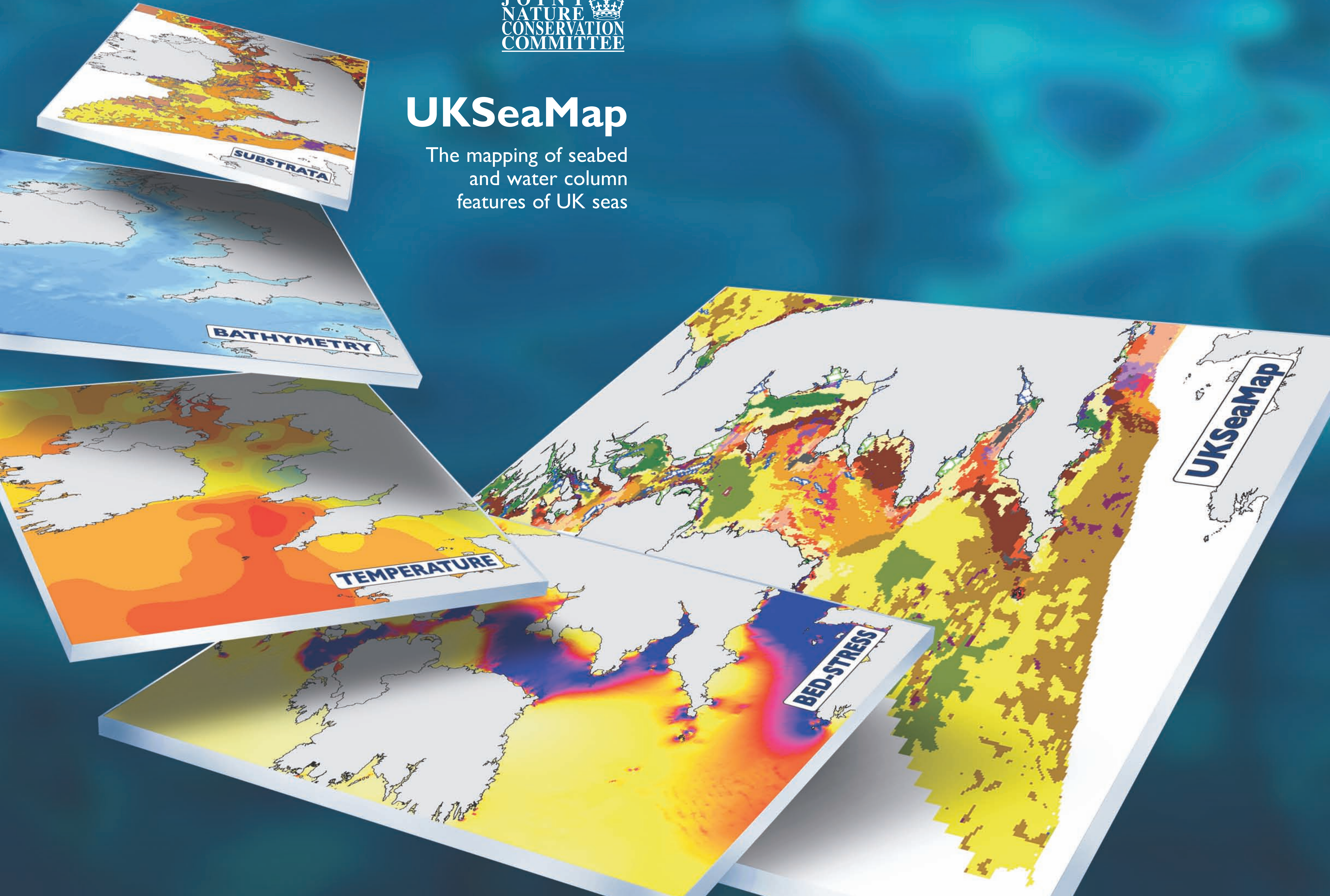
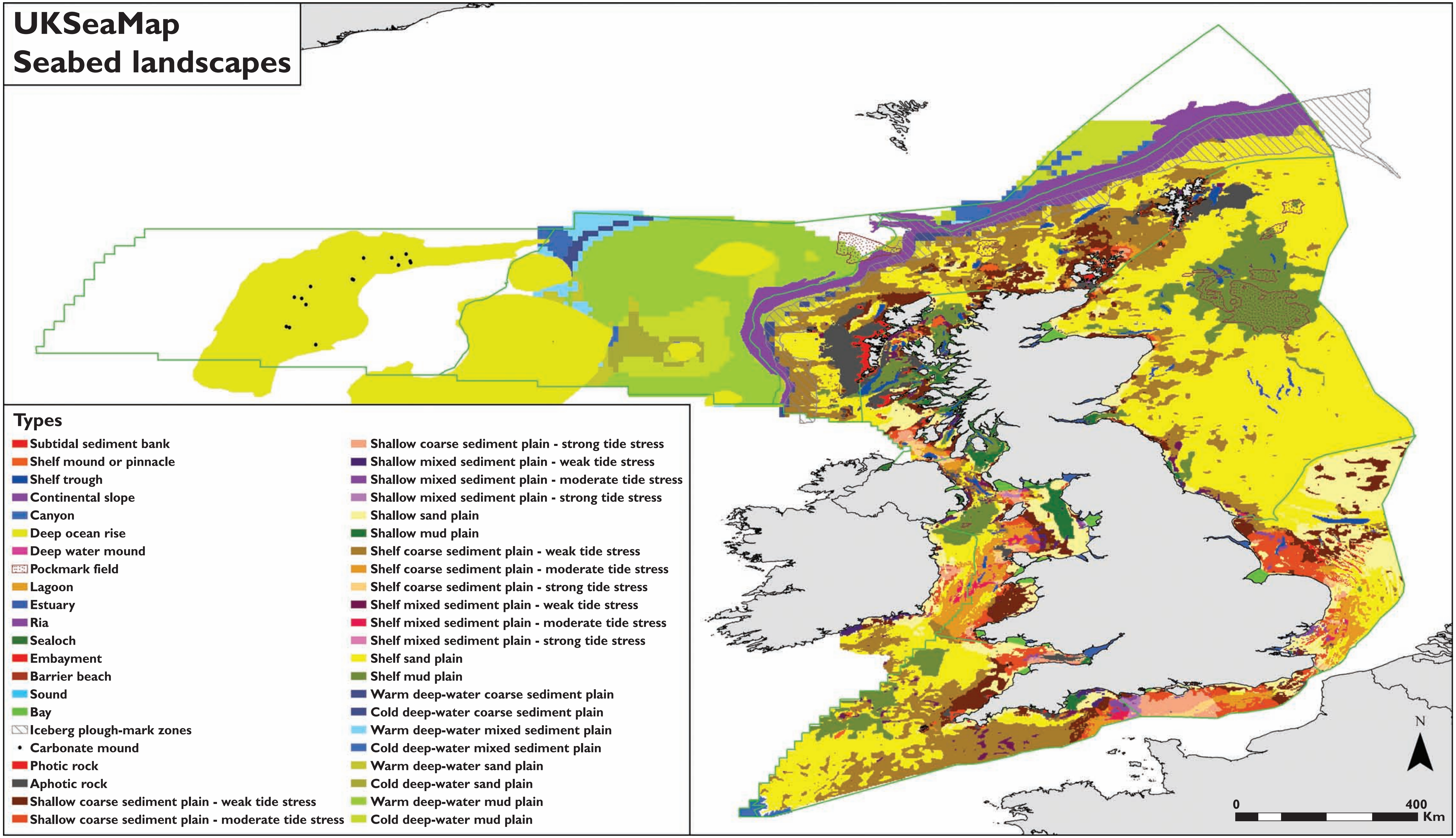
JOINT NATURE CONSERVATION COMMITTEE

UKSeaMap

The mapping of seabed
and water column
features of UK seas




UKSeaMap
Seabed landscapes
Types
Subtidal sediment bank
Shelf mound or pinnacle
Shelf trough
Continental slope
Canyon
Deep ocean rise
Deep water mound
Pockmark field
Lagoon
Estuary
Ria
Sealoch
Embayment
Barrier beach
Sound
Bay
Iceberg plough-mark zones
Carbonate mound
Photic rock
Aphotic rock
Shallow coarse sediment plain - weak tide stress
Shallow coarse sediment plain - moderate tide stress
Shallow coarse sediment plain - strong tide stress
Shallow mixed sediment plain - weak tide stress
Shallow mixed sediment plain - moderate tide stress
Shallow mixed sediment plain - strong tide stress
Shallow sand plain
Shallow mud plain
Shelf coarse sediment plain - weak tide stress
Shelf coarse sediment plain - moderate tide stress
Shelf coarse sediment plain - strong tide stress
Shelf mixed sediment plain - weak tide stress
Shelf mixed sediment plain - moderate tide stress
Shelf mixed sediment plain - strong tide stress
Shelf sand plain
Shelf mud plain
Warm deep-water coarse sediment plain
Cold deep-water coarse sediment plain
Warm deep-water mixed sediment plain
Cold deep-water mixed sediment plain
Warm deep-water sand plain
Cold deep-water sand plain
Warm deep-water mud plain
Cold deep-water mud plain
N
0
400
Km

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:

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.

Contents

1 Executive summary

One of the recommendations set out in the 2004 Working Group report to the UK Government under the Review of Marine Nature Conservation was that the process for identifying *marine landscapes*, trialled during the Irish Sea Pilot, should be refined, and that marine landscapes should be mapped for all UK waters. The UKSeaMap project was initiated to implement this recommendation.

This report summarises the methods used in identifying and mapping the seabed and water column features of UK seas. The report also summarises the potential uses and limitations of the marine landscapes approach. The work undertaken has the potential to underpin important aspects of sustainable development in the marine environment in the future, including strategic and spatial planning, the establishment of networks of protected areas, and the development of a marine surveillance framework.

1.1 Origins of the project

In 2004 the Defra-led Working Group on the Review of Marine Nature Conservation (RMNC) reported on its deliberations and recommendations, following a 4-year review of the needs and mechanisms for marine nature conservation in UK waters (Defra 2004). During this period, the RMNC had considered proposals for a framework to manage and protect our marine waters, which included defining the marine environment at a series of scales (regional seas, marine landscapes, habitats, species) relevant to different aspects of ecosystem functioning (Laffoley *et al*. 2000); it was envisaged that management approaches and mechanisms should operate at the most relevant of these scales (e.g. fisheries at the regional sea scale, marine protected areas at the marine landscape scale).

In order to evaluate this proposed framework, Defra established the Irish Sea Pilot (ISP) (Vincent *et al*. 2004), a JNCC-led project which included, *inter alia*, development of the marine landscape concept, and the production of a marine landscape map for this regional sea (Golding *et al*. 2004). The map was based on the integrated analysis, in a Geographical Information System (GIS) environment, of a series of environmental data sets (e.g. seabed substrata, depth, slope) which led to a classification of seabed and water column features; these were validated against biological sample data to test their ecological relevance.

On the basis of the value perceived in the ISP marine landscape map, in providing an ecologically-relevant broadscale map for large areas of study (e.g. whole regional seas) which could be used for policy and management purposes, a consortium of organisations agreed to fund the UKSeaMap project with the aim of extending the ISP maps to the whole of UK waters. Defra considered the availability of such maps could be useful in supporting the proposed Marine Bill.

UKSeaMap started in November 2004 and was completed in autumn 2006. It was funded by the Countryside Council for Wales, Crown Estate, Department for Environment, Food and Rural Affairs, Department for Trade and Industry, English Nature[1], Office of the Deputy Prime Minister[2], Royal Society for the Protection of Birds, Scottish Executive and Worldwide Fund for Nature and undertaken by the Joint Nature Conservation Committee.

1.2 Implementation of UKSeaMap

The aim of the project was to use available geological, physical and hydrographical data, combined where possible with ecological information, to produce simple broadscale and ecologically relevant maps of the dominant seabed and water column features for the whole sea area under UK jurisdiction.

The project has essentially been undertaken in two parallel phases, one for the seabed, and the other for the water column. In each, there has been a similar sequence of tasks:

- Define a series of environmental data layers which are needed to characterise the seabed and water column, i.e. those parameters which have most influence on its ecology and therefore make most sense to use as surrogates for its ecological character;
- 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 for analysis;
- Identify meaningful thresholds within each parameter to derive different classes for each data set (for example. high, moderate and low bed stress) and summarize the data layers across a vector grid;
- Analyse the data sets in an integrated manner (in a supervised classification) to produce classifications of the seabed and water column;
- Validate the resultant maps with ground-truth data (e.g. biological sample data);
- Characterise the final seabed and 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.

[1] Natural England since October 2006.

[2] Department for Communities and Local Government (DCLG) since May 2006.

1.2.1 Seabed features

The classification of the seabed focused firstly on topographic and physiographic characteristics, as these give rise to the most conspicuous landscape features (the mountains and valleys of the sea).

Bathymetric slope data were used to identify a series of topographic features away from the coastal zone, such as the large continental slope and seamount features and the smaller sandbank and underwater pinnacle features.

In the coastal zone, physiographic features such as estuaries, sealochs and bays were identified according to definitions developed for the Marine Nature Conservation Review and for application of the Habitats Directive.

As very large areas of UK waters are without significant topographic character (i.e. have negligible slope), a modelling approach was adopted to further divide these extensive areas of 'subtidal plain'. After assessing both the environmental parameters which have most influence on ecological character and the availability of suitable data, the following data layers were selected for analysis:

- **Seabed substratum** - the nature of the substratum (e.g. sand, mud) has a marked influence on the biological communities which live in or on them;
- **Light attenuation** - determines the depth to which macroalgae (e.g. kelp) can grow;
- **Depth** - increasing depth brings greater stability (in terms of temperature, salinity, wave action) and greater pressure, both parameters to which biological communities respond;
- **Bottom temperature** - broad biogeographic patterns across UK waters are reflected in major temperature changes and this is particularly relevant to variation in deeper waters;
- **Wave-base** - the depth to which waves can penetrate the sea and thus disturb the seabed, with marked effects on the resulting communities, and its communities varies considerably around the coast;
- **Near-bed stress** - bottom current has a strong influence on both the character of the seabed (sediment type, formation of surface features such as sand waves and ripples) and the biological communities it supports.

The GIS data layers 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; a coarser grid (25 times larger) was adopted for the north-west approaches, as data coverage were very sparse in this region. The resultant data sets were analysed in a supervised classification to derive a series of landscape types (e.g. shallow sand plains; deep-water mixed sediment plains).

The three sets of maps (topographic, coastal and modelled) were combined to derive the final seabed landscape map. This is illustrated in Figure 19; the seabed classification is provided at Table 6, which provides details of the 44 seabed types identified.

To assess the biological validity of the resultant maps, sample data (e.g. from grabs, underwater video) have been sourced from marine agencies, laboratories, consultancies and other institutions, as well as accessing JNCC and country nature conservation agency data holdings (in the Marine Recorder database). Approximately 32,000 samples were available for processing to habitat type according to the National Marine Habitat Classification (Connor *et al*. 2004), before being analysed against the landscape types to assess their ecological validity. This was undertaken by predicting the expected biological character, in terms of the range of habitat types, for each landscape type and interfacing the sample data with the landscape maps in GIS to determine the actual relationship. This was assessed at a grid cell level and at the whole landscape type level to enable conclusions about the validity of each landscape type to be drawn.

The results of the ecological validation have enabled an assessment of confidence in the landscape map to be produced, through indicating the proportion of cells and landscape types which are validated. This is presented as confidence maps.

1.2.2 Water column features

The classification of the water column focused on the main hydrographic parameters which influence ecological character. After assessing these and data availability, the following data layers were selected for analysis:

- **Salinity** - the salinity regime, which varies from brackish and estuarine through to fully marine, has a marked influence on the character of the pelagic biological communities;
- **Surface to seabed temperature differences** - this determines the degree of vertical mixing of the water column, indicating features such as thermoclines;
- **Frontal probability** - this indicates the presence of fronts which provide some distinct horizontal boundary zones in the water column.

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).

The resultant water column maps are illustrated in Figures 35-38 and a classification is provided at Table 10. There are 13 water column types defined.

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[3]. 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.

1.3 Consultation and dissemination

The project was steered by a Project Steering Group, comprising the funding bodies and the British Geological Survey, who have provided both management and technical oversight of the project.

Considerable technical input has been received from the major suppliers of geophysical, hydrographic and plankton data, namely Proudman Oceanographic Laboratory, British Geological Survey, SeaZone and the Sir Alister Hardy Foundation for Ocean Science.

