MODELLING SEABED HABITATS

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ABSTRACT

Within the marine environment, the EUNIS classification system attempts to define key environmental drivers that describe natural benthic habitats. The hierarchical nature of the system is initially broad, but becomes increasingly complex at finer biological scales such as communities and species. This project addressed the higher EUNIS levels. Each of the contributing physical parameters were split into categories using threshold values defined with the help of benthic ecologists familiar with the relative influence of such factors on seabed biology. Climatologies were confronted to in situ samples and observations to derive most reliable values. Historic data sets were collated, stitched and harmonised into mosaics which comprehensively covered the area of interest. The criteria analysis model was built in the ArcGIS model builder. Raster data layers were fed into the model at their nominal resolutions with automatic resampling producing a final output cell size of 100m.The model was designed to be as automatic as possible, with a view to enable easy update as new data layers come up. Maps were produced both as web products through WMS services and as paper prints with a dedicated symbology.

1 INTRODUCTION

The importance of seabed habitat mapping has become increasingly apparent in recent years. Information on seabed habitats is essential both for the development of new economic activities and for assessing the impact of these activities on the marine environment. Management policies and actions, including marine spatial planning, need to be informed by the best-available data if they are to achieve long-term sustainable use and management of the marine environment and its resources.

Making a habitat map in the usual way requires a succession of operations ranging from scoping surveys and work at sea by way of acoustic and seabed sampling, followed by data interpretation and map production. This has been amply described by e.g. the Mesh Guide to habitats mapping (Coltman *et al*., 2008). Comprehensive detailed mapping would be most welcome for managing our seas, however it is highly resource consuming and not economically feasible. Therefore in view of the requirements of the Marine Strategy Framework Directive (MSFD), which calls for continuous mapping that can be applied across marine regions, alternatives must be found.

To date there have been substantial efforts to map the marine seabed habitats of Europe at an international scale, following initial works by Roff and Taylor (2000), Connor (2006) with the UKSeaMap Project and Al-Hamdani (2007). These authors used existing physical data owing to its much greater coverage than biological data to create physical maps of the seabed using habitat proxies. However there remained a difficulty in comparing across regions at a European scale, arising from the differences in methodologies and classifications used.

The work presented here shows how some of these difficulties have been overcome to produce a seamless map of the European seabed. Two projects supported this, the EuSeaMap Project (Cameron and Askew, 2011) funded by the EU Commission under the aegis of the

DG/MARE EMODnet initiative, which covers four major European basins, and also its replica at a higher resolution covering the French coast, commissioned by the French Marine Protected Area Agency.

2 RATIONALE

The EUNIS (European Nature Information System) hierarchical habitat classification (Connor et al., 2004; Davies, 2004) has increasingly been used as a standard over the last decade. Many mapping studies are currently applying it and a number of countries have already translated their habitat maps into EUNIS. Although initially more adapted to the North and Celtic Seas, there have been efforts to incorporate additional habitat drivers (e.g. salinity in the Baltic) to make it suitable throughout Europe. As can be seen in figure 1, the EUNIS structure is such that its upper levels are a combination of abiotic factors (also called physical habitats) hosting lower level biota. The uppermost levels are concerned with depth zones – spanning from supralittoral to circalittoral and deep sea – and further down the levels on one side soft substratum is split into its various components (from coarse sediment to mud) and on the other rocky seabed is further described by its exposure, a key biocolonisation driver.

Figure 1 - Examples from the EUNIS hierarchy (in Cameron and Askew, 2011)

Even at the abiotic level addressed here, the biological relevance of these habitats rests with the way these EUNIS categories are translated from qualitative expert opinion to quantitative variables. As an example for level A3.1 in figure 1, what does "infralittoral" mean exactly,

how is its lower limit identified with high confidence? In which physical unit - shear stress, kinetic energy - should the seabed exposure be expressed?

