Towards prediction of seabed habitats

Jacques Populus*, Anouar Hamdi*,
Neil Golding, Vera Van Lancker***, Eric de Oliveira***

* Dyneco/Vigies, Ifremer, BP70, 29270 Plouzané, France, jpopulus@ifremer.fr
** Marine Habitats Team, JNCC, Peterborough, UK
*** Renard Centre of Marine Geology, Universiteit Gent, Belgium

Abstract

Marine seabed habitats are highly influenced by the geophysical variables they feature. These are firstly seabed type, topography and exposure, but in the more inshore areas also include water transparency, salinity, temperature etc.
Some relations have been established in a top-down approach between adequate combinations of these variables and the higher levels of the Eunis (European Nature Information System) habitat classification which is currently being used to harmonise seabed habitat mapping throughout Europe. These levels have been referred to as "Marine landscapes", as they are aggregations of a number of lower Eunis habitats from levels 4 to 6. More elaborate variables that are thought to have a bearing on habitat types can be computed from the initial basic ones through comprehensive use of GIS functions. The depth provides slope and orientation. An aggregation of currents and wave action on the seabed provides exposure. Sediment grain size along with currents and slopes allow bedforms on sedimentary bottoms to be predicted. Adequate binning of these quantities and their cross-tabulation leads to a number of landscape types which usually pertain to level 3, but also 4 at times. That raises the question: to which extent could assimilating of biological samples (by way of, e.g., a point–to-polygon method) allow a holistic habitat map at a lower typology level to be produced?
The notion of marine landscape can be further exploited to describe any particular habitat, provided that the distribution laws of this habitat with respect to the geophysical parameters are established on the basis of adequate field data sets. This is a bottom-up approach of habitat modelling adapted to mapping individual priority habitats for which field samples are available.

1) Introduction

There is a recognised lack of habitat maps throughout Europe, which the Mesh project is expected to provide remediation for. This situation varies from one country to another. In the UK, many local maps are available for the more inshore areas, whereas global maps covering the EEZ are lacking, in spite of of the large quantities of sample data collected and stored over the last decades. In France, it is rather the contrary: there are a number of global maps extending beyond the territorial waters, however they neither cover the EEZ nor are fully contiguous. More local maps are rarely available, although they are required under several legal obligations such as the European Habitat Directive (Natura 2000), for example, or the Ospar Convention on priority habitats. Complying with these needs (and many others) by direct observations would require considerable efforts which are outside of the scope of currently available means. The Mesh partnership has therefore embarked on predictive modelling with a view to a) on global scale, filling the gaps between existing habitat maps, b) on a local scale be able to predict the probability of the presence of key habitats on vast expanses of more inshore zones. Seabed modelling results from the fact that, observations, whether direct by sampling or indirect by remote sensing (visible or acoustic) are extremely costly and time consuming, and all the more so when the biology is concerned. Modelling has been developed by several authors with a view to producing an overall picture of large expanses of sea bottom (Roff and Taylor, 2000; Golding,

2004). The concept was also applied to the water column, for potential application to pelagic fisheries, for example.
Two general approaches are described here. The first (bottom-up) method tries to reproduce the abiotic levels of the Eunis classification. As it is based on the description of samples, it is limited by sample quality but has the advantage of being more likely to be homogeneous. The second method combines a number of environmental parameters and queries them to produce a Marine Landscape map related to habitats. In its application to the seabed, it depends more on seabed types in that the query will vary greatly between e.g. the North Sea with only sediments on the bottom and the Irish Sea with far more diversified bottom types. These two paths are by essence holistic (they concern all habitats) and also broadly based (in terms of space) as they intend to address wide gaps within the mapping coverage.

2) Habitat prediction rationale

2.1 The Eunis classification

The EUNIS Habitat classification is a comprehensive pan-European system to facilitate the harmonised description and collection of data across Europe through the use of criteria for habitat identification; it is a 6 level hierarchical system that covers all types of habitats from natural to artificial, from terrestrial to freshwater and marine (Connor, 2004 and http://eunis.eea.eu.int/habitats.jsp). Level 1 defines marine and terrestrial environmens. Level 2 is broad habitats. This reveals habitats that are not covered by seawater during low tide (as is the case, for example, for reefs). Level 3 is a breakdown of habitats implemented at what is still quite a small scale. This enables the hierarchisation to reflect the first differences at the level of biological flora and fauna present. It also demarcates the intertidal and subtidal zones. There are 18 ranges in this level (Table 1) which mainly differentiate zones according to their physical and hydrodynamic characteristics. Level 4 are biotope complexes. Each group comprises similar physical and biological characteristics. They are delimited using visual methods (surveys on the ground, sampling, interpretation of satellite images). Level 5 and 6 are biotopes and sub-biotopes. These classes of habitat are differentiated on the basis of the biological species that occupy them.

The Eunis classification was based on field observations and sampling. Recent methods pertaining to remote sensing (visible and acoustics) do not enable such detailed levels to be reached, but yield a gross description of ground units that need to be subsequently ground truthed and biologically described. However, a given remote sensing technique may immediately identify habitats located at different levels in the classification when their signature is quite clear. This is the case for e.g. maerl or seagrass beds, located far down the scale, whose assessment will require a very limited sampling effort. Conversely, sedimentary bottoms may be only grossly identified by remote sensing, and require a much heavier sampling effort to arrive at the same Eunis level.

2.2 The data driven approach

Modelling is basically made possible by knowledge of the environmental preferenda of habitats. The data driven approach relies on the physical description of the environment that is recorded with each sample. It is based on samples that allow the laws driving the presence of habitats to be established. It requires a sufficient number of samples to establish even very simple laws (wherever these samples are located). The final scale at which the map will be produced is not dependant on the samples. It will only depend on the scales of the contributing variables. Therefore, the scale in the wider subtidal zone is likely to be a global one because by nature physical parameters are usually mapped in a global way (all the more because they are hidden underwater). In the intertidal zone, we can get closer to reality because things are visible and also because advanced tools are able to finely capture the physiography. However, even there, some variables (e.g. exposure in intertidal areas) may be difficult for the observer to record, since they are the expression of rather subtle phenomena.

Table 1: Subset of the Eunis classification table limited to level 3 littoral and infralittoral

EUNIS level	EUNIS code	EUNIS name	Seabed substrata	Slope	Photic limits	Salinity	Temperature	Nearbed stress	Wave disturbance	Biology
0	0		Rock Coarse sediment Sand Mud Mixed	??	Photic Aphotic	Marine (oceanic) Marine (coastal) Estuarine (variable)	Cold temperate Warm temperate Warm Mediterrane	High Moderate Low	High Moderate Low	
1	A	Marine habitats				Freshwater (<0.5ppt)				
2	A1	Littoral rock and other hard substrata	Rock		Photic					
3	A1.2	Moderate energy littoral rock				Marine			Moderate	
3	A1.3	Low energy littoral rock							Low	
3	A1.4	Features of littoral rock		Rockpools, caves						
2	A2	Littoral sediment	Coarse sediment, sand, mud or mixed							
3	A2.2	Littoral sand and muddy sand	Sand							
3	A2.3	Littoral mud	Mud							
3	A2.4	Littoral mixed sediments	Mixed sediment							
3	A2.5	Coastal saltmarshes and saline reedbeds								Lifeforms
3	A2.6	Littoral sediments dominated by aquatic angiosperms								Lifeforms
3	A2.7	Littoral biogenic reefs								Lifeforms
3	A2.8	Features of littoral sediment								
2	A3	Infralittoral rock and other hard substrata	Rock		Photic					
3	A3.1	Atlantic and Mediterranean high energy infralittoral rock							High	
3	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock							Moderate	
3	A3.3	Atlantic and Mediterranean low energy infralittoral rock							Low	
3	A3.4	Baltic exposed infralittoral rock				Reduced or low	Baltic			
3	A3.5	Baltic moderately exposed infralittoral rock				Reduced or low				
3	A3.6	Baltic sheltered infralittoral rock				Reduced or low				
3	A3.7	Features of infralittoral rock								

