JOINT NATURE CONSERVATION COMMITTEE

UKSeaMap
The mapping of seabed and water column features of UK seas

October 2006

UKSeaMap was undertaken by JNCC on behalf of the following funding partners:

Cyngor Cefn Gwlad Cymru
Countryside Council for Wales

THE CROWN ESTATE

defra
Department for Environment Food and Rural Affairs

dti

NATURAL ENGLAND

RSPB

SCOTTISH EXECUTIVE

WWF

This report should be cited as:

Connor, D.W., Gilliland, P.M., Golding, N, Robinson, P., Todd, D., & Verling, E. 2006. *UKSeaMap: the mapping of seabed and water column features of UK seas*. Joint Nature Conservation Committee, Peterborough.

ISBN-10: 1 86107 590 1. ISBN-13: 978 1 86107 590 1

The UKSeaMap project has been part-funded by the Interreg IIIB Programme and is a contribution to the MESH project.

MESH MAPPING EUROPEAN SEABED HABITATS

This project has received European Regional Development Funding through the INTERREG III B Community Initiative

nwe eno INTERREG IIIB NORTH WEST EUROPE

Given the high degree of change in the water column over the course of a year, the data were processed according to four separate seasons (winter, spring, summer and autumn). Within the time constraints of the project, it was not possible to take full account for the 3-dimensional character of the water column; for instance, to reflect on the significant differences in temperature between surface and bottom waters, as this would have required a much more sophisticated modelling approach.

As with the seabed data, the GIS data layers for the water column were transformed for analysis into a grid across the UK Continental Shelf, each grid cell being 0.02 decimal degrees (about one nautical mile) wide. The resultant data sets were analysed in a supervised classification to derive a series of landscape types (e.g. frontal shelf water; well-mixed oceanic water).

To assess the biological validity of the resultant maps, biological data, in the form of distribution data for six plankton taxa from the Continuous Plankton Recorder scheme, were obtained from SAHFOS[8]. The taxa were selected because each was known to be an indicator of particular environmental conditions. An analysis of these data against the water column types led to results indicating the varying densities of each taxon with the water column type, and a comparison of the relative importance of each water column type for each taxon.

4 Seabed features – detailed methodology

4.1 Introduction

The seas around the UK are characterised by a complex coastal zone, in which the land-sea interface is represented by many types of coastline, an extensive continental shelf area extending to about 200m depth, followed by the continental slope which leads down to the deep sea zone. Within this general structure, major topographic features of the seabed, such as canyons, and seamounts, provide broadscale relief to the sea floor, representing the mountains and valleys of the marine environment.

In attempting to produce a landscape map for the seabed, it arguably was most appropriate to start from this broad scale perspective, and consider how this might influence the ecological character of the seabed habitats. Thus the initial strategy was to identify major topographical features, both offshore and on the coast, separating these from the large areas of seafloor which are without significant relief. For the latter, there was a need to further divide these areas using additional environmental variables, such as sediment type and depth, to more fully reflect their ecological variation.

The classification of seabed types was consequently undertaken in three phases:

- Identification of features based primarily on seabed topography – as GIS vector polygons;
- Modelling of seabed features to further subdivide the extensive sea floor plains which lacked significant relief, using an integrated analysis of environmental data sets in a vector grid format;
- Identification of coastal physiographic features, such as estuaries and sealochs – as GIS vector polygons.

4.2 Topographic and bed-form features

4.2.1 Use of bathymetry and derived slope data

Digital bathymetric data were used to identify and map the main topographic features. Two Digital Elevation Models (DEMs) for bathymetric data were used, namely the GEBCO digital atlas (**www.ngdc.noaa.gov/mgg/gebco/grid/1mingrid.html**) and SeaZone (www.seazone.com). Using the ESRI ArcGIS Spatial Analyst slope function, slope rasters were created for each data set to provide an indication of the steepness of the seabed terrain. Using the GEBCO DEM (Figure 1), at a 1 minute resolution, slope data for the entire UKSeaMap area were generated (Figure 2), enabling the identification of large topographic features, such as seamounts and banks (deep ocean rises). However, the relatively low resolution of GEBCO prevented the identification of the small to medium-sized topographic features and bed-forms. To resolve this, a DEM produced by SeaZone at a 250m resolution was trialled, from which slope was calculated (Figure 3). Unfortunately, this product contained some major anomalies, which led to problems correctly identifying bed-form features. In order to resolve this, a combination of the two DEMs and the British Geological Survey's DigBath250 bathymetric contour data (**www.bgs.ac.uk/products/digbath250**) was used to digitise the topographic and bed-form features.

[8] Sir Alister Hardy Foundation for Ocean Science

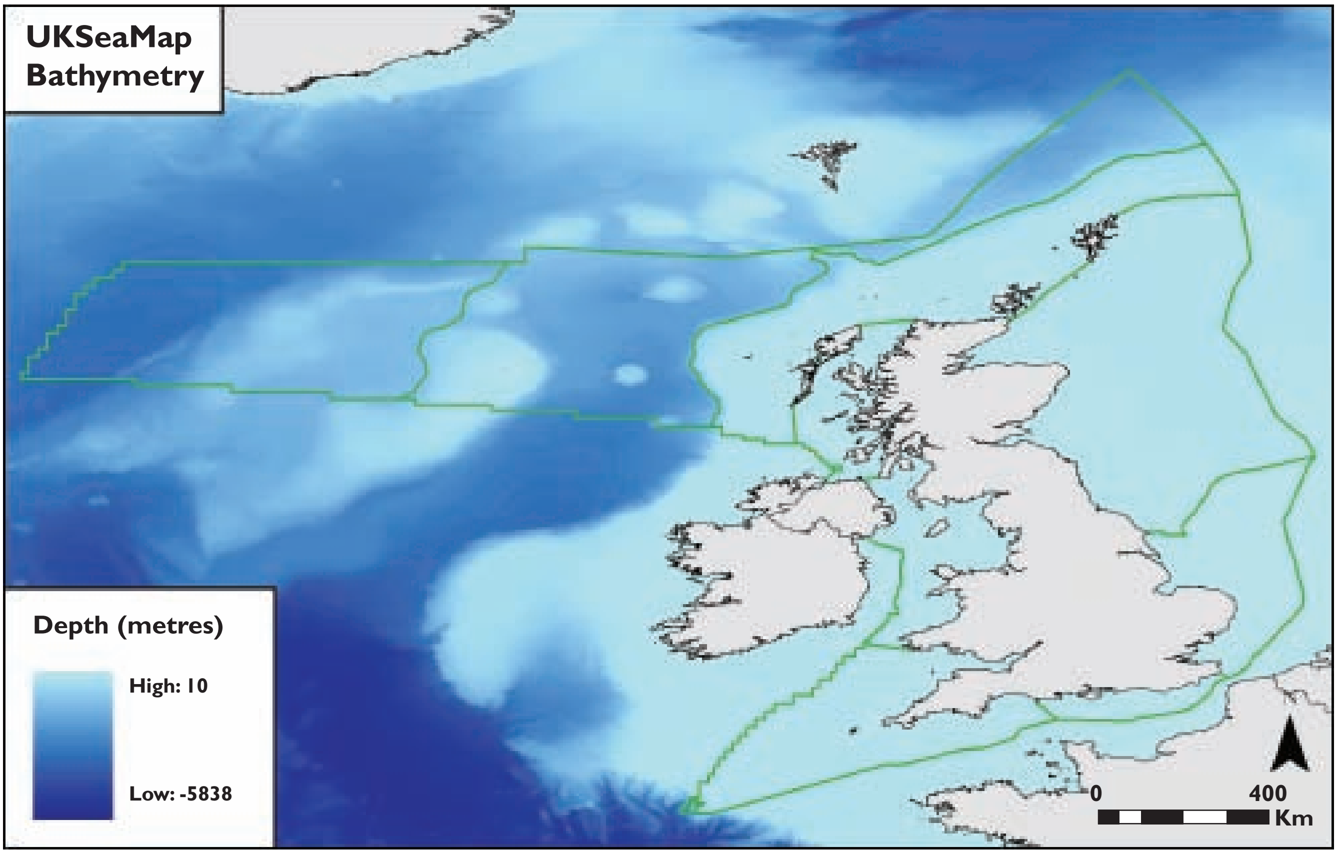

Figure 1. Bathymetric digital elevation model (DEM) (source: Gebco).

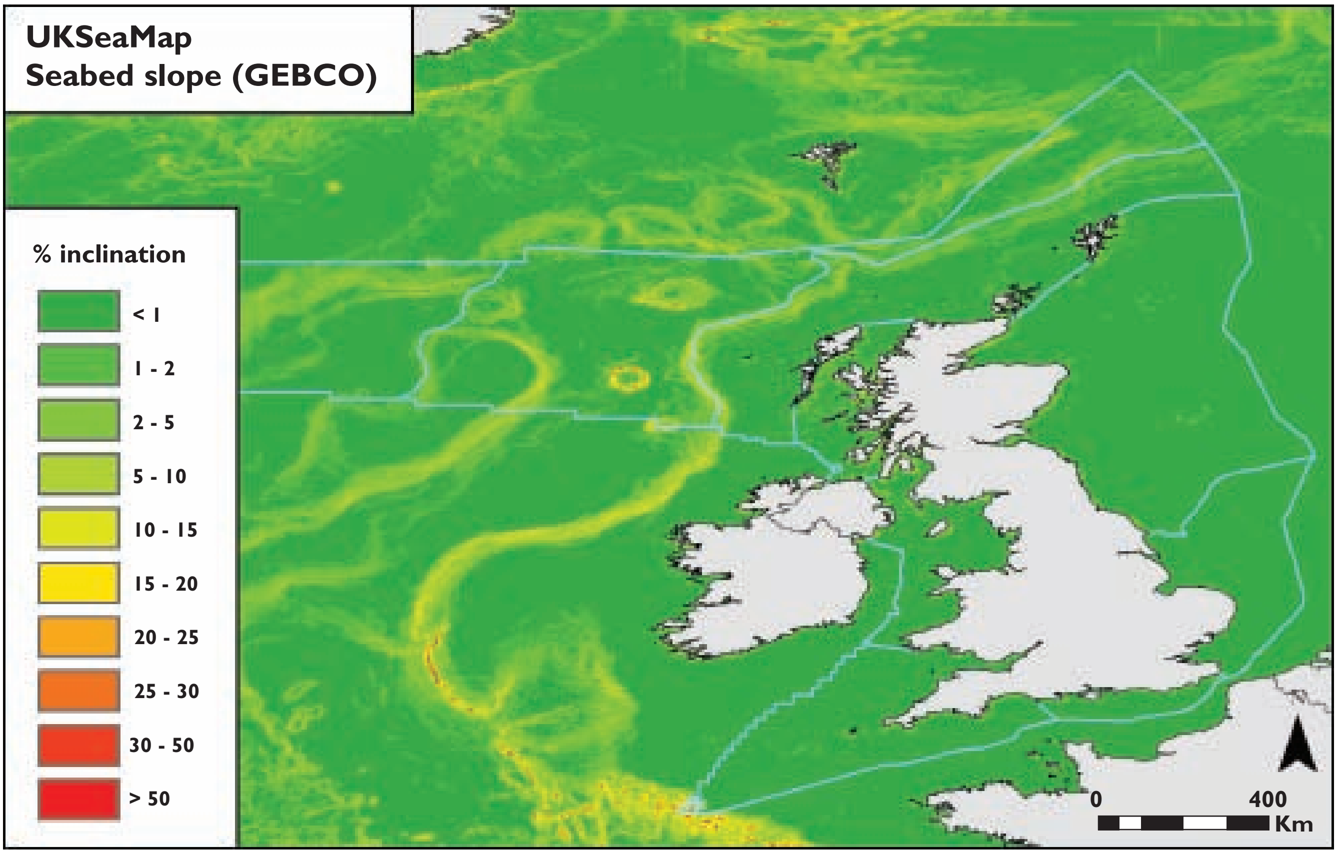

Figure 2. Seabed slope (derived from Gebco bathymetric DEM).

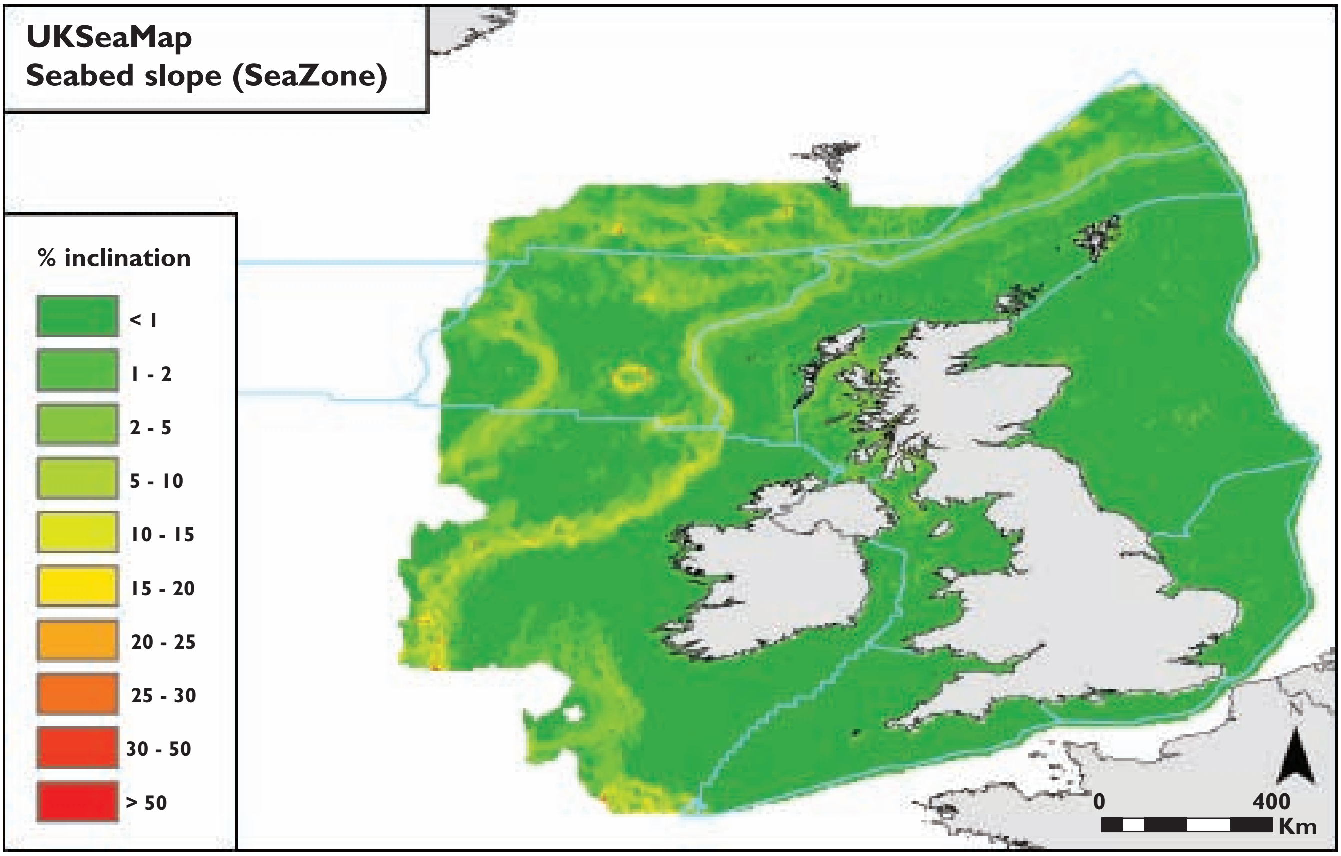

Figure 3. Seabed slope (derived from SeaZone bathymetric DEM).

To ensure consistency in interpretation of the slope data prior to digitising, topographic and bed-form features were identified by applying rules, based on the degree of slope and the shape of the feature, as detailed in Table 1. In addition, BGS have been developing a classification of seabed character and bed-forms (Ceri James, pers. comm.); some of these features were available as UK-wide maps in digital form and these were made available to UKSeaMap as polygon ESRI Shapefiles (see Figure 4). Other features in their classification, such as megaripple and sand wave fields are not yet available in digital form for the whole UK area; consequently have not been included in UKSeaMap.

In view of the need to use relatively coarse DEMs which provide full UK coverage, it has not been possible to identify small features which are known or likely to be present throughout the area. The resultant map of topographic features (Figure 4) should therefore be considered to represent only the most prominent features.

4.2.2 Topographic and bed-form features identified

Subtidal sediment banks: these are submerged, linearly-elongated, raised features of the continental shelf, composed of sediment (usually coarse sands and gravels) and marked by slopes (>2%[9]) rising from the shelf plain. They were identified from the bathymetric DEMs. Where they occur in waters above 20m depth, they can be considered to be examples of the EC Habitats Directive Annex I type *Sandbanks which are slightly covered by sea water all the time*[10].

Shelf mounds or pinnacles: these are submerged non-linear raised features of the continental shelf, marked by slopes (>2%) on three or more sides. They can be composed of either sediment (mounds tending to have smooth surfaces) or rock (pinnacles which may be rugged). They were identified from the bathymetric DEMs.

Shelf troughs: these are elongated depressions in the continental shelf, usually carved out of the seafloor by glacial processes, which remain unfilled or open, and which have a maximum water depth considerably greater than the surrounding seabed. They were identified by visual examination of a pixelated map derived from DigBath250, together with contours from DigBath250 and supplied as an ESRI shapefile by BGS.

9 The Irish Sea Pilot used a value of 1-8% slope on a vector data set (DigBath250); use of a 2% value on a raster data set for UKSeaMap identified a similar set of features.

10 Note: the definition of the Annex I type is considered to be broader; see Section 7.1.

Pockmarks: these are near-circular depressions typically 100m across and 1-4m deep, although some reach 500m in diameter and 20m deep. They are formed by fluid escape, generally of methane gas, through fine-grained sediment. Fluid escape through coarser sediment produces considerably smaller features or none at all. Cemented sediments or hand grounds can occur at the base of pockmarks. They are mostly known from the continental shelf and tend to occur in groups over large areas. All extensive pockmark fields have been identified by BGS and were supplied as an ESRI Shapefile.

Continental slope: this is the submerged edge of the continent where the angle of the seabed increases to >2% slope. It was identified from the bathymetric DEMs.