External review was sought through consultations with relevant technical and end-user organisations, including a technical consultation workshop in January 2006 and a wider review to over 100 consultees in May 2006.

To support these consultations, interim reports were prepared together with a dedicated web-based GIS application which shows the underlying data layers (maps) used and the resultant marine landscape maps. The maps are available at **www.jncc.gov.uk/UKSeaMap**. The GIS maps will also be made available via the MESH web-GIS application in due course (**www.searchMESH.net/webGIS**).

1.4 Potential uses and general limitations

1.4.1 Potential uses

The maps' primary purpose is to provide a national- and regional-level perspective on the UK's marine landscape types, including their distribution and extent, to support national and regional scale planning and management requirements. Potential uses are outlined below.

- **Protection of the marine environment** - this can generally be better informed through the availability of such holistic ecological maps, allowing all users and managers to have a better understanding of the nature and distribution of marine seabed and water column features; this is especially important because the UK has such extensive areas of sea to manage and protect and this environment is largely hidden from sight.
- **Strategic planning advice to industry** - the availability, for the first time, of a national ecological map for UK waters should enable advice to industry to take account of the distribution and extent of particular landscape features. In particular, it should be possible to assess whether specific industries may potentially have disproportionate impacts on particular types of marine landscape (at a national or regional level) and offer advice accordingly.
- **Marine spatial planning** - the emerging developments in marine spatial planning could be much better informed and follow the ecosystem-based approach to management, through the availability of the marine landscape maps. The use of landscape maps in such planning is most appropriate at the regional level, whilst the provision of marine habitat maps (e.g. through MESH) will offer a similar benefit at a more local level.
- **Monitoring and surveillance programmes** - to adequately assess the state of the marine environment, it is necessary to establish programmes which sample across the range of ecological features and have a sound geographical spread of sampling stations. The availability of a national ecological map should enabling sampling stations to be distributed in a more

[3] Sir Alister Hardy Foundation for Ocean Science

ecologically relevant manner; this should be an important consideration for the developing UK Marine Monitoring and Assessment Strategy (UKMMAS), and as JNCC develops its marine habitat surveillance programme.

- **European Directives** - implementation of the Water Framework Directive and the proposed Marine Strategy Directive (MSD), both of which are based on an ecosystem approach, should be better informed through the availability of marine landscape maps. The MSD is expected to require the description and mapping of marine habitats in each Member State.
- **Regional seas** - as part of the RMNC and to aid implementation of the Habitats Directive in the offshore zone, a provisional series of regional seas for UK waters was defined (Defra 2004). Now that the necessary hydrographic and physical data have been compiled by UKSeaMap, the proposed regional seas and their boundaries should be re-examined and, if necessary adjusted, to finalise the suite of regional seas.

1.4.2 General limitations

As the maps are based on a grid of about 1nm, and some of the underlying data are at coarser grids of 7 or 12km, the maps are unsuitable for fine-scale planning, for example for specific new developments. Rather, they are intended to give a broader regional and national perspective on the distribution of these features, and should enable more detailed data to be put in context. The assessment of confidence in the maps is intended to provide the user with an indication of the usefulness and limitations of the maps, or particular parts of the maps.

1.4.3 Relationship to Habitats Directive Annex I habitats and to MESH

Where possible the landscape types have been directly linked with Annex I features of the Habitats Directive; the landscape maps therefore provide an initial overview of Annex I distribution in the UK. However, as the Annex I habitats are specifically defined in EC guidance, and their definitions are subject to modification, the landscape maps should not be taken to encompass all areas that might qualify as Annex I habitat. For instance, the areas of reef habitat are significantly under represented in the landscape map (due to the lack of coastal rock in the substratum data set). Conversely only a portion of the sealochs, embayments and bays in the marine landscapes map will meet the EC definition for *Large shallow inlets and bays* (which is interpreted in the UK to have a particular depth limit).

The classification and mapping of seabed features provided by UKSeaMap (the marine landscape level) is much broader than that used within the MESH project, where the focus in on mapping according to the EUNIS habitat classification[4] (and subsequent correlation to Annex I habitats, OSPAR and BAP priority habitats). As such, the two approaches are complimentary, providing both coarse and fine scale classifications; the intension is to fully integrate the two within the MESH webGIS over the coming year.

1.5 References

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L. Lieberknecht, L.M., Northen, K.O. & Reker, J.B. 2004. The Marine Habitat Classification for Britain and Ireland. Version 04.05 (internet version: **www.jncc.gov.uk/MarineHabitatClassification**). Peterborough: Joint Nature Conservation Committee.

Defra. 2004. Review of Marine Nature Conservation: Working Group report to Government. London: Department for Environment, Food and Rural Affairs.

Golding, N., Vincent, M. & Connor, D.W. 2004. Irish Sea Pilot - Report on the development of a marine landscape classification for the Irish Sea. Peterborough: Joint Nature Conservation Committee (and online at **www.jncc.gov.uk/irishseapilot**).

Laffoley, D. d'a., Baxter, J., Bines, T., Bradley, M., Connor, D.W., Hill, M., Tasker, M. & Vincent, M. 2000. An implementation framework for conservation, protection and management of nationally important marine wildlife in the UK. (Report to the DETR Working Group on the Review of Marine Nature Conservation by the statutory nature conservation agencies, Environment Heritage Services (Northern Ireland) and JNCC). Peterborough: English Nature, Research Reports No. 394 (29 pp).

Vincent, M.A., Atkins, S.M., Lumb, C.M., Golding, N., Lieberknecht, L.M. & Webster, M. 2004. Marine nature conservation and sustainable development - the Irish Sea Pilot. (Report to Defra). Peterborough: Joint Nature Conservation Committee.

[4] The National Marine Habitat Classification for Britain and Ireland (Connor *et al.* 2004) has been fully incorporated into the European Environment Agency's EUNIS habitat classification, such that there is a one to one relationship between the two classifications. JNCC leads further development of the marine sections of EUNIS (for the north-east Atlantic and Baltic) via its work for the European Topic Centre on Biological Diversity.

2 Introduction and aims

The UKSeaMap project was set up by a consortium of UK Government departments and devolved administrations, government agencies and NGOs, and undertaken by the UK Joint Nature Conservation Committee. This end of project report provides a project overview, explains the work undertaken and describes the resulting outputs. The report complements, and is designed to assist users in understanding, a web-based GIS application where the key outputs, including data layers and resultant maps, can be viewed (**www.jncc.gov.uk/UKSeaMap**).

The aim of the project was to use available geological, physical and hydrographical data, combined where possible with ecological information, to produce a simple interpreted broadscale and ecologically relevant map of the dominant seabed, coastal and water column features (referred to as 'marine landscapes') for the whole sea area under UK jurisdiction. The resultant maps are intended to provide a national-level understanding of the range, extent and distribution of these broadscale features (marine landscapes) in UK waters. The output will provide an essential spatial information layer which, when combined with other environmental data, human activity information and regulatory information, will support more effective management of marine resources, improved interpretation of associated information, and assist implementation of national and international commitments and targets. These marine landscape maps are expected to help the UK Government and others deliver marine stewardship in the short to medium term, through better implementation of an ecosystem-based approach to management of the marine environment.

2.1 Rationale and background

Safeguarding our Seas (Defra 2002) set out how the UK Government will work to achieve their vision for the marine environment of "clean, safe, healthy, productive and biologically diverse oceans and seas". Such work included "to build on existing seabed mapping for coastal waters around the UK" and, in making best use of science, "..will also work toward providing publicly accessible integrated marine mapping..". A variety of reports and initiatives since then have reiterated the need for and importance of marine natural resource maps including *Charting Progress* (Defra 2005) which, in looking to the future, states "the lack of a basic habitat map of UK waters hinders the assessment of the current ecosystem 'state' and the effects on a wider scale. Such a map would provide a fundamental spatial planning tool".

There are a variety of needs which require broadscale information over large areas. For example (see Annex 1 for more details):

- Implementing the ecosystem approach, such as linking ecologically meaningful units of sea or seabed to the management of human activities;
- Providing ecologically relevant information in a common, easily interpreted format to underpin spatial planning and strategic assessment in support of a range of economic activities.
- Identifying marine protected areas, e.g. for the Habitats Directive and the OSPAR Convention.

There are a number of challenges to meeting these needs, specifically:

- Acquiring sufficient biological data for widespread direct mapping of ecological communities is possible but difficult, very expensive and would take many years;
- Making quick progress to implement a range of initiatives and meet short-term commitments and targets, such as those in support of the Convention on Biological Diversity, OSPAR strategies, various EU Directives, and further development of the EU marine thematic strategy, as well as the government's Marine Stewardship process;
- Providing relevant information to a number of industry sectors, such as aggregate extraction and wind farms, that need to evolve rapidly.

In a report (Laffoley *et al.* 2000) considered by the Review of Marine Nature Conservation (RMNC) (Defra 2004), it was noted that to improve stewardship and management of marine ecosystems an approach is needed that can operate on the relatively limited amount of environmental information available for offshore areas and that can be successfully applied, if necessary, over large areas of sea. At the same time, there has been a growing realisation within the UK (e.g. see Defra 2004) and elsewhere that conservation as well as wider marine stewardship should be striving to conserve representative spaces or landscapes, rather than just to preserve individual species and that there is a need to identify coherent marine management units to which specific conservation policies and use-management can be applied.

Thus, given the needs outlined above and taking account of the current challenges, a 'landscape' approach using available geological, physical and hydrographical features within, as far as possible, a defined hierarchical system from geophysical through to biological units appeared to be the only feasible way to rapidly provide a spatial basis to help deliver marine stewardship over large sea areas and within the timeframe of existing commitments and targets.

Laffoley *et al.* (2000) and subsequent papers highlighted that not only is such an approach favoured in a number of countries but that the relevant methodology that enables this approach to be implemented had been developed (see Box 1).

Box 1
Origin of the marine landscape approach

The concept of marine landscape mapping was developed for Canadian waters where studies demonstrated the value of geophysical mapping (Roff and Taylor 2000; Roff et al. 2003); the approach is based on using geological, physical and hydrographic data, in lieu of biological information, to prepare ecologically meaningful maps. The approach recognises that these parameters are important in determining the nature of biological communities, and is particularly well suited for areas away from the coastline where biological information is especially sparse or lacking, and/or where the regulation of human activity needs to be addressed at relatively broad scales. Roff and Taylor (2000) considered the concept could be applied to both the water column (using parameters such as water temperature, depth/light and stratification/mixing regime) and to the seabed (using parameters such as water temperature, depth/light, substratum type, exposure and slope). The development of this marine landscape mapping approach recognised that proper governance of the oceans required mapped information on the nature and distribution of marine features, so that regulation of human activities could be assessed in a more ecologically-meaningful manner and for environmental protection measures to be applied with a national perspective on the resource being managed. Given the high costs of collecting the necessary detailed survey data to produce such maps for large areas of sea, Roff and Taylor developed a more practical approach that could deliver broadscale maps, via modelling of available data, in a realistic timescale.

A similar approach is being explored in Australia, New Zealand and the United States and is being undertaken in the Baltic Sea within the Interreg-funded BALANCE project.

2.2 Development of marine landscape mapping in the UK – origins of UKSeaMap

The marine landscape approach was successfully trialled in the UK as part of the Review of Marine Nature Conservation (RMNC), which was established by the UK Government in 1999. In 2004 the Defra-led Working Group on the RMNC reported on its deliberations and recommendations, following a 4-year review of the needs and mechanisms for marine nature conservation in UK waters (Defra 2004). During this period, the RMNC had considered proposals for a framework to manage and protect our marine waters, which included defining the marine environment at a series of scales (regional seas, marine landscapes, habitats, species) relevant to different aspects of ecosystem functioning (Laffoley *et al*. 2000); it was envisaged that management approaches and mechanisms should operate at the most relevant of these scales (e.g. fisheries at the regional sea scale, MPAs at the marine landscape scale).

In order to evaluate this proposed framework, Defra established the Irish Sea Pilot (ISP) (Vincent *et al*. 2004), a JNCC-led project to test conservation management proposals at a whole regional sea scale which included, *inter alia*, development of the marine landscape concept in the UK, and the production of a marine landscape map for this regional sea (Annex 3, Golding *et al*. 2004). This broad-scale mapping approach is essentially a modelling technique, based on the integrated analysis in a GIS environment of a series of environmental data sets (e.g. seabed substrata, depth, slope) to derive a series of broad-scale mapped classes of seabed and water column features, termed 'marine landscapes'[5]. The resultant map was tested for its ecological validity by interfacing the mapped classes with ground-truth biological sample data (such as from grabs and underwater video records). The Irish Sea Pilot established that the marine landscapes defined were on the whole ecologically meaningful and at a scale which was relevant to the management of activities and to the identification of conservation measures at the regional sea scale.

The Irish Sea Pilot included a number of recommendations on the marine landscapes approach (see Annex 2) including that the approach "should be adopted as a key element for marine nature conservation and utilised in the spatial planning and the management of the marine environment". The Irish Sea Pilot work also provided some useful 'market research' on the marine landscapes approach. As a consequence, the added value of the marine landscape approach, compared to what is currently available and even in view of its limitations, gained wide acceptance in the UK as a useful basis to aid a variety of environmental management requirements, including marine spatial planning.

[5] 'Marine landscapes' was the term used to describe the features of the seabed and water column mapped in the Irish Sea Pilot. Its use has continued in this report as a generic term, although the classes mapped are a mixture of marine landscape types (*sensu stricto*) with some types such as sediment plains further sub-divided into broad habitat types (see Section 3.1). Many of the marine landscape types have similarities with the 'physiographic types' classification in the MNCR habitat classification (Connor *et al*. 1997), and the 'habitat complexes' of the EUNIS (European Union Nature Information System) habitat classification system, developed under the aegis of the European Environment Agency. The term 'marine landscape' used here is identical to the term 'seascape', which was used by Roff and Taylor (2000). However within the UK, the term 'seascape' was already in use to describe views out to sea from land (and vice versa), so the term marine landscape was adopted to avoid confusion.

This support and interest was reflected in the recommendations of the main RMNC report (Defra 2004) drawing on the Irish Sea Pilot (see Annex 2). In particular, the UKSeaMap project is implementing the *Key recommendation 3: Government should refine the process for identifying Marine Landscapes, and agree and map them in all UK waters* and specifically the supporting *Recommendation 3.1 A list of agreed Marine Landscapes should be developed for UK waters. The list identified for the Irish Sea should be expanded to include landscapes not found in the Irish Sea and further refined as necessary, in particular in relation to the water column. Work should be initiated to complete the mapping of these Marine Landscapes for UK waters.* Through links with the project Mapping European Seabed Habitats (MESH), UKSeaMap is also contributing to implementation of recommendation 3.3 to develop a list of internationally agreed marine landscapes for the North-east Atlantic and work to map these in collaboration with other countries (see **www.searchMESH.net**).

Refinement and further development of the methodology for identifying and representing marine landscapes is outlined in Section 3. In the course of this work it seemed helpful to elaborate on the term 'marine landscape' with reference to marine habitats and this is provided in Section 3.1.

2.3 Project development and set up

Based on the success of the marine landscapes approach in the Irish Sea Pilot, and endorsement within the RMNC project, and prompted by interest amongst a range of stakeholders, including a meeting of a wide range of interested organisations in August 2004, the statutory nature conservation agencies developed an outline project proposal to extend the approach to the entire UK Continental Shelf (Gilliland *et al.* 2004). Following consultation and discussion of the proposal, including a meeting of interested organisations in August 2004, the proposal was given widespread support and finalised. A consortium of UK Government departments, Agencies and NGOs agreed to fund the project, named UKSeaMap:

- Countryside Council for Wales
- The Crown Estate
- Department for Environment, Food and Rural Affairs
- Department for Trade and Industry
- English Nature[6]
- Office of the Deputy Prime Minister[7]
- Royal Society for the Protection of Birds
- Scottish Executive
- Worldwide Fund for Nature

The English Nature funding element is co-financed by the Interreg IIIB North-West Europe programme, as part of the MESH project (Development of a framework for Mapping European Seabed Habitats, **www.searchmesh.net**).

The consortium commissioned the JNCC to undertake the work through a Memorandum of Agreement. The project started in November 2004 and was due to run for approximately 18 months, ending in Summer 2006. The project was managed by a Project Steering Group, comprising the funding partners, JNCC as the working partner, and the British Geological Survey.