2.3 The top-down approach

The top-down approach currently referred to as the “Marine Landscape” or “Seascape” and widely reported in the literature is imposed by the lack of samples. The main examples can be found in Canada (Roff and Taylor, 2000), but also in the Irish Sea (Golding, 2004) and Belgium (Schelfaut, 2005). This approach is also somewhat scale-independant, since it can be produced at a global scale (e.g. the first two examples feature resolutions not better than one nautical mile), or at a more detailed scale (the Belgian example, with resolution of 200m), but will likely never be very local, since a landscape, being an assemblage of habitats, is bound to encompass quite a bit of terrain.

3) Material: environmental data sets for the Mesh area

3.1 Primary variables

Abiotic data relevant to habitats are listed in table 2**.** Not all of them have the same importance. It is currently recognised that depth, seabed nature and seabed exposure are leading drivers. Others are the light budget and temperature. This is confirmed by the fact that when looking at samples and their physical description, these three features are the most commonly mentioned (see table 1). However, this will also depend on the general habitat type and context. For habitats in the photic zone and especially their vegetal component, the light budget will be crucial. For sediment, the seabed grain size is of paramount importance, as may be the silt fraction.

Table 2: Datasets that can be used for compiling marine landscape maps (after ICES, 2006)

Type of dataset	Unit	Application
Bathymetry (incl. slope/topography)	Meter, gradient	Topography, 3D modelling, slope, ruggedness, bedforms, stability of habitats
Wave exposure/fetch	exposure coefficient	identification of potential habitats, range of organisms, orbital velocity
Surficial geology(seafloor typology)	lithology, area cover	identification of potential habitats, range of organisms
Sediment composition	grain size, geotechnical, acoustic & geochemical properties	Habitat complexity, heterogeneity
Maximum current (in given relevant time span)	knots, cm per second, direction	Adversity, identification of potential habitats, mobility of sediment, bottom stress,
Tidal range*/sea level changes	cm, meter	identification of potential habitats, zonation, exposure time (desiccation)
Shoreline (at HAT)	meter	outlining the Baltic Sea basin, GIS modelling
Benthic species	Benthic community	range of organisms, diversity
Temperature (surface, bottom, profile)	°C, (annual range, variability)	Biogeographic zones, special communities
Dissolved gases (oxygen, methane etc)	mg/l	Anoxic area or time period of deficiency, special communities
Water quality (nutrient concentration)	e.g. Tot N. Tot.P	level of eutrophication
Stratification	depth of thermo / pycnocline	
Transparency (Turbidity)	Secchi depth (m)	depth of photic zone, potential habitats, range of organisms
Anthropogenic impacts	multiple	Habitat modifiers
Salinity	PSU (max, min, range, rate of change)	potential habitats, range of organisms
Occurrence/frequency of algal blooms	Species, Chlorophyll, µg/l	presence absence in a specific area, areas occupied with large standing stocks of microalgae
Mixing regimes	cover (km2)	
Historical records		Past status of habitats

Figure 1 establishes a flow diagram for seabed habitat modelling. Primary variables combine to produce secondary variables such as bottom exposure or bedform probability, themselves input to habitat prediction models. As is stressed here in figure 1, the depth is involved at many stages: rather than the absolute depth value itself, its derivatives (slope and orientation) will be needed. In the computation of bedforms (itself a prediction) and of bottom exposure, fine knowledge of depth is of the utmost importance for the quality of the final result. When computing the flooding frequency of the intertidal zone, the elevation will be combined with tide data.

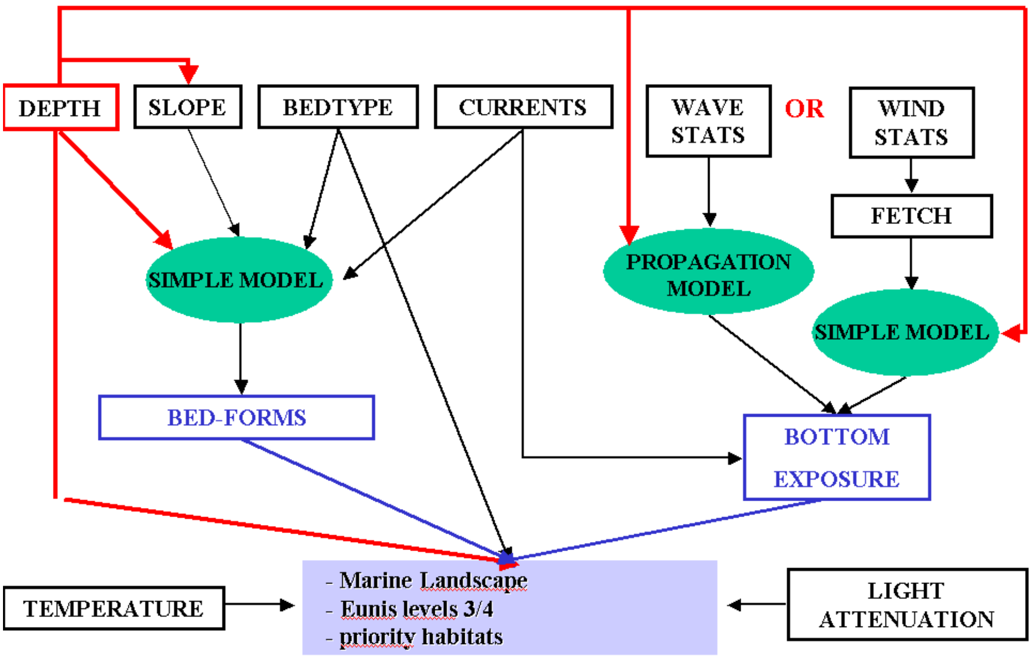

Figure 1: Data flow for habitat modelling

Bathymetry/topography

Bathymetry and topography often come from various sources, but the main one is records of soundings delivered by hydrographic offices. In France, many of these data have been digitized and are readily available in ascii digital form, but not often in gridded form. However there are still parts of the coastal zone where the data either haven't been produced digitally or are outdated or extremely sparse, especially over the so called "white ribbon" inshore. As regards the intertidal zone, only a few, very limited, parts of it have been mapped in great detail by Lidar surveys (both topographic and hydrographic) so far.