3 MATERIAL AND METHODS

3.1 SEABED SUBSTRATUM

A homogeneous seabed substratum map was produced by collating all sediment maps available for European seas. A great variety of maps was encountered, both in terms of scale and thematic content. Scales went from 1 : 50,000 in the case of high quality coastal maps (e.g. the Cartes G from SHOM - http://www.shom.fr/fr_page/fr_act_geo/siteg.htm) to 1:10M for the NOAA IBCM chart (International Bathymetric Map of the Mediterranean) which depicts the central Mediterranean Sea in very gross sediment polygons. Some maps were already summarised in a classification system, at best in an established one such as Folk, otherwise in an author's system, others were expressed in grain size. As the EUNIS classification uses seven classes for the Atlantic (coarse sediment, mixed sediment, sand, muddy sand, sandy mud, mud and rock), a transcription had to be made. In the latter case of grain size maps, the transcription was easy, in the former case of expert opinion it could be extremely demanding, and sometimes required the consultation of the authors themselves.

3.2 DEPTH ZONES

Also referred to as "biological zones" (Glémarec, 1973), these split the seabed from above the coastline (supralittoral) to the abyss. The higher and lower limits of these zones are shown in table 1. They result from consensus between marine biologists.

Table 1 – Limits of biological zones in the North, Channel, Atlantic, and western Mediterranean Seas - * North, Channel and Atlantic Seas ** Western Mediterranean Sea

Biological zone	Upper limit	Lower limit
Infralittoral (NCA* & Med**)	Lowest Astronomical Tide	Intersection of seabed and 1% surface light depth
Upper Circalittoral (NCA* & Med**)	Intersection of seabed and 1% surface light depth	Intersection of seabed and 0.01% surface light depth
Deep Circalittoral (NCA*)	Intersection of seabed and 0.01% surface light depth	200m isobath
Deep Circalittoral (Med**)	Intersection of seabed and 0.01% surface light depth	Shelf edge (manual delimitation)
Bathyal (NCA*)	200m isobath	2700m isobath
Bathyal (Med**)	Shelf edge (manual delimitation)	Shelf slopebreak delimited by the slope angle change occurring at the base of the continental margin (manual delimitation)
Abyssal (NCA*)	2700m isobath	n/a
Abyssal (Med**)	Shelf slopebreak delimited by the slope angle change occurring at the base of the continental margin (manual delimitation)	n/a

While some are clearly established, e.g. the infralittoral as the photic zone enabling plants to thrive, others remain vaguely defined such as the bathyal zone whose upper limit is still being

debated and hence fixed in the Atlantic by default at 200m depth. Recent knowledge on the shelf/canyon interface however seems to indicate this limit as being a change in gradient rather than a fixed depth, hence the specific efforts made in the EUSeaMap Project to come up with a more reliable delimitation.

To build the depth zones, several base layers were needed. Depth data in the form of DTMs (Digital Terrain Model) were collated much in the same way as sediment maps. For France, a 100m resolution DTM was produced thanks to the Naval Hydrographic and Oceanographic Service (SHOM) recently releasing their fairsheet soundings database. In the Mediterranean, a broad coverage DTM with 500m resolution was obtained from the Mediterranean Science Commission CIESM, resulting from the assemblage of recent multibeam surveys undertaken by a number of Mediterranean institutions.

Light data needed to define the infralittoral zone was obtained from the ocean colour satellite imager MERIS. Five years (2003-2008) of cloud-free imagery were statistically compiled into the "photic depth", referred to as the 1% depth penetration of incident light (Saulquin *et al*., 2010). Intersecting this depth with the local DTM yielded the photic/non photic status of the seabed.

3.3 EXPOSURE AT SEABED

The energy due to hydrodynamic forces at the seabed is a key habitat driver. Not only does it shape soft bottoms into bedforms but it also primarily conditions the presence of flora and fauna on rocky substrates (figure 1). Although biologists refer to qualitative expressions such as "moderately exposed", research is still needed to properly quantify what the biology is sensitive to. Bed shear stress in Newton.m^{-2} has been widely used (e.g. in UKSeaMap, 2006) but its definition strongly depends on the knowledge of bottom rugosity. Recent developments tend to address either kinetic energy at the seabed, hence ruling out rugosity, or even proxies such as surface exposure induced by waves.

This project computed bed shear stress as a combination of currents and waves. Best available runs from hydrodynamic models were statistically combined using quantiles to provide a "bed stress climatology". Three bed stress categories as per EUNIS were thresholded from these data. A resolution of 1km was reached in coastal areas in Atlantic zones, which remains too coarse to cross with the SHOM 100m resolution data but nonetheless provides a preliminary habitat division. In the Mediterranean, where the shores slope steeply with highly fragmented habitats, energy could not be used at this stage because of the resolution being too coarse, and recommendations were issued towards the improvement of oceanographic models.