Iceberg plough-marks: off the north and west coasts of the UK, on the edge of the continental shelf and on the upper continental slope, ridges of boulders and cobbles have been formed by the ploughing movement of icebergs through the seabed during the last ice age. These ridges are 10s to 100m wide and comprise turbated sediment often with boulders exposed on their berms. The troughs are in-filled with finer sediment winnowed from the berms and may be thick enough to largely in-fill the feature. There are few areas away from the shelf edge that show iceberg plough-marks. The zone occupied by iceberg plough-marks on the shelf edge was supplied by BGS as an ESRI shapefile.

Submarine canyons: located in the extreme south-west of UK waters, these are steep-sided valleys (>8% slope) cut into the continental slope, running perpendicular to the shelf edge. These canyons can occasionally be associated with powerful currents which scour the canyon out of the surrounding sediment. They were identified from the bathymetric DEMs.

Deep ocean rises: these are submerged, large, steep-sided (>8% slope) features rising from the abyssal plain. Large-scale features such as Hatton Bank are topographically as important as the George Bligh Bank and seamounts which are plotted. They were identified from the bathymetric DEMs.

Carbonate mounds: these are raised features of the deep sea floor, composed of carbonate material and which rise by up to 350m from the surrounding seabed. Data on the location of possible carbonate mounds in UK waters were compiled and supplied by BGS, based on a seismic grading from 1 – 5 as to their seismic resemblance to carbonate mounds known on the Porcupine Sea Bight. The carbonate mounds presented here are those graded 4 or 5 (the grades which are most like the carbonate mounds in the Porcupine Sea Bight). However very few of the UK sites have been ground-truthed to confirm they are carbonate mounds. The data set is not exhaustive, as it simply covers the positions of seismic profiles; there are likely to be many more mounds just off the lines surveyed to date.

Deep-water mounds: these are raised features of the deep sea floor, which are composed of material other than carbonate. The only examples identified at present are the Darwin Mounds, which are sand volcanoes with 'tails' and which have colonies of the cold-water coral *Lophelia pertusa* on their tops. Each mound is about 100m across and about 5m high; there are two areas or fields where the mounds are known to be common. Note that *Lophelia pertusa* is not restricted to this type of mound.

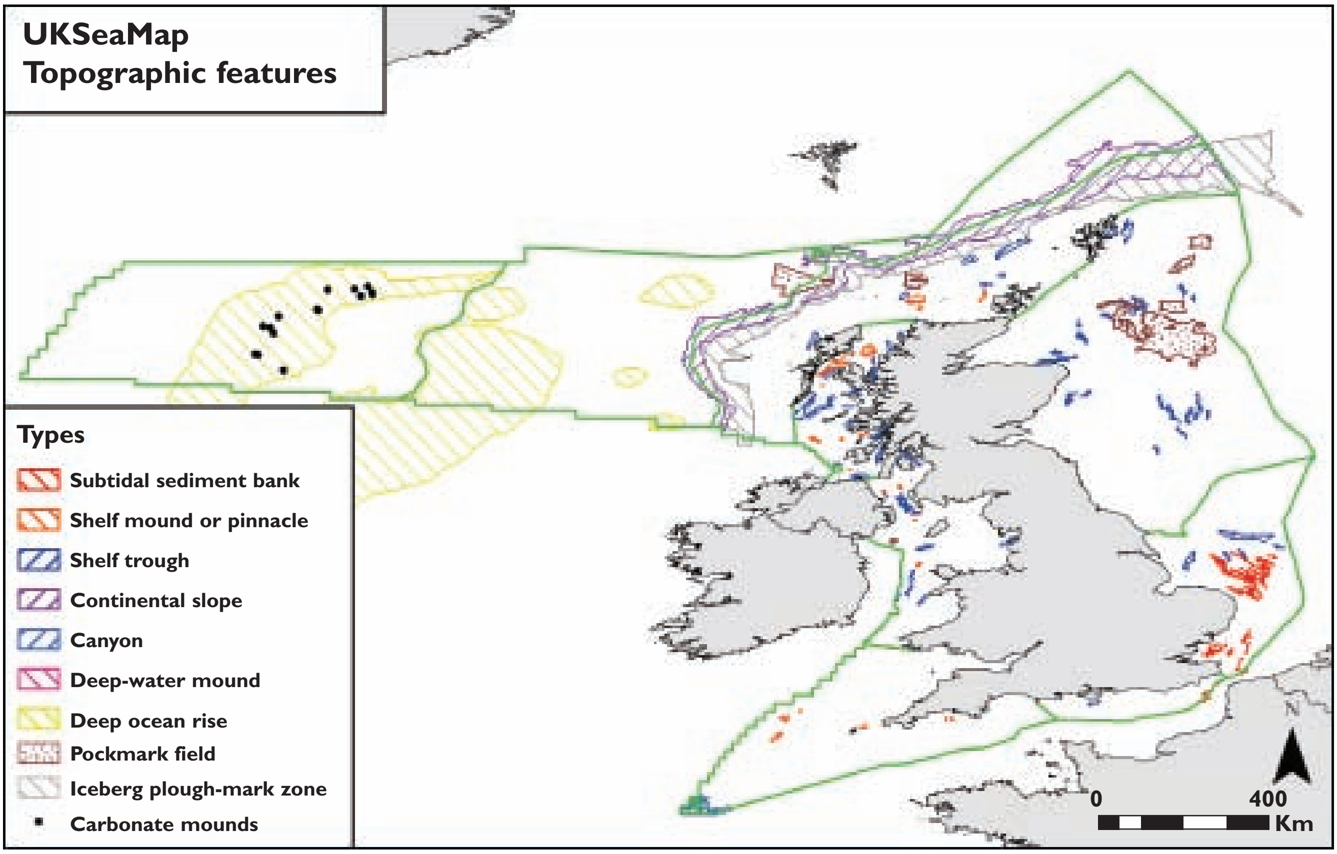

Figure 4. Topographic and bed-form features.

Table 1: Summary characteristics of topographic and bed-form features

Type	Slope	Substrata	Bathymetric zone
Subtidal sediment bank	>2%	Sediment (typically coarse)	Shelf feature – raised
Shelf mound or pinnacle	>2%	Variable (Rock and/or sediment)	Shelf feature – raised
Shelf trough	Variable	Variable (typically sediment)	Shelf feature – sunken
Pockmark field	negligible	Sediment (mud or fine sand)	Shelf and continental slope feature
Continental slope	>2%	Variable	Shelf break to continental rise
Iceberg plough-mark zone	Variable	Boulder and cobble ridges	Continental slope feature
Canyon	>8%	Variable (includes rock)	Continental slope feature
Deep ocean rise	>8%	Rock with sediment veneer	Deep water feature – raised
Carbonate mounds	unknown	Carbonate	Deep water feature – raised
Deep-water mound		Sand volcanoes with coral tops	Deep water feature – raised

4.3 Modelling seabed features

4.3.1 Approach and environmental parameters considered

Whilst topography was used to develop an initial set of marine landscape types for UK waters, the extensive areas of the sediment plains, which have limited topographic character (at the broadscale considered here), needed further discrimination to lead to maps which would better meet the aims of the UKSeaMap project. Consequently further characterisation of the sediment plains was modelled using geological, physical and hydrographic characteristics in a manner similar to that adopted in the Irish Sea Pilot (Golding *et al*. 2004). This approach recognises the strong correlation between environmental parameters and ecological character, such that mapping environmental parameters in an integrated manner can successfully be used to produce ecologically relevant maps.

There are a wide range of environmental parameters which influence ecological character; these have varying degrees of influence and lead to differences in ecological character at various scales (e.g. structurally determining habitat type, or determining the communities or individual species which occur in any particular place). To use such environmental data in the UKSeaMap context it was firstly necessary to review which environmental parameters were most relevant at the whole UK scale.

The following parameters were considered most relevant at the whole UK-scale:

- Substratum
- Depth
- Light penetration
- Wave action
- Currents
- Salinity
- Temperature

The following parameters were considered less relevant at the whole UK scale:

- Tidal range
- Oxygen
- Nutrients (in sediments and the water column)
- pH

For the most relevant parameters, consideration was then given as to the potential availability of suitable data sets at the whole UK level which would best represent each parameter, and in what form and how such parameters could best be used in a modelling context. The following sections describe how these issues were pursued, which data were obtained and how they were processed into a form suitable for eventual integrated analysis.

4.3.2 Data sets used

A number of data sets were collated for the project, although not all were used in the final analysis. Data were gathered from a variety of sources derived variously using modelling, remote sensing and direct sampling techniques to provide the initial data sets. All the data sets required considerable further processing to convert them to a format suitable for an integrated analysis.

The seabed modelling used data sets on:

- seabed substrata
- light attenuation
- depth
- maximum wave base
- bottom temperature
- maximum near-bed stress (induced by tidal currents)

Although salinity was considered an important parameter influencing the ecological character of seabed habitats, it was not felt necessary to incorporate it in the modelling phase, as the identification of coastal physiographic features, some of which specifically reflect differing salinity regimes (e.g. estuaries, lagoons), was considered to adequately account for this parameter (see Section 4.4).

The data sets are described in Sections 4.3.4 to 4.3.11, giving details of their source, technical development and the rationale behind their selection and categorisation.

4.3.3 Methodology adopted for data analysis

The Irish Sea Pilot (Golding *et al*. 2004) had adopted a supervised method for analysis of the seabed data layers, which were in vector polygon format and in which the data were categorised into a set of ecologically relevant classes. This methodology was reviewed and modified for use at the larger UK scale. The main considerations were whether to use continuous or categorised data, whether to adopt a supervised or unsupervised classification approach, and whether vector or raster GIS data should be used. Further discussion on these issues is given in Annex 4.

The numbers of data sets used and the ways in which they were or could be classified has a strong bearing on both the options for data analysis and the outcomes in terms of a final classification. Some (e.g. seabed substrata) were available in classified form, whilst others (e.g. light attenuation) were unclassified continuous data. An analysis of multiple data sets could lead to many possible combinations for each location (part of the seabed) and potentially to defining multiple 'landscape types'. This would be particularly marked if the continuous data sets were not simplified in some way. Whilst at one level this might reflect the complexities of the marine environment, it would not necessarily lead to a classification (and map) which defined seabed types at a suitable level of ecological discrimination (that is, some combinations of data may lead to 'types' which are insufficiently distinguishable from other types). Thus it was considered best to categorise each of the data sets into a small number of ecologically relevant classes (as was done for the ISP), so that when analysed with the other data sets, they had greatest potential to lead to ecologically useful seabed types.

The ISP had adopted a supervised classification process, in which the order of each data set in the analysis was predetermined, based on expert understanding of the importance of each parameter in determining the ecological character of habitats (primarily from knowledge gained in developing the national marine habitat classification; Connor *et al.* 2004). In the process of reviewing the ISP methodology, a number of alternative analytical methods were investigated. Multivariate analytical tools within the Primer software application were investigated and found unsuitable, as the software could not handle such large data sets and the results could not be transferred back into the GIS to display the resultant maps. Analysis within ArcGIS itself, using gridded data, was also investigated, but the only available classification algorithm was a maximum likelihood classifier, which is unable to analyse categorical data (such as the substrata data). It was concluded that the supervised approach should be retained, being both technically easier to implement and likely to lead to a more acceptable number of end classes (landscape types).

The flowchart below (Figure 5) describes the route taken to lead to a final map via such a supervised classification.

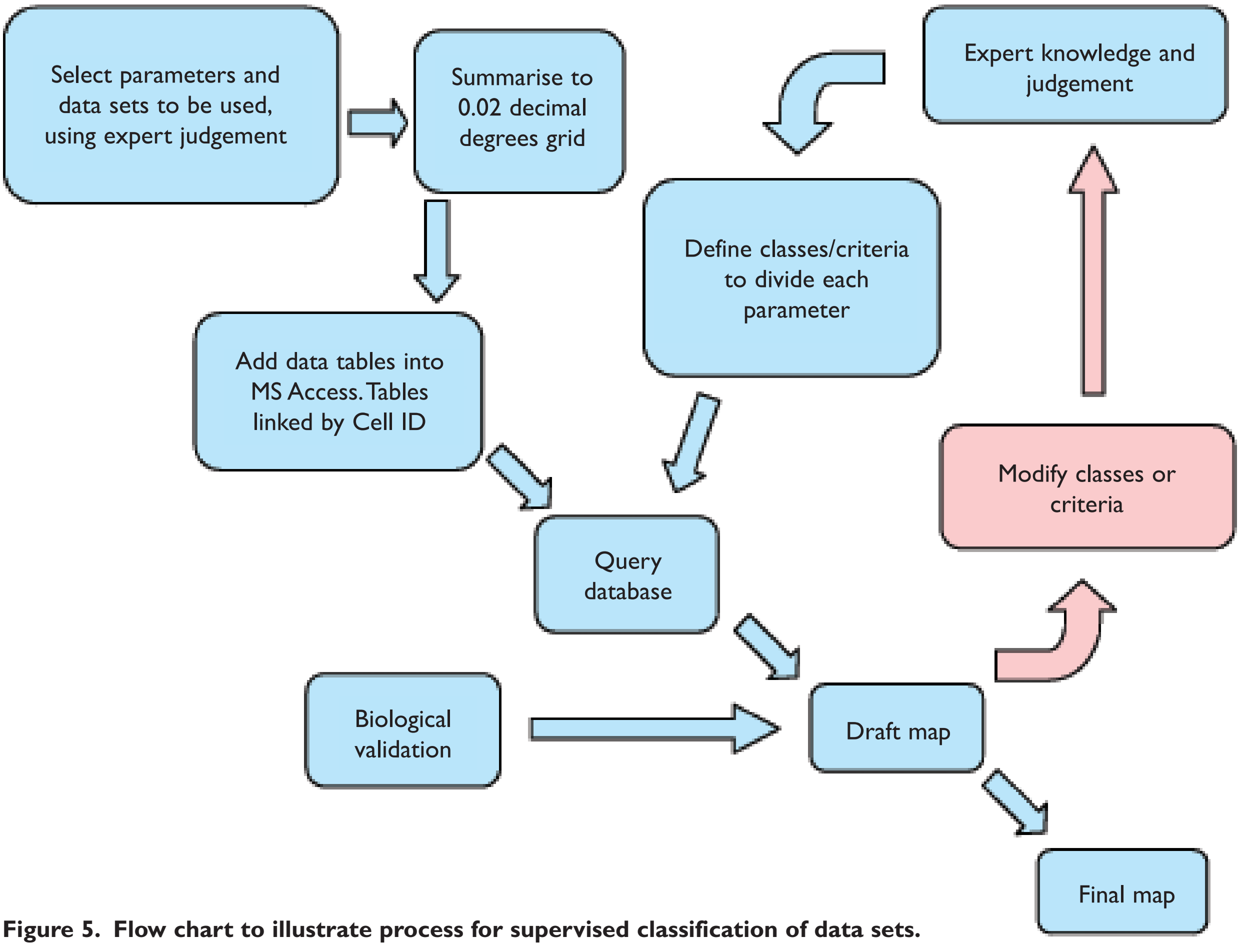

Figure 5. Flow chart to illustrate process for supervised classification of data sets.

The analysis of vector polygon data, as used in the ISP, has two main disadvantages. Firstly, the integration of different polygon data layers to form a new set of landscape polygons leads to the creation of 'sliver' polygons. These are very small polygons resulting from the overlay of different data sets and they seldom provide sensible areas (of landscape) on the final map. Secondly, the resultant map has smooth-edged polygons which imply a level of precision in the landscape boundaries which is inappropriate considering the modelled nature of the analysis. To overcome both of these issues, and to significantly improve the technical delivery of the analysis, the input data layers were converted into a vector grid. A grid (or net) of 0.02 decimal degrees (approximately one nautical mile) was adopted, as this seemed to best reflect the resolution of the most detailed data layer (the seabed substrata). For the region beyond the continental shelf to the north and west of Scotland, the data had a considerably lower resolution and so here a grid 25 times the size was adopted. Each data layer was summarised to this grid (by assigning the most common category within the grid cell), leading to each grid cell being assigned a single value (category) for each data layer (e.g. sand, shallow depth, moderate bed stress and so on). This enabled the data to be queried via an MS Access database in a supervised classification. Using the net for the analysis in this way has a number of additional benefits. It allows for straightforward analysis of both continuous raster data and vector maps. The need to create vector features, such as polygons, from continuous raster data is avoided so if it is decided to change threshold values used in the analysis, it is a simple task to reanalyse the data without the need to create new input maps and re-run the entire analysis.

4.3.4 Seabed substrata

A description of the surficial substrata of the seabed is considered essential in generating ecologically relevant seabed types, as the type of substratum has a strong influence on the nature of the biological communities it supports. Preparation of a suitable seabed substratum data layer was mainly undertaken on behalf of UKSeaMap by the British Geological Survey (BGS), as described by Cooper *et al.* (2005).

A whole UK seabed substratum map is available from BGS as the DigSBS250 digital product, which is a polygon data set at 1:250,000 scale according to fifteen classes in the Folk classification scheme, together with a rock outcrop category. As these sixteen classes provided more detail than was deemed necessary, BGS were commissioned to simplify the map into five classes which would better reflect the broad substratum types used in seabed habitat classifications (Connor *et al.* 2004; EUNIS), namely:

- Rock
- Coarse sediment
- Mixed sediment
- Sand and muddy sand
- Mud and sandy mud

Thirteen of the fifteen categories of the Folk classification were combined, using SQL and the merge command, to create the four main sediment classes required (Figure 6). The remaining two categories (muddy sand and slightly gravely muddy sand) were split at the 8:2 sand to mud ratio to provide polygons to add to either the 'sand and muddy sand' or 'mud and sandy mud' classes. Polygon boundaries for these two new categories were manually edited by BGS, based on individual sediment sample data. Additionally consideration was given to dividing the Folk gravel class, which includes boulders, cobbles, pebbles and gravels, into two classes (as boulders and cobbles support significantly different biological communities); however suitable detail within the BGS data sets was only available for a few regions, so any resultant map would be inconsistent across the UK.

There were several areas of UK seas within the DigSBS250 data set which are blank, reflecting the absence of data when this data set was compiled. These areas include the shallow near-shore coastline where the BGS programme did not extend, and also areas in the Atlantic North West approaches and Faroe-Shetland Channel. The coastal fringe was updated using the seabed substrata data collated (by BGS) for the Water Framework Directive typology project (Rogers *et al.* 2003); this project used the same five substratum classes. Some offshore blank areas were reduced by including data from the BGS 1:1,000,000 seabed sediment maps (BGS 1987) and more recent unpublished data.