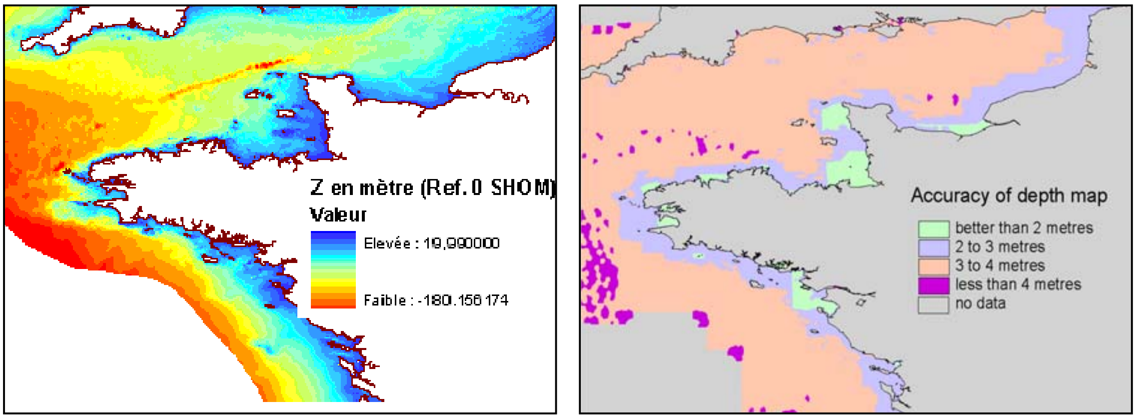

Figure 2: Compilation of depth data for the French Mesh area at a resolution of 1 km (left), confidence map (right).

Depth data were compiled and interpolated by kriging to produce two layers, one at 1 km resolution partly covering the shelf area (shown in figure 2). A confidence map was also computed by quadratically summing the sounding accuracy and the kriging error. Another layer at a resolution of 150 metres was produced from the same source data only on very coastal cells where data density was sufficient to allow it. Either of these two layers can be readily used for habitat modelling.

The level of resolution of gridded files obtained by interpolation of the soundings is at most 20 metres, while the Lidar data density allows a mesh size of 2-3 metres. The confidence in the gridded data influences the confidence inherent to the isolines derived from them.

Seabed type

Seabed map availability and formats vary quite a bit throughout the Mesh area. The British Geological Survey owns a 1:250,000 digital map of the British Iles that can be purchased under licence. In France SHOM currently produces seabed nature maps (called “Cartes G”, scale 1:100,000) which cover most of the territorial waters, whereas more generally, historic maps have been produced by individual authors. Both series were digitised, stitched and translated into a common 9 class simplified classification (whose legend appears in figure 3). Either of these two compilations can be used for modelling purposes, depending on the level of detail required.

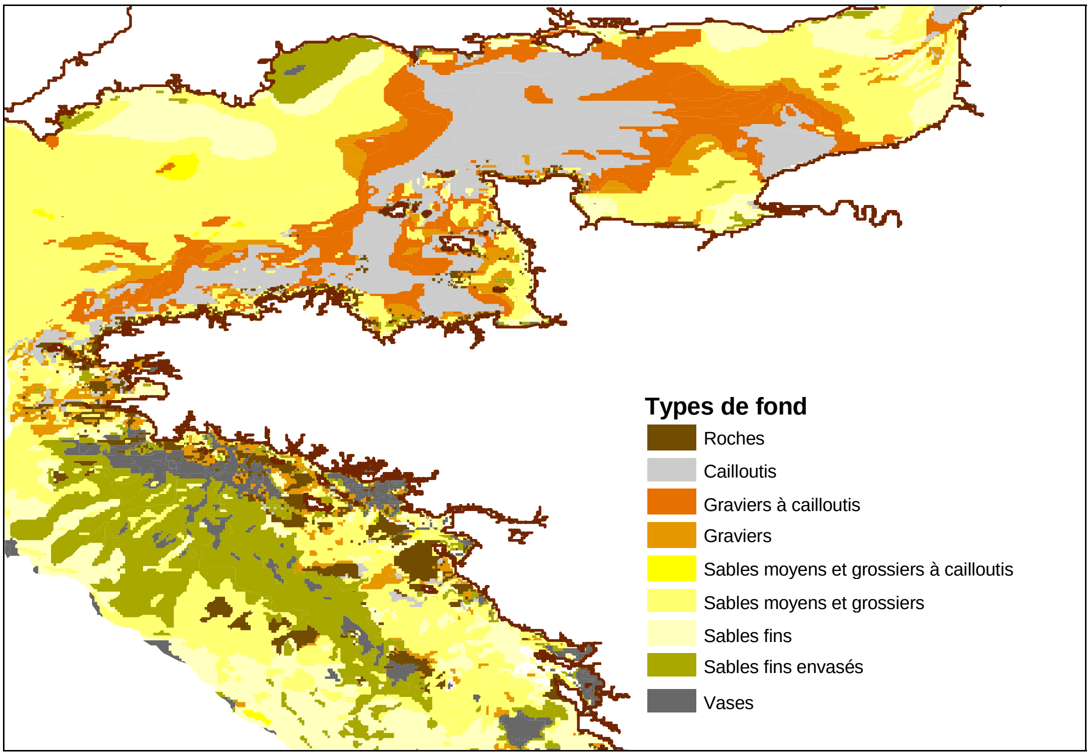

Figure 3: Compilation of seabed type data with a nine class harmonised classification.

Furthermore, as maps use different classifications systems in the Mesh countries, it appeared relevant to the partnership to bring these data sets into a homogeneous system, the Folk classification (Folk, 1954). Due to some copyright limitations attached to the data, a simplified six class version was adopted, which produceda homogeneous data layer over most of the Mesh area with resolution of one nautical mile. Further refinements in both resolution and semantics will be possible in future, provided the right data are made available to the project.

Water transparency

Water transparency is relevant only in the photic zone (mostly at depths of less than 40 metres). It is derived from satellite ocean colour imagery, either Seawifs or Meris, with respectively 1 km and 300m resolutions. Semi-empirical algorithms compute the diffuse attenuation coefficient induced by particulate and dissolved matter.

3.2 Secondary variables

Bedforms

Based on the literature (Van Hoey *et al.*, 2004), it is not possible to demarcate seabed marine landscapes solely based on grain-size distribution, and it is therefore necessary to include other datasets such as bed morphological features which are relevant to the biology. Bibliographic research (Berné, 1990) on marine seabed forms, usually referred to as bedforms (or marine hydraulic dunes), has shown that they are sediment structures usually formed by sands of varying particle size, graded from fine to coarse which vary in size from a few tens of centimetres up to several hundred metres. Bedforms are currently identified using acoustic techniques (sidescan sonar) but of course there are huge gaps where no recent geophysical surveys have taken place. No reference could be found related to models enabling charting of bedform indices. Research is often based on the mapping of seabed forms obtained through interpretation of acoustic surveys at some of the sites that are subsequently used to validate the models.

To overcome this, it was first necessary to regroup the parameters providing information on the formation and localisation of bedforms, to discover how they could be exploited, and where they could be found (if they could not be obtained directly). At this point, it seemed important to meet with experts in the field to discuss the choice of parameters and the formulae they might use in any calculations. The last step was to refine the data analysis model to arrive at a scoring chart for the presence of bedforms. First, slope and orientation were retrieved from the bathymetry. The slope was divided into 3 equal population ranges to produce the slope index. As bedforms generally form in areas oriented perpendicularly to tidal currents (Ehrhold, 1995), the direction of propagation of tidal currents (extracted from current data) and the orientation were classified in relation to their difference of angle. The resulting layer for this classification is called the exposure index. The next step was to calculate the bottom friction speed for the tidal currents, as well as the critical dislodging speed for tidal current and seabed sediments, respectively. The resulting map was called the friction index.

