Marine landscape maps: methodology and potential use.

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Abstract

The Marine Landscape is a concept that originated in Canada (Roff and Taylor 2000) and was recently implemented in UK and Europe in the respective frames of the UKSeaMap (Connor 2006) and Mesh projects. It aims to describe the marine environment with respect to its main geophysical features, in terms of both the seabed and water column. Marine landscape maps are not a surrogate for genuine habitat maps which are produced by incorporating biological data from samples to the physical map. They provide a more global vision of our coastal and shelf environment in terms of their main physiographic traits and hence act as a support for national/regional policy and spatial planning. While initially applied on a more global scale (resolution of one nautical mile), the concept was taken forward and applied to the French coastal approaches where digital data sets were available at higher density. The classification used for a landscape map is quite flexible. It will not be the same in a full sedimentary type of seabed or a rocky foreshore and differs in fully marine or in more continental seas such as the Baltic, for example. It needs to be adapted on a case-by-case basis to the local physiography and also to be discussed with the main stakeholders to best serve their needs. The paper discusses the methodology used to produce a seabed map, mainly relying on data cross-tabulations within a GIS, and deals with both raster and vector data. Validation against historic habitat maps is presented. Problems linked to discrepancies in data resolution are also discussed. Finally an application making use of the landscape map for conservation issues in Brittany is discussed.

Introduction

Marine spatial planning is a process by which the sustainable exploitation of marine resources can be managed and planned. It should be based on best available information. There is awareness that in order to preserve individual species there is a need to identify coherent marine management units to which specific measures can be applied (Connor 2006). Environmental mapping information and particularly marine habitat maps are of paramount importance for a number of policy and management issues: ecosystem functioning, fisheries management, Marine Protected Area (MPA) designation, industrial and energy projects, shipping lane maintenance etc. There is –an ongoing need to collect further seabed information to support decision-making, but the first step is to make best use (or re-use) of already existing information and maps and to properly publicise and disseminate it to the stakeholders.

Several initiatives at European level have made substantial progress in mapping the seabed of European seas on a global scale (ICES 2007). This is the case for programmes such as Interreg's Balance (www.balance-eu.org) in the Baltic and Mesh in North-West Europe (http://www.searchmesh.net/), MARGIS in Germany (Pesch, in press) and OSPAR for selected priority habitats (http://www.searchnbn.net/hosted/ospar/ospar_text.html). Substantial work has also been carried out in the North Sea under various initiatives, however, there is as yet no complete map of the seabed there.

The Mesh project took forward the transnational idea of harmonising already existing historic data sets and above all providing a common frame for future work to all practitioners and users in the field of seabed mapping. A key asset is the pan-European EUNIS habitat classification (http//eunis.eea.eu.int/habitats.jsp), whose development and maintenance is the responsibility of the European Environment Agency. Although harmonisation is a key issue among European nations to make it possible to aggregate maps and provide a unified management tool, there maybe a benefit in having several classification schemes over a given area, if they are deemed to serve different purposes.

Seabed modelling – the Marine Landscape approach

Classification of the marine environment can be approached in a number of ways and at a variety of levels of detail, depending on the purpose of the classification, the methods used and the data available. For environmental management purposes, it is important to classify the marine environment in an ecologically meaningful manner in order to support an ecosystem-based approach to management (Mesh 2007).

For the seabed, classification has typically been achieved through characterisation of seabed features by habitat type, but the habitat approach to classification takes only limited account of broader patterns in seabed character, such as seabed morphology determined by major geological and hydrographic processes (Roff 2000). Each marine landscape (ML) type will comprise a series of habitat types, some of which are typical of (or specific to) the landscape type. In addition, many habitat types can occur in several landscape types (for example, seagrass beds can occur in sea-lochs, bays and estuaries) – this means that the two approaches to classification are related to each other but cannot be fully integrated into a single hierarchical classification (Connor *et al.* 2006; Mesh 2007).

Whilst the habitat mapping approach is most suited to detailed (fine-scale) classification of the seabed (including field surveying and habitat mapping), the broader classification of marine landscapes was originally seen as a global scale endeavour (Roff 2000) meant to provide full coverage of vast areas of seabed particularly useful for wider management purposes. In fact, landscape is a fractal notion, since even a diver would have his own landscape, i.e. a specific terrain configuration within a field of view of less than 100 metres. It also remains valid at very detailed scale. Habitat maps for most European shores are either lacking or the coverage is extremely patchy – what hydrographers call the “white ribbon”. – Therefore, by dealing with marine landscapes in more detail, some steps can also be made in predicting local habitats as an alternative to actual surveying. This is clearly illustrated by an initiative to predict kelp’s presence in the coastal waters of Brittany (Meleder 2007), where indeed the drivers to its presence are not different from those used for marine landscapes: depth and slope, water transparency, seabed stress, temperature. Therefore on a local scale, the prediction of particular habitats will naturally come into play to further refine the marine landscape where feasible.

The Marine Landscape concept was fully developed in the UK by the Joint Nature Conservation Committee (Connor 2006) with the UkSeaMap project. The idea was to cover all UK waters with marine landscape maps, following a trial in the Irish Sea (the Irish Sea Pilot, Golding 2004). The aim of the project was to use available geological, physical and hydrographical data, combined where possible with ecological data to produce simple broadscale and ecologically relevant maps of the dominant seabed.