The extensive consultation that went into developing the project proposal has continued during the project. External review has been sought through consultations with relevant technical and end-user organisations, including a technical consultation workshop involving a range of experts in January 2006, the purpose of which was to comment on the technical development and characterisation of the data sets, the supervised classification methodology and to discuss draft maps of the seabed and water column features. Subsequently, there was a wider review to over 100 consultees in April-May 2006. Considerable technical input has been received from the major suppliers of geophysical, hydrographic and plankton data, namely Proudman Oceanographic Laboratory, British Geological Survey, SeaZone and the Sir Alister Hardy Foundation for Ocean Science. An ad hoc peer review process of the approach to the water column work, seasonal water column data and maps was undertaken. The approach has also been discussed with colleagues in other countries through the MESH project and at international conferences (GeoHab 2005, 2006; Marine Nature Conservation in Europe 2006).

To support these consultations, interim reports were prepared, together with a dedicated web-based GIS application (**www.jncc.gov.uk/UKSeaMap**) which shows the underlying data layers (maps) used and the resultant marine landscape maps.

[6] Referred to as English Nature throughout the report but as of 2 October 2006 English Nature was superceded by a new body "Natural England".

[7] Department for Communities and Local Government (DCLG) since May 2006.

2.4 Geographical scope and regional seas

UKSeaMap aimed to produce landscape maps covering the whole of UK waters (i.e. the full extent of UK jurisdiction).

For the seabed, some limitations in the availability of key data sets have restricted the coverage possible (particularly to the far north of Shetland and to the far west of Scotland). Additionally the entire Irish Sea has been included, covering the same area as the Irish Sea Pilot, and enabling comparison with the marine landscape map produced for the ISP. As the data on seabed substrata did not extend beyond the boundaries of UK waters (except in the Irish Sea), it was not possible to map seabed types in waters of adjacent countries.

For the water column, the available modelled data covered a geographical area greater than UK waters, extending to cover parts of the North Sea, the Channel and to the west of Ireland. Consequently it has been possible to produce water column maps covering a larger area, although again it has not been possible to include the far north and west within UK waters.

In the maps presented in this report, the outer limits of UK waters (the UK Continental Shelf area), together with the proposed regional seas boundaries (Defra 2004) are shown. The regional seas boundaries are based on major physical and hydrographic differences across UK waters; many of these are apparent from the base maps of, for instance, bathymetry and bottom temperature.

2.5 Potential uses

During the course of undertaking UKSeaMap there has been further consideration of the potential uses of the outputs, although this was not a key aspect of the project. In highlighting these for the benefit of potential end users it is important also to point out some of their limitations to inform their effective use. The map's primary purpose is to provide a national- and regional-level perspective on the UK's marine landscape types, including their distribution and extent, to support national and regional scale planning and management requirements. Such uses could include:

- **Protection of the marine environment** - this can generally be better informed through the availability of such holistic ecological maps, allowing all users and managers to have a better understanding of the nature and distribution of marine seabed and water column features; this is especially important because the UK has such extensive areas of sea to manage and protect and this environment is largely hidden from sight.
- **Strategic planning advice to industry** - the availability, for the first time, of a national ecological map for UK waters should enable advice to industry to take account of the distribution and extent of particular landscape features. In particular, it should be possible to assess whether specific industries may potentially have disproportionate impacts on particular types of marine landscape (at a national or regional level) and offer advice accordingly.
- **Marine spatial planning** - the emerging developments in marine spatial planning could be much better informed and follow the ecosystem-based approach to management, through the availability of the marine landscape maps. The use of landscape maps in such planning is most appropriate at the regional level, whilst the provision of marine habitat maps (e.g. through MESH) offers a similar benefit at a more local level.
- **Marine protected areas** - within an overall balanced approach to marine environmental management, MPAs play an important role, both in protecting specific features and in providing a refuge for biodiversity generally; as such they can provide the reference areas against which the state of the rest of the marine environment can be assessed (for instance as required by the Water Framework Directive). In the latter role, the identification of a suite of MPAs which representative the full range of ecological character present in UK waters is important. The availability of holistic landscape maps will facilitate the identification of such a representative suite of MPAs to be identified; this will help fulfil OSPAR obligations (requiring a network of MPAs by 2010) and the recommendations by the RMNC for the identification of a set of Nationally Important Marine Areas.
- **Monitoring and surveillance programmes** - to adequately assess the state of the marine environment, it is necessary to establish programmes which sample across the range of ecological features and have a sound geographical spread of sampling stations. The availability of a national ecological map should enable sampling stations to be distributed in a more ecologically relevant manner; this should be an important consideration for the developing UK Marine Monitoring and Assessment Strategy (UKMMAS), and as JNCC develops its marine habitat surveillance programme.
- **European Directives** - implementation of the Water Framework Directive and the proposed Marine Strategy Directive, both of which are based on an ecosystem approach, should be better informed through the availability of marine landscape maps. The latter is expected to require a characterisation of the marine environment including a description of its main types of habitat and its physical and hydromorphological character. UKSeaMap outputs can make a significant contribution to this aspect of the Directive.
- **Regional seas** - as part of the RMNC and to aid implementation of the Habitats Directive in the offshore zone, a provisional series of regional seas for UK waters was defined (Defra 2004). Now that the necessary hydrographic and physical data have been compiled by UKSeaMap, the proposed regional seas and their boundaries should be re-examined and, if necessary adjusted, to finalise the suite of regional seas.

2.6 General limitations

As the maps are based on a grid of about 1 nm (see Section 4.3.3), and some of the underlying data are at coarser grids of 7 or 12 km, the maps are unsuitable for fine-scale planning, for example for specific new developments. Rather, they are intended to give a broader regional and national perspective on the distribution of these features, and should enable more detailed data to be put in context. The assessment of confidence in the maps (Section 4.8) is intended to provide the user with an indication of the usefulness and limitations of the maps, or particular parts of the maps.

A number of data sets do not fully cover all UK waters, or use modelled data which is less accurate at the outer boundaries of its coverage. Consequently the final marine landscape maps do not provide full coverage of UK waters. Additionally in some coastal areas there is a significant under representation of rock in the seabed substratum data set, which has had a significant effect on the biological validation and confidence assessment in these areas (see Sections 4.6 and 4.8).

Section 7 considers the relationship between the outputs from UKSeaMap (i.e. a marine landscape classification and maps) and existing schemes for listing marine features requiring protection (e.g. Habitats Directive Annex I features, OSPAR List features). Wherever possible a direct relationship between the features protected by these conservation mechanisms and the landscape types adopted by UKSeaMap has been maintained, ensuring that UKSeaMap outputs are, as far as possible, compatible with the conservation mechanisms currently in use. However, as UKSeaMap has addressed the characterisation of the marine environment in a more holistic and systematic manner, and at a particular scale or resolution, the relationship to features on these conservation lists is not always simple. Thus UKSeaMap contributes to the mapping of some features on the Habitats Directive and OSPAR lists, but is not intended to provide comprehensive maps of all features listed.

Following on from the above, UKSeaMap has not set out to provide information about existing marine protected areas, to assess the relationship between existing MPAs and the outputs from UKSeaMap, or to identify possible new areas for protection.

3.1 Landscapes and habitats - different approaches to classifying the environment

Characterisation and classification of the marine environment can be approached in a number of ways and at a variety of levels of detail, depending on the purpose of the classification, the methods used and the data available. For environmental management purposes, it is important to characterise the marine environment in an ecologically meaningful manner in order to support an ecosystem-based approach to management. This is a central aim of the UKSeaMap project. Additionally, this characterisation can be approached based on scientific principles and/or more from a lay perspective. The Irish Sea Pilot yielded a marine landscape map and classification which met with widespread recognition for its usefulness from marine managers and stakeholders alike. In addition, this map included a balance between strictly technical approaches and the use of more lay terms.

In essence, a lay person would describe the terrestrial landscape in terms that are a mixture of topographic features (e.g. hills and valleys) and broadscale 'habitat' features (e.g. woodland, marshland) and a similar view of the output from the Irish Sea Pilot resonated amongst the wider marine community. Therefore, within both the UKSeaMap and more general discussions, the term 'marine landscape' is used in this wider sense. However, from a more technical perspective, and for the purposes of scientific discussion, it is helpful to recognise a distinction between marine landscapes *sensu stricto* and the wider understanding of marine landscapes, and this is elaborated on below.

For the seabed, classification has typically been achieved through characterisation of seabed features by ***habitat*** type, in which each habitat is defined on the basis of a combination of its physical and biological characteristics (e.g. a kelp forest occurring on shallow subtidal rock) – these are sometimes referred to as ***biotopes***. This approach to classification is reflected in the National Marine Habitat Classification for Britain and Ireland (Connor *et al.* 2004; **www.jncc.gov.uk/MarineHabitatClassification**) and its European counterpart, the EUNIS habitat classification (**http://eunis.eea.eu.int/habitats.jsp**). These classifications are presented in a hierarchical manner, such that similar biological communities are aggregated together into broader types (e.g. kelp forest and kelp park types sit within a broader kelp habitat category). The broader classes (that is, EUNIS level 4 and higher) are increasingly defined on physical parameters in a way that is still ecologically relevant – this is because the character of the biological communities is very closely determined by the surrounding environment (the nature of the seabed, salinity, currents and so on).

The habitat approach to classification takes only limited account of broader patterns in seabed character, such as seabed morphology determined by major geological and hydrographic processes. Thus features such as seamounts and estuaries can be considered to occur at a scale above the habitat scale; each comprises a suite of habitat types in a more topographically-defined feature – at this level of classification, the features are described as ***marine landscape*** types and can be considered to be broadly equivalent to mountains, valleys, plains and rivers in the terrestrial environment. Each marine landscape type will comprise a series of habitat types, some of which are typical of (or specific to) the landscape type; additionally they may occur in a particular pattern (such as a zonation of habitats from the top of a seamount to the bottom). In addition, many habitat types can occur in several landscape types (for example, seagrass beds can occur in sealochs, bays and estuaries) – this means that the two approaches to classification are related to each other but cannot be fully integrated into a single hierarchical classification. Annex 7 shows the relationship between habitats and landscapes.

Whilst the habitat approach is most suited to detailed (fine scale) characterisation of the seabed (including field surveying), the broader classification of marine landscapes is particularly useful for wider management purposes, as management is often most easily applied at this scale (e.g. for a whole estuary), rather than a component habitat.

Given the topographic emphasis of the marine landscape concept, its application to the water column is less valid, as topographic distinctions cannot be applied to the water column. Nevertheless, the pelagic environment can be classified using hydrographic characteristics (such as temperature and salinity) in a way which is ecologically relevant. This has been attempted here; the outputs probably best equate to the habitat concept, albeit at a very coarse scale.

3.2 Refinement of methodology used for the Irish Sea Pilot

The methodology and data sets used in the Irish Sea Pilot were reviewed and further refined in the light of the need to:

- Map a significantly larger geographical area,
- Include a broader range of landscape types,
- Handle much larger data sets, and
- Acquire data layers which covered a much greater geographical area.

This led to the inclusion of both additional parameters and different data sets for the same parameters, and to the adoption of a different method for analysing the data layers, whilst retaining the same overall approach. In addition, an assessment of confidence in the resultant maps has been developed here, developing new confidence mapping techniques to reflect the reliability of both the overall classification of features and their individual occurrences.

3.3 Consideration of different analytical methods

During the development phase of the project, there were a number of different methodological options available to analyse the environmental data sets. The main considerations were whether to use either a supervised or unsupervised classification approach, and whether vector or raster GIS data should be used. Each method had its advantages and disadvantages, which are detailed in Annex 4.

From a review of the different methods and the data types that were to be used within the project, it was decided to use a vector grid to summarise the data and a supervised classification approach for the majority of the analysis (the seabed and water column modelling – Sections 4.3 and 5.3). This followed a classification tree method that determines which order the different data layers are incorporated into the analysis. It results in a flexible methodology that can be used with continuous data, categorical data or a mixture of the two. Flexibility comes from the fact that branches of the tree can easily be added to or removed and the criteria for decisions (thresholds of input values) can be readily changed.

The supervised analysis approach using a regular vector grid over the whole UK sea area was supplemented by the use of detailed polygon data sets defining topographic and coastal features (Sections 4.2 and 4.4). The final seabed maps are presented as vector data layers incorporating the modelled data and the mapped features. The water column analysis is based entirely on raster data though the final maps are presented as vector layers.

3.4 General approach to data collation and processing

The project has essentially been undertaken in two parallel phases, one for the seabed, and the other for the water column. In each, there has been a similar sequence of tasks:

- Define a series of environmental data layers which are needed to characterise the seabed and water column, i.e. those parameters which have most influence on its ecology and therefore make most sense to use as surrogates for its ecological character;
- 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 for analysis;
- Identify meaningful thresholds within each parameter to derive different classes for each data set (for example. high, moderate and low bed stress) and summarize the data layers across a vector grid;
- Analyse the data sets in an integrated manner (in a supervised classification) to produce classifications of the seabed and water column
- Validate the resultant maps with ground-truth data (e.g. biological sample data);
- Characterise the final seabed and 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.

3.4.1 Seabed features - overview

The classification of the seabed focused firstly on topographic and physiographic characteristics, as these give rise to the most conspicuous landscape features (the mountains and valleys of the sea).

Bathymetric slope data were used to identify a series of topographic features away from the coastal zone, such as the large continental slope and seamount features and the smaller sandbank and underwater pinnacle features.

In the coastal zone, physiographic features such as estuaries, sealochs and bays were identified according to definitions developed for the Marine Nature Conservation Review and for application of the Habitats Directive.

As very large areas of UK waters are without significant topographic character (i.e. have negligible slope), a modelling approach was adopted to further divide these extensive areas of 'subtidal plain'. After extensive assessment of both the environmental parameters which have most influence on ecological character and the availability of suitable data, the following parameters were selected for use in the analysis:

- **Seabed substratum** - the nature of the substratum (e.g. sand, mud) has a marked influence on the biological communities which live in or on them.
- **Depth** - increasing depth brings greater stability (in terms of temperature, salinity, wave action) and greater pressure, both parameters to which biological communities respond. Two further parameters were incorporated into the depth parameter:
  - **Light attenuation** - determines the depth to which macroalgae (e.g. kelp) can grow
  - **Wave-base** - the depth to which waves can penetrate the sea and thus disturb the seabed, with marked effects on the resulting communities, and its communities varies considerably around the coast.
- **Bottom temperature** - broad biogeographic patterns across UK waters are reflected in major temperature changes and this is particularly relevant to variation in deeper waters.
- **Near-bed stress** - bottom current has a strong influence on both the character of the seabed (sediment type, formation of surface features such as sand waves and ripples) and the biological communities it supports.

GIS data layers representing the parameters above 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; a coarser grid (25 times larger) was adopted for the north-west approaches, as data coverage were very sparse in this region. The resultant data sets were analysed in a supervised classification to derive a series of landscape types (e.g. shallow sand plains; deep-water mixed sediment plains).

The three sets of maps (topographic, coastal and modelled) were combined to derive the final seabed landscape map.

To assess the biological validity of the resultant maps, sample data (e.g. from grabs, underwater video) have been sourced from marine agencies, laboratories, consultancies and other institutions, as well as accessing JNCC and country nature conservation agency data holdings (in the Marine Recorder database). Approximately 32,000 samples were available for processing to habitat type according to the National Marine Habitat Classification (Connor *et al.* 2004), before being analysed against the landscape types to assess their ecological validity. This was undertaken by predicting the expected biological character, in terms of the range of habitat types, for each landscape type and interfacing the sample data with the landscape maps in GIS to determine the actual relationship. This was assessed at a grid cell level and at the whole landscape type level to enable conclusions about the validity of each landscape type to be drawn and identify modifications.

The results of the ecological validation have also enabled an assessment of confidence in the landscape map to be produced, through indicating the proportion of cells and landscape types which are validated. This is also presented as confidence maps.

3.4.2 Water column features - overview

The classification of the water column focused on the main hydrographic parameters which influence ecological character. After assessing these and data availability, the following data layers were selected for analysis:

- **Salinity** - the salinity regime, which varies from brackish and estuarine through to fully marine, has a marked influence on the character of the pelagic biological communities;
- **Surface to seabed temperature differences** – this determines the degree of vertical mixing of the water column, indicating features such as thermoclines;
- **Frontal probability** – this indicates the presence of fronts which provide some distinct horizontal boundary zones in the water column.