The chart of indices of bedform presence is the result of the equal population classification of the value that results from this function:

[Probability of presence of bedforms] =
50% [Friction index] + 30% [Exposure index] + 20% [Slope index]

In this function, different weightings were attributed to each index. The friction index and the exposure index are factors for bedform formation. Bedform formation is the result of the dislodging, conveyance and deposition of grains of sand. The main condition for bedform formation is therefore the dislodging of the grain. The higher the correlation is between the friction and the dislodging speed, the more probability there is of bedform formation. For this reason, we attributed the highest weighting to the friction index. Since the slope is used only to localise the areas having a high probability of bedform occurrence, the lowest weighting was attributed to the slope index. Some results are shown in figure 4. Many of the bedforms in this area consist of large hydraulic dunes extending over many kilometres, which in this case have a distinctive bathymetric signature. However the model is capable of predicting even the smaller bedforms, thanks to both the detailed sediment map used and the area's specific geography which creates highly consistent current dynamics

Nearbed stress

Nearbed stress is a very important driver for habitats in many ways. On sediment bottoms, the shear stress will produce bedforms which influence habitat distribution. On rocky substrata (subtidal and intertidal alike), the presence and type of vegetation are known to be closely linked to water dynamics. Wave and tidal currents generate stress at the sea bed by the complex turbulent flow patterns over small scale bed roughness. Currents occur even in deep water (for instance in the English Channel) whilst wave action is limited to the so called wave base (see 4.1). As shown in figure 1, the contribution of waves can be obtained through two different paths, either using wave statistics and a propagation model or using fetch, a proxy for waves. An inventory of data relating to wind, swell and tidal current over the entire study zone is indispensable in order to obtain a dependable set of data. Although current data are now easily available thanks to progress in deterministic modelling, statistical data about wind and swell are still rather scarce indeed.

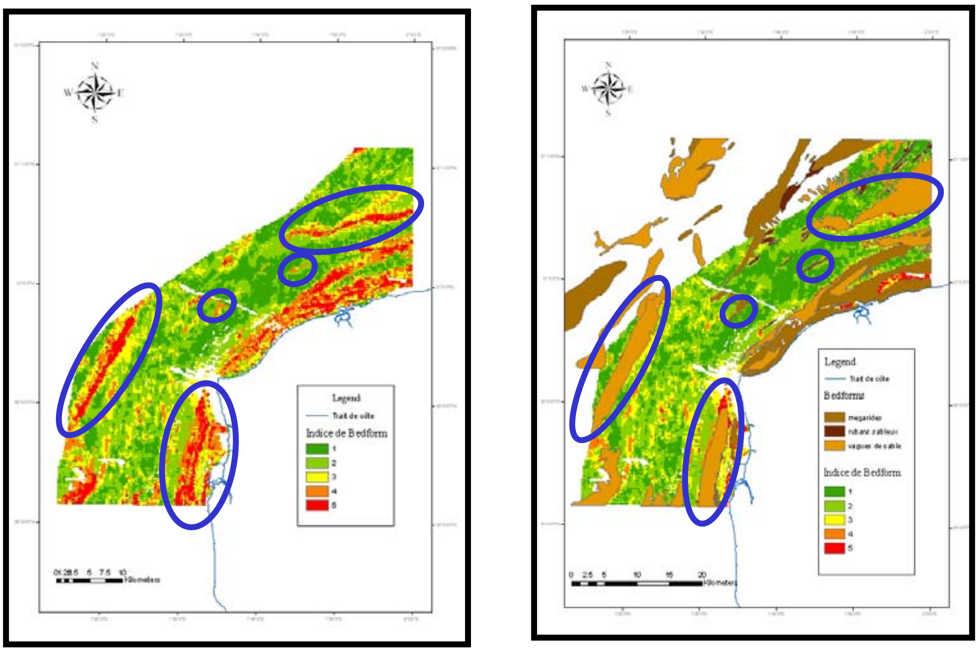

Figure 4: Prediction of bedforms in the Dover Strait from model (left), actual bedform map from side scan sonar interpretation (right).

Calculating the speed of friction of the tidal current as well as that of the swell enables the near-bed stress to be estimated. This method is difficult from a technical point of view because we do not fully understand the way in which these two components combine (Lacombe, 1965). Friction due to currents will not be looked at here in detail as it is relatively straightforward and strongly depends on a drag coefficient that may be considered constant on a whole region for the first approximation.

De Oliveira (2005) propagated some statistical wave data to the inshore zone on a section of the coast, however this is doubly limited in that wave data (themselves coming from models) are still very sparse and propagating them requires high quality depth data and efficient code. The current level of resolution will therefore vary according to a) the resolution of the initial wave or wind data sets (which in some cases is no better than 10-20 miles), and b) the quality of the depth DTM (Digital terrain model) used in the process, leading to final resolutions between 300 metres and one nautical mile.

The fetch can be used as a wave proxy to describe the sea state and its influence on bottom. The fetch represents a measure of the area of water put into motion by the wind. A fetch index called the Relative Exposure Index (REI, Kelly, 2001) is calculated at any offshore point near the coastline. In this case, the fetch is the distance from the point of wind creation in relation to the coast in the direction of the wind. This index is calculated by evaluating for each of the eight possible wind directions the product of the maximum monthly wind speed and the frequency of this speed, and the fetch, as shown by the following formula: $REI = \sum_{i=1}^{8} \frac{(V_i P_i F_i)}{1000}$ where V is the maximum monthly wind speed, P the wind frequency and F the fetch in the given wind direction.

This was applied to Trégor, a coastal region of North Brittany where swell data were available from a previous study (De Oliveira, 2005). The surface exposure was the REI above and the bottom exposure was obtained by dividing it by the depth. A comparison was made between a) the modelled surface exposure index and the significant wave height statistical data and b) the modelled bottom exposure bottom and the shear stress computed from the swell with those resulting from REI, the four maps classified using an equal population classification with indices 1 to 10 are shown in figure 5 for surface and bottom. Good agreement was found for the surface, with a limitation due to the diffraction capacity of ocean waves, which the fetch cannot show. The agreement for the bottom still has to be refined.