Other Mesh partners adapted the ML to their specific environment. In the North Sea, the Dutch and the Belgians (Schelfaut 2005, Doornenbal 2007) modified the drivers to reflect the particular conditions of seabeds dominated by fine sediments.

Material and methods

Definition of relevant classes

Seabed classes were defined in the frame of the UkSeaMap project. In the present application to the coast of France, considering that the bio-geography is rather similar to that of the British Isles, the same classes were provisionally kept.

Basically this definition has been primarily driven by several considerations, first of all the scope of the marine landscape but also the environmental data sets generally available, along with in-depth knowledge of the EUNIS classification system (Connor *et al.* 2004; www.jncc.gov.uk/MarineHabitatClassification). The ML classes were meant to have a relevance to EUNIS lower level habitats. Of course this definition has a bearing on how the various parameters will be broken down into classes themselves. In the case of the Atlantic coast habitats, EUNIS level 4, which is the lowest abiotic level for sediment bottoms, only distinguishes between 5 types of sediment. For continuous parameters such as bedstress or incident light, the definition of relevant thresholds will also be a key element in the final result.

The UkSeaMap worked at a resolution of one nautical mile. The project first identified remarkable structures (seabed features) which were processed independently: for the high seas these are based on large high sea topographic features such as troughs, ridges, seamounts, etc. Likewise, on the coast, some specific physiographic configurations (coastal features) were identified such as loughs, rias, lagoons, estuaries, etc.

As our application was more coastal from the outset (anticipating a resolution up to 150 metres at places), it was decided to skip this feature classification and apply the seabed classification methodology to the entire area where source data were available. Besides, the deep water classes (depths more than 200m) were not addressed here, and the slope being roughly less than 2% all over the coastal seabed, we also disregarded topographic slope as a driver. Our considerations were rather to try to handle varying data resolutions to allow refinement in the inshore zone with regard to the UkSeaMap. The classification tree is shown in Table 1 and the parameters it contains are described in more detail in the following section. Sediment classes were first split into “depth zones”, themselves differently assessed for hard or soft bottom. Classes were further refined with respect to the bed shear stress, which here applies only to coarser sediment. Leaving out the application of various bed stresses to rocky substrate is acceptable with the UkSeaMap resolution of one nautical mile, however this needs to be discussed as resolution increases. In much the same way, bed stress’s relevance to sandy beds, not detailed earlier, may need further thinking.

Data layers and cut offs

Given these three parameters and the resulting 18 classes expected to occur over the study area, the next steps are to examine how relevant data will be sourced and what cut offs should be selected.

Seabed substrata

The substratum is of course the leading parameter that conditions biological life on the seabed. Several sources of substratum maps are available on the French coast and shelf. Considering the extent of the Mesh area (the Channel and north Biscay), a global data set with full coverage, referred to as the Larsonneur/Lesueur sediment map (scale 1/500000) was immediately available.

Table 1. Classification tree for French marine landscape class definition (modified from UkSeaMap).

Substrate (Folk 5)	Depth zone	Bedstress (tidal current)	Marine landscape class
Rock	Photic	Any	Photic rock
	Aphotic	Any	Aphotic rock
Coarse sediment	Shallow (coastline to wave base)	Weak	Shallow coarse sediment plain - weak tide stress
		Moderate	Shallow coarse sediment plain - moderate tide stress
		Strong	Shallow coarse sediment plain - strong tide stress
	Shelf (wave base to 200m)	Weak	Shelf coarse sediment plain - weak tide stress
		Moderate	Shelf coarse sediment plain - moderate tide stress
		Strong	Shelf coarse sediment plain - strong tide stress
Mixed sediment	Shallow (coastline to wave base)	Weak	Shallow mixed sediment plain - weak tide stress
		Moderate	Shallow mixed sediment plain - moderate tide stress
		Strong	Shallow mixed sediment plain - strong tide stress
	Shelf (wave base to 200m)	Weak	Shelf mixed sediment plain - weak tide stress
		Moderate	Shelf mixed sediment plain - moderate tide stress
		Strong	Shelf mixed sediment plain - strong tide stress
Sand	Shallow (coastline to wave base)	Any	Shallow sand plain
	Shelf (wave base to 200m)	Any	Shelf sand plain
Mud	Shallow (coastline to wave base)	Any	Shallow mud plain
	Shelf (wave base – 200m)	Any	Shelf mud plain

This assemblage had already been simplified from its initial classification (containing two layers, one for grain size one and another for mineralogy) into a ten-class map visible in the left part of Figure 2. The UkSeaMap project had reduced the initial sixteen classes of the BGS map into the so-called 5-class Folk classification limited to rock, coarse sediment, mixed sediment, sand and muddy sand, mud and sandy mud. We reproduced this translation in the present work although it posed a few problems, especially with the gravel class and the distinction between mixed sediment and coarse sediment. This is reflected in the upper right part of the Folk sediment trigon with a coarse sediment class extending far towards the higher sand fraction (Figure 1).