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

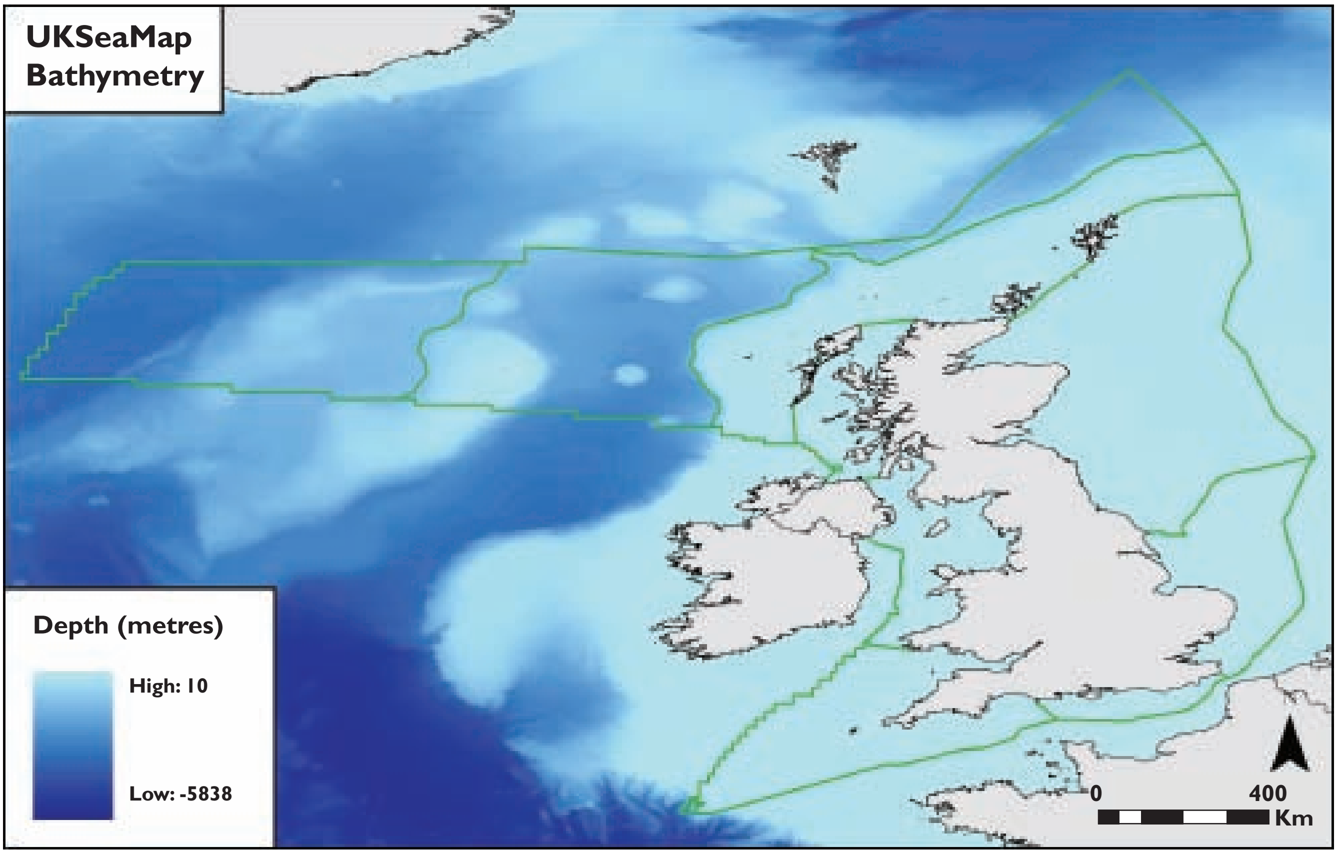


Figure 1. Bathymetric digital elevation model (DEM) (source: Gebco).

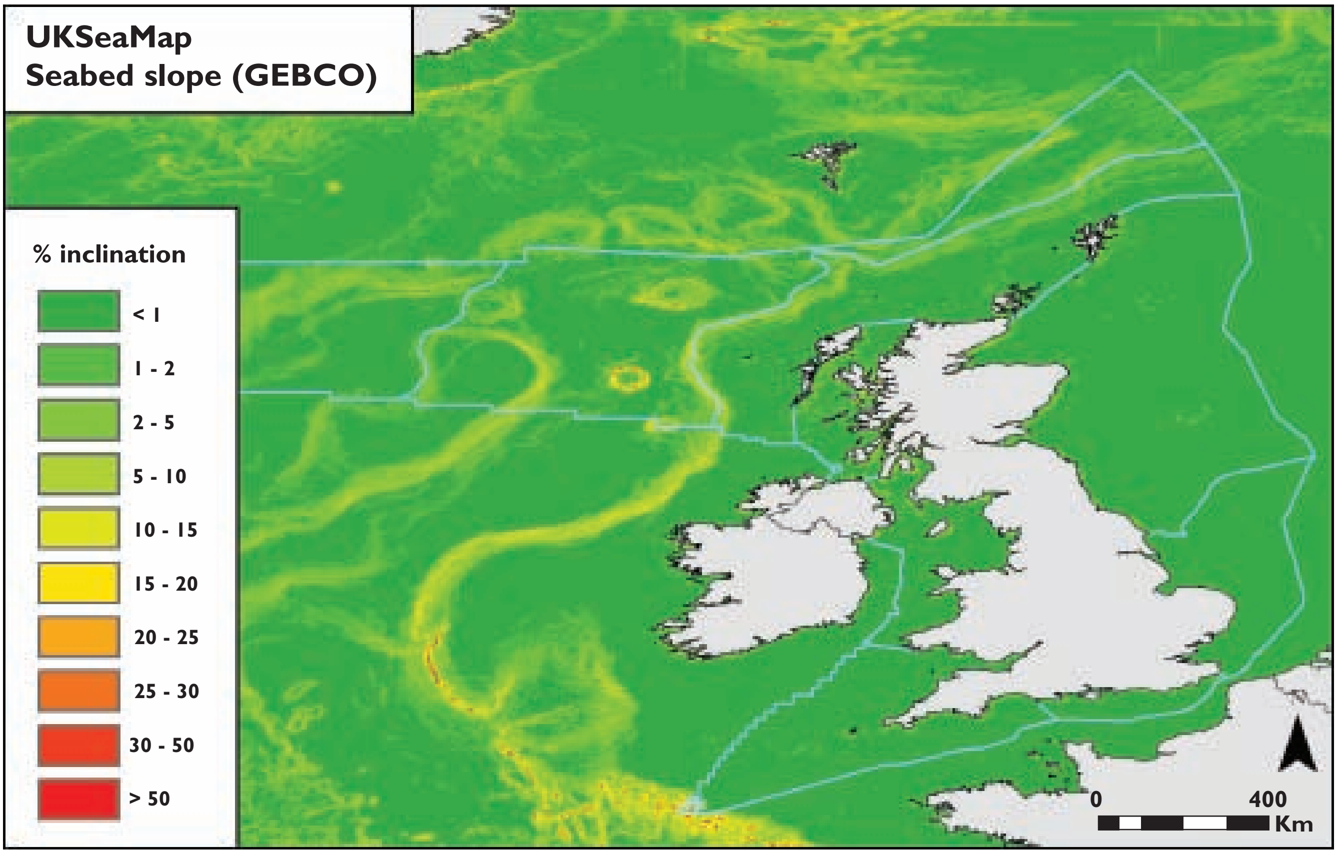


Figure 2. Seabed slope (derived from Gebco bathymetric DEM).

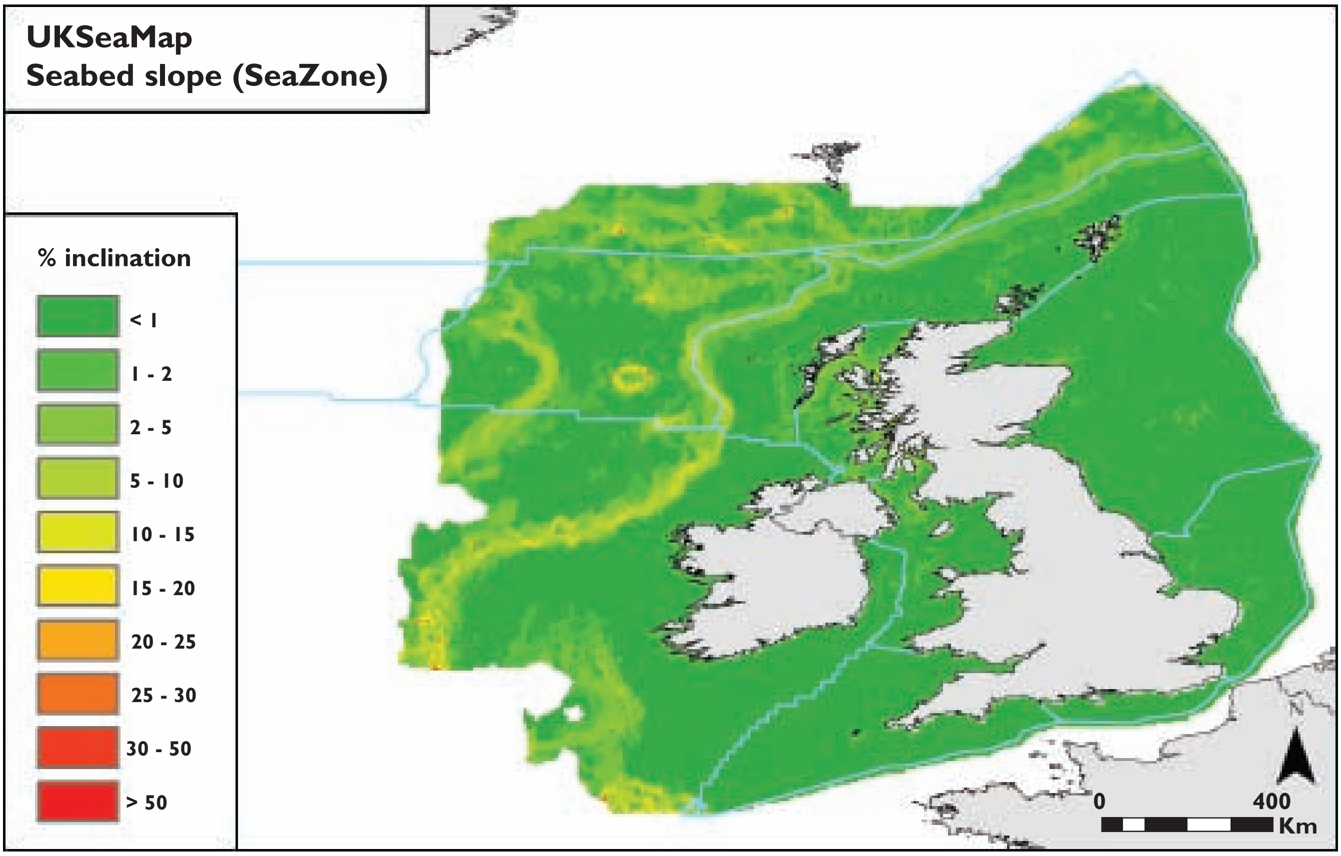


Figure 3. Seabed slope (derived from SeaZone bathymetric DEM).

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.

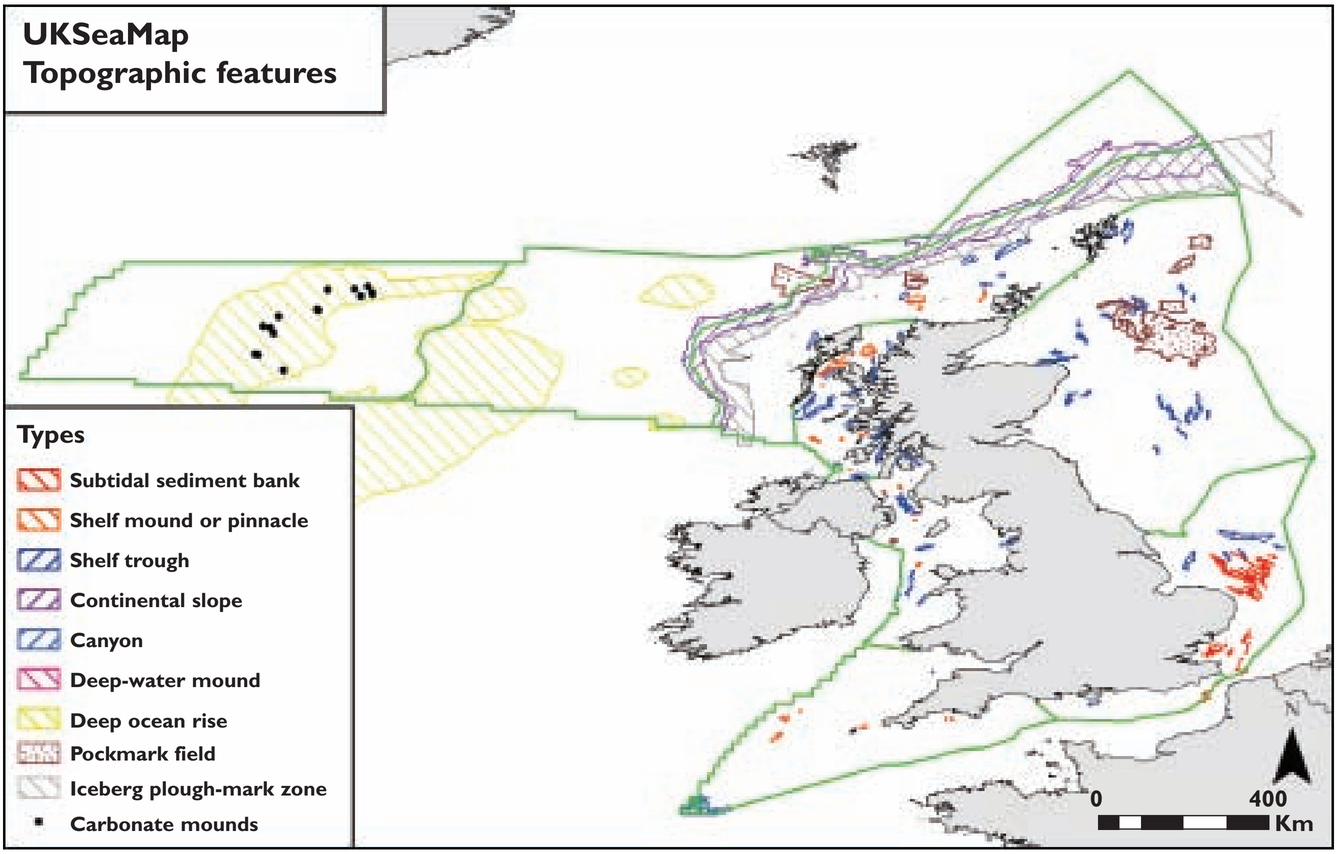


Figure 4. Topographic and bed-form features.

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.