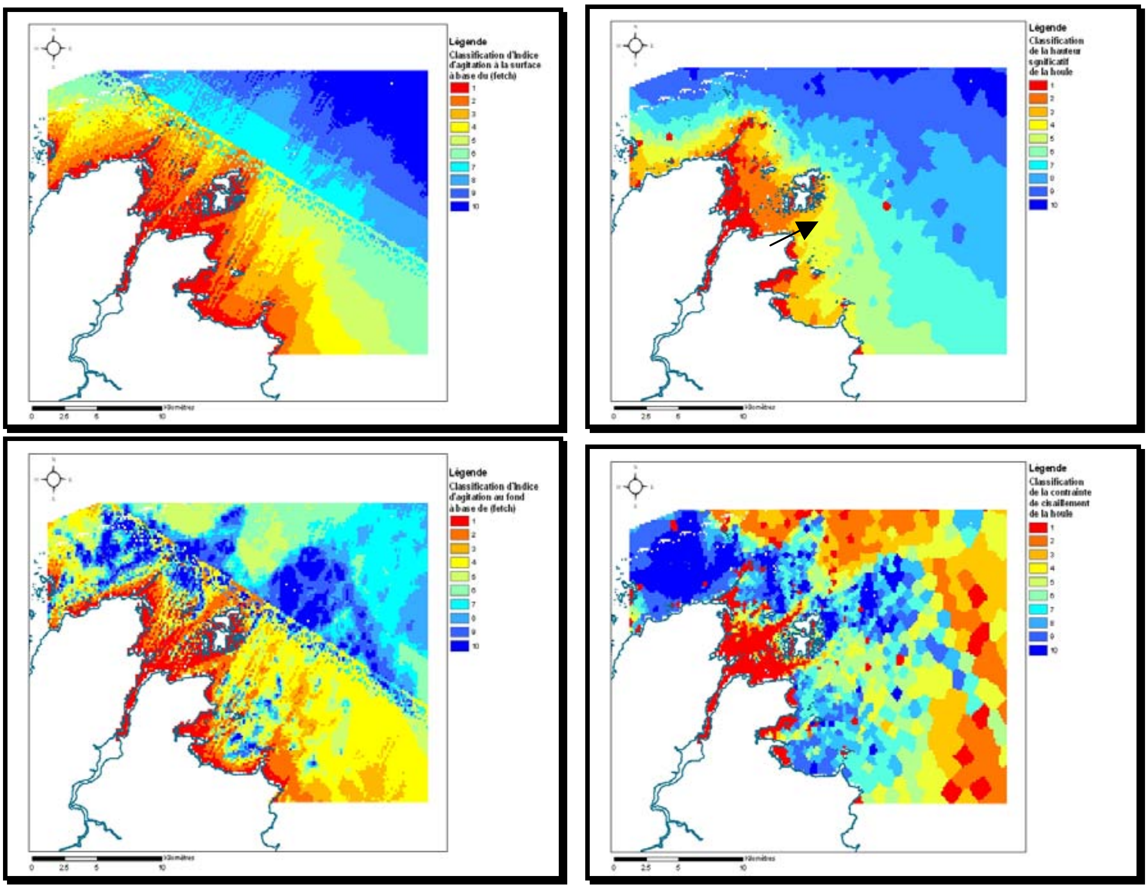

Figure 5: Surface exposure from fetch (top left) and significant wave height statistics (top right), bottom exposure from fetch (bottom left) and from waves (bottom right).

4) Modelling methods

4.1 Developing a broad-scale predictive EUNIS habitat map

Background

The upper classification hierarchy (Eunis level 1, 2 & 3) is largely driven by physical variables. Each habitat class within Eunis is defined by a combination of environmental variables (not unique) together with its associated biological community. By using as many as possible of the key physical and environmental variables listed above and recording them along with benthic samples, it is possible to reconstruct in a bottom-up approach the upper classification hierarchy which the sampled habitat belongs to. These variables are: substratum (e.g. bedrock, fine sand, cobbles, etc), depth band (e.g littoral, circalittoral, etc), near bedstress (or a proxy to it) and water transparency (e.g. Secchi disk depth) etc.

Datasets

The seabed sediment dataset for the MESH area was produced by combining national seabed sediment datasets from the five Mesh countries. Datasets ranked according to the Folk classification were reclassified to a simplified 5 class system (rock, coarse sediment, sands and muddy sands, muds and sandy muds and mixed sediment).

Table 2: Triplets of value issued from benthic samples

		Rock/Reef	Coarse Sediment	Sands and muddy sands	Muds and sandy muds	Mixed sediment
High energy	Infralittoral	111	121	131	141	151
	Circalittoral	211	221	231	241	251
	Deep circalittoral	311	321	331	341	351
	200m to 1000m	411	421	431	441	451
	> 1000m	511	521	531	541	551
Moderate energy	Infralittoral	112	122	132	142	152
	Circalittoral	212	222	232	242	252
	Deep circalittoral	312	322	332	342	352
	200m to 1000m	412	422	432	442	452
	> 1000m	512	522	532	542	552
Low energy	Infralittoral	113	123	133	143	153
	Circalittoral	213	223	233	243	253
	Deep circalittoral	313	323	333	343	353
	200m to 1000m	413	423	433	443	453
	> 1000m	513	523	533	543	553

Bathymetric data were derived from the Gebco digital atlas (1 minute grid resolution) and used in combination with other data to determine depth zones as adopted in Eunis. Data on the depth of light penetration into the water column were used to delineate the infralittoral/circalittoral boundary. These data were derived from ocean colour observations made by the SeaWiFs satellite which takes a measurement of the amount of light in the blue-green part of the spectrum that penetrates the water column. As it is widely stated in the literature that the lower limit of the infralittoral zone is broadly correlated with the depth at which the available light is 1% of surface incidence, crossing the Gebco bathymetry and the light attenuation coefficient lead to determining the areas of seabed where light intensity is ≥ 1%.

Going deeper, the boundary between the shallower zone of periodically-disturbed seabed (the “Infralittoral and Circalittoral étages of Glémarec”, 1973) and the deeper zone of undisturbed seabed (the Offshore Circalittoral étage of Glémarec) was obtained by computing the maximum wave-base depth, defined as the maximum depth at which the passage of a wave causes motion in the water column. Typically this boundary occurs at about 50-70m in depth around the North-East Atlantic. Maximum wave length data, measured over a 10-year period, were provided by the Proudman

Oceanography Laboratory, derived from the proWAM 12 km wave model. The wave-base was then queried with bathymetry within the Access database to identify areas of seabed which were shallower than the maximum wave-base, and used to generate a maximum wave base data layer.
For the purposes of this work, bed stress was used as a surrogate for 'energy' levels, which are used within the Eunis classification (predominantly in the rock sections). Bed stress was computed from the maximum tidal current data (disregarding wave data, not available for this study). Data from a 1.8 km tidal application of Polcoms (Proudman Oceanographic Lab Coastal Ocean Modelling System; HOLT, 2005) were mapped after being divided into three categories, namely weak (0-1.8 N/m2), moderate (1.8-4.0 N/m2) and strong (above 4.0 Ns/m2).

Table 3: Correlation between triplet codes in table 1 and EUNIS marine habitat types

		Rock/Reef	Coarse Sediment	Sands and muddy sands	Muds and sandy muds	Mixed sediment
High energy	Infralittoral	A3.1	A5.12	A5.23 or A5.24	A5.33 or A5.34	A5.43
	Circalittoral	A4.1	A5.13	A5.25 or A5.26	A5.35 or A5.36	A5.44
	Deep circalittoral	A4.27 or A4.33	A5.14	A5.27	A5.37	A5.45
	200m to 1000m	A6.1	521	A6.3 or A6.4	A6.5	A6.2
	> 1000m	A6.1	621	A6.3 or A6.4	A6.5	A6.2
Moderate energy	Infralittoral	A3.2	A5.12	A5.23 or A5.24	A5.33 or A5.34	A5.43
	Circalittoral	A4.2	A5.13	A5.25 or A5.26	A5.35 or A5.36	A5.44
	Deep circalittoral	A4.27 or A4.33	A5.14	A5.27	A5.37	A5.45
	200m to 1000m	A6.1	522	A6.3 or A6.4	A6.5	A6.2
	> 1000m	A6.1	622	A6.3 or A6.4	A6.5	A6.2
Low energy	Infralittoral	A3.3	A5.12	A5.23 or A5.24	A5.33 or A5.34	A5.43
	Circalittoral	A4.3	A5.13	A5.25 or A5.26	A5.35 or A5.36	A5.44
	Deep circalittoral	A4.27 or A4.33	A5.14	A5.27	A5.37	A5.45
	200m to 1000m	A6.1	523	A6.3 or A6.4	A6.5	A6.2
	> 1000m	A6.1	623	A6.3 or A6.4	A6.5	A6.2

Data analysis

All data were summarised to a vector grid (or net) of approximately one nautical mile which covered the extent of the MESH project area. Each data set was segmented into categories that reflect the important divisions in the EUNIS habitat classification scheme and each cell was assigned a value for each of the three key variables (depth zone, seabed type and energy). Bathymetry, wave-base depth & light attenuation were queried in combination to derive the first digit. The second digit refers to sediment type (e.g. rock, sands, muds etc). The third and final digit refers to maximum bed-stress (a surrogate for the energy levels used in EUNIS). Triplets of vakue of these three variables are shown in table 2. These triplet codes were then used to identify groups of EUNIS level 3 & 4 types (as is shown in table 3). Typically it was possible to identify some EUNIS level 4 types in the sublittoral sediment section of EUNIS, whereas rock habitats could only be identified to level 3. Note that this approach highlighted possible habitat types which are not currently represented under the EUNIS classification (identified in grey in table 3).