The rock category in DigSBS250 was supplemented by data from previous work undertaken by BGS for JNCC to identify 'potential reef' habitat to aid implementation of the EC Habitats Directive (Graham *et al.* 2001). This 'potential reef' data set included five categories, which were treated as shown in Table 2, replacing DigSBS250 data at the locations where they occurred. Additionally point data available in the SeaZone digital charts, indicating a rocky seabed, were overlain on the DigSBS data set and vector grid to identify further areas that might better be interpreted as rock. Where point samples were in sufficiently high density (>5 per grid cell), the cell was treated as rock habitat; this was applied to 29 grid cells.

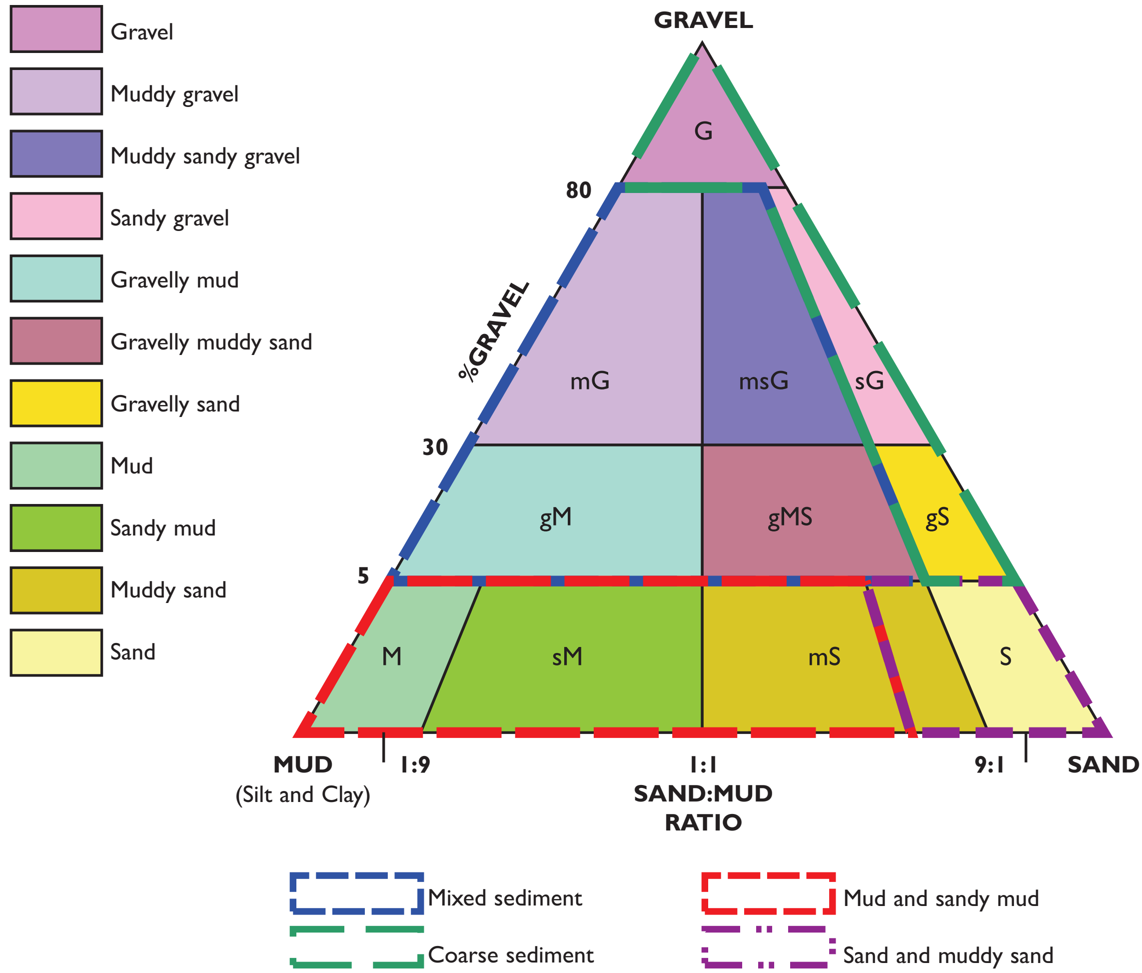

Figure 6. Folk sediment trigon, modified to show the aggregation of classes into four main sediment classes (coarse, mixed, sand, mud).

Table 2: Treatment of categories defined as 'potential' reef for the Habitats Directive

Category of 'potential reef' (for Habitats Directive)	Treatment in UKSeaMap
Biogenic reef	Included as rock
Gravel	Included as Coarse sediment, not as rock
Iceberg plough mark zones	Treated as a bed-form
Rock/Quaternary	Included as rock
Rock/Gravel	Included as rock

The resultant map of seabed substrata, according to the five classes, is shown in Figure 7.

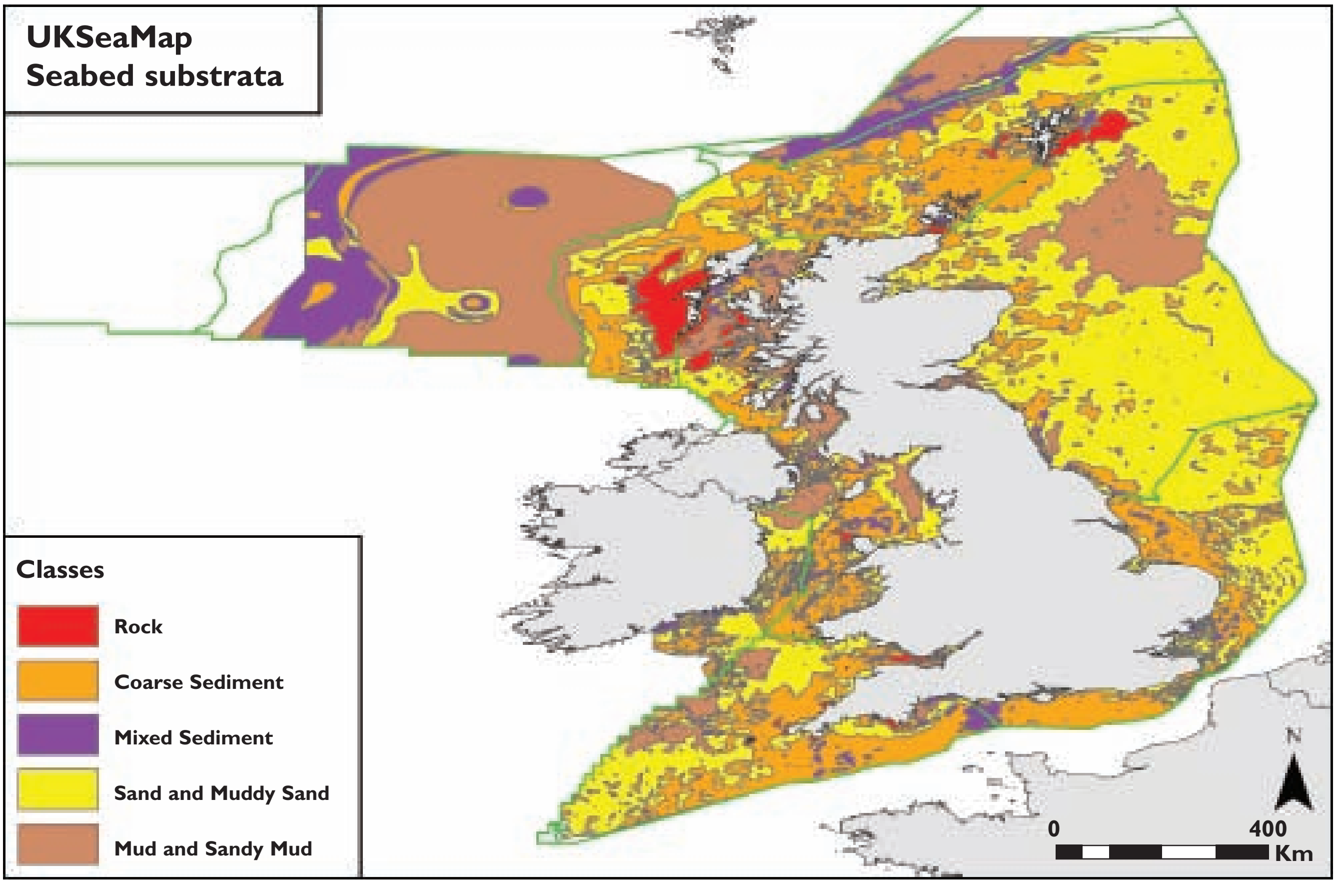

Figure 7. Seabed substrata (derived from BGS DigSBS250 and other sources – see text).

4.3.5 Depth zonation taking into account light, energy and temperature

A zonation with depth is one of the most important parameters in determining ecological changes from the intertidal zone through to the deepest areas of the bathyal and abyssal plains. Such a zonation is influenced, not simply by the depth itself, but by a series of environmental parameters (particularly light penetration, temperature, wave action and salinity), which vary somewhat independently of each other and which interact in an often complex manner, particularly in the shallow coastal zone, to influence ecological character. Thus, rather than simply using depth itself, a series of parameters (light, wave base and temperature) have been analysed and integrated to reflect four major depth zones:

- Photic zone: from coastline (0m) to photic depth (rocky substrata only)
- Shallow zone: from coastline (0m) to wave base
- Shelf zone: from wave base to shelf break (200m depth)
- Deep-water zone: >200m depth (further divided, based on temperature, into cold and warm realms)
- Cold deep water zone: >200m depth and <4°C

The way in which these zones have been determined and the data used are described in Sections 4.3.6 to 4.3.10.

4.3.6 Coastline

The level of Highest Astronomical Tides (HAT) is usually taken to mark the transition from the terrestrial environment to the marine. However such a datum is not available for the entire coast, so a more practical upper boundary to the photic and shallow depth zones was taken as the Mean High Water datum, as provided in the coastline data set (World Vector Shoreline; **www.csc.noaa.gov/shoreline/world_vec.html**).

4.3.7 Photic depth

To reflect the significant change from shallow kelp-dominated rocky habitats in the infralittoral zone to deeper animal-dominated rocky habitats in the circalittoral zone, the depth of light penetration into the water column was used to predict the distinction between these two zones. It is widely cited in the scientific literature that the lower limit of the infralittoral zone is broadly correlated with the depth at which available light is 1% of surface irradiance.

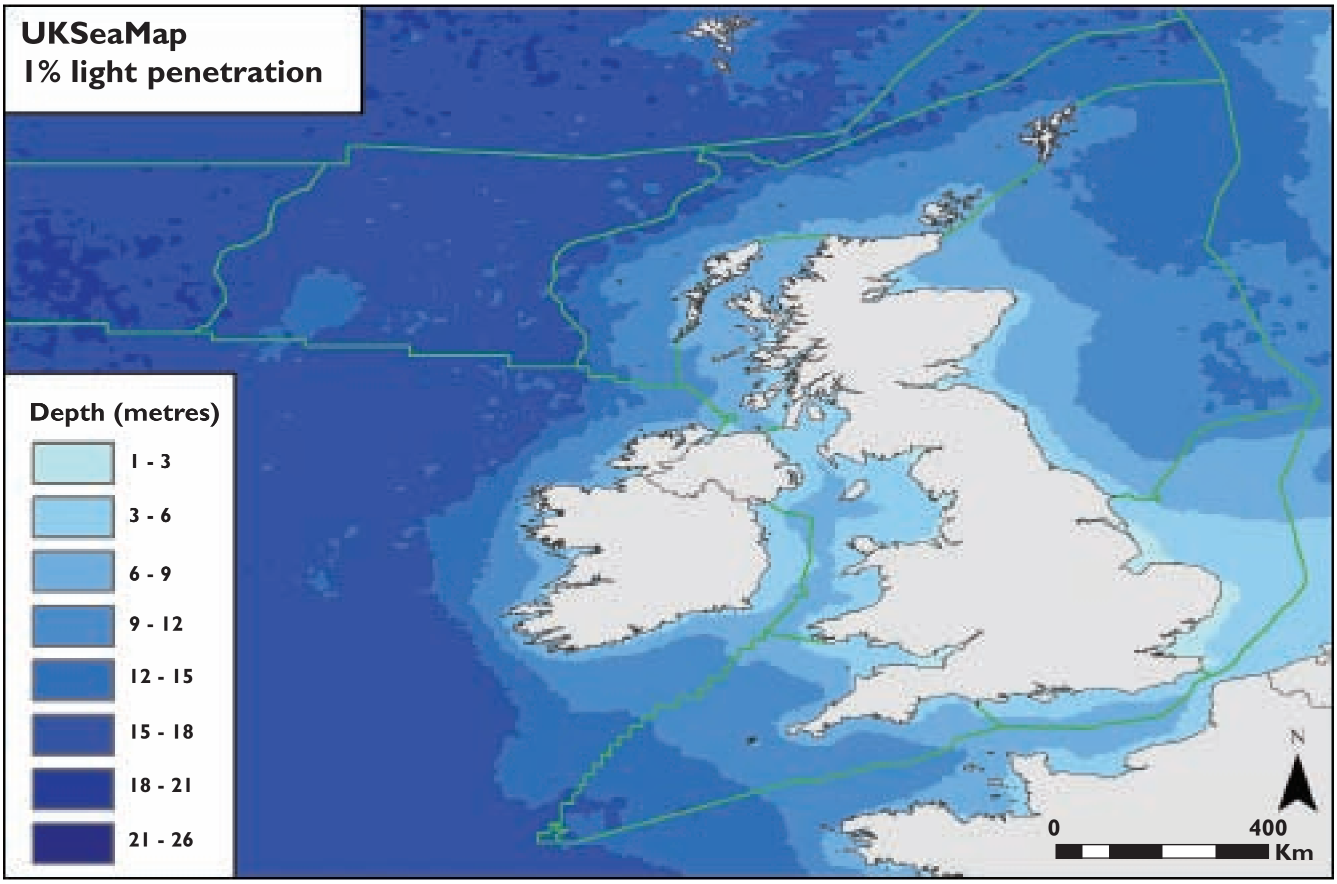

Figure 8. Mean annual depth to which 1% of surface light penetrates the water column (source data from SeaWiFS via POL)

Light attenuation data were derived from ocean colour observations made by the SeaWiFs satellite which makes a measurement of the amount of light in the blue-green part of the spectrum that penetrates the water column. The data were derived from daily images at ~9km resolution for January to August for the years 1998 - 2004 and for September to December for 1997 – 2003, and supplied by the Proudman Oceanographic Laboratory (POL). However because there appears to be no clear indication if there is a particular time of year at which to measure the 1% irradiance[11], a mean annual light attenuation figure was used, derived from the sum of the four seasonal data sets (Figure 8).

The light attenuation data were then interfaced with bathymetric data to determine where the photic zone coincided with the seabed (Figure 9) and this was used to subdivide the rock category of the seabed substrata data set into photic and aphotic classes.

[11] Professor Christine Maggs (Queen's University, Belfast) advised that the maximum depth penetration of kelp is more likely to be related to the annual photon density, and Dunton (1990) showed that in both Antarctica and the Arctic it was the annual light budget that counted. Kelp plants store photosynthate then start growing in the dark in winter. Their photoperiodism means that the new blade is stimulated by the short days of autumn. Gametophytes require a small amount of blue light and it is thought that any light will contain enough blue light.

Figure 9. Photic and aphotic light attenuation classes derived from light attenuation data set.

Consideration was given to extending this photic/aphotic division to the remaining four sediment classes. It was decided, however, not to pursue this; whilst photic depth is of particular significance for rocky substrata, distinguishing the major kelp forest habitat from deeper water habitats, there is not such a marked biological difference between shallow (photic) and deeper (aphotic) sediments. Additionally expanding the analysis to the four sediment classes would create many more seabed classes (classes more akin to habitat types) than would be of practical use at the scale required for UKSeaMap.

4.3.8 Wave base

The wave base is defined as the maximum depth to which the passage of a wave causes motion in the water column; it is equal to half the wave length. Below the wave base the water remains stationary as the wave passes. The wave base therefore distinguishes between shallower disturbed waters and deeper undisturbed waters. Where the wave base is deeper than the depth of water, the waves are able to disturb the seabed and hence have influence on its biological communities. The maximum wave base, as measured over a period of years, can therefore be used to define a shallower zone of periodically-disturbed seabed (the Infralittoral and Circalittoral étages of Glemarec 1973) and a deeper zone of undisturbed seabed (the Offshore Circalittoral étage of Glemarec). Typically this boundary occurs at about 50-70m depth around the UK.

Maximum wave length data, measured over a 10-year period and derived from the proWAM 12km wave model, were provided by POL (Figure 10). This data set was used to generate a maximum wave base data layer, which was intersected with bathymetric data to determine where the maximum wave base would disturb the seabed, thus distinguishing a 'shallow zone' from a 'shelf zone' (Figure 11).