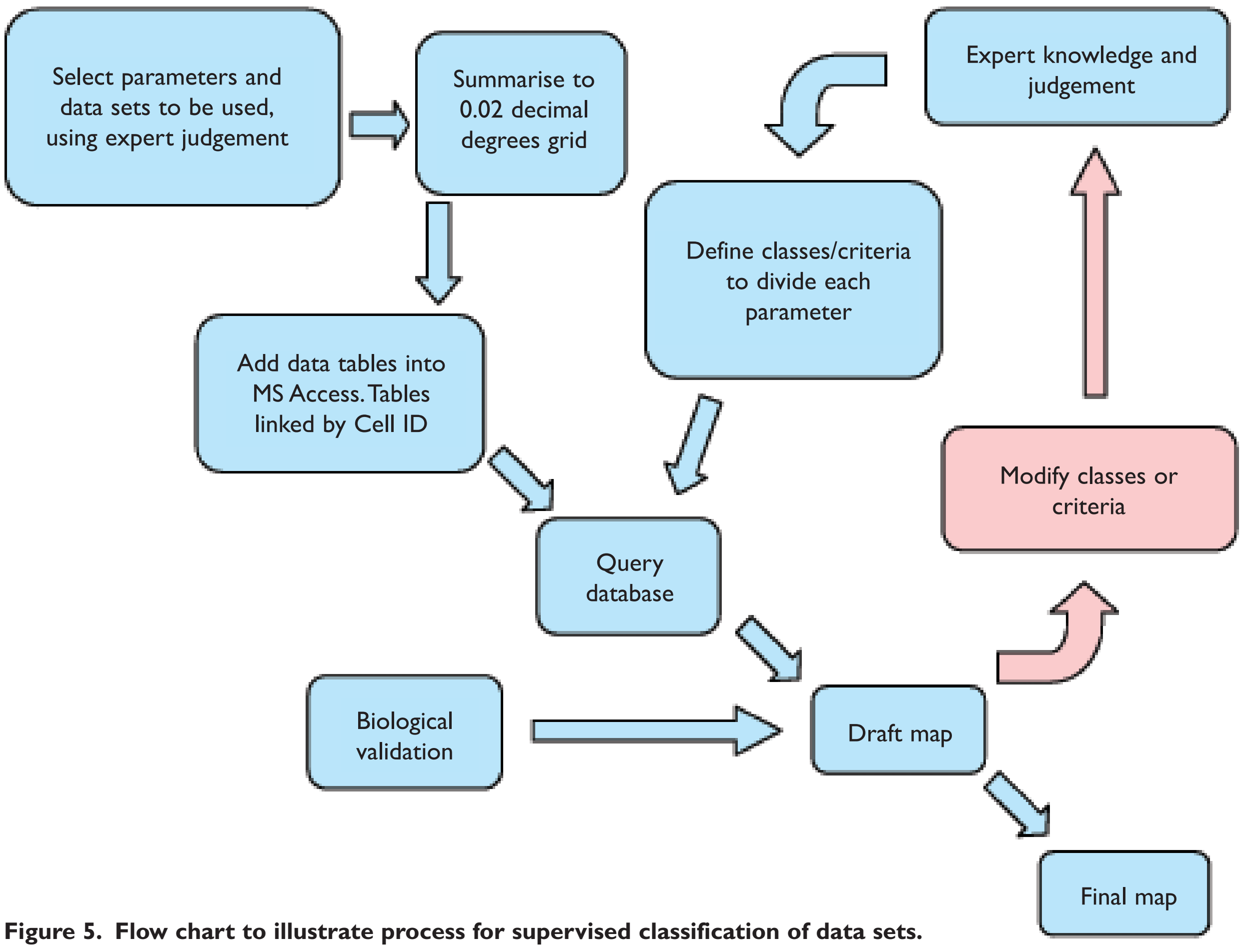


Figure 5. Flow chart to illustrate process for supervised classification of data sets.

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.

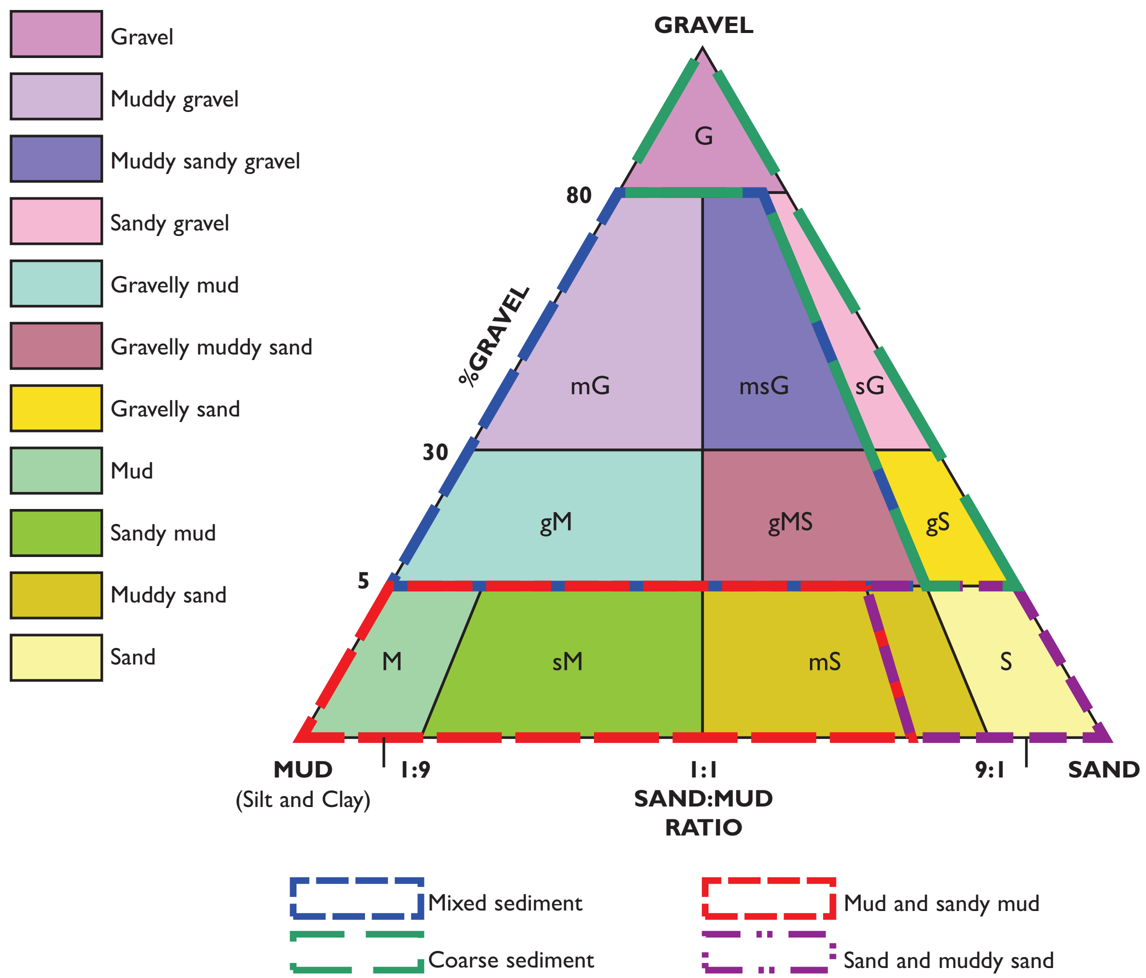


Figure 6. Folk sediment trigon, modified to show the aggregation of classes into four main sediment classes (coarse, mixed, sand, mud).

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.

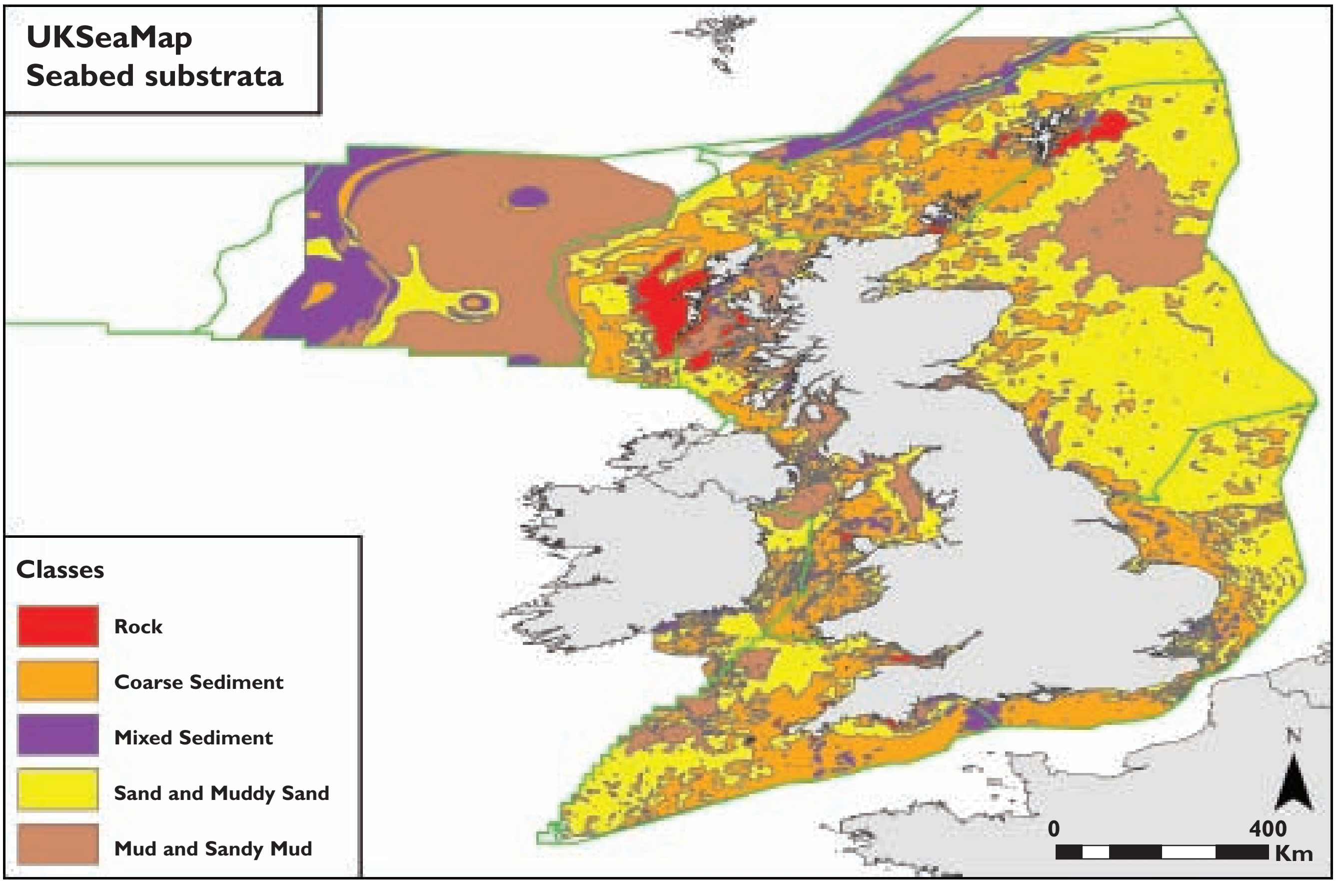


Figure 7. Seabed substrata (derived from BGS DigSBS250 and other sources – see text).

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.

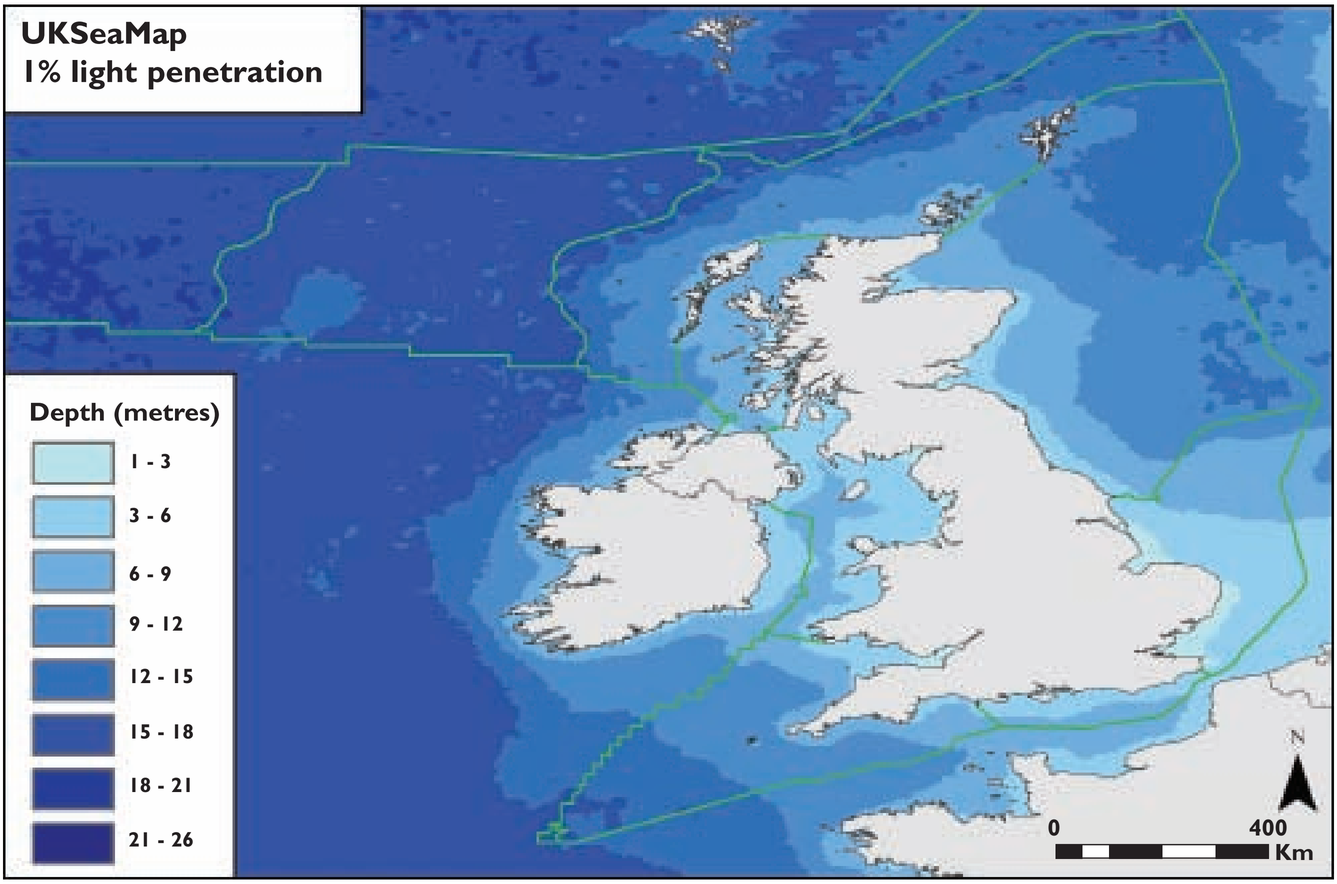


Figure 8. Mean annual depth to which 1% of surface light penetrates the water column (source data from SeaWiFS via POL)

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).

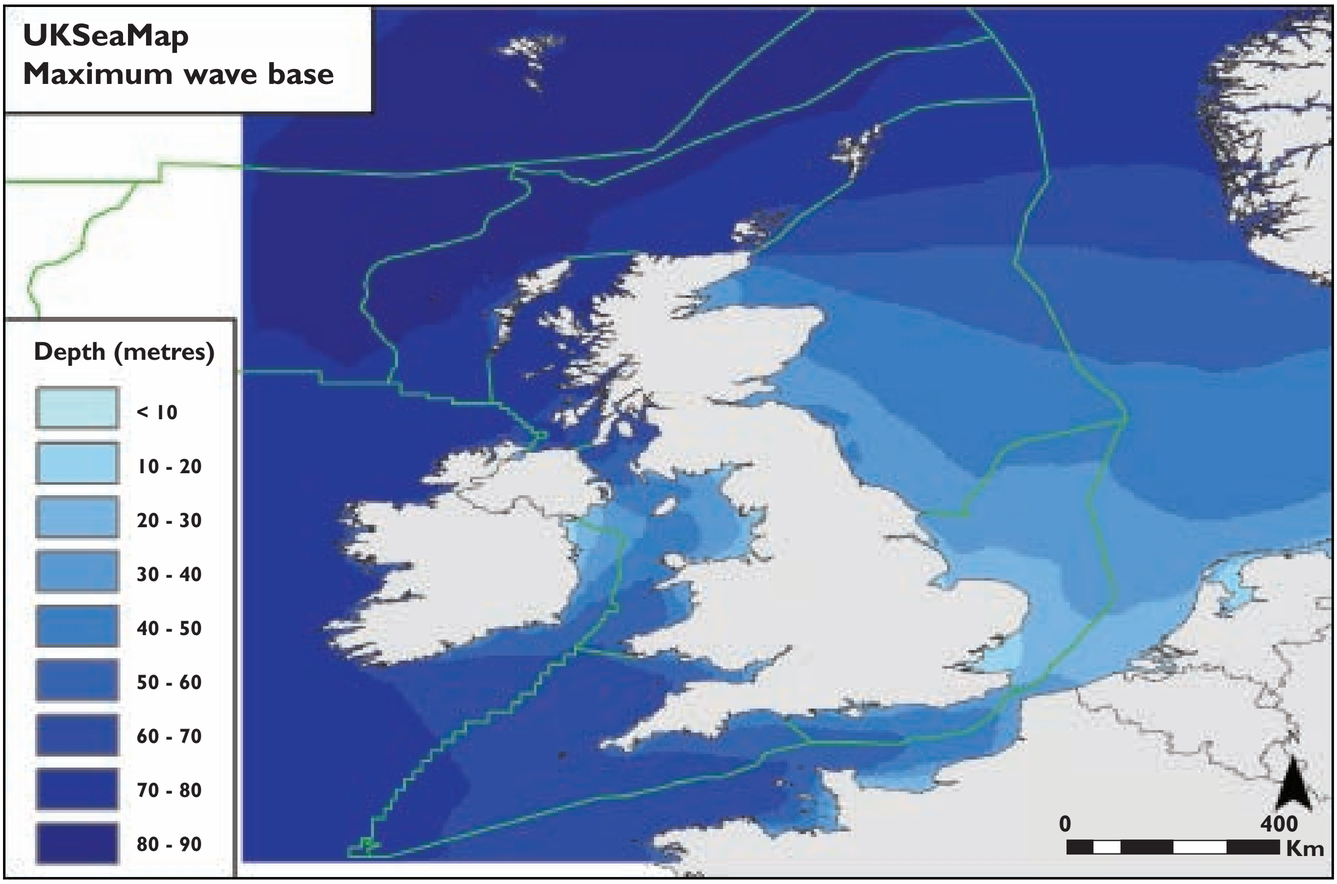


Figure 10. Maximum depth to which waves penetrate the water column (wave base) (source data from POL).