4.2 The Marine Landscape approach

Background

The concept of 'Marine Landscapes' is based on using geophysical and hydrographical data to identify habitat types in the absence of biological data. If reliable, such an approach would enable management measures for offshore areas to be developed with confidence in the absence of biological data, which is very expensive to obtain in offshore areas. The Marine Landscape approach was formalised in the framework of the Irish Sea Pilot (JNCC, 2004) which was to help develop a strategy for marine nature conservation that could be applied to all UK waters and, with international collaboration, the adjacent waters of the north-east Atlantic. It is currently being applied to the whole of the UK coastal and shelf waters. The application to the Belgian continental shelf involved some tuning of the methodology, due to specific seabed conditions prevailing theree. Through these two examples, the applicability to a wider scope is examined.

Data sets and methodology

Roff and Taylor (2000) developed their classification using, in relation to the seabed, factors such as water temperature, depth/light, substratum type, exposure and slope, and, in relation to the water column, factors such as water temperature, depth/light and the stratification/mixing regime.
In the Irish Sea Pilot case bathymetry (Dig Bath) and seabed (Dig SB250) data were obtained under licence from the BGS in the format of ArcView8 compatible files. These data, combined with bedform and slope data, were most useful in defining and mapping of marine landscapes. Hydrographical data (including data on water temperature, salinity, currents and frontal systems) were provided by the Proudman Oceanographic Laboratory, the British Oceanographic Data Centre and the Plymouth Marine Laboratory. These hydrographical data were used in the definition of certain seabed marine landscapes and also in the definition of water column types. The data used were modelled data and required considerable manipulation.
Bathymetry and seabed sediment data were converted from polyline to polygon format and merged with derived slope data in the GIS using a process called a 'union'. This process merges the attributes of each of the dataset into a single one, allowing easier querying with the GIS. Other datasets, including generalised bedforms, maximum bed stress (bottom current) and gas seeps, were overlaid on this 'union' layer. Practical criteria were developed to enable the separation of marine landscapes into distinct types. Some key criteria were depth, substratum type, bed-stress/current strength, topography/slope and related factors. Account was taken, with respect to coastal (physiographic) features, of existing definitions (e.g. the definitions applied to Habitats Directive Annex I habitat types). Biological characterisation was achieved by linking the available biological data to the relevant marine landscapes by joining the data spatially within the GIS and aggregating data to the biotope complex level of the national habitat classification. Because much of the biological data used were Irish Sea data, this method was to some extent self validating (i.e. it was possible to identify marine landscapes from geophysical and hydrographic data and characterise them with actual biological data for the same areas). However, because biological data were sparse for offshore areas, the biological characterisation of marine landscapes which occur offshore was necessarily predicted by extrapolation from other data, and not confirmed.
In the Belgian example, the bathymetry and slope dataset were provided with a resolution of 80 m. The maximum bed stress and the median grain-size of the surficial sediment dataset had a resolution of 250 m. The resolution plays an important role in determining the accuracy of the final product. The layer with the poorest resolution generally sets the accuracy of the end result, even though some of the created polygons may be better. In practice, this means that the marine landscapes defined in this study

have an overall accuracy of 250 m. It was decided to use vector data and therefore it was necessary to convert some of the available datasets from raster to features. After conversion, the datasets used were further processed. Each attribute table was annotated with the unique attributes of properties of the datasets and merged with the others, using the union command in GIS. This process combines all attributes of the variables used into one major attribute table and makes it easier to query the GIS. Using polygons has advantages as well as disadvantages. One disadvantage of working with a vector data structure is that the boundaries between different features are crisp and definite.
ArcView8 proved suitable for most of the Marine landscape data analysis and mapping requirements, although some data conversion required the 'Spatial Analyst' extension. The final datasets (shape files) can be viewed using the free ArcExplorer package. ArcGIS was found to integrate well with Microsoft Access databases, and, through Access, with Microsoft Excel spreadsheets.

5) Preliminary results and discussion

5.1 The modelled broad-scale Eunis habitat map

Figure 6 shows a draft map illustrating the modelled distributions of broad-scale EUNIS habitats across the MESH project area (called the "triplet map"). Each of the habitat codes listed in table 2 corresponded to one/or group of EUNIS marine habitat classes as shown in table 3. There were occasions when no EUNIS equivalent to the habitat code was available. This was particularly notable for the offshore habitats, which are not fully represented in the current version of the EUNIS habitat classification scheme. This broadscale modelling may highlight these currently undefined habitats, and with further ground-truthing, could allow development of the EUNIS marine habitat classification.
This map remains basic in that it is based of simple data sets, in terms of both spatial and semantic resolutions, mostly noticeable over the English Channel and the North Sea which feature only two classes of gravelly sands and muddy sands**.** Rocky substrata being rare except on the margins, they hardly appear at all. This map represents the first level of a transnational approach, however being over-simplified, it may not be appropriate even for very general planning. There are many ways forward, mainly through improving the quality of the data sets and moving to improved resolutions. Obviously, this would not entail much change for the offshore area (as the map will not go beyond describing the abiotic realm associated with habitats) but would definitely enhance the coastal zone. The next step is quite a weighty one in terms of knowledge and as far as biology is concerned at Eunis levels 4 to 6, the way forward would be to assimilate biological samples with this map. This process will depend on the availability and density of opportunistic samples, since even where samples are available they are unlikely to be optimally positioned with respect to the map classes.
In order to examine the biological value of the triplet map (Schelfaut, 2006), the Belgian part of it was validated by means of an extensive biological dataset of over 700 samples which was spatially joined to the triplet map, hence providing a summary of the number of samples lying in each habitat type. At first glance the four zones of the triplet map match rather well the distribution patterns of 3 of the 4 major macrobenthic communities as they occur on the Belgian shelf (*Ophelia limacina, Nephtys and Macoma balthica*). However one of the most important macrobenthic communities, the *Abra Alba* one, is not unambiguously present in the triplet map. The main problem is that the communities do not exactly match classes in the EUNIS classification, which emphasizes the need to properly define the Eunis classes from the field samples in the first place.