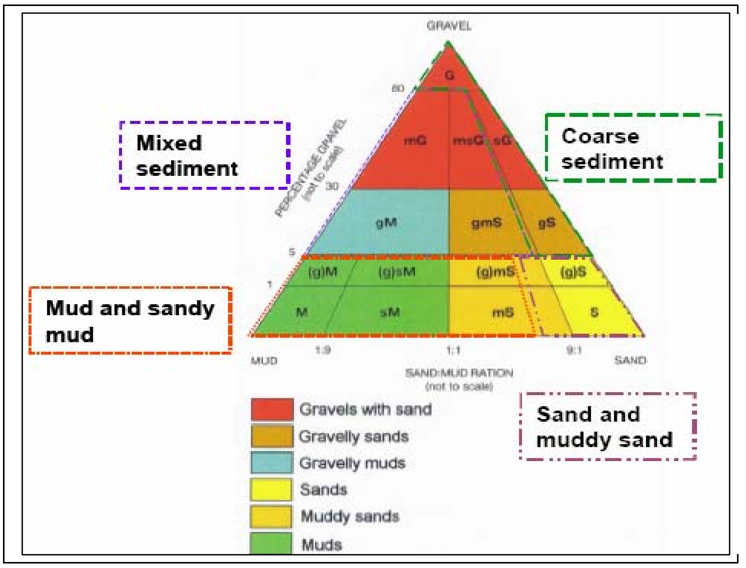

Figure 1. The Folk classification trigon and simplified version (Connor 2006)

As this choice particularly affected the seabed description of the Channel, due to its strong dominance by coarse sediment, more importance was given to the mixed sediment class by slightly decreasing its mud to sand ratio. This allowed the border between coarse sands and gravel to remain clearly visible in Figure 2 which is a response to the different hydrodynamic conditions prevailing in the two parts of the western Channel.

Other types of seabed maps are available on the French coast, namely the ongoing 1/50000 series produced by the French Hydrographic Office (SHOM) however they have not yet achieved full coverage and due to the nature of their native classification they are more difficult to translate into Folk 5. Potential sediment refinements of this layer are examined in more detail in the discussion.

Depth zonation

Depth is also a key driver that intervenes at various levels of the procedure (Populus 2006). Rather than absolute depth value, habitat mapping is concerned with "depth zones" (Glémarec 1973) that do not follow isobaths but result from a combination of local depth and other factors such as light, bottom energy or temperature.

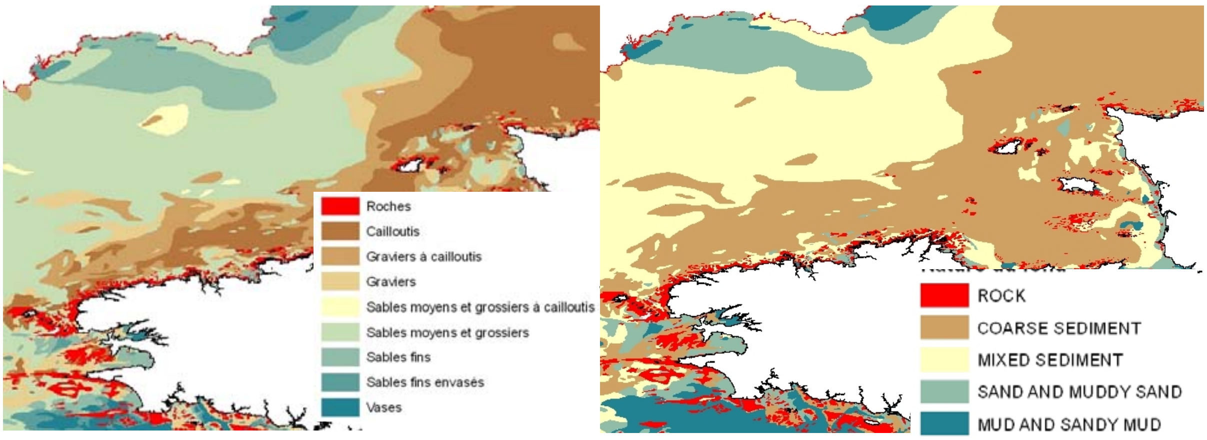

Figure 2. Sediment map converted from 10 class classification (left) to Folk 5 classes (right)

On rock substrates, the presence of fixed vegetation is mostly governed by the light budget, which defines the photic zone as opposed to the deeper aphotic one. Water transparency is expressed by the extinction coefficient of photosynthetic active radiations called Kpar. This coefficient is derived from radiances computed from SeaWiFs satellite imagery (Gohin *et al.* 2005). Data are yearly averages over the period 1998-2004 for pixels of 1.1 km. From the Kpar value, the depth Z at which the fraction of incident light is only 1% can be computed using the formula:

$$Fr = e^{z \times Kpar\ annuel}$$

Once this "photic depth" is known, it is intersected with the local depth to define the photic line (Figure 3, top right). As shown in Table 2, Ifremer data available for the Channel had to be complemented by much coarser data from POL for Biscay.

On sediment bottoms, benthic life is controlled by the disturbance induced on the bottom by the swell orbital velocity. Once the typical wave climate is known over an area, the wave base can be derived from it as being half the maximum wave length. Intersecting this wave base depth with local depth generates the wave base line. Data used here were sourced from POL (12 km resolution proWAM model over a 10 year period) for the area north of Raz de Sein and as a proxy, the circalittoral contour provided by Glémarec's (1973) habitat maps of southern Brittany. Each depth point was compared to the wave base depth to be classified as either "shallow" or "shelf" (Figure 3, bottom).