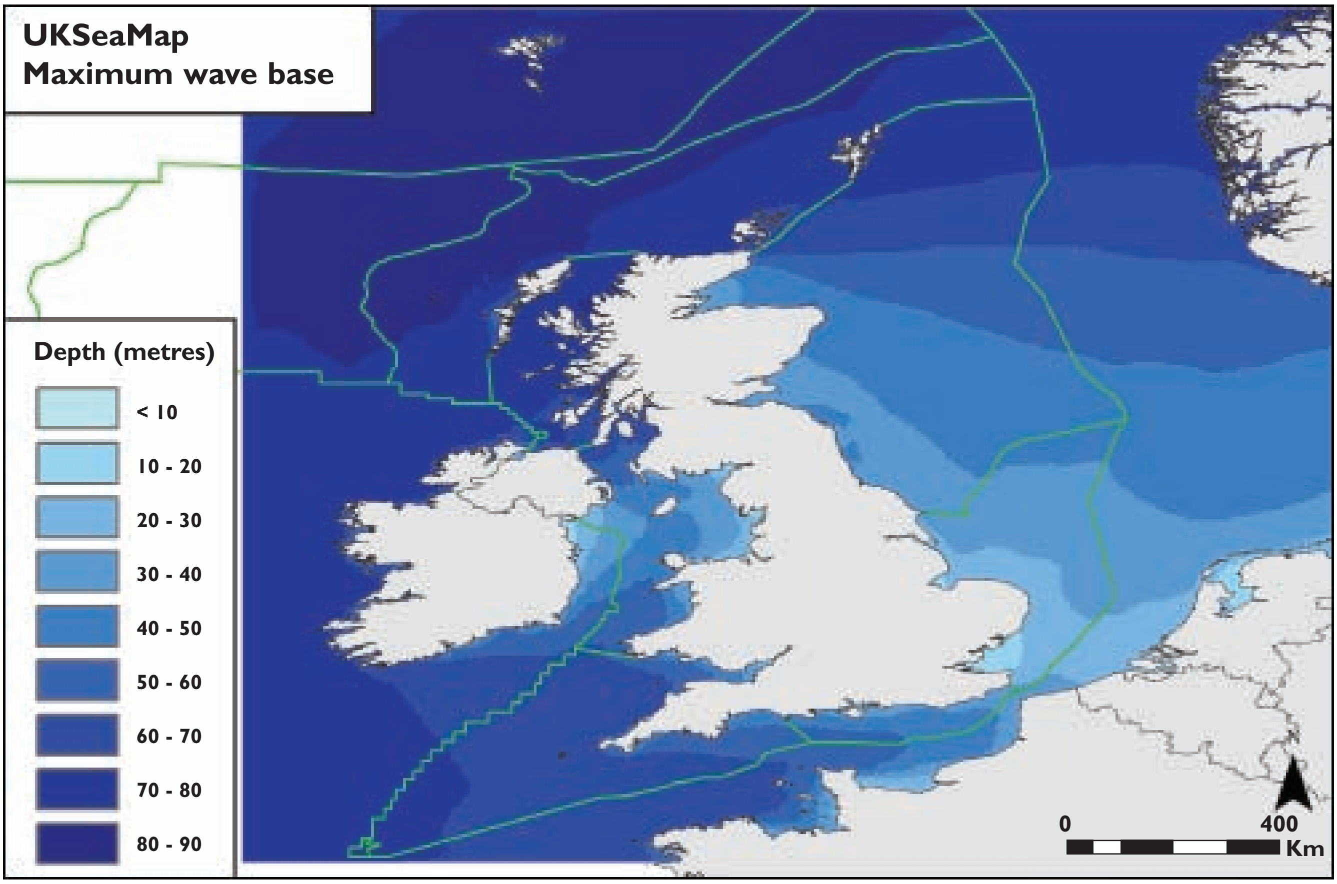

Figure 10. Maximum depth to which waves penetrate the water column (wave base) (source data from POL).

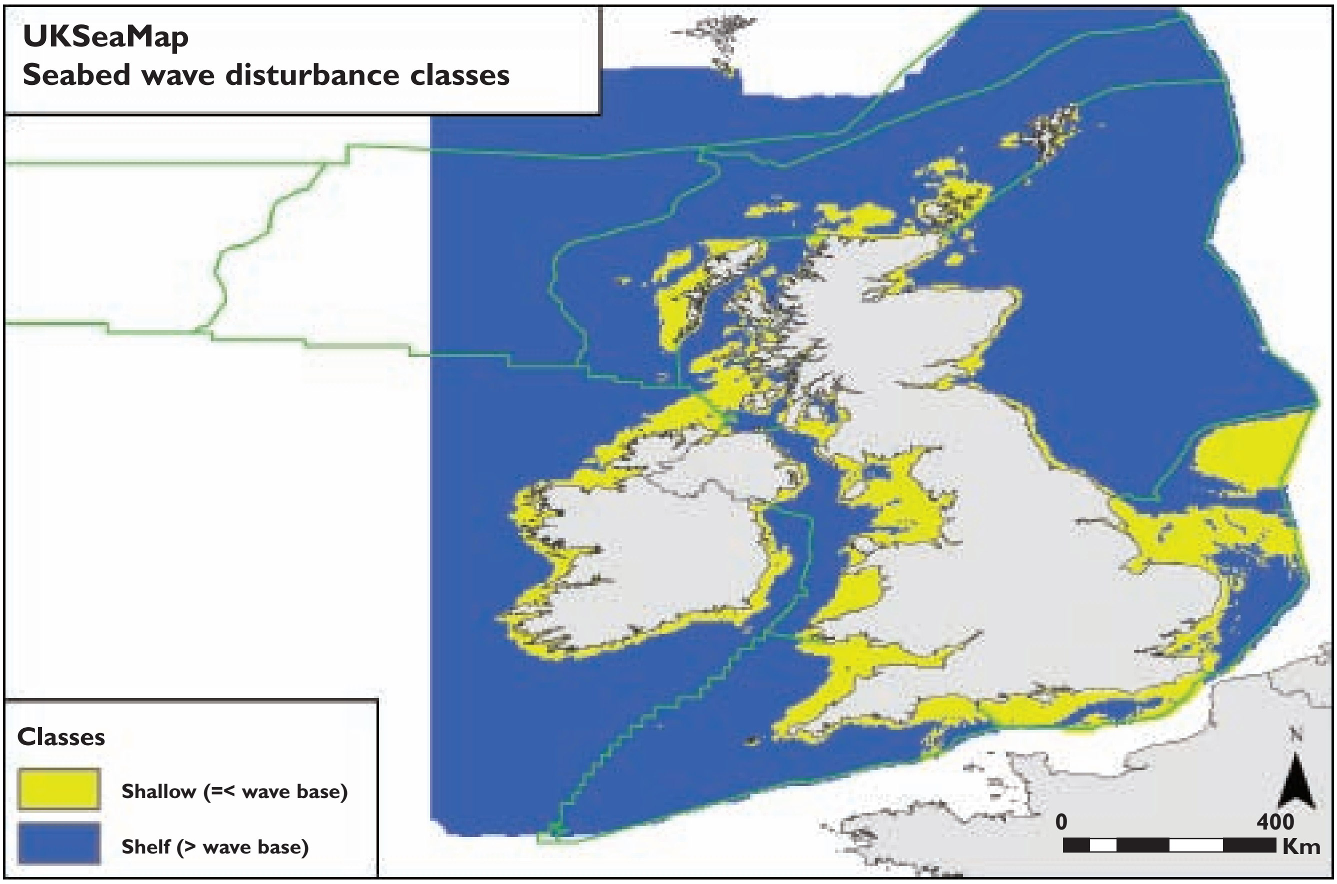

Figure 11. Shallow (disturbed) and shelf (undisturbed) depth classes derived from the maximum wave base.

4.3.9 Bathymetry

The bathymetric data sets described in Section 4.2.1 provided the 200m depth contour, equating to the shelf break boundary, a marked zone of change in biological communities in UK waters between the shallower continental shelf and the deeper continental slope.

4.3.10 Bottom temperature

Water temperature varies greatly across UK seas, with latitude, seasonally, and with depth and each has influence on ecological character. There is a general trend from warmer (surface) waters in the south and west through to colder waters in the north and east, reflecting Britain's situation in a boundary zone between Lusitanian and Boreal biogeographical provinces (Dinter 2001). Seasonal variation is greatest in shallow coastal areas, becoming increasingly insignificant beyond 200m depth.

The latitudinal variation (Lusitanian to Boreal) is reflected in marked differences in the species composition within habitats between the south-west and north-east regions of the UK. However because this temperature transition appears to be gradual across the UK seas, and is reflected primarily at the species and community level, it was considered best to apply any biogeographical division of UK seas to the final maps, e.g. such as any agreed follow-up to the regional sea boundaries proposed in the RMNC (Defra 2004), rather than integrate this influence into the seabed analysis. Such an application would be appropriate for selecting marine protected areas to represent the range of ecological character across the UK (e.g. as rocky coasts in the south-west are biologically distinct from those in the north-east).

The most marked temperature transition in UK waters is in the deep-water zone where a strong temperature discontinuity, around the 4°C isotherm, separates the warmer water regions influenced by the North Atlantic Drift to the south from the colder water regions influenced by Arctic waters to the north. This latter discontinuity has been incorporated into the analysis.

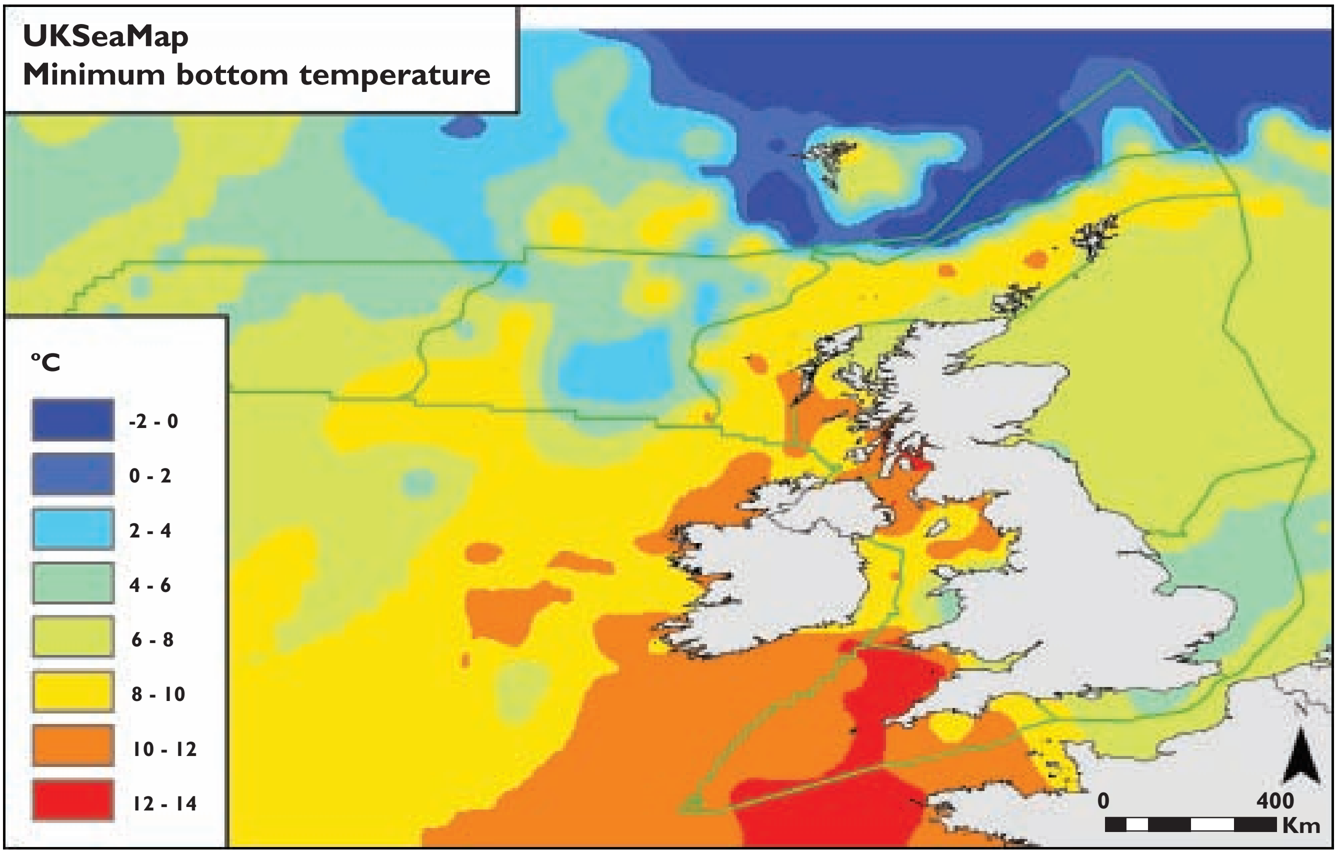

Figure 12. Minimum bottom temperature (source data from ICES).

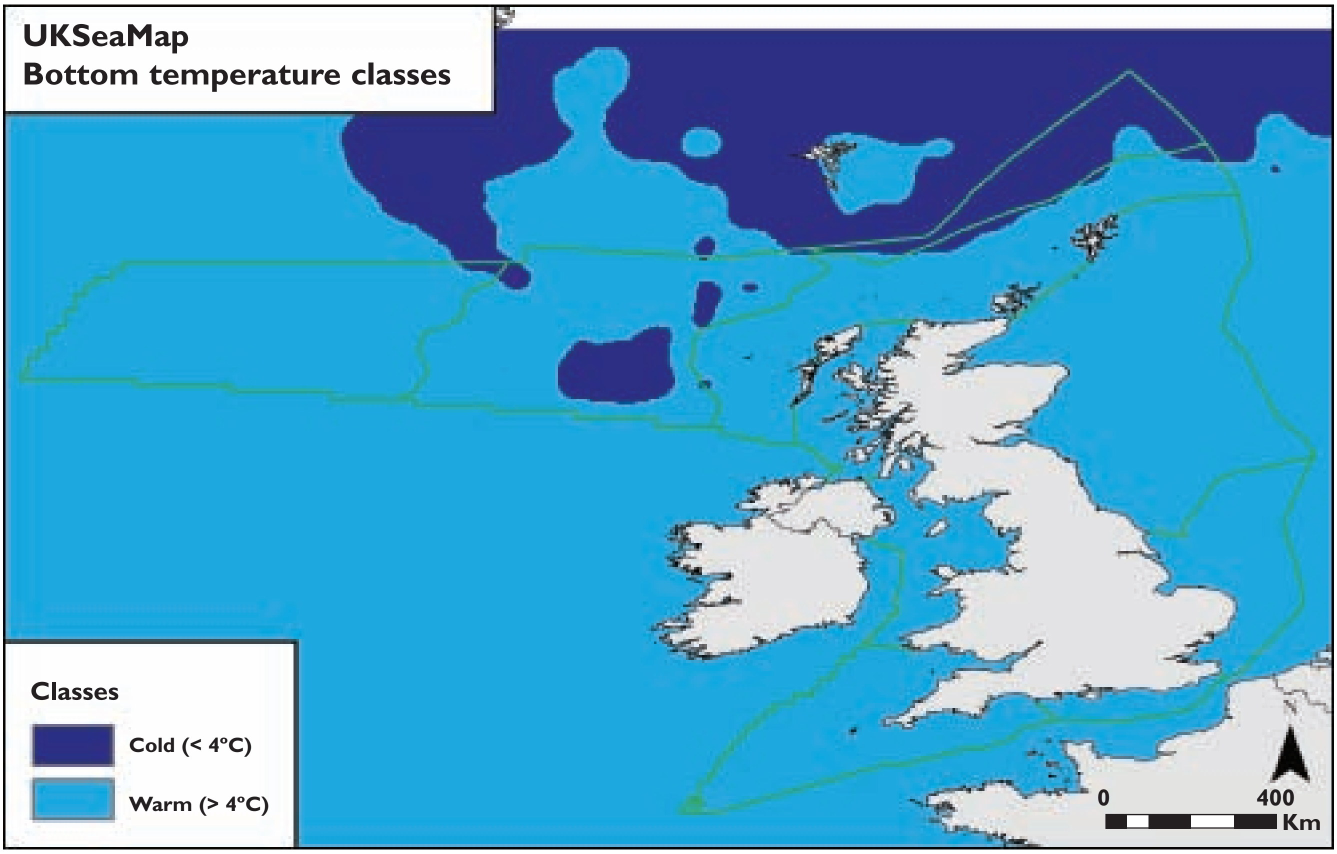

Figure 13. Cold and warm water zones derived from minimum bottom temperature data set.

A bottom temperature data set was obtained from the International Council for the Exploration of the Seas (ICES) and interpolated using the spline method (Figure 12). Minimum bottom temperature was used to split deep waters (>200m in depth), into warm and cold water realms across the 4°C threshold (Figure 13).

4.3.11 Maximum near-bed stress (from tidal currents)

Bed stress, a shearing force per unit area exerted on the seabed by water movements above the seabed, is a useful parameter to determine seabed disturbance arising from tidal or residual currents. Bed stress varies with water depth and substratum type; the bed stress value could be the same in two areas, even though the current speed in the water column above may be very different. The degree of bed stress has an influence on both seabed substratum type and the associated biological communities, particularly the epibiota (surface-dwelling community).

Data from a 1.8 km tidal application of POLCOMS (Proudman Oceanographic Lab Coastal Ocean Modelling System) were mapped (Figure 14), using the maximum tidal current data, as biological communities tend to reflect the maximum water movement rather than an average. The data set was divided into three categories, namely weak (0 - 1.8 Newtons/m^2 [8]), moderate (1.8 – 4.0 Newtons/m^2) and strong (>4.0 Newtons/m^2) as shown in Figure 15. These categories were selected to be biologically meaningful, equating as closely as possible to those used by the Marine Nature Conservation Review (Connor and Hiscock 1996).