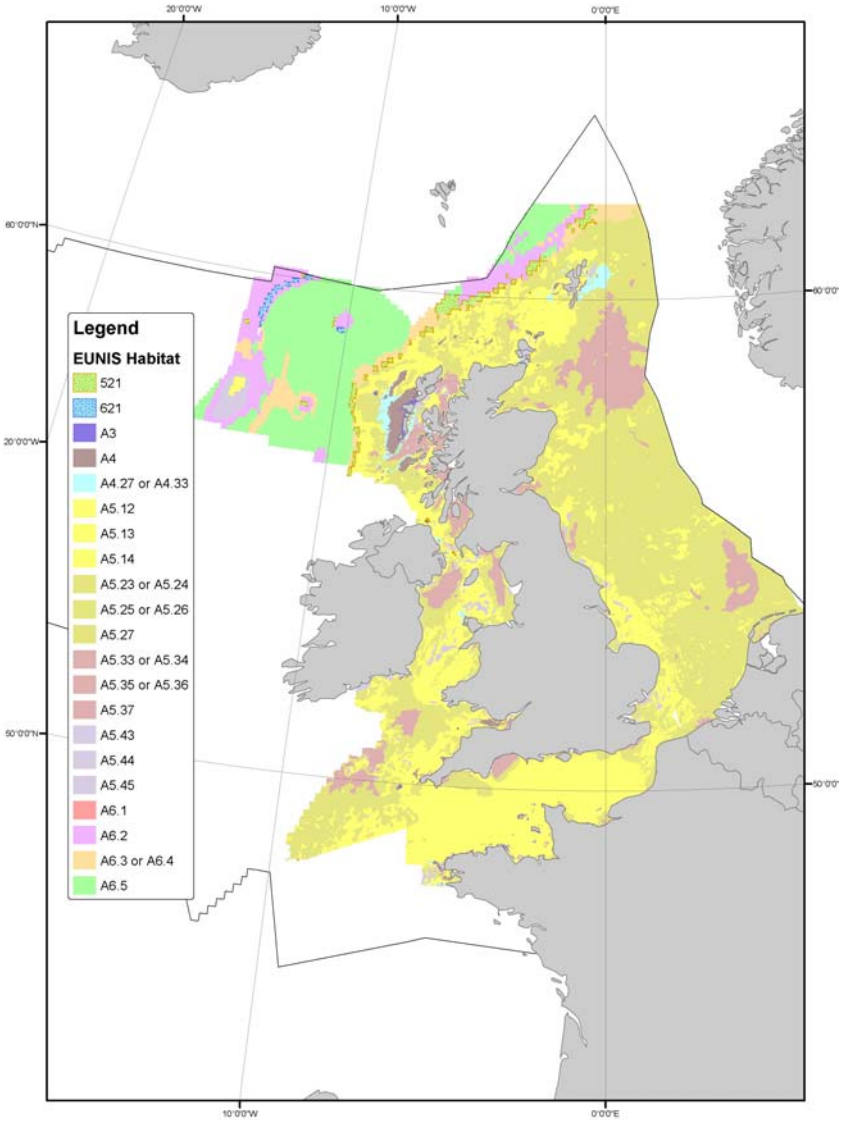

Figure 6: Draft modelled broad-scale EUNIS habitat types for the MESH project area

5.2 The Marine Landscape map and its relevance to planning

For the Irish Sea three main groups of marine landscapes were identified, i) coastal (physiographic) marine landscapes, ii) seabed marine landscapes, iii) water column marine landscapes. Eighteen coastal and seabed marine landscape types were identified, the distribution of which is shown in figure 7. The distinguishing geophysical and hydrographical characteristics of each of the coastal and seabed marine landscapes were summarised (Vincent *et al.*, 2004), along with the biological characterisation (Connor *et al.* 2003) carried out by spatially joining samples to polygons.
There was a good correlation between the marine landscapes identified and the character of the seabed, which stood true for the biological characterisation; in general the relation between marine landscapes and biological communities is very strong, but locally there can be considerable variation and complexity. These marine landscapes would need to be extended for use in areas outside of the Irish Sea.
The Belgian shelf being fully sedimentary the median grain-size and the mud content are the most discriminating parameters towards the prediction of benthic communities (Van Hoey *et al.*, 2004). Using a multivariate Kriging technique that involved bathymetrs as a secondary variable (Verfaillie *et al.*, in prep.), eight classes were distinguished based on the median grain-size (D_{50}) dataset, with 50 µm break

values. Bedforms were also an input variable to landscapes, as bedforms are thought to have a relation to sediment seabed habitats.

There were fundamental discrepancies between data queries in the two sites. Slope was not a key variable in the Irish Sea whilst three slope classes were identified in the Belgian shelf, grain size was split into three types and eight types respectively on the two sites. This shows the marine landscape remain a notion specific to broad seabed types, which probably limits its value as a generic tool. The value of the marine landscapes approach is that it uses data which are supposed to be currently available to enable management strategies for the marine environment to be developed and implemented. Clearly habitat information derived from future biological survey will be more accurate than marine landscape maps developed largely from geophysical and hydrographical data. As such survey information becomes available over time, marine landscape maps will need to be refined to accommodate it.

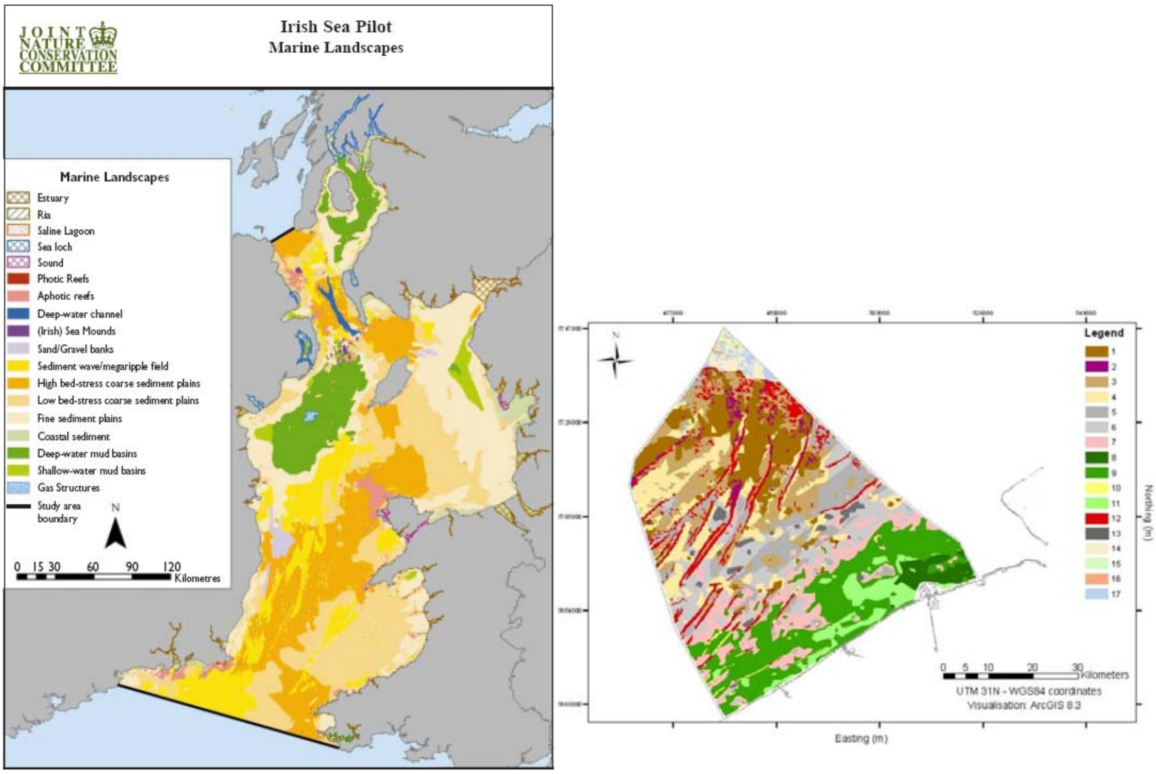

Figure 7: The Irish Sea Pilot and Belgian shelf marine landscapes maps respectively showing 18 and 17 classes.