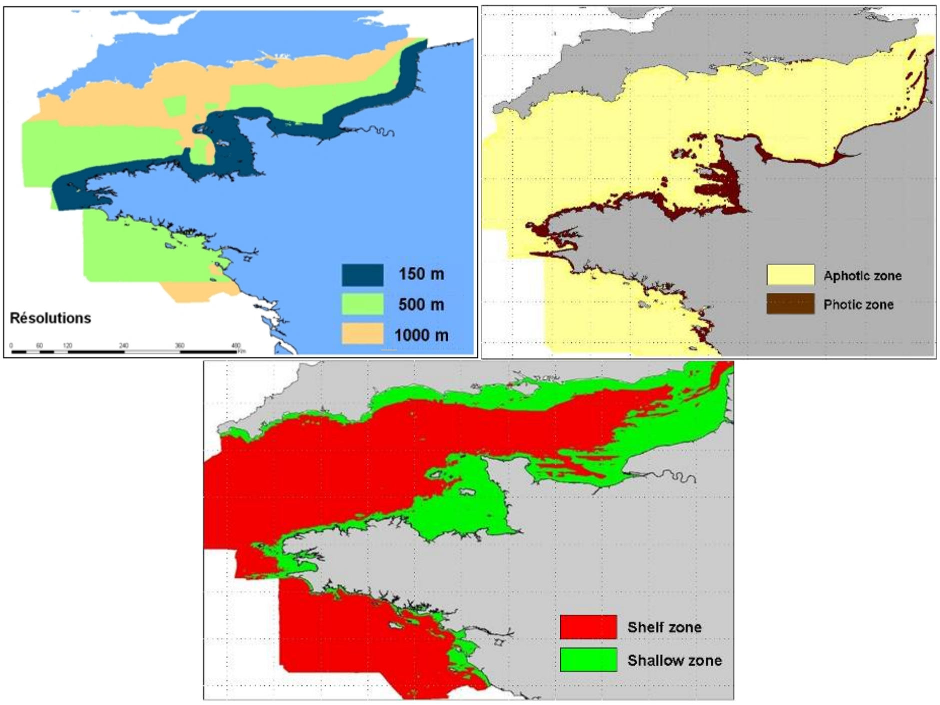

Figure 3. Depth zones used for marine landscape (top left), photic/aphotic zones (top right) and shallow/shelf zones (bottom)

For this work, depth was available at three specific resolutions. Two depth models had been previously generated from a unique set of depth data points from various origins available in-house. These gridded models had been generated by kriging source data on a) a 1 km resolution grid file appropriate for the shelf area b) a 150 m grid file that was limited to the coastal zone (roughly the territorial waters) as justified by sufficient source point density. Additionally, a 500 m grid file made with depths from sounding minutes was recently provided to us by SHOM. The latter file partly overlaps the first two. At any given location within the Mesh area, whichever data were of best quality were kept in the ML process. Figure 3 (top left) shows the extents of these three data sets. In southern Brittany, the SHOM file in green was deemed to be more relevant than our 150 m depth file and kept as lead data.

Table 2. Data sources

Geographic area	ML parameters	Depth	Swell wave-length	Light attenuation	Currents	Sediment map
Channel	Substratum					Larsonneur 1/500000
	Photic depth	Ifremer : 150 m Shom : 500 m Ifremer : 1000 m		Ifremer Kpar 1000 m		
	Depth zone	Ifremer : 150 m Shom : 500 m Ifremer : 1000 m	POL : 12 km			
	Bedstress				POL 1 nm	
Bay of Biscaye	Substratum					Lesueur 1/500000
	Photic depth	Shom: 500 m Ifremer : 1000 m		POL Kpar 9 km		
	Depth Zone		Glemarec Map contour			
	Bedstress				Ifremer 2 km	

Bed shear stress

Bed stress is defined as the pressure exerted by moving water in the vicinity of the bottom. It has a very strong influence on bottom morphology and associated marine life. On sediment bottoms, it is the driver for bedforms. On rocky bottoms, it influences the fixation of kelp and fauna. Bed stress has two origins, i.e., currents and wave orbital velocity, which combine in a complex way which is not precisely known. Researchers from the Proudman Oceanography laboratory (POL, Holt 2006) recommend as a rough guide to simply add them. The bed shear stress is given by the following formula (Le Hir 2003):

$$U_* = \frac{\overline{U}\kappa}{Ln\left(\frac{h}{ez_0}\right)}$$

where U is the maximum 2D current velocity in m.s^{-1}, K the Karman constant, h the water height, e the sediment porosity and z_0 the skin friction coefficient. The skin friction coefficient can vary threefold with bottom grain size. UkSeaMap chose z_0= 0.003 as an average friction value and this rule was followed here.

Bed stress was divided into three categories, namely weak (0 to 1.8 N*m^{-1}), moderate (1.8 to 4 N*m^{-1}) and strong (> 4 N*m^{-1}), considered to be biologically meaningful by the Marine Nature Conservation Review (Connor and Hiscock 1996).

The origin of the data is summarised in Table 2. A closer look reveals the heterogeneity of the data sources and resolutions. As hardly any single data set covered the whole study area, data had to be taken from various sources and their resolutions happen to vary between 150 m and 12 km.

GIS methodology

In the case of the UkSeaMap, the marine landscape was seen from the start as a computation process expression involving a number of parameters at a single global resolution of one nautical mile. In fact, this concept can be expanded to become a multi-resolution one: where finer resolution source data exist, why not fully benefit from this by producing a finer marine landscape? This means from the very start that the raster form is not appropriate, as it cannot feature variable resolution. Rendering the finer resolution of a set of sources with different resolutions would involve expressing each of them into a gridded file whose resolution would be chosen as the finest of them all. This would entail interpolating any coarser resolution to this finest one. In our present case, given the increased resolution at the coast (150 metres typically available for bathymetry, 300 m for currents), this would mean ending up with quite a number of huge raster files (about 4000*4000 pixels to cover the area of interest) with a lot of redundancy and gaps due to the particular shape of the French marine area.