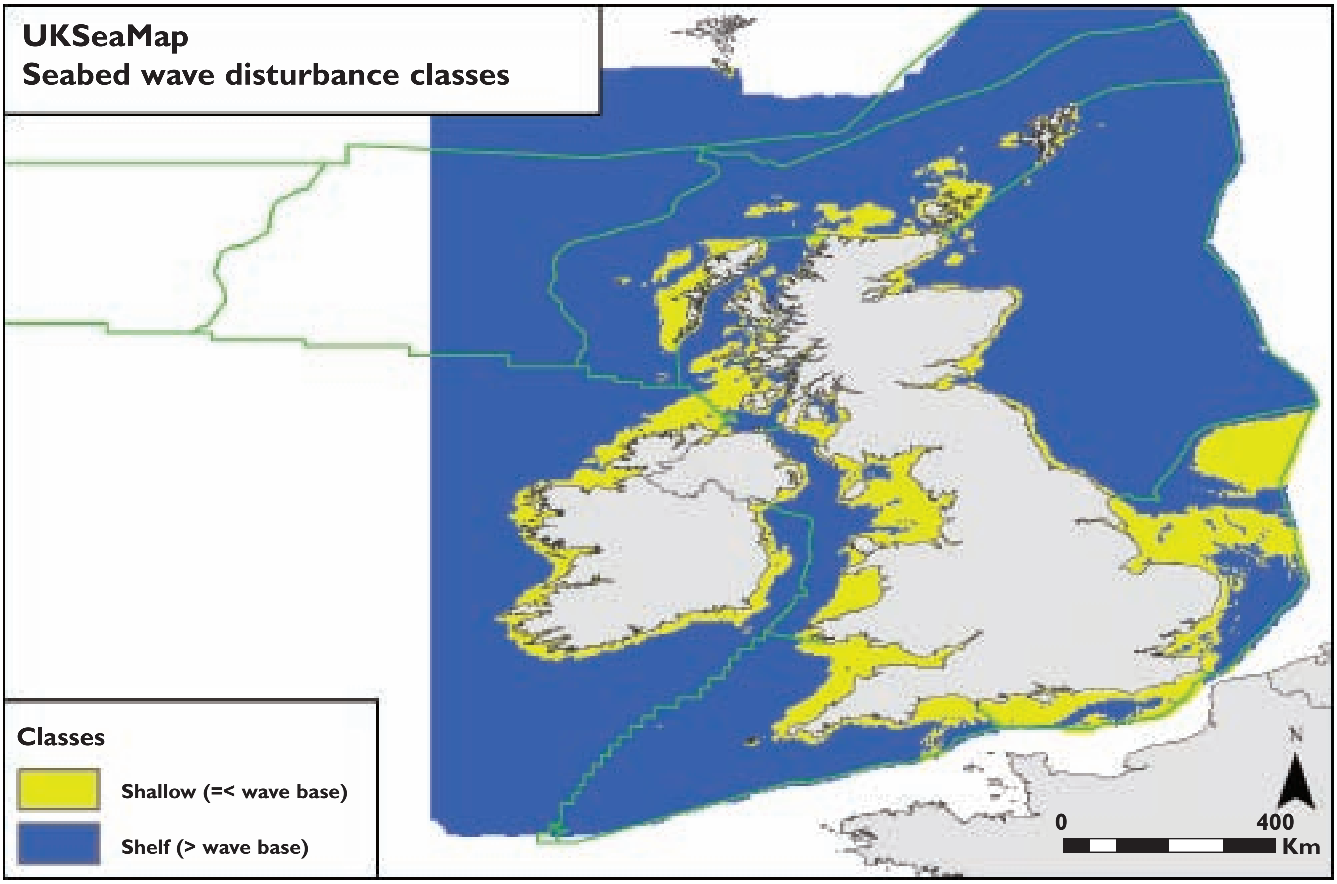


Figure 11. Shallow (disturbed) and shelf (undisturbed) depth classes derived from the maximum wave base.

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.

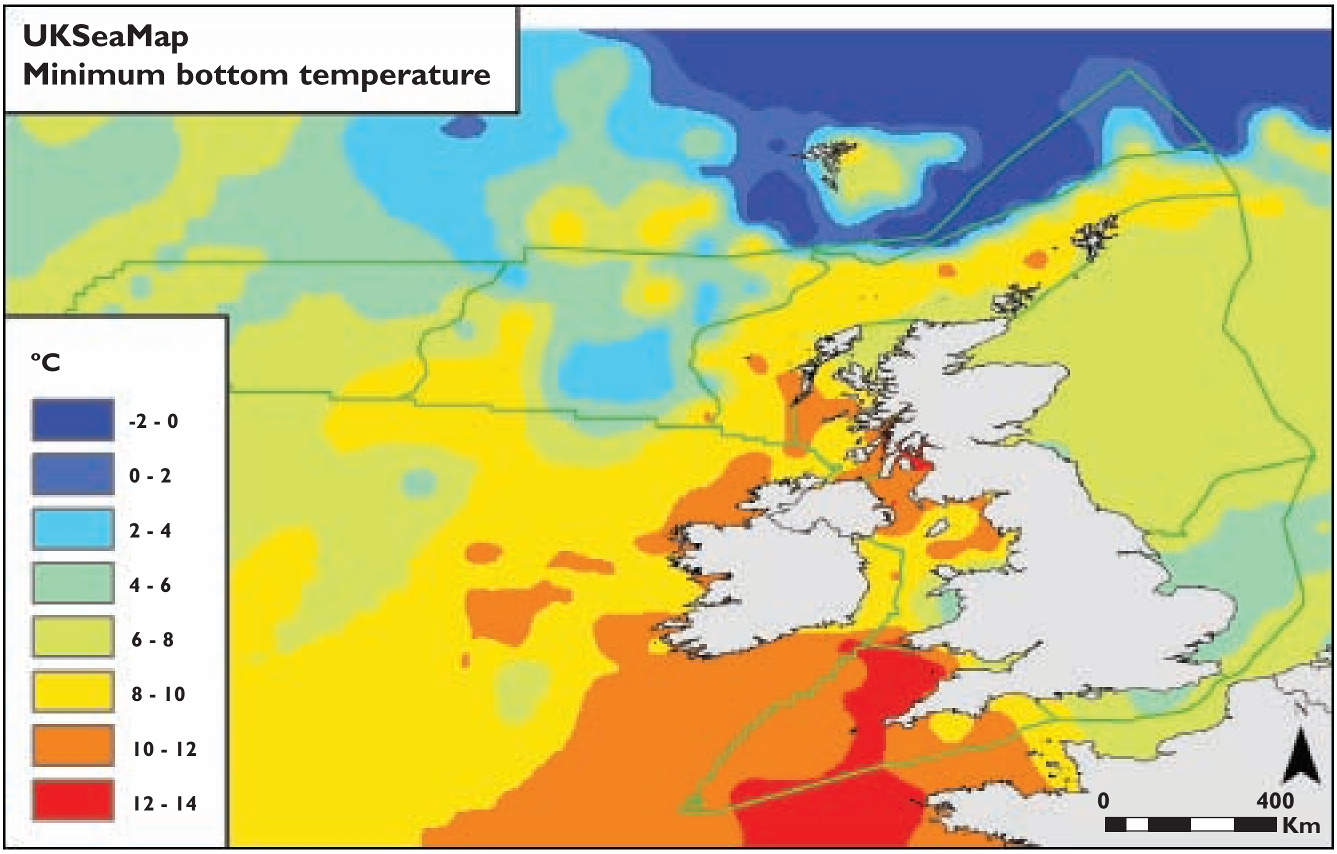


Figure 12. Minimum bottom temperature (source data from ICES).

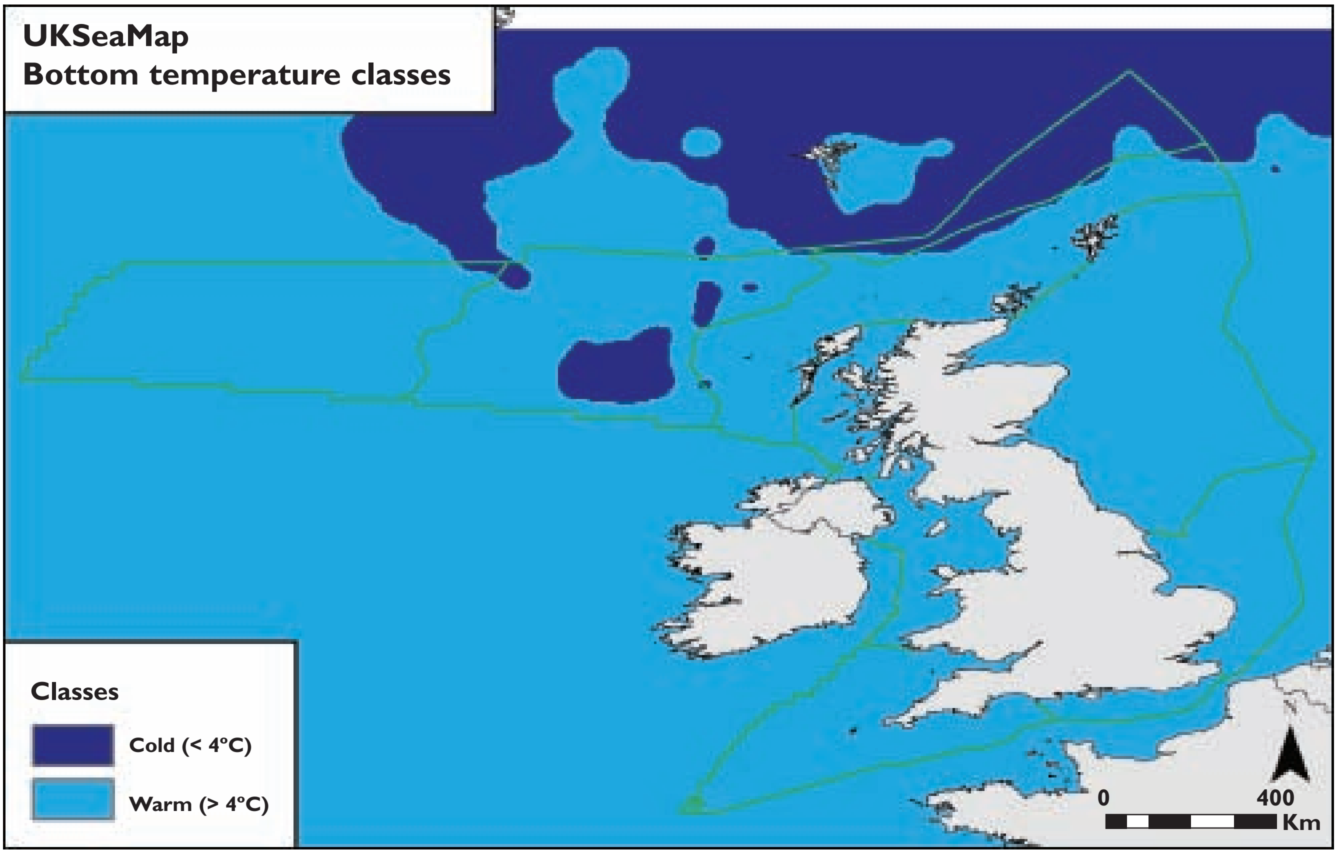


Figure 13. Cold and warm water zones derived from minimum bottom temperature data set.

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

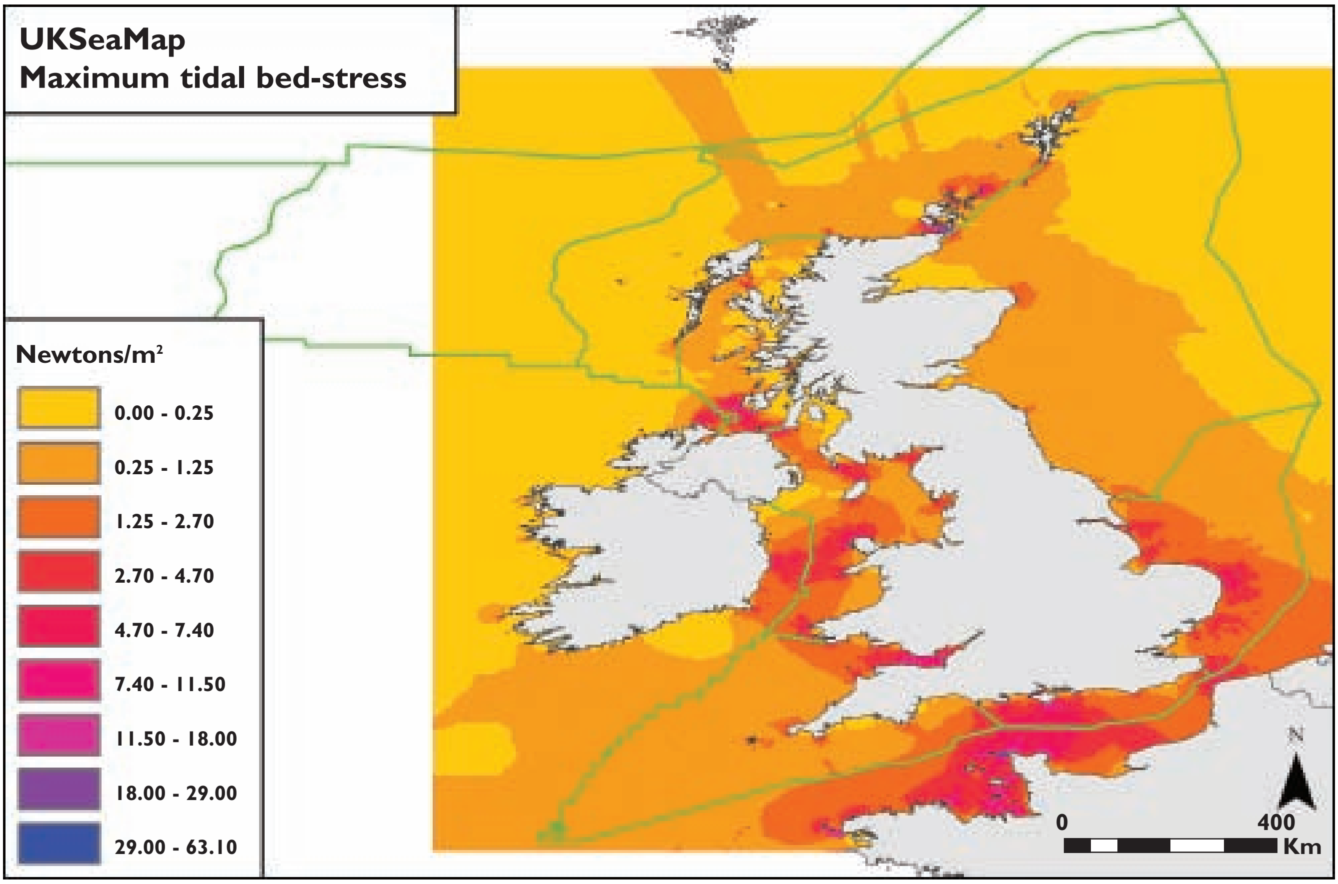


Figure 14. Maximum tidal bed stress from POLCOMS model (source data from POL).