[8] SI equivalent measure = Pascals

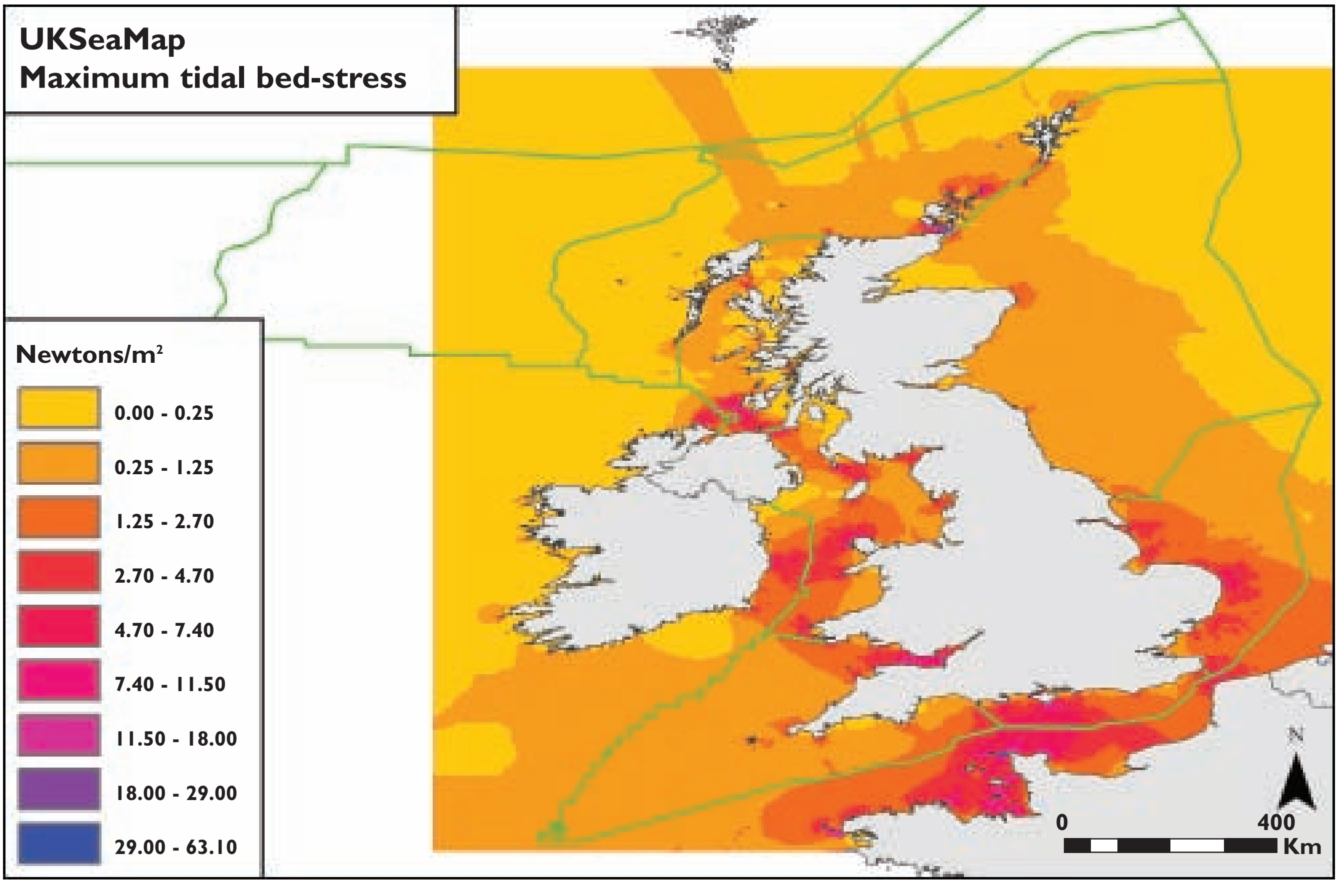

Figure 14. Maximum tidal bed stress from POLCOMS model (source data from POL).

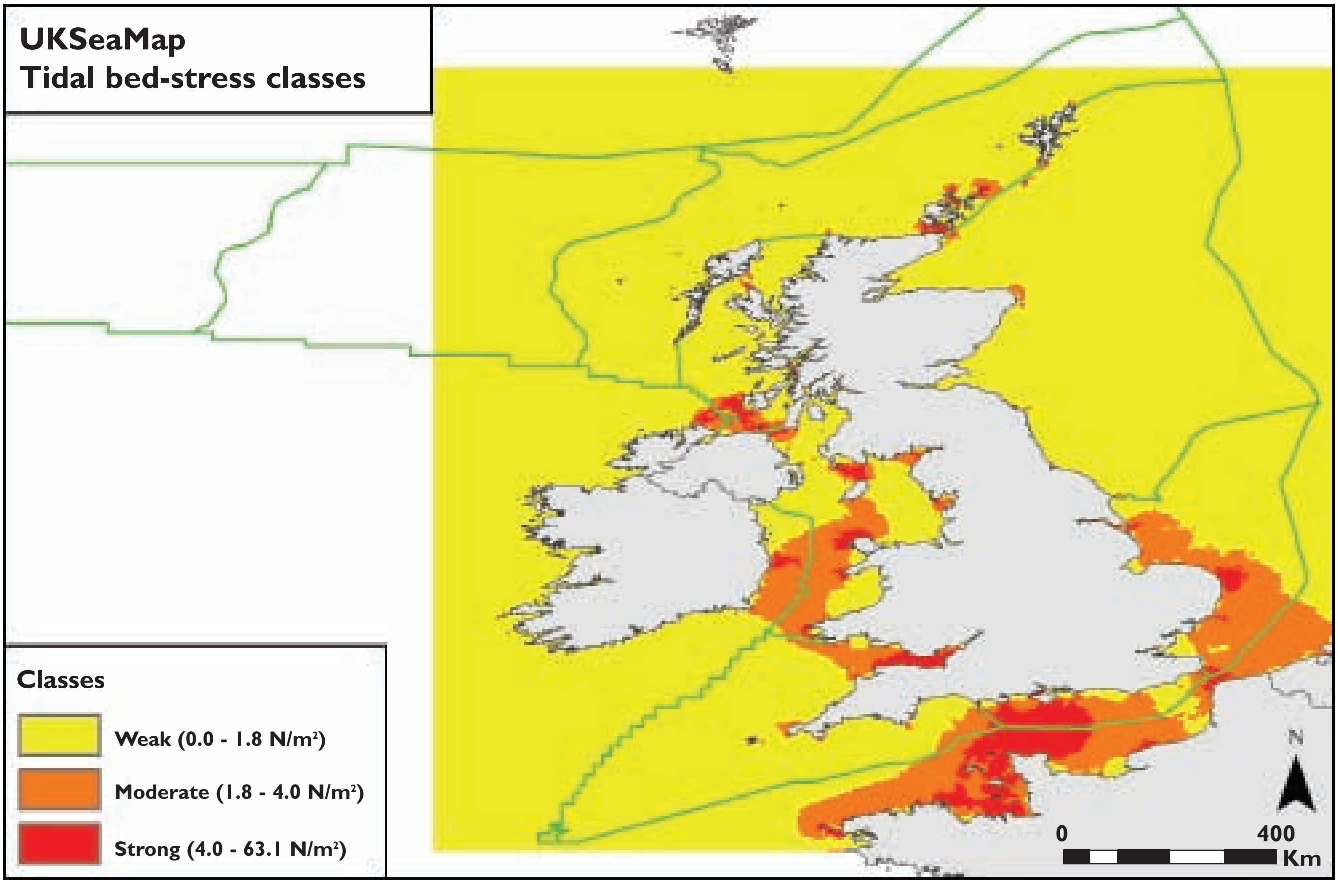

Figure 15. Maximum tidal bed stress classes used in seabed analysis.

4.3.12 Seabed data layers analysis

A classification tree was developed, based upon the categorised data sets described above (seabed substrata, photic depth, wave base, bathymetry, bottom temperature and tide-generated bed-stress). Table 3 outlines the classification tree used in the supervised analysis, and indicates the final map classes from this process (illustrated in Figure 16). Bed stress subdivisions were not applied to the rock categories, as it was considered this would lead to unnecessarily fine subdivisions, given the extent of rock habitat in the data set. As the bed stress model indicates only weak bed stress conditions in waters deeper than 200m, bed stress was also not applied to the deep-water categories. Temperature, on the other hand, was only applied to the deep-water zone, as this is where the marked temperature discontinuity occurs.

Table 3: Classification tree for the seabed data layers analysis

Slope	Substratum	Depth zone (includes photic depth, wave base and temperature)	Bed-stress (from currents)	Resultant seabed type
Negligible (<2%)	Rock	Photic	Any	Photic rock
		Aphotic	Any	Aphotic rock
	Coarse sediment	Shallow (coastline - < 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 - 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
		Warm deep-water (>200m and >4°C)	Any	Warm deep-water coarse sediment plain
		Cold deep-water (>200m and <4°C)	Any	Cold deep-water coarse sediment plain
	Mixed sediment	Shallow (coastline - < 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 - 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
		Warm deep-water (>200m and >4°C)	Any	Warm deep-water mixed sediment plain
		Cold deep-water (>200m and <4°C)	Any	Cold deep-water mixed sediment plain
	Sand	Shallow (coastline - < wave base)	Any	Shallow sand plain
		Shelf (wave base - 200m)	Any	Shelf sand plain
		Warm deep-water (>200m and >4°C)	Any	Warm deep-water sand plain
		Cold deep-water (>200m and <4°C)	Any	Cold deep-water sand plain

Slope	Substratum	Depth zone (includes photic depth, wave base and temperature)	Bed-stress (from currents)	Resultant seabed type
Negligible (<2%)	Mud	Shallow (coastline - < wave base)	Any	Shallow mud plain
		Shelf (wave base - 200m)	Any	Shelf mud plain
		Warm deep-water (>200m and >4°C)	Any	Warm deep-water mud plain
		Cold deep-water (>200m and <4°C)	Any	Cold deep-water mud plain

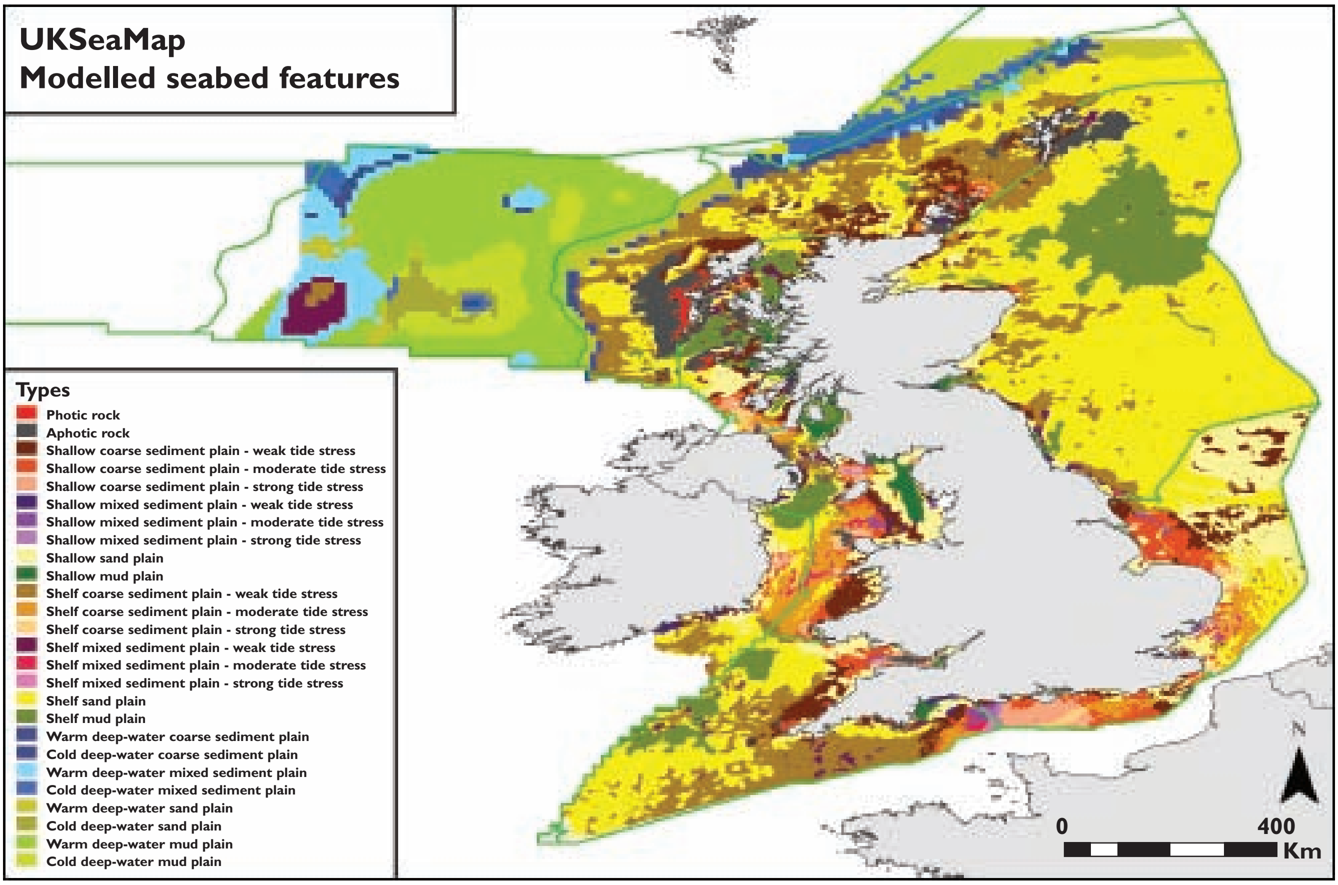

Figure 16. Seabed types derived from supervised classification tree analysis.

4.4 Coastal features

4.4.1 Identification of coastal physiographic features

The UK coastline has a varied and often complex nature, resulting from a series of landform processes, such as glaciations, over geological time periods, and these have led to a mixture of indentations (marine inlets), more linear stretches of open coast and coasts with adjacent islands and rocks of varying complexity. Characterisation of this complex coastline is an important aspect in developing a marine landscape map for UK waters as, although it lies at the margins of UK seas, it is the most visible and heavily used part of the marine environment.

A classification of these coastal physiographic features was developed for the JNCC Marine Nature Conservation Review (Connor *et al.* 1997), to complement a more detailed marine habitat classification for Britain and Ireland. This physiographic classification itself drew upon previous more detailed classifications, particularly for estuaries, sealochs and lagoons. In assessing the distribution and extent of EC Habitats Directive Annex I habitat types for Jackson and McCleod (2000), the physiographically-defined marine types (*Estuaries*, *Lagoons* and *Large shallow inlets and bays*) were defined and mapped for UK coasts in a GIS, and individual examples cross-referenced to the MNCR physiographic types.

For UKSeaMap, the MNCR physiographic classification has been further considered in the light of the broader whole UK seas perspective (Table 4); the first three types (linear coast, islands/rock, and offshore seabed) have been addressed as part of the open coast modelling (Section 4.3), whilst the remainder (excepting voes) have been retained as a set of coastal physiographic types, incorporating definitions which are compatible with the Habitats Directive Annex I types. Voes have been combined with sealochs, given their typically elongate character and glacial origin. The resultant set of coastal features is shown in Figure 17 and defined in Table 5.

Table 4. Relationship between MNCR physiographic types (Connor *et al*. 1997) and the UKSeaMap coastal features.

MNCR physiographic type	Treatment in UKSeaMap
Open coast	
Linear coast	Not used; see modelling Section 4.3
Islands / rocks	Not used; see modelling Section 4.3
Offshore seabed	Not used; see modelling Section 4.3
Semi-enclosed coast	Retained as Bay
Strait / sound	Retained
Barrier beach	Retained
Enclosed coast	
Embayment	Retained
Sealoch	Retained, merged with voe
Voe	Retained, merged with sealoch
Ria	Retained
Estuary	Retained
Isolated saline water (lagoon)	Retained

Table 5. Outline definitions of the coastal physiographic features (modified from Connor *et al*. 1997).

Coastal type	Description
Bay	An area of open coast bounded by headlands, which provide some shelter from along-shore winds, but which is predominantly open to onshore winds (compare 'embayment').
Sound (or strait)	Channels between the mainland and an island, or between two islands which are open at both ends to the open coast (excludes similar features or narrows within marine inlets such as sealochs).
Barrier beach	Coastal features caused by long-shore drift which create sheltered areas (of sediment) behind them.
Embayment	An enclosed area of coast in which the entrance provides shelter from onshore winds for the major part of the coast inside, but which is not a sealoch, voe, ria, estuary or lagoon.
Sealoch	Glacially–formed inlets (fjords, fjards) of western Scotland and Ireland, including the voes of Shetland. Typically elongate and deepened by glacial action with little freshwater influence. Often with narrows and sills dividing the loch into a series of basins. For sub-divisions (fjordic, fjardic and open sealochs) see Howson, Connor and Holt (1994).
Ria	Drowned river valleys of south-west Britain. Often with a greater presence of rock and more marine in character than estuaries.
Estuary	Downstream part of a river where it widens to enter the sea. Often with significant freshwater influence and predominantly comprising sediment habitats. For sub-divisions (coastal plain, bar-built and complex) see Davidson *et al*. (1991).
Lagoon	Enclosed bodies of water, separated or partially separated from the sea by shingle, sand or sometimes rock and with a restricted exchange of water with the sea, yielding varying salinity regimes. For sub-divisions (isolated saline lagoon, percolation saline lagoon, sluiced saline lagoon, silled saline lagoon, saline lagoon inlet) see Joint Nature Conservation Committee (1996).

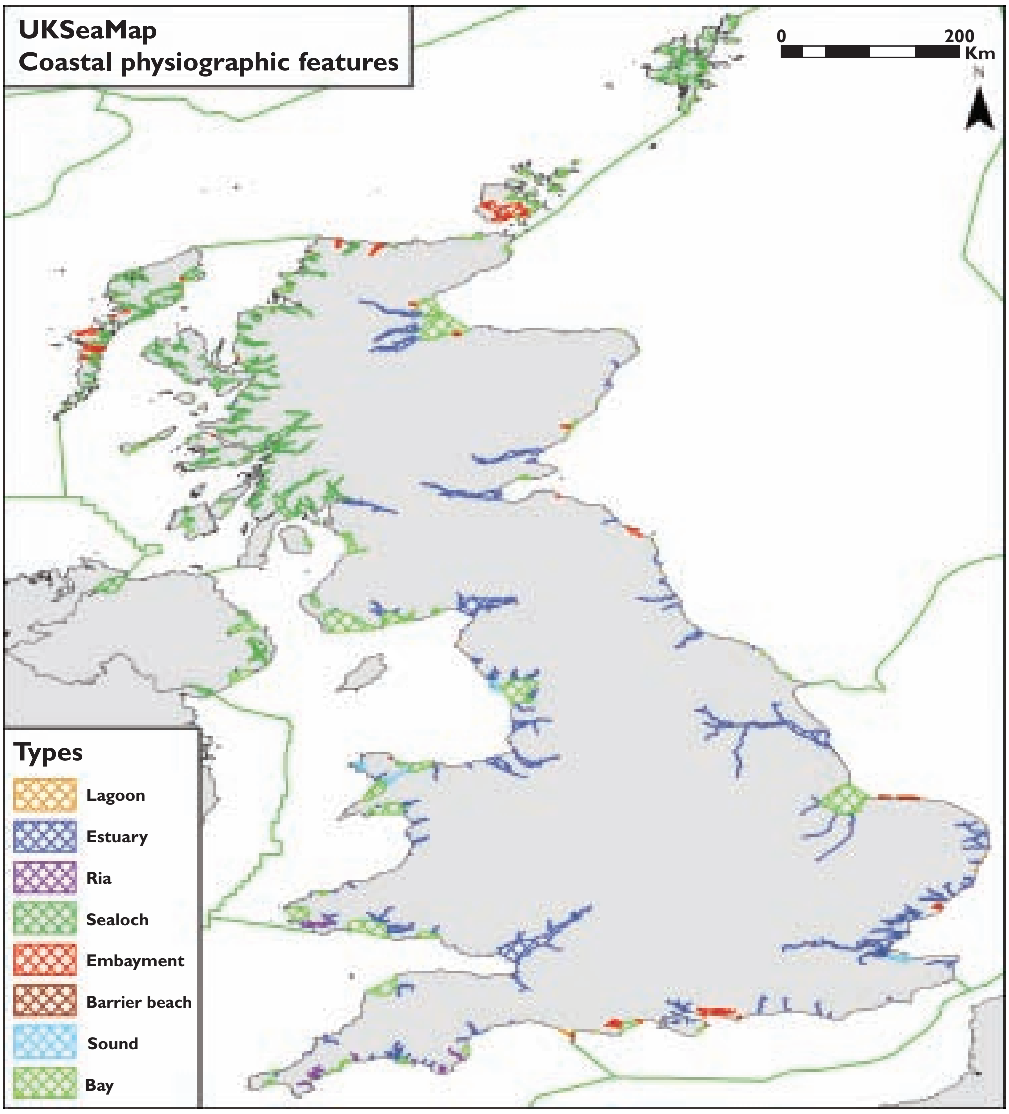

Figure 17. Coastal physiographic features.