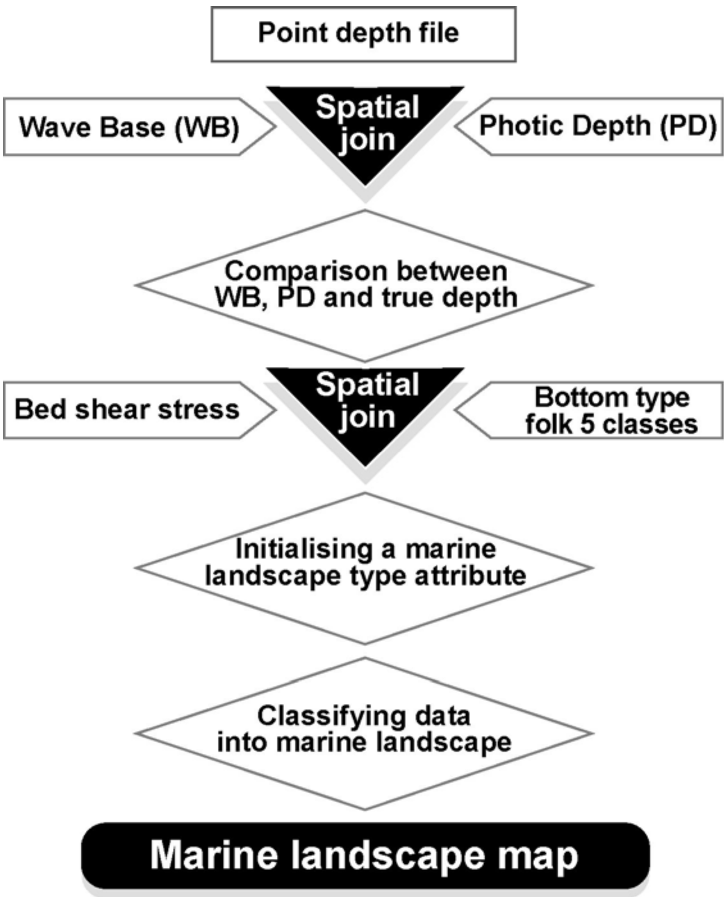

Figure 4. Marine landscape computation flowchart

It was therefore decided to work with point grid files obtained by converting depth DTMs into their centroids and to “accumulate” all variables by way of spatial joints onto these centroids. To give an idea of the number of points concerned, the 150, 500 and 1km DTMs respectively contained 1,122,000, 230,000 and 43,000 points. Instead of having many raster files, basically one for each particular computation, the picture here is made up of three bathymetric point files with as many attributes as required to express the spatial joints and compute the final query. Of course, each of these three depth files underwent strictly the same process described in Figure 4, the only difference between them being their dot spacing.

Table 3 gives a view of the variables that had to be computed prior to being assembled into marine landscape classes. It shows that for any spatial joint, the joining distance is kept, which provides a quality element when trying to look at the map confidence.

Table 3. Attributes of the depth point file

Attributs de Join_Output

Shape	bathy	Distance	Kpar	Wavebase	DATA	Photic_dep	Wave_class	seabed
Point	-13.1	2177.509	0.33778	32.16	COARSE SEDIMENT	Aphotic	Shallow	Shallow coarse sediment plain-moderate tide stre
Point	-14.35	2028.873	0.33778	32.16	COARSE SEDIMENT	Aphotic	Shallow	Shallow coarse sediment plain-moderate tide stre
Point	-15.24	1880.453	0.33778	32.16	COARSE SEDIMENT	Aphotic	Shallow	Shallow coarse sediment plain-moderate tide stre
Point	-10.47	1805.703	0.33489	32.16	COARSE SEDIMENT	Photic	Shallow	Shallow coarse sediment plain-moderate tide stre
Point	-9.551	1664.434	0.33489	32.16	COARSE SEDIMENT	Photic	Shallow	Shallow coarse sediment plain-moderate tide stre
Point	-9.786	1524.835	0.33489	32.16	COARSE SEDIMENT	Photic	Shallow	Shallow coarse sediment plain-moderate tide stre

Once these three marine landscape point files were obtained, it was necessary to convert them into a unique polygon file, as this was the final format required.

This is not a straightforward operation with a categorical attribute. The necessary steps are as follows:

- convert the categories into numeric codes using a look up table;
- convert the three grid point files into three raster files (by simple attribution of each point value to the underlying grid centroid) ;
- convert the raster files into polygon files; and
- inverse transform the codes into categories.

In the end, three polygon files at different scales were available, which of course overlapped one another just the way the initial depth DTMs did. The final step was then to “clip” these three files to ensure a clean final topological file. The 1km marine landscape was first clipped by that of 500m, which was in turn clipped by the 150m one. The resulting polygon file is of “variable scale”: it contains large polygons offshore and smaller ones going inshore, which enables the user to zoom in over coastal areas.