4 MODELLING

Modelling was performed in raster mode, which is the most convenient and efficient way to combine multiple continuous variables. ESRI® ArcGIS™ 9.3 *ModelBuilder* was used. It allows model design, i.e. to graphically chain together tools using the output of one tool as the input to another. Models designed through *ModelBuilder* can be saved and executed multiple times. The Spatial Analyst™ extension was also used, in which raster combination through the concept of "map algebra" can be performed.

One of the main challenges of the project was to build reusable models, i.e. models that could be run, when improved datasets become available, by people with little experience in computer programming or in the use of ArcGIS™ *ModelBuilder*. Thus an ArcGIS™ toolbox

was built. The project used the Mercator/WGS84 coordinate system because most of the input data layers were generated in this coordinate system. This limited layer resampling, an operation that is always detrimental to the quality of the final result. The cell size of the modelled map was set at 100 m.

5 RESULTS

Figure 2 shows the result obtained in Brittany at the scale of 1 : 300,000. A major difference of environment is quite obvious between the North and the South. The North, which represents the southern part of the Channel, a dynamic macrotidal area, is occupied by coarse sediments (brown tones to beige). In its north-western part, the infralittoral rocky (purple and pink tones) is a narrow band that does not extend into deeper zones. In the north-east, bays present vast infralittoral areas, always containing coarse substrata, whereas fine sediments are found in the estuaries and inshore areas.

In southern Brittany, the strong exposure to waves does not allow very fine deposits except in the more protected Vilaine bay (south-east, darker green) where mud can be found (*infralittoral and circalittoral fine mud* EUNIS habitats, in dark green). Fine deposits can however occur in the deeper circalittoral area, which is protected from the action of the waves by the water column, in particular in the famous 100 meter deep "Grande Vasière" (*deep circalittoral mud* EUNIS habitat, in light green). Rocky outcrops (purple and pink tones) are frequently found at diverse depths close to the islands.