For more detailed definitions used to define these features in a GIS, refer to Annex 5.

4.5 Seabed features classification and map

On the basis of the three sets of seabed types produced from the topographic/bed-form analysis, the seabed modelling and the identification of coastal features, a combined classification and map of seabed features has been compiled (Table 6; Figures 18 and 19). Figure 19 has been magnified to better illustrate some of the detail in the seabed features; these enlarged maps are given in Annex 6.

The topographic, bed-form and coastal physiographic features have been identified based primarily on their shape, whilst the seabed modelled features are mapped based on substratum, depth and energy. As a consequence, the two sets of data overlap. The final map has therefore been presented in two forms:

- With topographic and coastal features shaded, overlying the seabed modelled features (solid colours) to allow the underlying seabed character to show through (Figure 18).
- With topographic and coastal features in solid colours, overlying and obscuring the seabed modelled features, such that the latter are only visible where they occur as plains (i.e. <2% slope). This presents a slightly simpler map (Figure 19). Note that the pockmark fields and iceberg ploughmark zones are retained as hatched features, because both represent areas in which these features occur, rather than the actual features themselves.

Figure 19 better fits the concept of marine landscapes and what was intended in the aims for UKSeaMap, in that it has no overlapping features. However some end users may find it useful to see the complete coverage of modelled features in conjunction with the topographic features, as shown in Figure 18; this is particularly helpful for the very extensive areas covered by the deep-ocean rises.

Table 6. Seabed features classification and main characteristics

Marine landscape type	Substratum	Depth range (m)	Bed stress (currents)	Slope and additional descriptors	Area (km^2)	% of total UKCS
Enclosed coast						
Lagoon	Mainly sediment, limited rock (except in Scottish lagoons)	0-5m (exceptionally to 40m)	Weak currents (strong in entrance channels)	Characteristics quite variable. Limited water exchange with open sea (may be completely cut off). Salinity regime may be highly variable or relatively stable, but is typically reduced.	24	0.0
Estuary	Mainly sediment; limited rock	0-30m	Variable; moderate to strong in channels	Strong salinity gradient from riverine head to open sea mouth	2,881	0.3
Ria	Rocky perimeters, with sediment basins	0-20m	Variable; moderate to strong in channels	A drowned river valley; often v-shaped in cross section	104	0.0
Sealoch	Rocky perimeters, with sediment basins	0-200m	Weak, but moderate to strong over sills	Includes fjords (have shallow sill and deep basins), fjards (generally shallower with many islands) and voes (elongate glacial features in Shetland)	2,856	0.3
Embayment	Mostly sediment	0-30m	Weak, but moderate in entrance channels	Enclosed, but limited freshwater influence.	596	0.1
Open coast and continental shelf						
Semi-enclosed coastal features						
Barrier beach	Mostly sediment	0-10m	Weak, but moderate to strong in entrance channels		29	0.0
Sound or strait	Rocky perimeters, with coarse sediment channels	0-30m	Moderate to strong	Narrow channel, open at both ends	91	0.0
Bay	Rocky perimeters, with sediment basins	0-50m	Weak		5,291	0.6
Shallow coastal plain features						
Photic rock	Rock, boulder and cobble	Coastline to 1% photic limit	Variable	Variable	7,155	0.8

Marine landscape type	Substratum	Depth range (m)	Bed stress (currents)	Slope and additional descriptors	Area (km^2)	% of total UKCS
Aphotic rock	Rock, boulder and cobble	Below 1% photic limit	Variable	Variable	10,968	1.2
Shallow coarse sediment plain - weak tide stress	Coarse sediment	Coastline to wave base	Weak	Negligible slope	33,694	3.9
Shallow coarse sediment plain - moderate tide stress	Coarse sediment	Coastline to wave base	Moderate	Negligible slope	16,745	1.9
Shallow coarse sediment plain - strong tide stress	Coarse sediment	Coastline to wave base	Strong	Negligible slope	7,869	0.9
Shallow mixed sediment plain - weak tide stress	Mixed sediment	Coastline to wave base	Weak	Negligible slope	2,922	0.3
Shallow mixed sediment plain - moderate tide stress	Mixed sediment	Coastline to wave base	Moderate	Negligible slope	2,021	0.2
Shallow mixed sediment plain - strong tide stress	Mixed sediment	Coastline to wave base	Strong	Negligible slope	952	0.1
Shallow sand plain	Sand and muddy sand	Coastline to wave base	Variable	Negligible slope	48,218	5.5
Shallow mud plain	Mud and sandy mud	Coastline to wave base	Variable	Negligible slope	6,893	0.8
Shelf plain features						
Shelf coarse sediment plain - weak tide stress	Coarse sediment	Wave base - 200m	Weak	Negligible slope	76,492	8.8
Shelf coarse sediment plain - moderate tide stress	Coarse sediment	Wave base - 200m	Moderate	Negligible slope	17,433	2.0
Shelf coarse sediment plain - strong tide stress	Coarse sediment	Wave base - 200m	Strong	Negligible slope	2,840	0.3
Shelf mixed sediment plain - weak tide stress	Mixed sediment	Wave base - 200m	Weak	Negligible slope	3,951	0.5

Marine landscape type	Substratum	Depth range (m)	Bed stress (currents)	Slope and additional descriptors	Area (km^2)	% of total UKCS
Shelf mixed sediment plain - moderate tide stress	Mixed sediment	Wave base - 200m	Moderate	Negligible slope	2,260	0.3
Shelf mixed sediment plain - strong tide stress	Mixed sediment	Wave base - 200m	Strong	Negligible slope	285	0.0
Shelf sand plain	Sand and muddy sand	Wave base - 200m	Variable	Negligible slope	215,215	24.7
Shelf mud plain	Mud and sandy mud	Wave base - 200m	Variable	Negligible slope	44,605	5.1
Coastal and shelf bed-form features						
Subtidal sediment bank	Coarse sand or gravel; sands and muddy sands	Above wave base	Variable	>2%	1,210	0.1
Shelf mound or pinnacle	Rock and/or sediment	0-200m	Variable	>2%	1,124	0.1
Shelf trough	Sediment	>20m below general depth of surrounding seabed	Variable, often strong	Notable slope	6,519	0.7
Pockmark field	Mud or fine sand	50->200m	Weak	Shallow depressions, fluid escape (methane gas)	23,169	*
Continental slope and deep sea						
Continental slope and deep sea topographic and bed-form features						
Continental slope	Sediment	>200m	Variable	>2%	36,534	4.2
Iceberg plough mark zone	Boulder/cobble with sediment	~150m->500m	Variable		29,478	*
Canyon	Typically rock with sediment	>150m - >2000m	Variable	>8%	1,395	0.2
Deep-ocean rise	Typically rock with sediment	Rising > 800m from depths of 1500m	Variable	>8%	87,907	10.1
Carbonate mound	Carbonate	500-1100m (Hatton Bank)	Variable	Biogeochemical formation	No extent data	-

Marine landscape type	Substratum	Depth range (m)	Bed stress (currents)	Slope and additional descriptors	Area (km^2)	% of total UKCS
Deep-water mound	Sand volcanoes with coral on top	900-1200m	Variable		52	0.0
Continental slope and deep sea plain features						
Warm deep-water coarse sediment plain	Coarse sediment	>200m & >4°C	Variable	Negligible slope	3,781	0.4
Cold deep-water coarse sediment plain	Coarse sediment	>200m & <4°C	Variable	Negligible slope	386	0.0
Warm deep-water mixed sediment plain	Mixed sediment	>200m & >4°C	Variable	Negligible slope	5,407	0.6
Cold deep-water mixed sediment plain	Mixed sediment	>200m & <4°C	Variable	Negligible slope	4,880	0.6
Warm deep-water sand plain	Sand and muddy sand	>200m & >4°C	Negligible	Negligible slope	6,076	0.7
Cold deep-water sand plain	Sand and muddy sand	>200m & <4°C	Negligible	Negligible slope	5,597	0.6
Warm deep-water mud plain	Mud and sandy mud	>200m & >4°C	Negligible	Negligible slope	56,327	6.5
Cold deep-water mud plain	Mud and sandy mud	>200m & <4°C	Negligible	Negligible slope	23,509	2.7
Unclassified					118,808	13.6
Total					**871,901**	**100.0**

* Iceberg ploughmark zone and Pockmark fields are mapped as overlays, and so are not included in total area or % given.

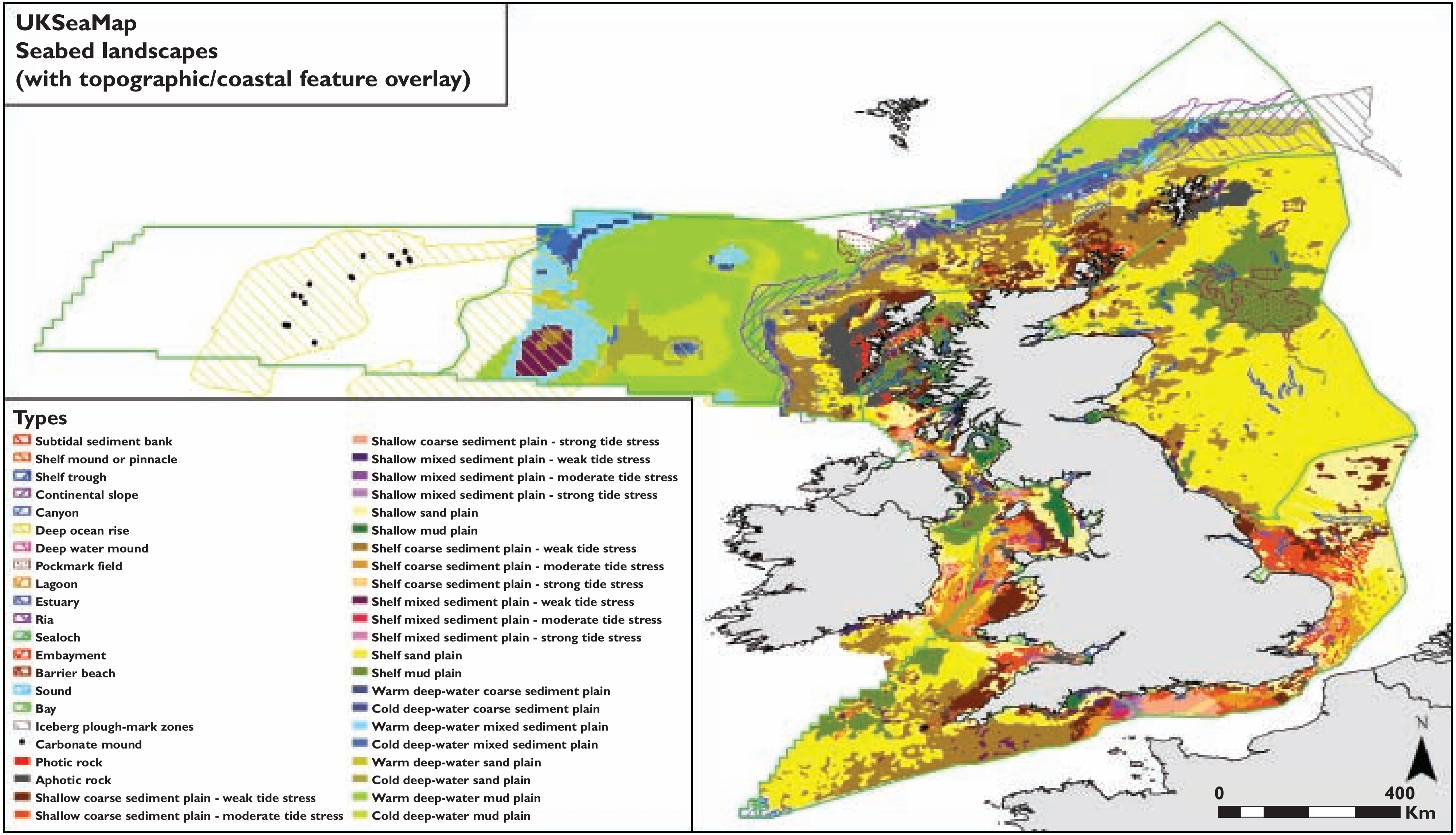

Figure 18: Map of seabed landscape types (topographic and coastal types shown as overlays – hatched colours).

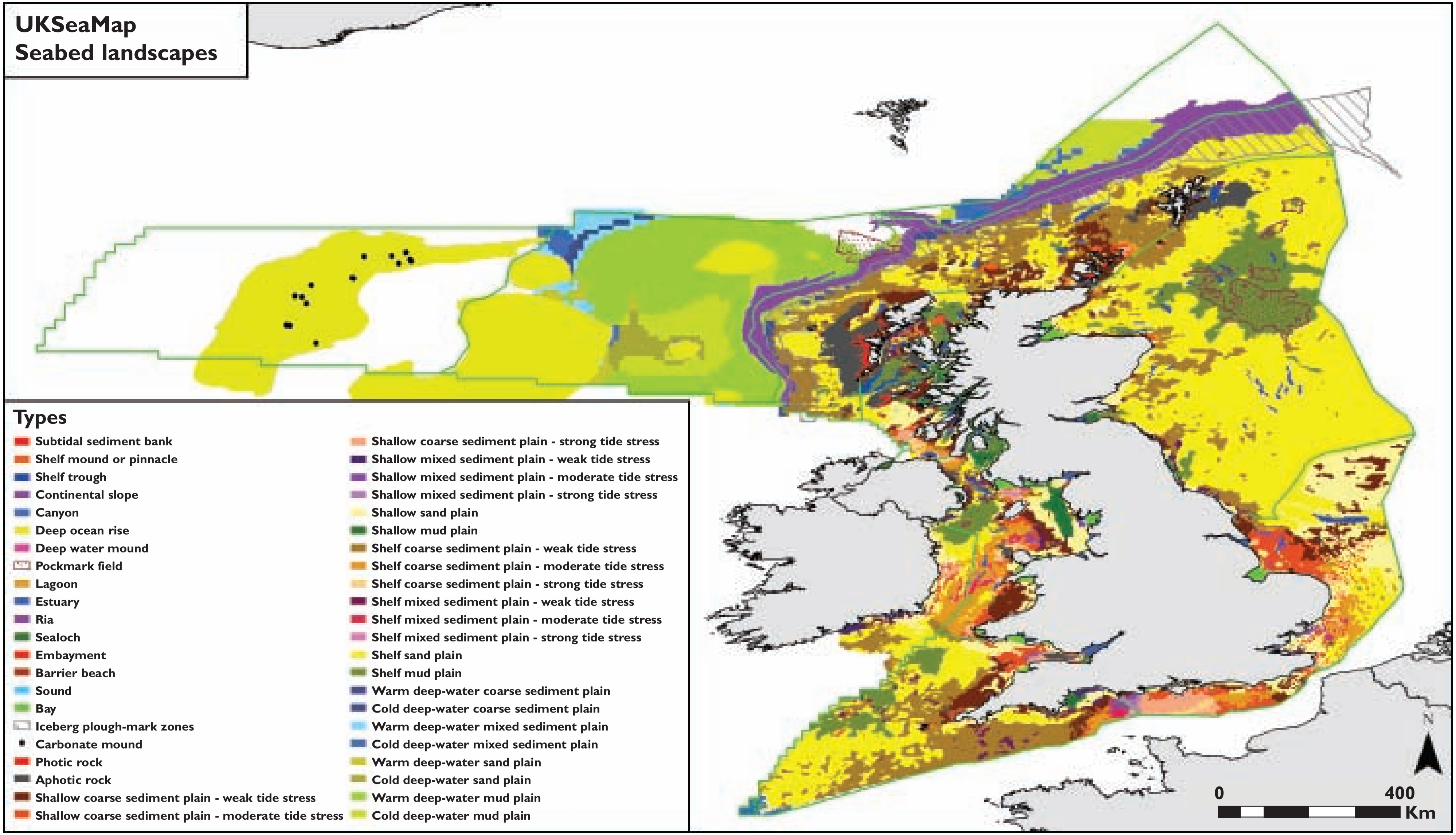

Figure 19: Map of seabed landscape types (topographic types shown obscuring modelled types – solid colours).

4.6 Biological validation

4.6.1 Overview

The purpose of this phase of UKSeaMap was to test the ecological validity of the maps derived from the geological, physical and hydrographic data processing. This validation process has been undertaken through the following steps:

- Collation of benthic sample data, for sites throughout the study area, to provide ground-truth information on the biological character of the seabed (often also information on sediment type and depth);

- Analysis of the benthic sample data to identify the habitat (biotope) class for each sample, to provide a common interpretation of the benthic data;

- Development of a prediction as to which habitat types might be expected to occur within each landscape type, to formulate the hypothetical basis for comparing the ground-truth data with the modelled landscape map;

- Analysis of the ground-truth data against the landscape map to test how well the prediction holds up in reality;

- Use of the results of the analysis to define the degree to which the landscapes types were validated (correlated), expressing this both numerically and as maps (Section 4.8);

- Interpretation of the results to assess possible causes of any poor correlation, leading where necessary to modification of the original model and to refinement of the (predicted) biological characterisation of the landscape types.