Results and discussion

Two different files are shown in Figure 5. To the left is the coarser resolution of 1 km covering the whole Mesh area. Southern and western Biscay are not covered due to the lack of bottom type data at these locations. Overall, the Channel exhibits a rather homogeneous seabed dominated by coarse sediment (gravel and pebble) spreading across the shallow and shelf zones and characterised by strong or moderate bed stress. Southern Brittany, beyond a coastal rocky ridge, is dominated by a shelf mud plain with sandy patches called la Grande Vasière, a habitat for Nephrops species. The bed stress was shown to remain low over the whole area, however it should be noted that the bed stress computation was based on currents only. These are known to be weak altogether in southern Brittany except for a few more inshore locations. Wave contribution, although potentially significant was not taken into account, which is an improvement issue for the model.

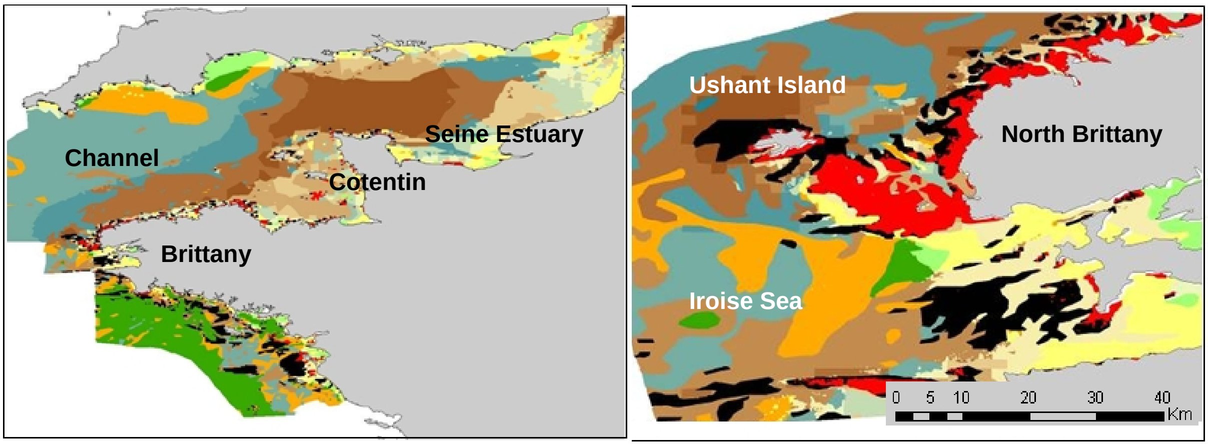

Figure 5. ML computed at depth points: 1 km resolution shelf file on the whole area (left), 150m resolution coastal file focused on the Iroise Sea (right). See Figure 6 for caption.

To the right is a view of the marine landscape of the tip of Brittany (Iroise Sea) on a 150m resolution, which illustrates the extensive rocky substratum present in this area. It is interesting to note that on the northern coast there is a clear transition from photic to non-photic rock (red to black), whereas to the centre, the large rock platform is mostly bordered by “photic sediment”. The Mer d’Iroise landscape is a very heterogeneous one, as is the case in the vicinity of the Channel Islands, where extremely contrasting water dynamics have shaped quite conspicuous features.

Figure 6. Marine landscape classes applying to ML map in Figure 5 (after UkSeaMap)

Looking at the global marine landscape (Figure 5), it appears that the high seas are dominated by large surface units while the coastal zone is much patchier. Although some small sized habitats do thrive in the deeper shelf zone (such as deep coral or sponge communities), this phenomenon can be expected and is due to two combined effects. On one hand, the inshore area is known to be more heterogeneous mainly because of the presence of rocks but also because of physical gradients that create a more complex geomorphology. Even in the upper infralittoral, let alone in the intertidal zone, some habitat units reach very small sizes. On the other hand, there is a bias naturally induced by the data themselves. Approaching the shore, data sets tend to be finer and finer as a result of the way these data were collected. This is particularly true with bathymetry (Populus 2006) which conditions many a parameter of the marine landscape (namely currents, photic depth, wave base), hence bringing about more detailed contours.

More generally, one has to question the soundness of merging data at different resolutions and be aware of the quality of the result and sensitivity of the model. It would be an illusion to select a dense depth file as a support for the computation and spatially join to it data say ten times coarser. In this case, the resulting units would be very gross and would not convey a feeling of confidence. The first rule is: the more essential a given layer is in the process, the more detailed it ought to be. In the marine landscape case, the key entry is the substrate and its resolution primarily conditions the output. The related parameters come into play to divide this layer into sub-classes.

Figure 7 shows examples of the marine landscape map around Ushant Island in Brittany. The black class is aphotic rock. On the marine landscape map, the above mentioned Larsonneur/Lesueur map was adopted as the substrate layer, in spite of some conspicuous flaws such as the rectilinear boundary of the black patch north of Ushant. The improvement that can be expected from better data can be seen in figure 7 (c), which displays the rock layer of the “SHOM carte G” seabed type series, not used in this study. Although the improvement is striking, it would be an illusion to incorporate this layer without simultaneously improving concurrent layers. This is demonstrated by Figure 7 top views where two different resolutions of current computation (Tessier 2006) clearly influence the outputs. On the scale of this coastal ML example (based on 150m depth resolution), it is worthwhile to use a 400 m mesh size rather than a kilometric one, since the step-like aspect then disappears but it would not worth the efforts to dramatically increase this level of detail, all the more because bed stress is only a secondary parameter.