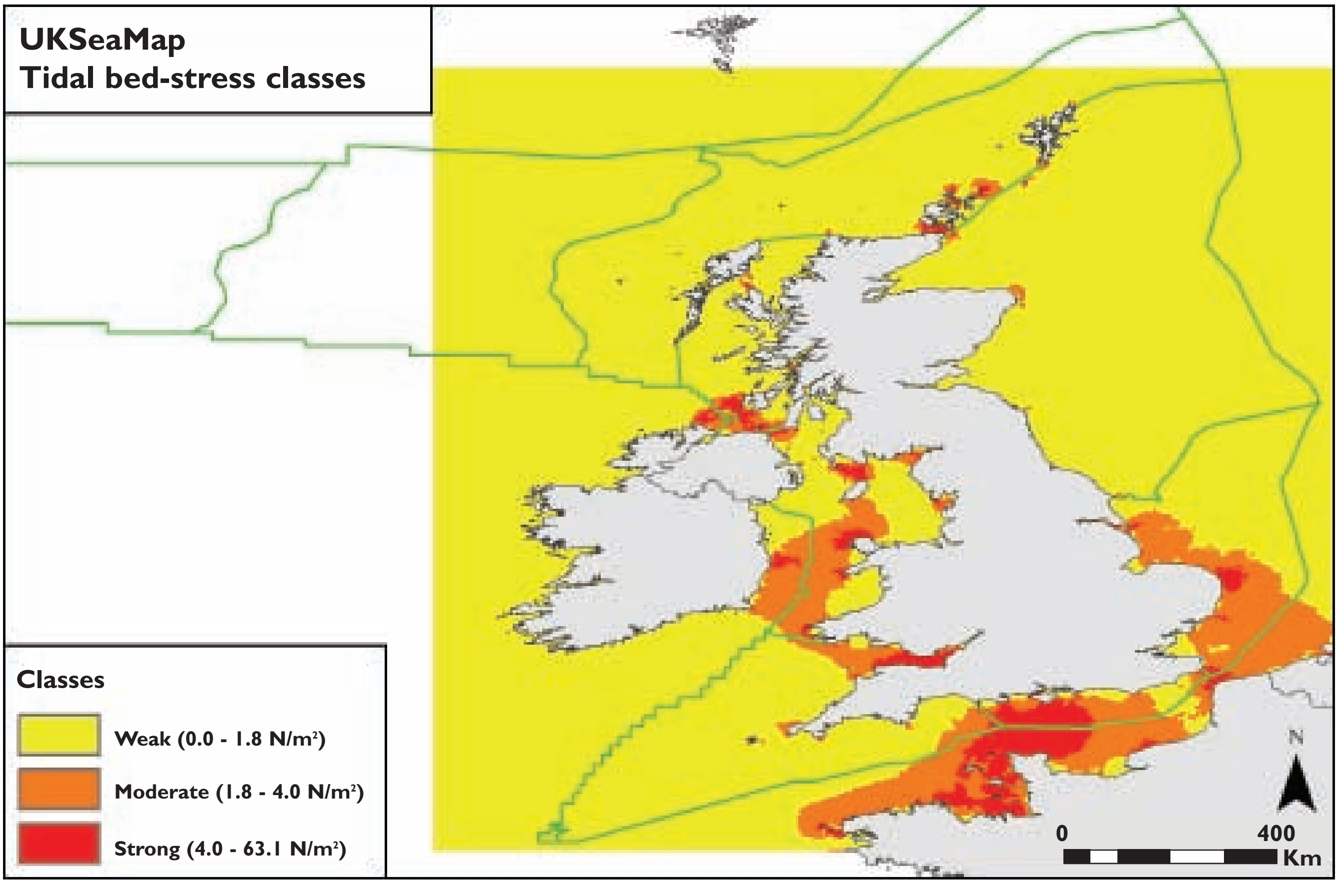


Figure 15. Maximum tidal bed stress classes used in seabed analysis.

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

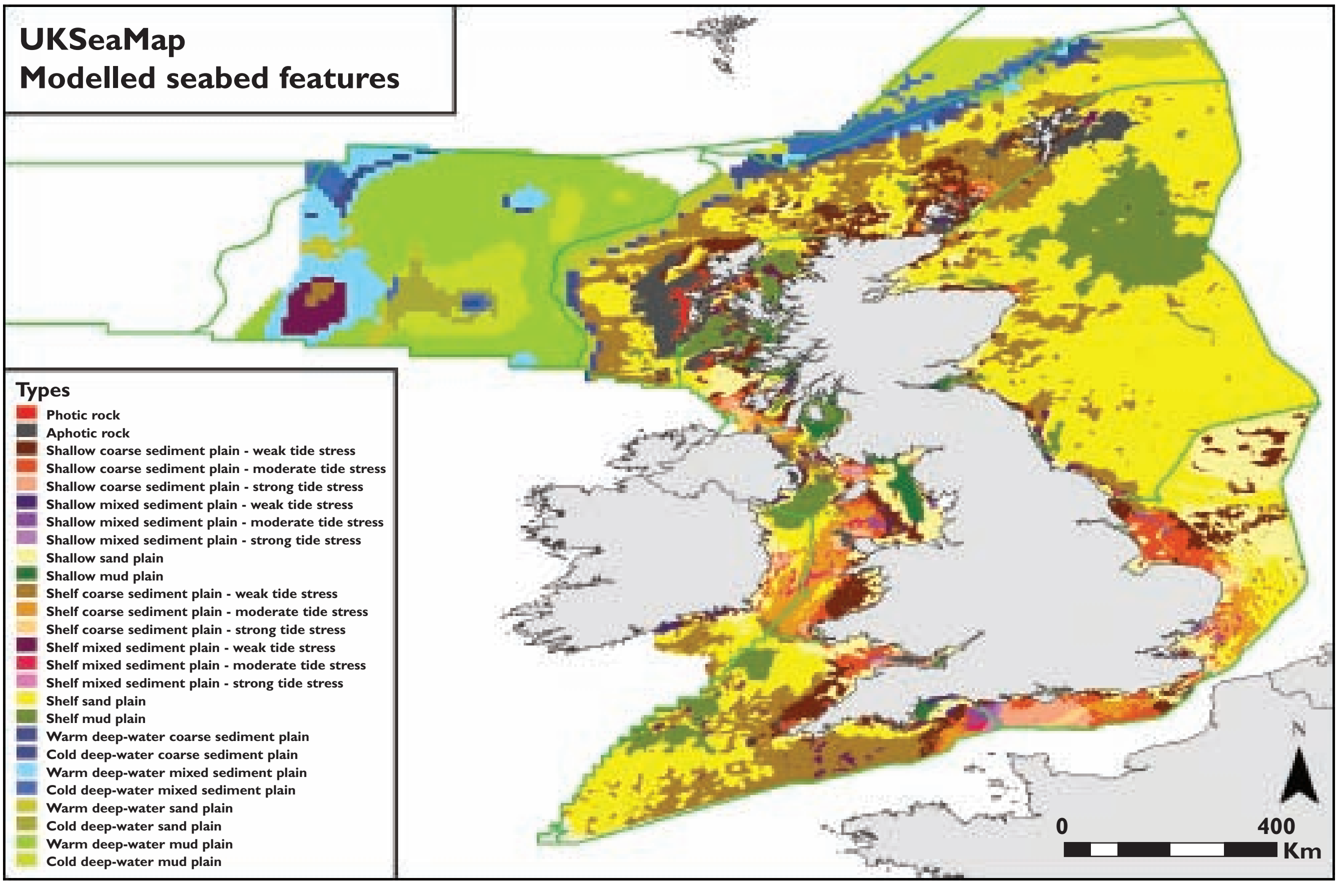


Figure 16. Seabed types derived from supervised classification tree analysis.

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).

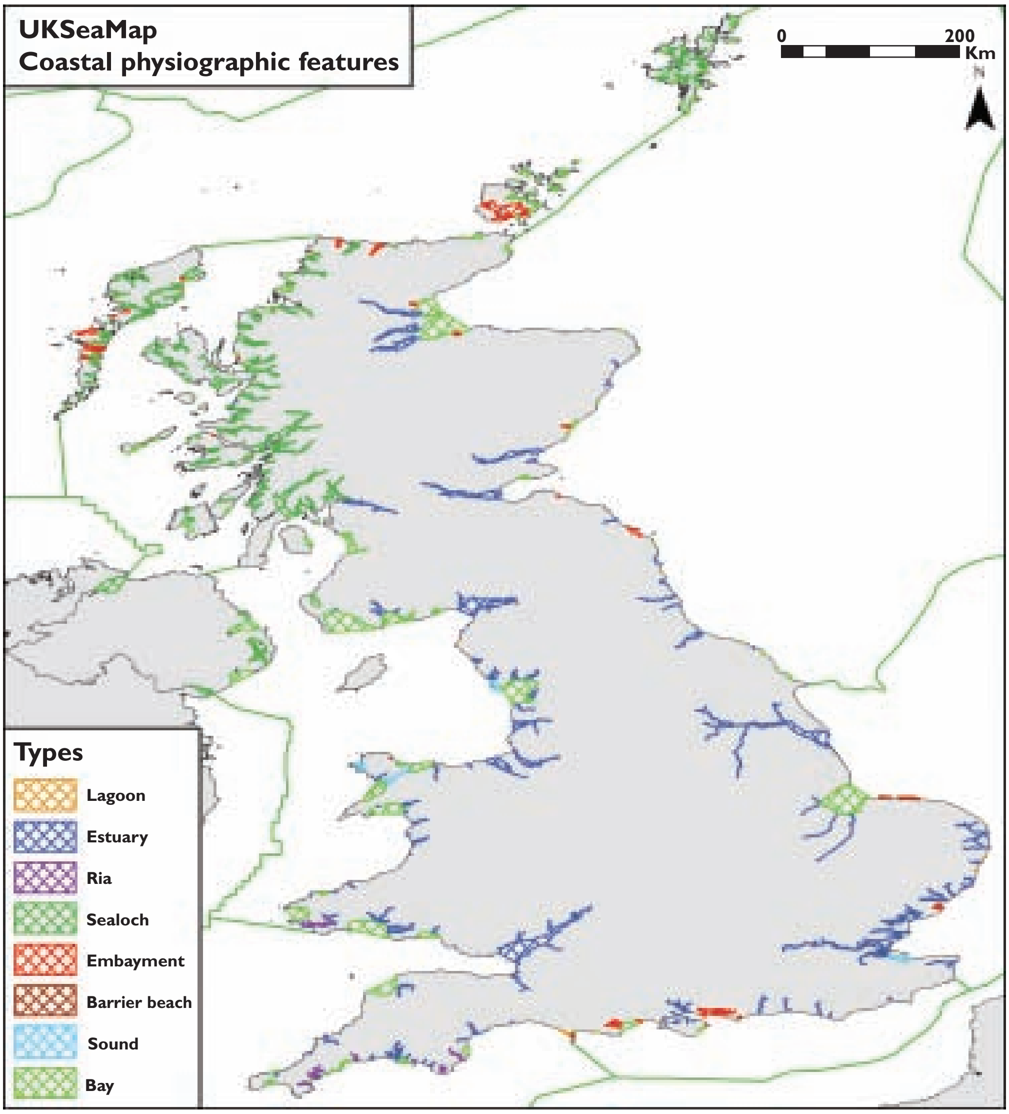


Figure 17. Coastal physiographic features.

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.

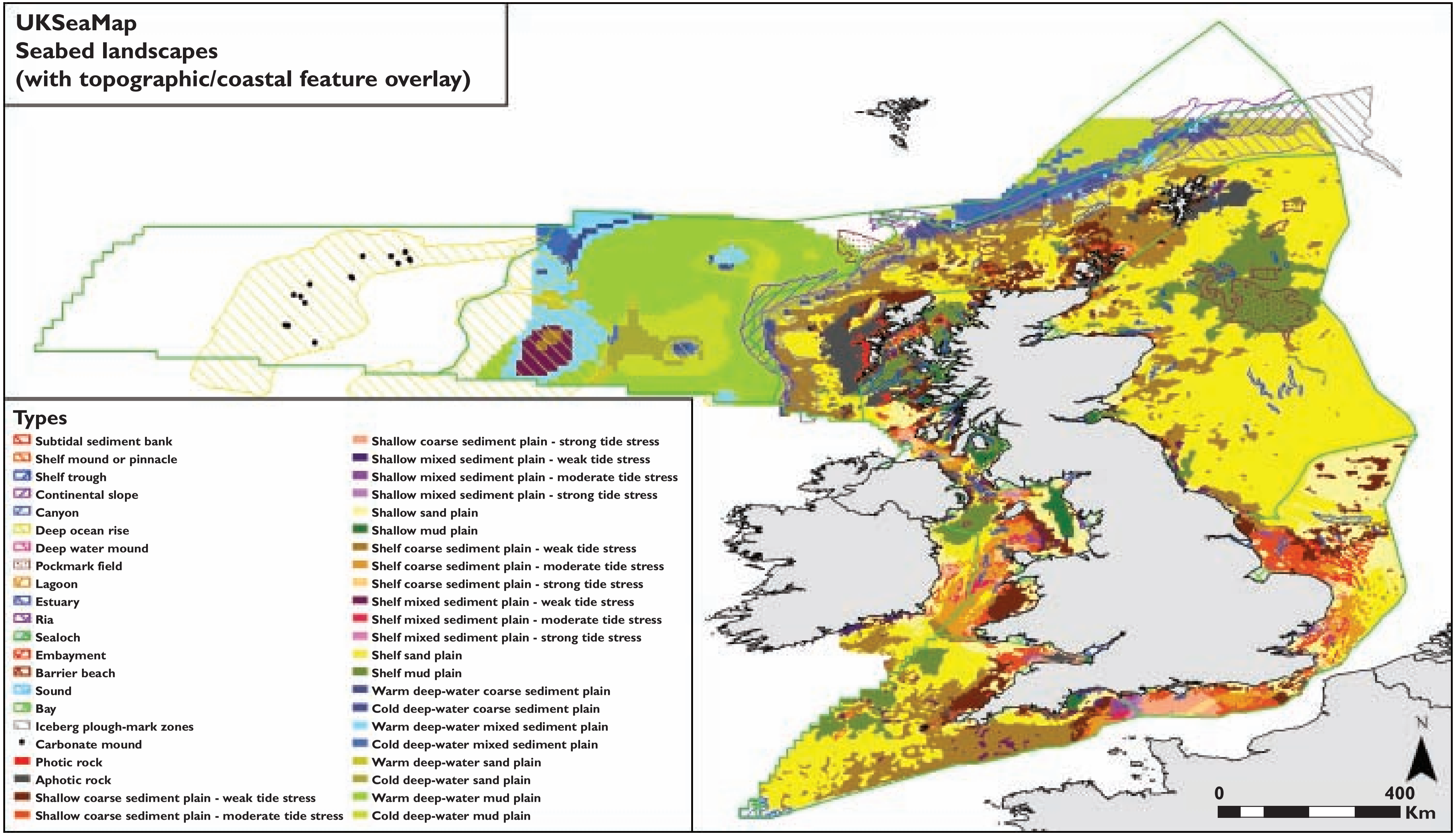


Figure 18: Map of seabed landscape types (topographic and coastal types shown as overlays – hatched colours).