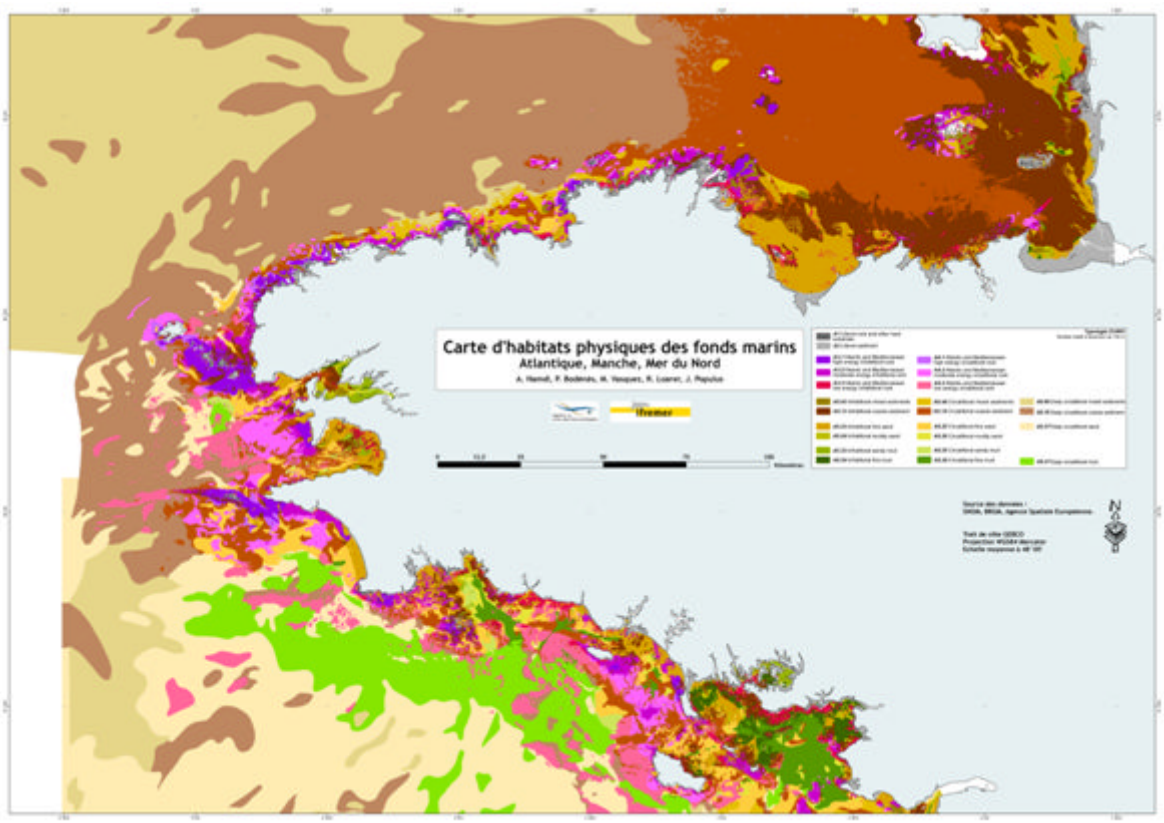

Figure 2 - Example of 1 : 300,000 map. Rocky dominant habitats are in purple to pink colours, coarse sediment in brown to orange tones and muddy sediments in green colours.

Note that in southern Brittany, the model uses very fine scale “Cartes G” maps of seabed substrate, from the SHOM, thus great detail appears very clearly there. By contrast in the

North only the broad scale sediments map of the Channel (BRGM / CNEXO) was available. It results in smoother habitat units.

6 CONFIDENCE ASSESSMENT

It is important to show that seabed habitat maps, both interpreted and modelled, are a version of reality, and it is therefore essential to show which datasets require future improvements , and where. Confidence maps, which provide a spatial assessment of confidence in the final maps, are an effective way of achieving this, and are considered to be a final product alongside the seabed habitat maps themselves.

These maps were made by simply assessing the confidence value of two key layers, namely substrate, according the Mesh methodology (Coltman 2008) and bathymetry, and computing a weighted sum of the two scores. Using these two layers is relevant because they carry a major part of the variance of the final maps. Indeed the depth is strongly involved in hydrodynamic models that provided the project with wave and current layers, and also contributes to the computation of all the biological zones. The confidence map of the western Mediterranean Sea is illustrated in figure 3.

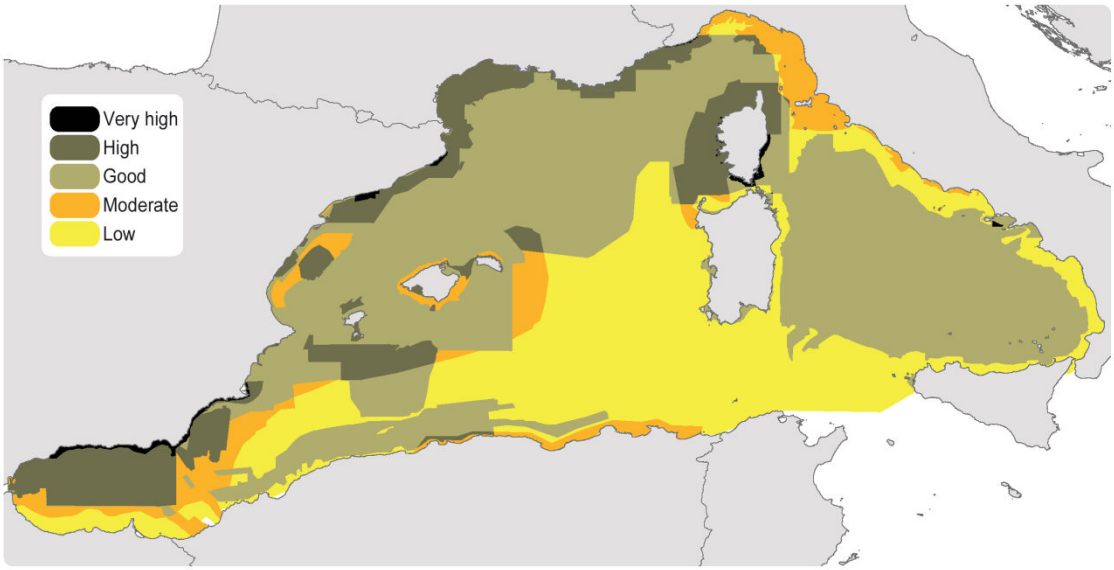

Figure 3 – An example of a confidence map

7 PRODUCTION OF PRINTED MAPS

The modelled seabed habitat maps are available free of charge to users through the Ifremer web mapping portal (www.ifremer.fr/sextant). It was nonetheless considered important to edit a paper version of the maps, which gives a stronger signature to the project and provides a level of additional use, particularly in expert or stakeholder working groups.