4.6.2 Data sources and their acquisition

The validation has been undertaken using sublittoral benthic sample, video survey and sediment (particle size analysis) data, which have been collated from a number of sources, including government marine agencies, laboratories and environmental consultancies. The distribution of data used for the validation is shown in Figure 20 and the data sets used are listed below. Although there is a coastal bias within the validation data set as a whole, considerable effort was made to rectify this by specifically targeting data for the offshore area during the final substantial data acquisition phase.

Approximately 32,000 samples originating from a variety of different sources were used for the validation process:

- Sublittoral data held by JNCC in the Marine Recorder database. This includes:
  - Marine Nature Conservation Review survey data
  - Countryside Council for Wales survey data
  - Environment and Heritage Service survey data
  - English Nature survey data
  - Scottish Natural Heritage survey data
  - Irish Sea Pilot survey data
  - Data from the MarLIN database
  - Marine Conservation Society data
  - National Parks and Wildlife Service Ireland BioMar survey data
  - CEDaR Northern Ireland survey data
- Irish Seabed Image Archive
- EC Biodiversity database
- Envision video data
- UKOOA – UK Benthos database
- Environment Agency
- National Marine Monitoring Programme
- CEFAS North Sea Benthos 2000 data
- Data obtained from Emu Ltd. – English and Welsh coasts and offshore
- Data obtained from ABPMer – English coast
- Data obtained from MES – English and Welsh coasts and offshore

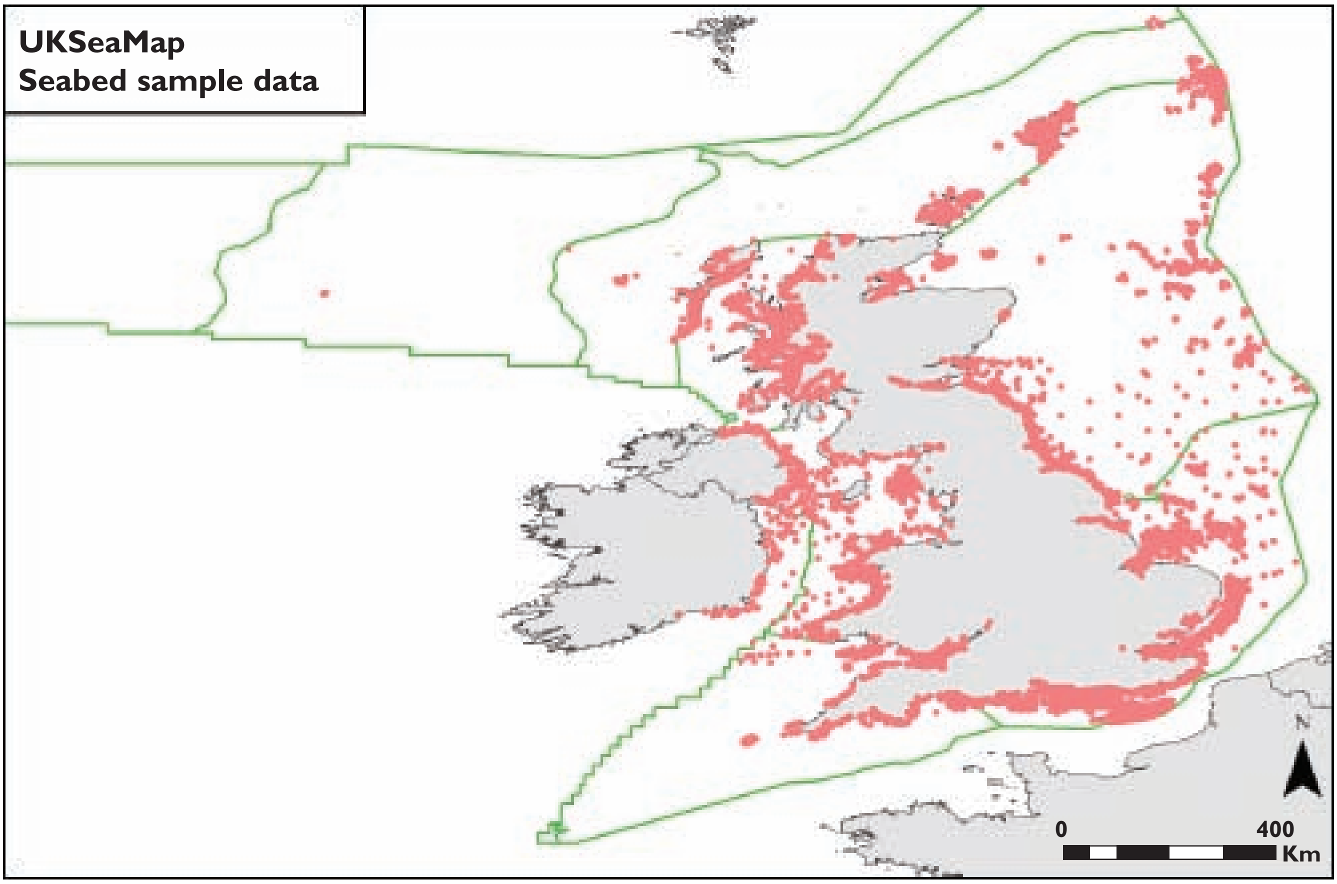

Figure 20. Map showing the distribution of benthic sample data used in the biological validation process.

4.6.2.1 Processing of benthic data

The data sets above were transformed into a standardised format to enable their incorporation into the JNCC's Marine Recorder database (**www.jncc.gov.uk/MarineRecorder**), which would facilitate the further processing required of the data.

In order to perform the biological validation, it was essential that each sample used was assigned a habitat (biotope) code according to the National Marine Habitat Classification (Connor *et al.* 2004). This provides the common language for the interpretation of the benthic sample data, and is particularly important given the size of the data sets and the very broad range of ecological character to be assessed. It is possible to assign sample data to any of the six levels in the classification; however, for the purposes of UKSeaMap it was considered that working to level 4 (Biotope Complex) was sufficiently detailed.

A significant proportion of the available data had already been analysed to habitat classes in the classification. The remaining samples were processed firstly by merging the Marine Recorder data sets into a single Marine Recorder Snapshot database to provide a simplified data structure for reporting purposes. Using predefined routines in the Marine Recorder Report Wizard, the sample data were then exported in the correct format to be used in JNCC's Habitat Matching Program (**www.searchMESH.net**; Chapman 2006). This is a software application, newly-developed as part of the Mapping European Seabed Habitats (MESH) project, which automates data were assigned at Biotope Complex level, equivalent to EUNIS level 4.

4.6.3 Predicting a correlation between habitat classes and landscape types

In order to use the ground-truth benthic sample data to validate the landscape maps, it was necessary to develop an expected correlation between the two classification schemes that could then be used to test the observed relationship. This was undertaken on the basis of using the definitions of each habitat type and assessing their relationship to the expected character of each landscape type. For instance, the *photic rock* landscape type should by definition include any habitats which both occur on rock and support algal communities, but exclude habitats occurring on sediment or supporting faunal-dominated communities.

As the landscape scheme is a much broader classification than the habitat classification scheme, this essentially meant defining for each landscape type which habitat classes might occur in it, in a one-to-many relationship. Because some habitat classes could occur in several landscape types (for example, seagrass beds can occur in sealochs, bays and on the open coast), this was best done by developing a correlation matrix or Look-Up Table (LUT) that specifies the relationship between the habitat classes and the landscape types. The use of a LUT, a technique that has been utilised in research for terrestrial environments, allows the comparison of data in two different classification schemes. Three possible relationships were defined:

- 1 = Expected relationship (Samples from Habitat X match Landscape type Y)
- -1 = Unexpected relationship (Samples from Habitat X do not match Landscape type Y)
- 0 = Uncertain relationship (the relationship between Habitat X and Landscape type Y is unclear. In certain circumstances, samples from Habitat X may match Landscape type Y)

Using the LUT it is possible to assess to what level the sample data supports or contradicts the mapped landscapes. The LUT and further details on its development and use are given in Annex 7.

4.6.4 Analysis and results – validity of seabed types

In ArcGIS, the sample data described above were spatially interfaced with the seabed landscape map, such that in addition to a habitat code each sample also contained data relating, where relevant, to each of the following aspects of the landscape map:

- Modelled landscape type
- Coastal physiographic type
- Topographic feature type
- A coastal buffer indicating position relative to the coast (within or outside 3 nautical miles) (see Section 4.6.6)

Each sample was then given a LUT value (-1, 0 or 1) based on the predicted relationship between the habitat code and the landscape type assigned to it. In cases where samples fell within both a modelled landscape type and a coastal physiographic or topographic feature, the LUT value associated with the physiographic/topographic types over-rode that of the modelled landscape type (reflecting the preferred dominance of these features over the modelled data in the final landscape map – Figure 19). Using these LUT values, it was possible to assess whether each sample had an 'expected' 'unexpected' or 'uncertain' relationship with the underlying landscape type. From this was determined both a conservative (the proportion of data falling into expected definitions only) and an optimistic (the proportion of data falling into either expected or uncertain definitions) estimate of the degree of correlation for each landscape type (Table 7).

Analysing the data in this way gave an indication of the level of support given by the sample data for each landscape type. However, as the samples were not evenly distributed across the landscape map, they did not evenly cover each of the landscape types and in many cases only covered a small proportion of the area of each landscape type. In particular, the high density of sample data in the coastal zone provided a strong bias in data coverage. As a consequence of these points a further assessment was made by reviewing the sample data within each cell of the net used to create the map. The number of samples in each cell and their LUT values were assessed and those cells with more than 50% of samples having an 'unexpected' relationship were deemed not to be validated. A more detailed description of the data analysis for the correlation process is given in Appendix 7.

Table 7 provides a summary of the analysis, at both a 'landscape type' and a 'cell' level[1], with more detailed data given in Annex 8. In the table, at the cell level, the percentage of cells validated (i.e. in which half or more of its samples have an expected or uncertain relationship to the landscape type) is given (for example, 93% of the 27 cells falling with lagoons were validated by the sample data). At the landscape level, the minimum and maximum levels of correlation are given, indicating the percentage of samples falling within the expected definition (minimum) or expected and uncertain definitions (maximum). Where there were a significant number of samples not matching (validating) the landscape type, the main habitat types of these samples are given, together with possible explanations for the poor correlation.

---

[1] An additional analysis was undertaken at the 'polygon' level, to assess which polygons appeared to match the character expected of the landscape type, based on whether 50% or more of the cells in a polygon were validated by the sample data. As the results were broadly similar to those presented here, the additional detail has not been given.

Table 7: Summary of biological correlation data at cellular and landscape levels against the seabed landscapes types (for habitat codes refer to Connor *et al*. 2004) (see also Figures 21 and 22)

Landscape type	By cell		By landscape type			Main habitat types not matching	Comments
	Total no. of cells	% cells validated	Total no. of samples	Min. % correlation (expected)	Max. % correlation (expected + uncertain)		
Enclosed coast							
Lagoon	27	93	137	67	96		
Estuary	539	99	3697	57	99		
Ria	78	97	965	65	97		
Sealoch	1101	100	6640	93	100		
Embayment	138	99	861	47	96		
Open coast and continental shelf							
Semi-enclosed coastal features							
Barrier beach	0						
Sound	36	100	410	48	97		
Bay	510	100	1459	61	99		
Shallow coastal plain features							
Photic rock	284	68	1637	61	61	CR; SS.SMp; SS.SCS	Lack of 'rock' data within BGS data set
Aphotic rock	51	39	225	36	36	IR types	Poor distinction remains between photic/aphotic (infralittoral/ circalittoral) despite amendments to light attenuation boundary
Shallow coarse sediment plain - weak tide stress	793	30	2747	22	23	Rock types; SS.SMx; SS.SSa	% Correlation increases when area outside buffer is taken alone
Shallow coarse sediment plain - moderate tide stress	825	53	3293	34	37	Rock types; SS.SMx; SS.SSa	% Correlation increases when area outside buffer is taken alone
Shallow coarse sediment plain - strong tide stress	259	42	1104	24	26	Rock types; SS.SMx; SS.SSa	% Correlation increases when area outside buffer is taken alone
Shallow mixed sediment plain - weak tide stress	204	25	653	22	25	Rock types; Infralittoral sands	
Shallow mixed sediment plain - moderate tide stress	39	31	303	24	26	Rock types; SS.SCS	

Landscape type	By cell		By landscape type			Main habitat types not matching	Comments
	Total no. of cells	% cells validated	Total no. of samples	Min. % correlation (expected)	Max. % correlation (expected + uncertain)		
Shallow mixed sediment plain - strong tide stress	15	40	109	17	19	Rock types; SS.SCS	
Shallow sand plain	1127	43	4063	29	34	Rock types; SS.SCS	% Correlation improves outside coastal buffer, but still ~350 samples were assigned to SS.SCS
Shallow mud plain	256	48	658	23	32	Rock types	% Correlation increases to 80% when area outside the buffer is taken alone
Shelf plain features							
Shelf coarse sediment plain - weak tide stress	90	7	226	0	3	SS.SCS.ICS	Poor distinction between shallow/shelf landscapes; HMP problem
Shelf coarse sediment plain - moderate tide stress	174	6	433	0	3	SS.SCS.ICS	Poor distinction between shallow/shelf landscapes; HMP problem
Shelf coarse sediment plain - strong tide stress	19	11	55	0	5	SS.SCS.ICS	Poor distinction between shallow/shelf landscapes-HMP problem; very low sample size
Shelf mixed sediment plain - weak tide stress	17	41	58	3	14		Sample size too low for results to be reliably interpreted
Shelf mixed sediment plain - moderate tide stress	6	50	7	29	43		Sample size too low for results to be reliably interpreted
Shelf mixed sediment plain - strong tide stress	0						No samples
Shelf sand plain	767	7	2029	1	4	Mud types; Sandy muds; SS.SCS	Poor distinction between sand and mud - 367 samples are in 'mud' rather than sand.
Shelf mud plain	194	66	446	12	55	Rock types; Muddy sands; Infralittoral muds	Many rock samples found in mud within coastal buffer - % validated increases to 70% when area outside the buffer is taken alone

Landscape type	By cell		By landscape type			Main habitat types not matching	Comments
	Total no. of cells	% cells validated	Total no. of samples	Min. % correlation (expected)	Max. % correlation (expected + uncertain)		
Coastal and shelf bed-form features							
Subtidal sediment bank	9	100	16	31	88		
Shelf mound or pinnacle	13	100	53	66	100		
Shelf trough	33	94	137	20	63	IR types	
Pockmark field	0						
Continental slope and deep sea							
Continental slope and deep sea topographic and bed-form features							
Continental slope	2	0	17	0	0		No types in LUT to validate feature
Iceberg plough mark zone	0						No types in LUT to validate feature
Canyon	0						No samples
Deep ocean rise	2	0	27	0	0		No types in LUT to validate feature
Carbonate mound	0						No samples
Deep-water mound	0						No samples
Continental slope and deep sea plain features							
Warm deep-water coarse sediment plain	1	0	1	0	0		No types in LUT to validate feature
Cold deep-water coarse sediment plain	0						No samples
Warm deep-water mixed sediment plain	0						No samples
Cold deep-water mixed sediment plain	0						No samples
Warm deep-water sand plain	0						No samples
Cold deep-water sand plain	0						No samples
Warm deep-water mud plain	0						No samples
Cold deep-water mud plain	0						No samples

4.6.5 Coastal physiographic and topographic feature correlation

The results indicate that the coastal physiographic features and The tpographic features on the shelf were very well validated overall, though it is notable that a large proportion of uncertain relationships involving these features were defined in the LUT, and the range between the maximum and minimum correlation could be greatly reduced if these relationships were more clearly defined. The topographic features on the continental slope and in the deep sea remain unvalidated, because of both the lack of sample data and because the habitat classification does not extend in enough detail to these zones to provide habitat types for the LUT.

4.6.6 Modelled landscape types correlation

There was significant variability across the modelled landscape types, with some (e.g. *Photic reef*, *Shelf mud plain*, *Shallow mixed sediment plain*) appearing to be well validated, whilst others (e.g. *Shallow* and *Shelf coarse sediment plains*) seem to have a poor correlation. A number of factors have been identified as having an influence on the correlation overall, with the relative importance of each factor expected to vary depending on the landscape type in question:

Scale of modelling and validation data sets

The data sets used for modelling are at a significantly coarser resolution than the biological correlation data. Consequently it can be expected that not all sample data will match exactly with the more generalised modelling data.

Coastal rock

There is a significant underestimate of coastal rock data within the substratum data set (DigSBS typically excludes the near-shore zone and the WFD typology data set, which was summarised to 1 nautical mile, under-represents coastal rock), compared to the biological data available. Additionally there is a high density of rocky habitat data in some areas, which has further biased the results.

The over representation of coastal rock data in the validation data set is problematic when combined with the under representation of rock data within the BGS data set, and means that rock habitat is likely to exist in areas that are not identified as such by the BGS data set (Annex 9 provides a map indicating where rock habitat occurs according to the available sample data). As is suggested in Table 7, the over representation of samples for rock habitat occurs in particular within the shallow coastal zone types and this greatly reduced the percent correlation of those landscape types and masked other patterns within the correlation.

To help redress this bias, a coastal buffer was used to split the UKSeaMap area into 'coastal' (within 3nm of the shore) and 'offshore' (outside 3nm) zones. A separate analysis was then performed on the data falling inside and outside the buffer. Table 8 shows the results of this analysis.

