spots (e.g. kelp forests, coral reefs)

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