Eight maps were created according to the geography of French coasts and respecting certain physiographic units. For example, as illustrated in figure 2, the whole Brittany region could be presented on a single map, as was also the case for the Basse-Normandie region. The presentation of a map, obtained by the use of symbology for the map legend, is an important aesthetic element which conditions the success and ease of comprehension of the map. To date there is no real community dealing with the cartographic representation of seabed habitats and whereas important efforts were made by European teams to set up and then popularize EUNIS, the harmonization in terms of cartographic presentation remains almost non-existent.

Our objective was to have an similar symbology for the paper maps and the maps presented on the internet. If with the internet technologies that are used by Ifremer, the open source platform MapServer, it is easy to build a simple fill symbol (i.e. only filled with colours), building a more sophisticated fill symbol, which makes use of lines or patterns, is more difficult and usually tedious. Thus we made the choice to use a simple colour scheme, which was not that easy considering the number of habitats that had to be presented (25 in the Atlantic for example), and considering the fact that the human eye can only distinguish between a very few colours simultaneously.

Some simple rules guided the choice of colours. First of all the patchy or small habitats were enhanced by giving them a bright saturated colour (as opposed to pastel ones) to make them more visible. Conversely, colours of similar habitats when going from the shore to the high sea across biological zones were desaturated. Generally, habitat extent increases accordingly and this results in more pastel colours being more aesthetic over vast areas (e.g for the Mediterranean's huge bathyal and abyssal zones).

8 NEXT: IMPROVED INPUT DATA LAYERS TO REDUCE UNCERTAINTY

8.1 BATHYMETRY

It is reasonable to expect a DTM homogeneous in quality on the largest part of the French coast. The SHOM should release in the future higher quality data resulting from recent digitalization, from new acquisitions, as well as from the update of its collections. Some areas will remain poorly covered, e.g. southern Biscaye where the 100 m model computed for the project is a very rough interpolation. Fortunately these areas with a very strong sandy dominance remain less interesting with respect to benthic habitats.

8.2 SEABED SUBSTRATA

Seabed substrata layers can be split into two zones. As regards the continental shelf, we cannot expect a lot of improvement in the next few years because a broad scale survey program of the French continental shelf is not currently being envisaged. The maps made in the context of Natura 2000 network or Marine Strategy Framework Directive (MSFD) will fill these blanks only in very small and patchy areas. Nor will the surveys and the processing of data acquired in the past by the national fleet significantly fill these gaps. It will thus be necessary to continue to live on rough historic maps such as those used in this project.

Concerning the coastal zone, improvement can be expected. The SHOM continues its task of increasing its "carte G" collection, at the approximate rate of two maps a year. With this rhythm the Gulf of Lions, the Loire estuary and some of the other gaps should be processed within the next five years (http://www.shom.fr/fr_page/fr_act_geo/siteg.htm).

8.3 OCEANOGRAPHY

Oceanography data are basically light and hydrodynamic models for waves and currents. Concerning the former ones we cannot expect improvement because the current satellite MERIS still hasn't any announced successor. Its current 250m resolution is nonetheless already considered completely compatible with 100m resolution seabed habitat modelling.

The data computed by hydrodynamic models has a strong improvement potential. A resolution from 200 to 300 m might be reached within the next two or three years. As regards currents, it would be advisable to convince more specialists of the usefulness of the habitat

modelling concept by increasing their involvement in future projects. Skills have recently been organized in Ifremer concerning waves, and this should accelerate the production of fine models. It is important to remember that once models have been implemented they need to run for a while (2 to 3 years) in order to compute a reliable climatology.

9 CONCLUSION

Although not achieving a full habitat map, the modelled physical Eunis map yields a novel view of the seabed. This assemblage of physical features was made possible by the recent availability of homogeneous data sets and time series of oceanographic data affecting the seabed. As new data sets become available it will undergo improvements in terms of resolution and content. While being now a rough-and-ready alternative to biocenotic maps, a next step might be to collate - or collect if necessary - some biological data to reach more detailed levels of the Eunis classification.

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