Table 8: Analysis of biological correlation data against modelled seabed types for area inside and outside a 3nm coastal buffer

Landscape type	Inside 3nm buffer			Outside 3nm buffer		
	Total no. of samples	Min % correlation (expected)	Max % correlation (expected + uncertain)	Total no. of samples	Min % correlation (expected)	Max % correlation (expected + uncertain)
Enclosed coast						
Lagoon	137	67	96	0		
Estuary	3652	58	99	45	44	100
Ria	965	65	97	0		
Sealoch	6637	93	100	3	67	100
Embayment	861	47	96	0		
Open coast and continental shelf						
Semi-enclosed coastal features						
Barrier Beach	0			0		

Landscape type	Inside 3nm buffer			Outside 3nm buffer		
	Total no. of samples	Min % correlation (expected)	Max % correlation (expected + uncertain)	Total no. of samples	Min % correlation (expected)	Max % correlation (expected + uncertain)
Sound	410	48	97	0		
Bay	1236	61	99	223	64	100
Shallow coastal plain features						
Photic rock	1615	61	62	22	14	14
Aphotic rock	194	34	34	31	48	48
Shallow coarse sediment plain - weak tide stress	1910	12	13	837	44	45
Shallow coarse sediment plain - moderate tide stress	1658	11	14	1635	57	60
Shallow coarse sediment plain - strong tide stress	822	10	11	282	66	69
Shallow mixed sediment plain - weak tide stress	546	21	24	107	26	27
Shallow mixed sediment plain - moderate tide stress	262	21	24	41	39	39
Shallow mixed sediment plain - strong tide stress	105	18	20	4	0	0
Shallow sand plain	2838	24	28	1225	40	49
Shallow mud plain	566	16	24	92	71	82
Shelf plain features						
Shelf coarse sediment plain - weak tide stress	48	0	0	178	0	4
Shelf coarse sediment plain - moderate tide stress	11	0	0	422	0	3
Shelf coarse sediment plain - strong tide stress	22	0	0	33	0	9
Shelf mixed sediment plain - weak tide stress	17	0	6	41	5	17
Shelf mixed sediment plain - moderate tide stress	0			7	29	43
Shelf mixed sediment plain - strong tide stress	0			0		
Shelf sand plain	35	0	3	1994	1	4
Shelf mud plain	58	0	5	388	14	63
Coastal and shelf bed-form features						
Subtidal sediment bank	0			16	31	88

Landscape type	Inside 3nm buffer			Outside 3nm buffer		
	Total no. of samples	Min % correlation (expected)	Max % correlation (expected + uncertain)	Total no. of samples	Min % correlation (expected)	Max % correlation (expected + uncertain)
Shelf mound or pinnacle	4	75	100	49	65	100
Shelf trough	88	5	43	49	49	98
Pockmark field	0			0		
Continental slope and deep sea						
Continental slope and deep sea topographic and bed-form features						
Continental slope	0			17	0	0
Iceberg plough mark zone	0			0		
Canyon	0			0		
Deep ocean rise	0			27	0	0
Carbonate mound	0			0		
Deep-water mound	0			0		
Continental slope and deep sea plain features						
Warm deep-water coarse sediment plain	1	0	0	0		
Cold deep-water coarse sediment plain	0			0		
Warm deep-water mixed sediment plain	0			0		
Cold deep-water mixed sediment plain	0			0		
Warm deep-water sand plain	0			0		
Cold deep-water sand plain	0			0		
Warm deep-water mud plain	0			0		
Cold deep-water mud plain	0			0		

From the reanalysis (Table 8), the extent to which the coastal rock samples were affecting the correlation results for the data set as a whole (Table 7) is indicated by the fact that 17 of the 21 shallow and shelf plain features have improved percentage correlations (some significantly) outside the 3nm buffer.

Photic/aphotic rock boundary

The analysis revealed that the modelled depth boundaries for the photic/aphotic rock categories needed to be assessed against biological data to ensure the most appropriate boundaries had been selected. An examination of the data has revealed that although the samples associated with *Aphotic rock* are primarily from rock habitats, there is still some confusion between photic and aphotic zones, as 38% of the samples falling within the *Aphotic rock* type actually come from the infralittoral (photic) part of the habitat classification.

Sediment class boundaries

Biological communities tend to strongly reflect the sediment type in which they live, and this has been used to help define the sediment habitat in the habitat classification in which there are four main sediment classes defined (Connor *et al.* 2004) (Figure 6). However in reality there is a continuum of biological character across the boundaries of these classes, rather than any hard boundaries. The biological validation undertaken here has revealed a significant number of samples technically fall the 'wrong side' of the boundary, thus suggesting non-validation of the landscape type. This is particularly marked for the sandy mud and muddy sand part of the analysis and appears to be the underlying cause for the poor correlation of the *Shelf sand plain* landscape type, which contained a large number of samples belonging to the 'mud' part of the classification. Similarly shallow coarse sediment samples were frequently found in the related mixed sediment landscape types.. This aspect of the analysis needs further examination to assess the scale of the differences between the sample data and the sediment data layer and how this might best be resolved.

The Folk definition of gravel, as used in the BGS data set, is very broad and includes particles ranging from 2mm in diameter (gravel size) up to 2048mm (very large boulders). This might explain why some of the coarse sediment plains have validation rock samples within them.

Bed stress

The validation process has not clearly supported the divisions for the shelf and shallow coarse and mixed sediment plains into the three bed stress classes (strong, moderate, weak). In addition there appears to be an unexpected negative correlation between bed stress and seabed substratum types (large areas of coarse sediment with weak bed stress) (Table 6). Consequently the validity of the sub-divisions needs further consideration, including a more detailed assessment of the correlation results. Nevertheless, in view of the importance of bed stress in determining seabed character and because the broadscale pattern distinguished by it appears sensible, the three sub-types have been retained, pending further investigation.

Habitat Matching Program and habitat classification

The Habitat Matching Program (HMP) is a newly developed software application and there may be areas of the habitat classification for which it is working less effectively than others. Although the significance of this is not known, it should be considered when evaluating the validation process. For example, the *Shelf coarse sediment plain* landscape type was often matched to infralittoral coarse sediment (SS.SCS.ICS) samples. For the most part, shelf landscape types are associated with deep water (>50m), and samples from here should not have habitat codes from the infralittoral zone (typically <15m). This could point to an assignment problem within the HMP that could be addressed by undertaking a further more detailed analysis of those parts of the classification that are not well represented by sample data.

Data quality

Inevitably datasets of the scale used here, which are summarised to cover the whole UK, will represent the general trends across the UK and will not always be correct at the fine scale. Some particularly important aspects are mentioned above. In addition, the sample data set was very large (~32,000 samples) and came from many different sources, and it too is likely to have some data quality issues, which may have resulted in the incorrect assignment of habitat codes. These issues are likely to have affected the results of the validation to some extent.

4.7 Biological characterisation of seabed features

An initial indication of the biological character of each landscape type has been expressed through a correlation of the landscape types with the EUNIS classification (Annex 7). This table formed the basis of the LUT for the biological validation process and would benefit from re-examination in the light of the validation process with a view to removing some of the uncertain relationships.

4.8 Confidence assessment

4.8.1 Aspects considered and approach to assessment

The data used to derive the seabed landscape map comes from a wide range of sources, having themselves been variously developed at many different resolutions through direct observation, remote sensing and modelling. These data have been further processed here before analysing in an integrated manner to model the distribution of seabed types. Such factors contribute to provide degrees of certainty and uncertainty in the resultant landscape maps. Additionally, the ground-truth data available are not evenly distributed geographically or across the landscape types. To help ensure end users are aware of these underlying issues, it is therefore considered important to assess and present aspects of confidence in the resultant maps.

Confidence assessment for marine habitat mapping is a newly-developing area, with techniques on how best to do this currently being developed as part of the MESH project. From a UKSeaMap perspective, the general approach adopted was as follows:

- For each underlying data set (substratum, temperature, etc.), provide good metadata to indicate the source of the data, how the data were processed and the resolution of the data set.
- Consider whether the resolution of the data sets, individually or combined, could be represented on a map.
- For each marine landscape type, express the amount of ground-truth validation data available and the degree of consistency in habitat type (compared to the expected character of the landscape type).
- For each area for a particular landscape type, express the amount of ground-truth data available and the degree of consistency in habitat type (compared to the expected character of the landscape type). This may be best expressed via maps.

4.8.2 Presentation of confidence assessments

The pixelated appearance of the final landscape map (Figures 18, 19; Annex 6), resulting from the two grids applied to the data, is intended to indicate that the maps should not be considered to have as a high a level of precision, as might be implied from maps that have smooth boundaries between polygons. The use of a much coarser grid for deep waters beyond the continental shelf reflects the fact that the data are much less detailed in this region.

Metadata giving details of the source and timescale represented for each data set is available on the mapping website (see Section 6) so that it can be viewed along with the maps themselves. This allows users to check such information at any time. Making detailed metadata available in this way, alongside the data itself, was felt to be more important than displaying it graphically in a map.

The more important elements to display cartographically are the results from the biological validation process described in Section 4.6. This provides an assessment of the landscape map at the level of individual grid cells and at the landscape type level. Maps of each of these levels are presented in Figures 21 and 22. These maps provide a graphical representation of the data given in Table 7 and were produced followed the method outlined in Section 4.6. In Figure 22 the mapped categories are as follows: poor correlation (0-25%), moderate correlation (25-50%) and good correlation (>50%). These cut-off values have been selected following consideration of the level of validation achieved in other modelling studies. UKSeaMap is rare in providing a confidence assessment in this way; it is likely that the results of the validation process used here would compare favourably with other marine modelling outputs, especially given the scale of the UKSeaMap area.

The maps (Figures 21 and 22) show that there is in general a greater confidence in more shallow and coastal areas, which is thought to result from a number of factors, although there is also good confidence in some offshore areas that have been well studied. The BGS sediments data set is generally based on more sample points in the shallower areas and is therefore likely to be more reliable in these areas than in deeper water. Also the coastal bias of the available ground truth data is also likely to impact this as it means that there are generally smaller sample sizes in the analysis for offshore landscape types. In cases where the Habitat Matching Program was used to assign habitats to samples, this is expected to be more reliable in shallow areas as the standards used within the HMP are better developed for these areas than for offshore areas. An exception to this general pattern relates to the *Shelf mud plains* in the northern North Sea and the Irish Sea, which are very well supported in the validation process.

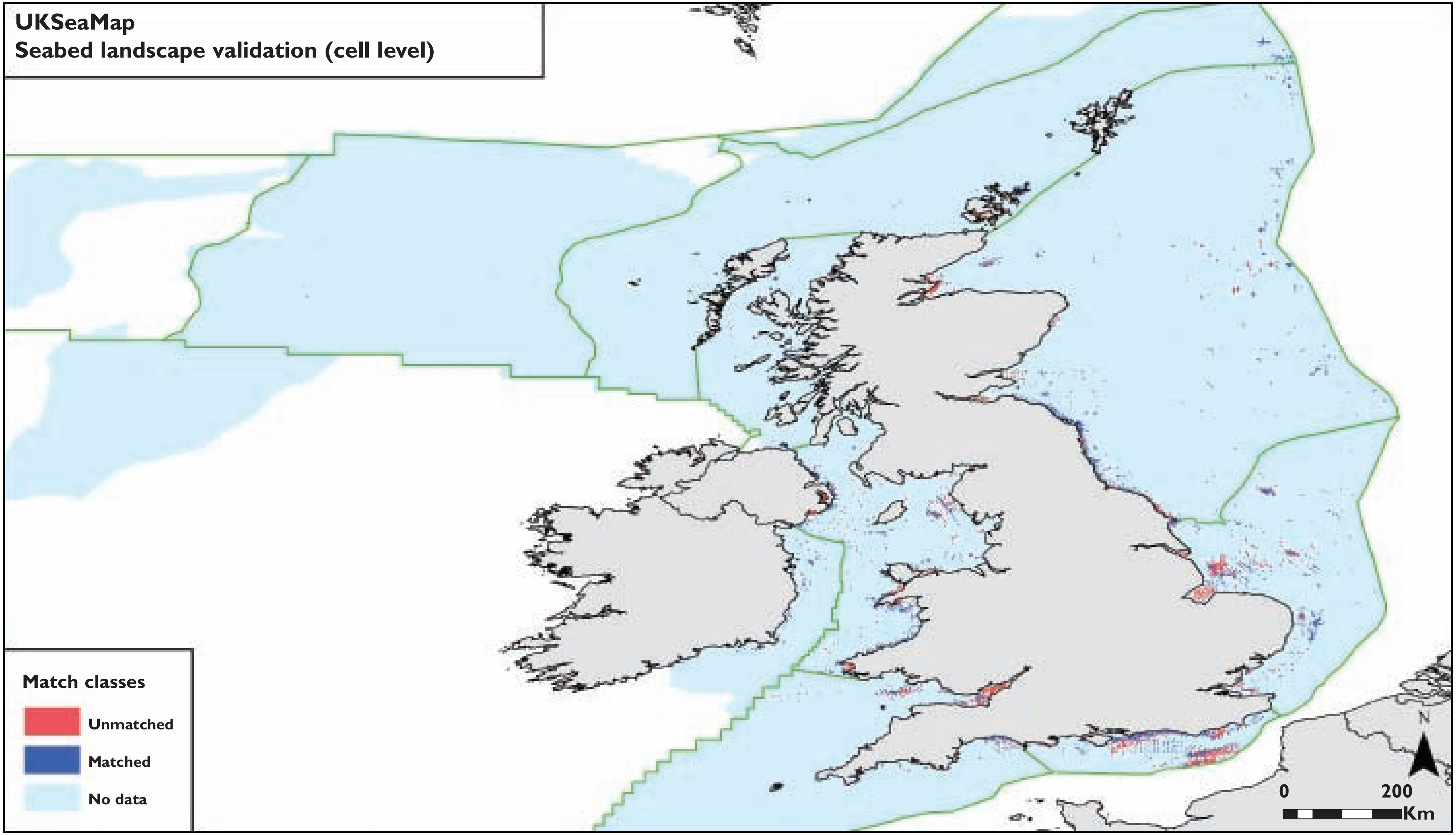

Figure 21: Map showing whether the biological validation data, at the grid cell level, supported the predicted character of the underlying landscape type (refer to text for full explanation and see also Table 7)

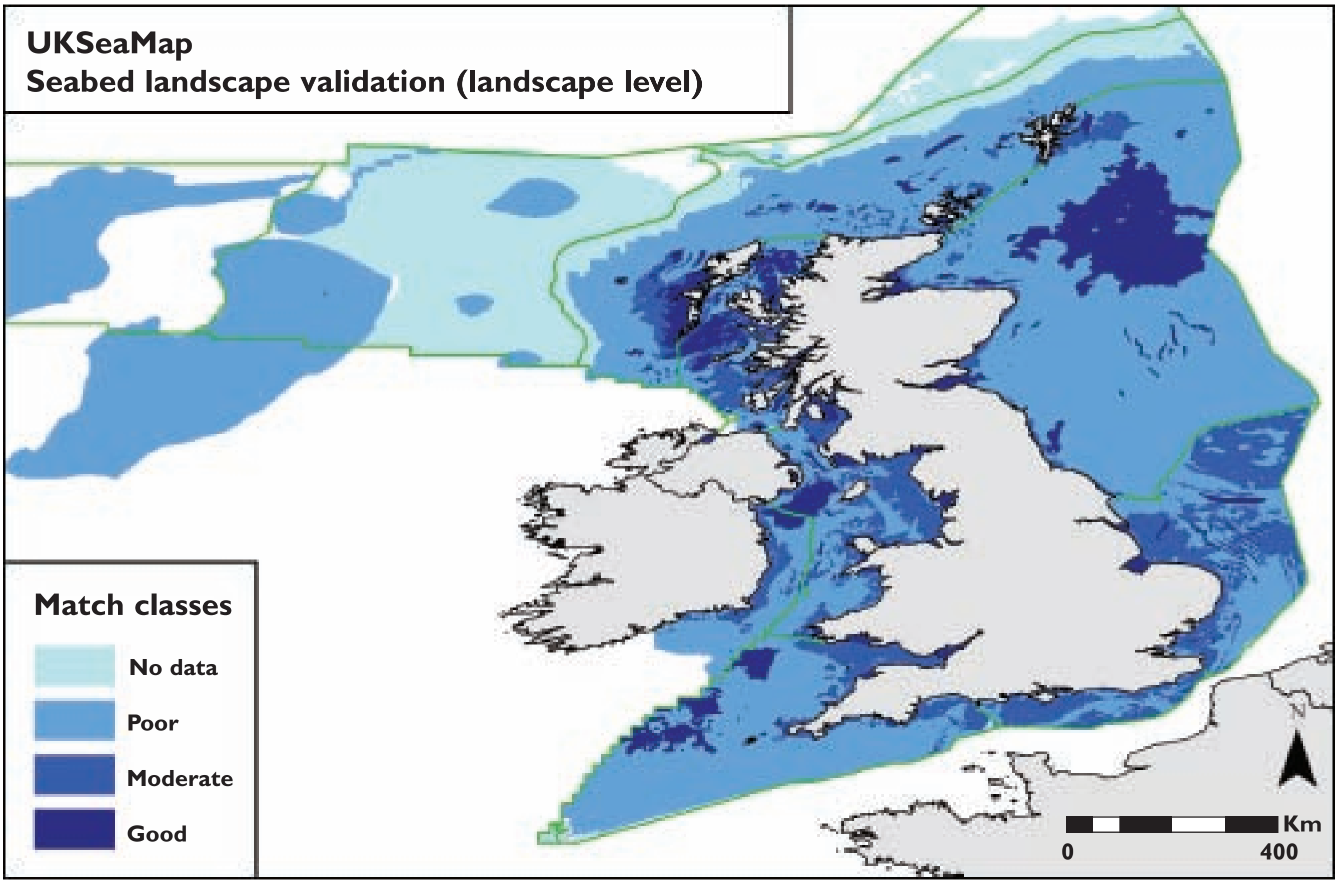

Figure 22: Map showing the degree to which the biological validation data, at the landscape level, supported the predicted character of the underlying landscape type (refer to text for full explanation and see also Table 7)

5.1 Overview

The general approach to development of maps to represent the ecological character of the water column or pelagic environment followed that for the seabed modelling, that is:

- Define a series of environmental data layers which are needed to characterise the water column;
- Source the required data sets, where possible to provide data layers covering the whole (or majority of) UK seas;
- Process the data into suitable GIS formats, including categorising each data set;
- Analyse the data sets in an integrated manner to produce classifications of the water column;
- Validate the resultant maps with ground-truth data (e.g. biological sample data);
- Characterise the final water column classifications according to both abiotic (physical, hydrographic) and biological characteristics;
- Present the underlying data layers and resultant maps in a web GIS application;
- Assess the level of confidence that can be placed in the resultant maps.

The key difference in methodology was that the data sets were processed and summarised according to four seasons to better reflect the highly mobile nature of the pelagic environment:

- Winter – December, January and February
- Spring – March, April and May
- Summer – June, July and August
- Autumn – September, October and November

In contrast to classifying the seabed features, the water column has a 3-dimensional aspect to its character, and is affected in particular by significant changes in temperature with depth. Within the timescale and resources available for the UKSeaMap project, it was only possible to consider the water column in a 2-dimensional perspective.