Although there was generally a good correlation between the marine landscapes and both the nature of the seabed and its biological character, there may be considerable local complexity which cannot be addressed at this level. The marine landscape approach should be adopted as a key element for marine nature conservation and utilised in the spatial planning and management of the marine environment. It is quite likely that this approach is transferable with little modification to adjacent seas of broadly similar character. It is suggested that the list identified for the Irish Sea be expanded to include landscapes not found in the Irish Sea and further refined as necessary. From there on, the occurences of these lansdcapes should be summarised within the main regional seas of Europe and their vulnerability to principal human activities assessed.

5.2 Technical aspects

Some technical aspects linked with data handling need to be taken into consideration. Firstly the importance of metadata should be stressed. Many of them were not readily available when the various

data mentioned in this paper were collated, which significantly limited the value of the data. The Mesh project established its own discovery metadata (a few core fields) but recommended the availability at all times of the ISO 19115 metadata.
For zonal data generally two types of formats are encountered, the raster and vector types. While each of them have their own advantages and drawbacks (a number of surveys nowadays deliver data in raster form right away), when time comes to process them jointly as exposed above, clearly the raster form offers is of great advantage when querying the layers using map algebra. However some rules of good sense have to be kept in mind, an essential one being that the layer with the poorest resolution sets the accuracy of the end result. This appears when it may be necessary to "rasterize" a layer at high resolution to keep track of precise polygon contours (e.g. regulated areas). When cross tabulating with lower resolution data, the end result will not be able to restitute the detail of the original layer. However there remains the possibility to overlay the vector file on top of the final raster map. In addition, the pixelated appearance of the final maps does not give the impression of the high precision which is often falsely attributed to polygon maps with their smoothed boundaries.

6) Conclusion: the way forward

Global maps are bound to be transnational. Data standards need to be adopted across borders, and public funded data should be made available to the wider community under the aegis of the European Union. This was the case within the Mesh project, where a strong effort was made towards homogeneous classifications across the participating countries. Practically this allowed drafting a common sediment map and also a Eunis habitat map. This took considerable efforts since the various classifications in use locally did not overlap and trade-offs had to be found.
The way forward could consist in identifying three spatial levels over the shelf and coastal waters of north-west Europe. As shown above, at global/regional scale (resolution on the order of one nautical mile), levels 3 to 4 in the Eunis classification were reached. This was also the resolution of the Irish Sea marine landscapes. The next step could be to biologically characterize each of these polygons as best as possible using all existing samples across the project partnership. This would result in assemblages of individual habitats with potential dominant ones. It is questionable at this level to recommend more sampling with a view to better qualifying the biological content of these polygons.

Improving the resolution as was the case of the Belgian example brings in new possibilities, since this implicitly means that the individual variables are known to a much finer level of detail. Other variables could also be brought in such as bedforms or water transparency in the photic zone, which were not significant at one mile resolution but gain relevance as scale increases. However the key condition to these approaches is that some correspondance be known between these variables and the particular Eunis levels or marine landscapes going to be retained. It has be shown above that building the so-called triplet map or querying the physical layer to produce landscapes was essentially based on experts' knowledge. Improving this level might imply either surveying or ground truthing some of the key environmental variables, and also biological sampling at some particular locations to improve the knowledge of the main drivers of the presence of habitats.
The third level is the local one, where single habitats are modelled (usually priority ones as per Ospar; http://www.jncc.gov.uk/page-1583). Much information regarding environmental variables limiting the ranges of the species is held on the MarLin website (http://www.marlin.ac.uk/). Many of these priority habitats in the coastal zone have limited spatial extension and therefore the description of their drivers needs to be quite detailed, which is a challenge in terms of data collection. Various methodologies are being used and concern e.g. intertidal and subtidal seaweeds in Brittany (fuzzy logic, de Oliveira, 2005), maerl beds in Northern Ireland (Birkett, 1998), the distribution of eelgrass in coastal lagoons (Kelly, 2001), or *Sabellaria* biogenic reefs in the UK (general linear regression model used by English Nature). Probably more dedication should be placed in modelling such habitats because they have been recognized as high stakes in coastal management.

References

BERNE S., 1990 - Architecture Et Dynamique Des Dunes Tidales, Thèse de doctorat, Ifremer.

BIRKETT D.A., MAGGS, C.A. & DRING, M.J.,1998. Maerl (volume V) An overview of dynamic and sensitivity characteristics for conservation management of maerl in SAC's. *Scottish Association for Marine Science/UK Marine SAC's Project*.

CONNOR, D.W., ALLEN, J.H., GOLDING, N., LIEBERKNECHT, L.M., NORTHEN, K.O. and REKER, J.B. (2003) The National Marine Habitat Classification for Britain and Ireland. *Version 03.02.* © 2003 Copyright JNCC, Peterborough ISBN 1 86107 546 4 (internet version available online at www.jncc.gov.uk/MarineHabitatClassification).

CONNOR D. et al., 2004 – The Marine habitat classification for Britain and Ireland, JNCC.

DE OLIVEIRA E., POPULUS J., GUILLAUMONT B., 2005. Using Lidar survey and satellite imagery for predictive modelling of coastal habitats - A case for seaweed in Brittany (France). Earsel SIG "*Remote Sensing of the Coastal Zone*", Porto, June 9-11, 2005.

EHRHOLD A., 1995 - Dynamique De Comblement d'un Bassin Sédimentaire Soumis à Un Régime Mégatidal : Exemple de la Baie Du Mont-Saint-michel, Thèse : Université de Caen.

FOLK, R.L., 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal of Geology* 62 (4), 344-359.

GOLDING N. et al, 2004 – The Irish Sea Pilot : Report of the Development of a marine Landscape classification for the Irish Sea, JNCC,.

HOLT J., Geophysical Characteristics of UK waters for Habitat Classification, 2005. Proudman Oceanographic Laboratory, Liverpool L5 6DA, UK.

ICES, 2006. Report of the working group on marine habitat mapping, 4-7 April 2007, Galway, Ireland.

JNCC, 2004 - Irish Sea Pilot. *Report to DEFRA* by the Joint Nature Conservation Committee.

KELLY et al., 2001 – Predictive mapping for management and conservation of seagrass beds in North Carolina, *Aquatic conservation: Marine and Freshwater ecosystems*, Volume 11: page 437-451(2001).

LACOMBE, 1965- Cours d'océanographie physique : Paris.

MARLIN (http://www.marlin.ac.uk/)

OSPAR Priority habitats (http://www.jncc.gov.uk/page-1583)

ROFF J. and TAYLOR M, 2000 – National frameworks for marine conservation – a hierarchical geophysical approach, Aquatic conservation: Marine and Freshwater ecosystems, Volume 10: page 209- 223 (2000).

SCHELFAUT K., 2005 – Defining marine landscape on the Belgian continental shelf as an approach to holistic habitat mapping, Université de Gand, Master's thesis.

SCHELFAUT K., 2006. Biological validation for the Belgian part of the Mesh triplet map. Pers. Comm.

VAN HOEY, G., DEGRAER, S., VINX, M., 2004. Macrobenthis community structure of soft bottom sediments at the Belgian continental shelf. Estuarine, Coastal and Shelf Science; 59, 599-613.

VINCENT, M.A., ATKINS, S.M., LUMB, C.M., GOLDING, N., LIEBERKNECHT, L.M., and WEBSTER, M. (2004). Marine nature conservation and sustainable development - the Irish Sea Pilot. Report to Defra by the Joint Nature Conservation Committee, Peterborough.