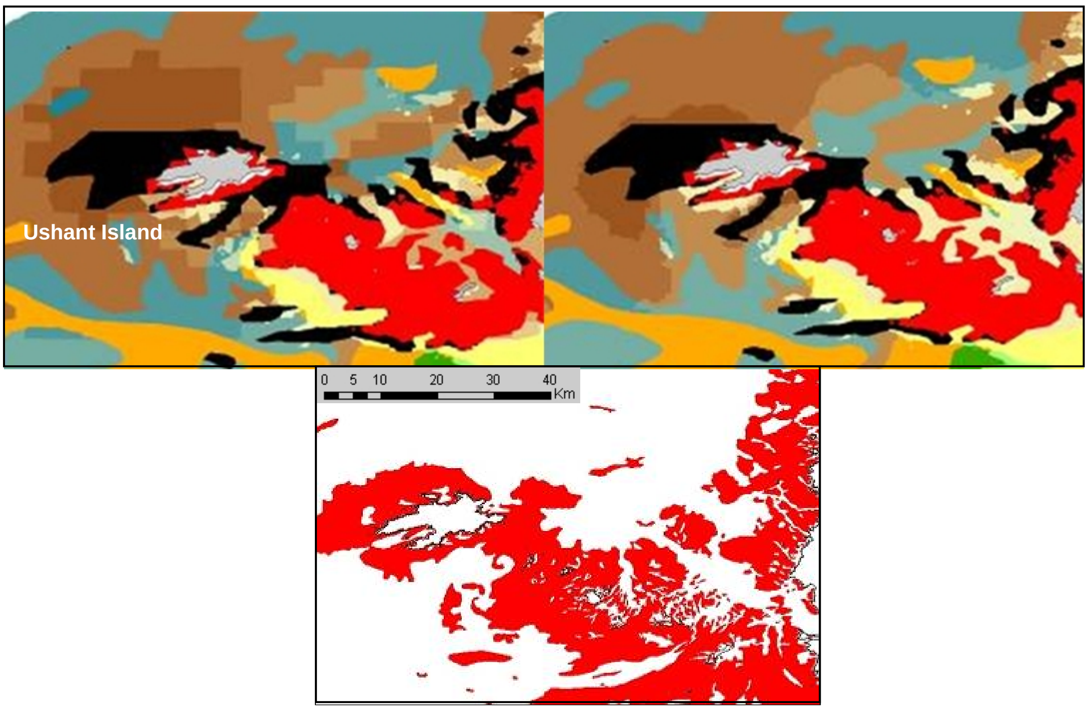

Figure 7: Ushant Island marine landscape with resolution of bottom currents layer of 1 nautical mile (source POL, upper left) and 400m (source Ifremer, right), rock layer from SHOM carte G (bottom).

Finally the importance of parameter cut offs should be noted. These breakpoints are established considering the relevance to the biology and any change to them will result in a somewhat different map.

While the 5-class Folk is fairly straightforward, the inclusion of subclasses would need to be thoroughly thought out. As an example, for the Dutch continental shelf highly dominated by fine sediment, the ML study (Doornenbal 2007) adopted three sediment drivers, namely the median grain size, mud content and gravel content, with respectively three, two and two classes. Out of the twelve potential combinations only five were chosen, considering for example that a mud fraction above 15% overrode the medium grain size of the sand fraction. For bed stress, the breakpoints adopted by the Dutch were 0.5 and 1.0 $N{*}m^{-2}$ rather than 1.8 and 4 $N{*}m^{-2}$ in our case, which shows the relevance of weaker bed stress with regard to the fine sediment dominance on the Dutch continental shelf.

Way forward

The UkSeaMap terms of reference aimed to deliver a unique landscape map over the UK seas and from there to promote it over the whole Interreg NW marine area as a key transnational deliverable of the project. Although the quality of this first attempt served its purpose, there are many ways of improving the product to serve more local needs than initially considered. The two major tracks are a) improving the resolution andb) improving the class description/thresholds.

Improvements in resolution are crucial for depth models, as depth has a bearing on all the parameters. For the bed stress and wave base, this is made possible by the recent availability of two high quality digital depth models (reaching a 25 m resolution in places at the coast). Computation of high resolution orbital velocities and wave lengths then becomes possible, but this is quite a heavy task.

Wave orbital velocity is needed in the bed stress calculation. The computation using tidal currents alone is believed to underestimate the natural disturbance on the bottom, as is illustrated in Figure 3 for south Brittany. An improvement of this parameter is expected by propagating wave statistics of a 5 km resolution coastal model (recently made available) to the inshore area.

Concerning light irradiance data, Seawifs catalogues are now available over the whole Bay of Biscay. Envisat Meris images with 300m resolution are more widely distributed now, however it will be some time before statistics can be built up. Not much can be expected on this front in the near future.

As regards improvement of the seabed substrata class description, looking at EUNIS classification level 4 on sediment bottoms, two additional classes for sand and mud can be found that were not taken into account in the simplified Folk classifications used here. The SHOM 1/50000 "G map" series on the French coast, albeit not complete for the whole coastal zone not only provide these extra classes but also some additional detail on the coarse sediments and their mud fraction. Besides, detailed sediment description is not only interesting per se, it also intervenes in the bed stress computation and should be incorporated to retrieve more reliable values, since, as was mentioned earlier, the friction coefficient could vary to a large extent with grain size.

More detailed rock substrate contours would also be quite valuable. Immediate improvements are expected from using the "G map" and potential ones are provided by extracting the rock contours from very high resolution Lidar depth model where available (Meleder 2007).

As a result of these considerations, the ML map lends itself to frequent updates, as better data becomes available. There is no need to wait for major deliveries of comprehensive data layers. As even partial depth updates come in, the ML map can be updated locally. It may be that only one type of depth resolution is concerned, hence simplifying the updating process. However, with new depth files the whole process (Figure 4) will need to be run again from the start. If secondary layers are updated, their spatial joints have to be updated as well and the ML class computation rerun. Of course, the whole subsequent process of generating polygons from the ML raster file also has to be rerun in all cases.

The respective advantages of the vector and raster data formats can also be discussed. The vector mode may be awkward at high resolution when the number of points becomes very high. It is also true that spatial joints are heavily time-consuming operations, which is not the case with raster files where map algebra is a very quick and efficient process. However these joints allow the operator to keep track of the joint distance, an indication of resolution consistency across the various layers. Joint distances then enable an internal confidence assessed to be performed, which can be a simple combination of the three distances of the point to pixel joints shown in Figure 4. The ML points could then be flagged according to this quality attribute and for example overlaid to the ML map.

While there are numerous ways forward in terms of data collation and improvement, validation is another important item that deserves examination. Although this study could not address it within its time frame, validation can be performed either by using seabed samples as in the UkSeaMap study, or by using EUNIS maps. Both methods entail specific difficulties, since field samples provide very local and detailed views of the seabed that need to be related to a EUNIS class first, whereas EUNIS maps are usually historic and may have a degree of uncertainty and/or obsolescence. However since the marine landscape class definition follows EUNIS as closely as possible and uses parameters which are the backbone of the classification, a rather good agreement can be expected. One potential danger with EUNIS maps based on samples only (as opposed to maps made with “coverage” survey tools) is that one could end up validating the EUNIS maps rather than the ML map without being aware of it.

Rather than a formal statistical validation, a confidence index could be built as a composite of spatial joint distances in some kind of weighted sum. The essential point is for the user to have a certain degree of “confidence” in the map, in order to decide on a sound basis which additional sampling or surveying efforts should be undertaken.

A preliminary application at national level: pre-selection of MPAs

The marine landscape maps produced within the framework of the MESH project are proving very useful for designing the French MPA network strategy. For the first time, the French environmental authorities are able to show a full-extent map which allows the most prominent features of the seabed to be visualized at a glance and gives a feel of large homogeneous structures such as:

- the great northern Biscay mud plain,
- the large shelf of photic rock surrounding the islands of the Iroise Sea (Figure 6), home to one of the world’s largest kelp fields, which extends to the east as a fringe to the entire northern coast of Brittany (Figure 5), and
- the outer Seine Estuary (Figure 5) which lies in the lee of the Cotentin peninsula, hence featuring much more diverse hydrodynamic features and more varied bottom types than the central Channel.

Although they are only models (whose correspondence with communities and habitats needs further assessment), these marine landscape maps give a preliminary view of the type of heterogeneity that can be found in the Iroise Sea or in the larger Saint-Malo Bay (and its associated Mont Saint-Michel Bay, Figure 8), which is a key consideration, along with other parameters for the designation of marine protected areas.

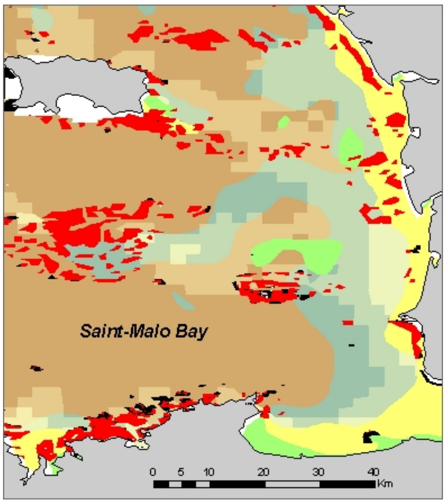

Figure 8. Marine landscape for the larger Saint-Malo Bay.

Basically, what is sought is a mapping tool giving access to a consistent view of the whole coastal and shelf area, with an estimate of confidence. The seabed marine landscape, expressed in this paper as a combination of seabed composition and exposure, could be augmented not only with geomorphological features (major bedforms, as was the case in the topographic layer of the UkSeaMap), but also with the so-called “water column landscape” (describing salinity and temperature variations, stratification, local upwellings etc.), hence providing a synthesis of our marine habitat knowledge. It would also need to be overlaid with priority habitat data, where available.

Conclusion

Given the scarcity of mapping resources in the coastal zone, we must remain pragmatic, make use of all potential information and re-work data sets towards our specific goals. Combining abiotic data layers has been shown to be a viable way to approach habitats types, or in some cases, to predict priority habitats, as was demonstrated in several recent projects and in Mesh in particular. All these efforts are convergent and ideally would find their best expression in a homogenous EUNIS nomenclature. However, alongside this common scheme, local expressions of the marine landscape that are best fitted to local needs should also be made available, as was demonstrated in Belgium (Schelfaut 2005), in The Netherlands (Doornenbal 2007) and also in the Baltic Sea (www.balance-eu.org).

Validation remains to be performed by working out statistics in a confusion matrix. The feedback could certainly lead to a better definition of the thresholds for parameter cut offs.

Within the French coastal management community, the relevance of seabed mapping is generally not fully recognised in environmental assessments and impact studies. Although it is a very new concept, the marine landscape can provide an initial approach to deal with spatial planning when habitat data are lacking.

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