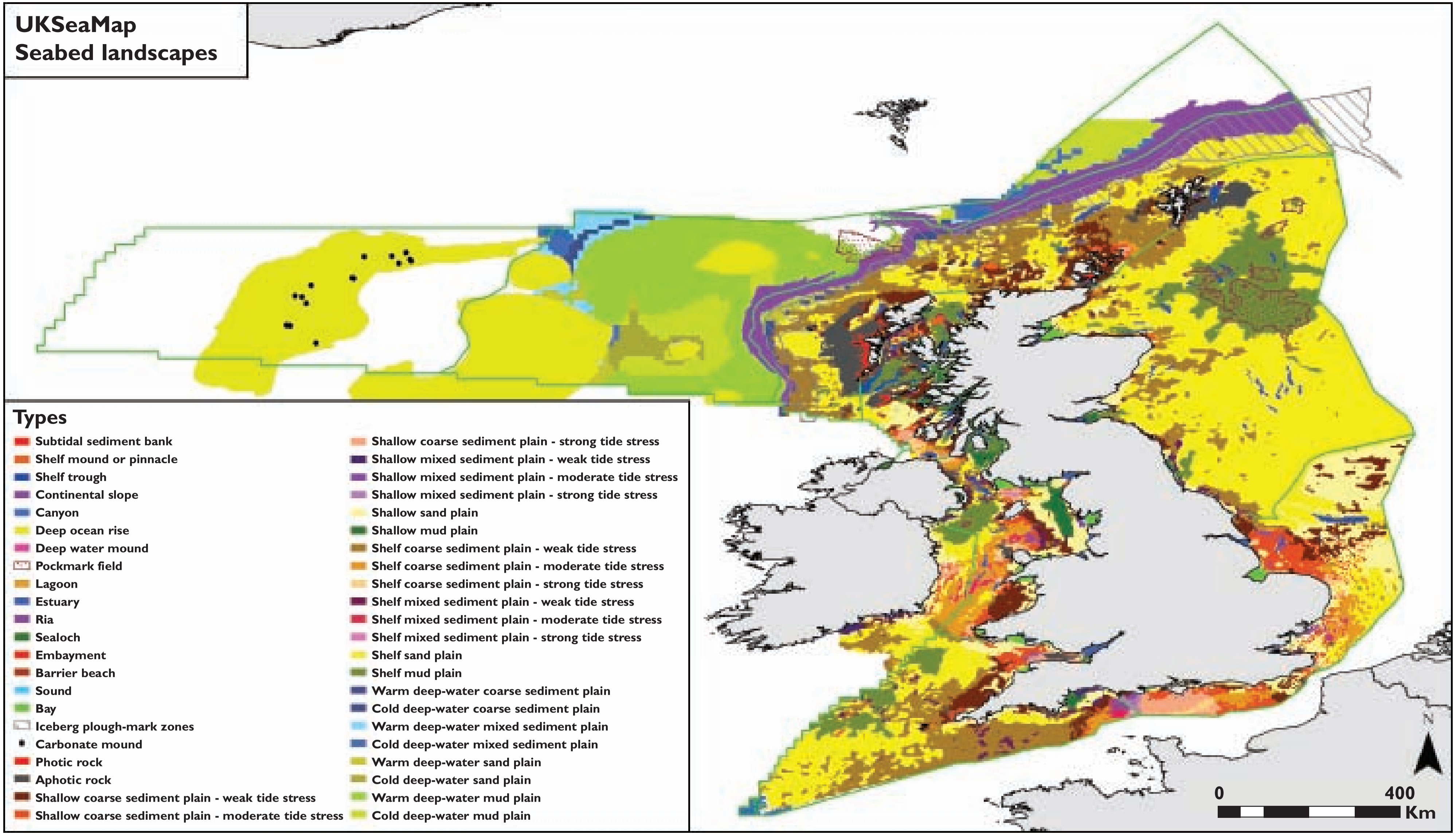


Figure 19: Map of seabed landscape types (topographic types shown obscuring modelled types – solid colours).

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

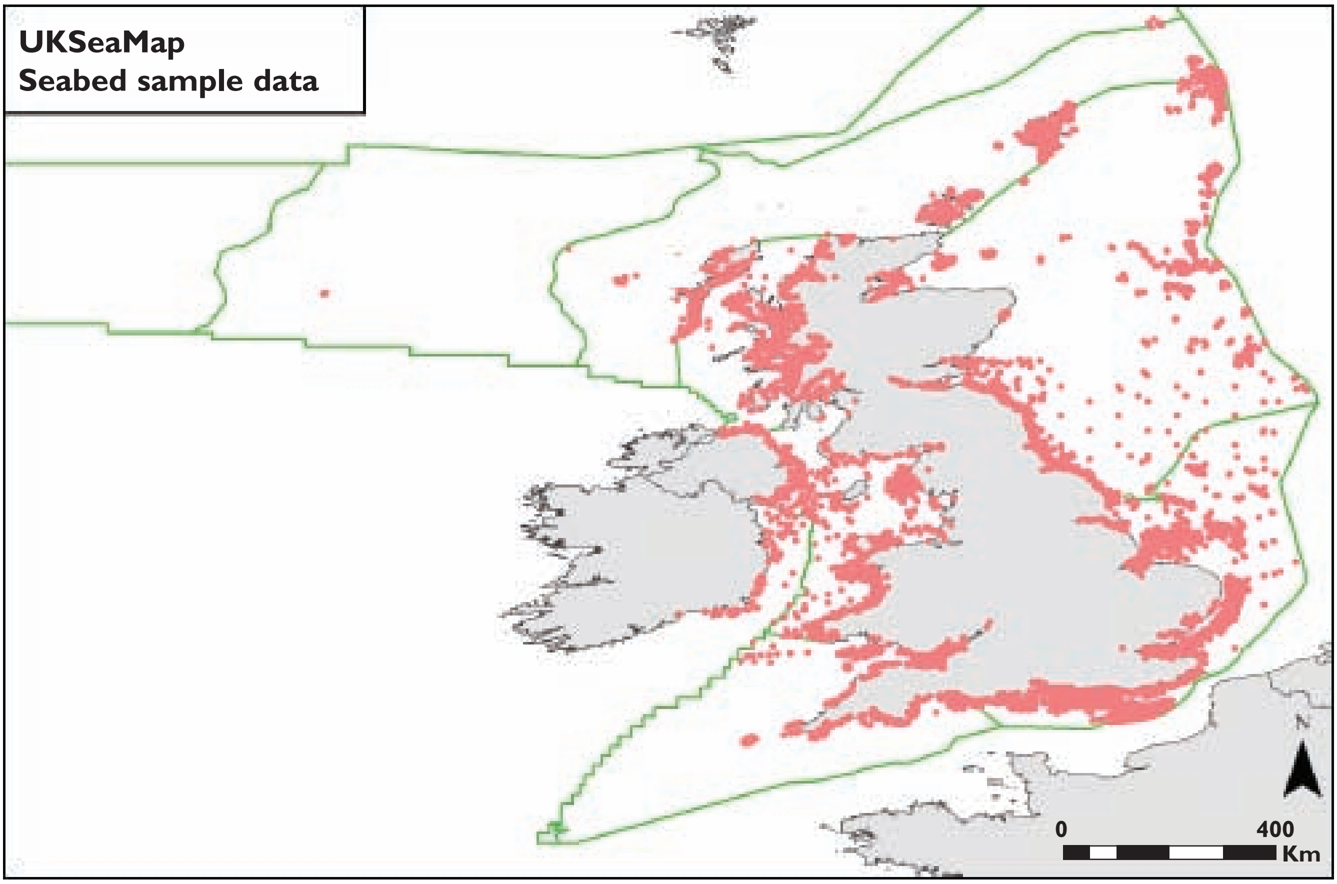


Figure 20. Map showing the distribution of benthic sample data used in the biological validation process.

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.

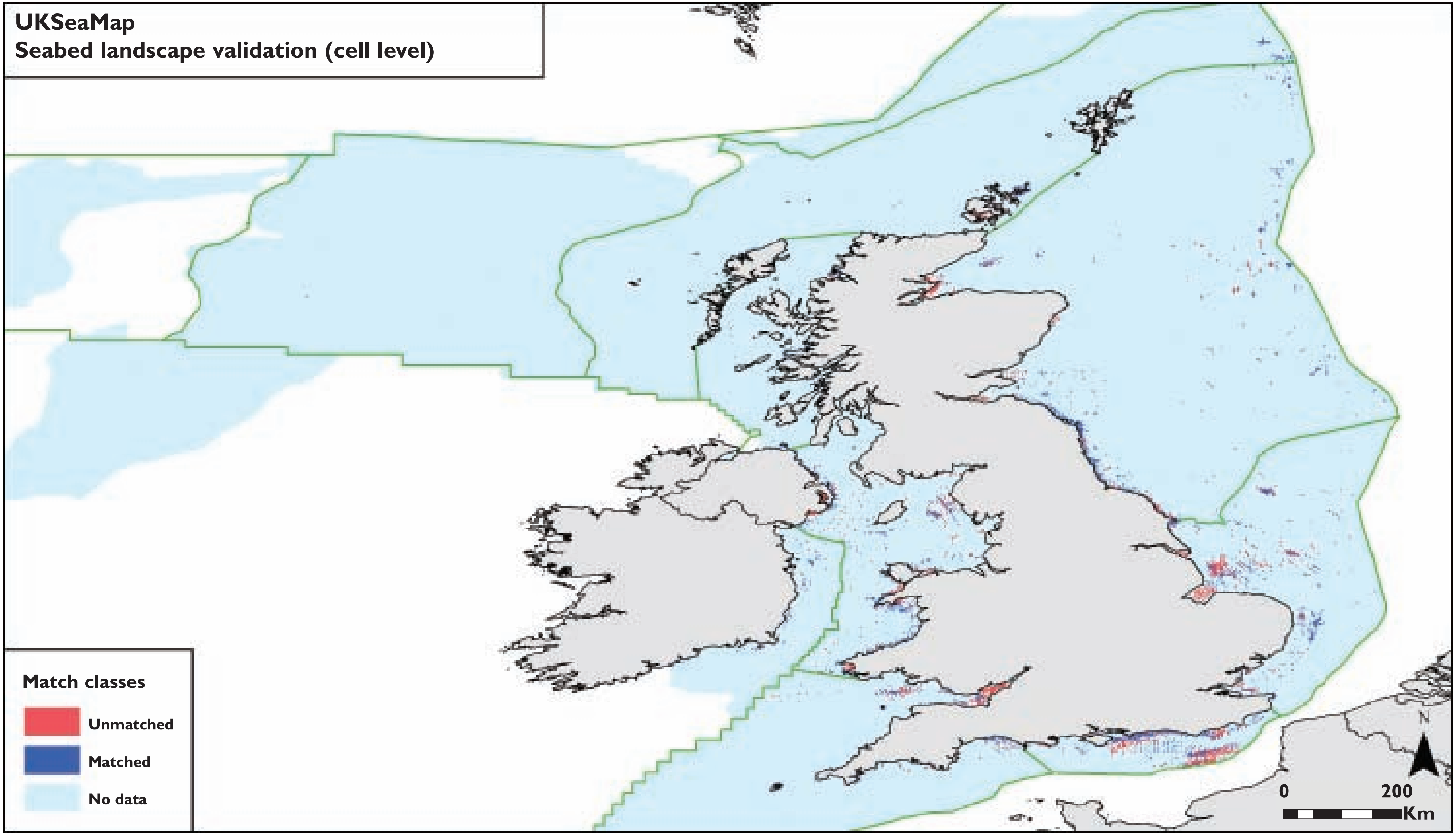


Figure 21: Map showing whether the biological validation data, at the grid cell level, supported the predicted character of the underlying landscape type (refer to text for full explanation and see also Table 7)

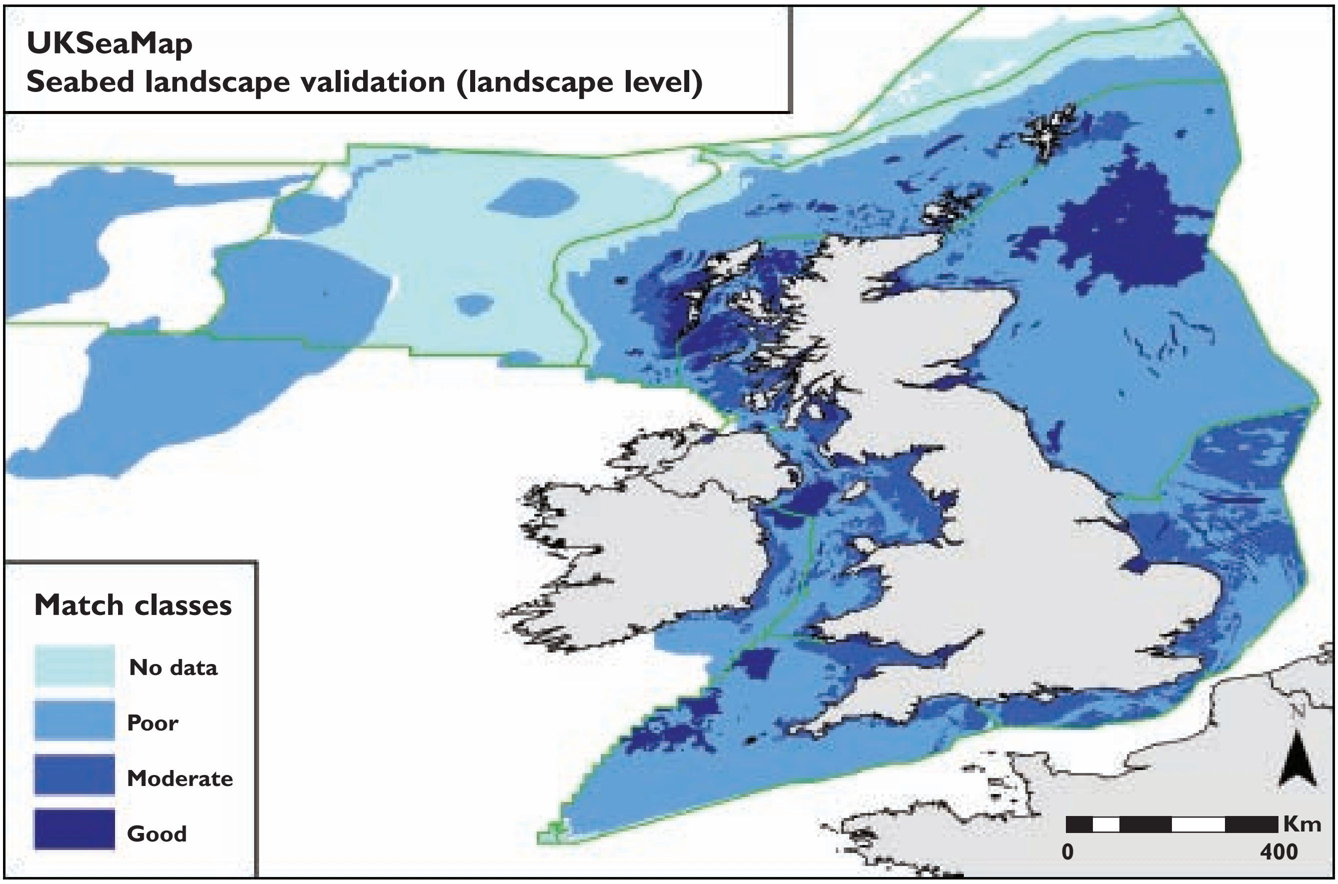


Figure 22: Map showing the degree to which the biological validation data, at the landscape level, supported the predicted character of the underlying landscape type (refer to text for full explanation and see also Table 7)

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.

5.2 Water column data layers and their processing

A number of hydrographic data sets were obtained from the Proudman Oceanographic Laboratory (POL), and assessed for relevance to modelling water column types:

- Shelf surface salinity
- Atlantic surface salinity
- Sea surface temperature (remotely sensed data)
- Sea bottom temperature (modelled data)
- Surface to bed temperature difference (modelled data)
- Stratification probability (modelled data)
- Frontal probability (modelled data)
- Potential energy anomaly (modelled data)
- Shelf mixed layer depths (modelled data)
- Atlantic mixed layer depths (modelled data)
- Tidal stress (spatially referenced point values)
- Wave stress (spatially referenced point values)

After consideration of their potential role in defining water column types, and because some were effectively replicating other data sets (e.g. stratification probability and surface to seabed temperature difference), the data sets to be used in the final analysis were refined to the following:

- Surface salinity (shelf and Atlantic)
- Surface to bed temperature difference
- Frontal probability

Further details on those data sets which were not used in the analysis are provided in Annex 11.

5.2.1 Surface salinity

Salinity was selected as the initial classification parameter used for generating water column types, as it has a major role in determining biological character, varying from inshore estuarine and coastal conditions through to fully saline oceanic waters. The following categories in the salinity data were adopted:

- Estuarine (<30‰)
- Coastal or Region of Freshwater Influence (ROFI) (>30‰, but <34‰)
- Shelf (>34‰, but <35‰)
- Oceanic (>35‰)

Two separate data sets comprising shelf and beyond shelf (Atlantic) data were used to map surface salinity. Away from the shelf the data points used to create the raster layer were sparse but have enabled the North East Atlantic Approaches and the Rockall Trough and Bank regions to be mapped, as these were gaps in the shelf data set. Throughout the year surface salinity figures in the beyond shelf data set remain >35‰ and therefore fall within the Oceanic waters category. The resultant surface salinity maps are shown in Figures 23-26.

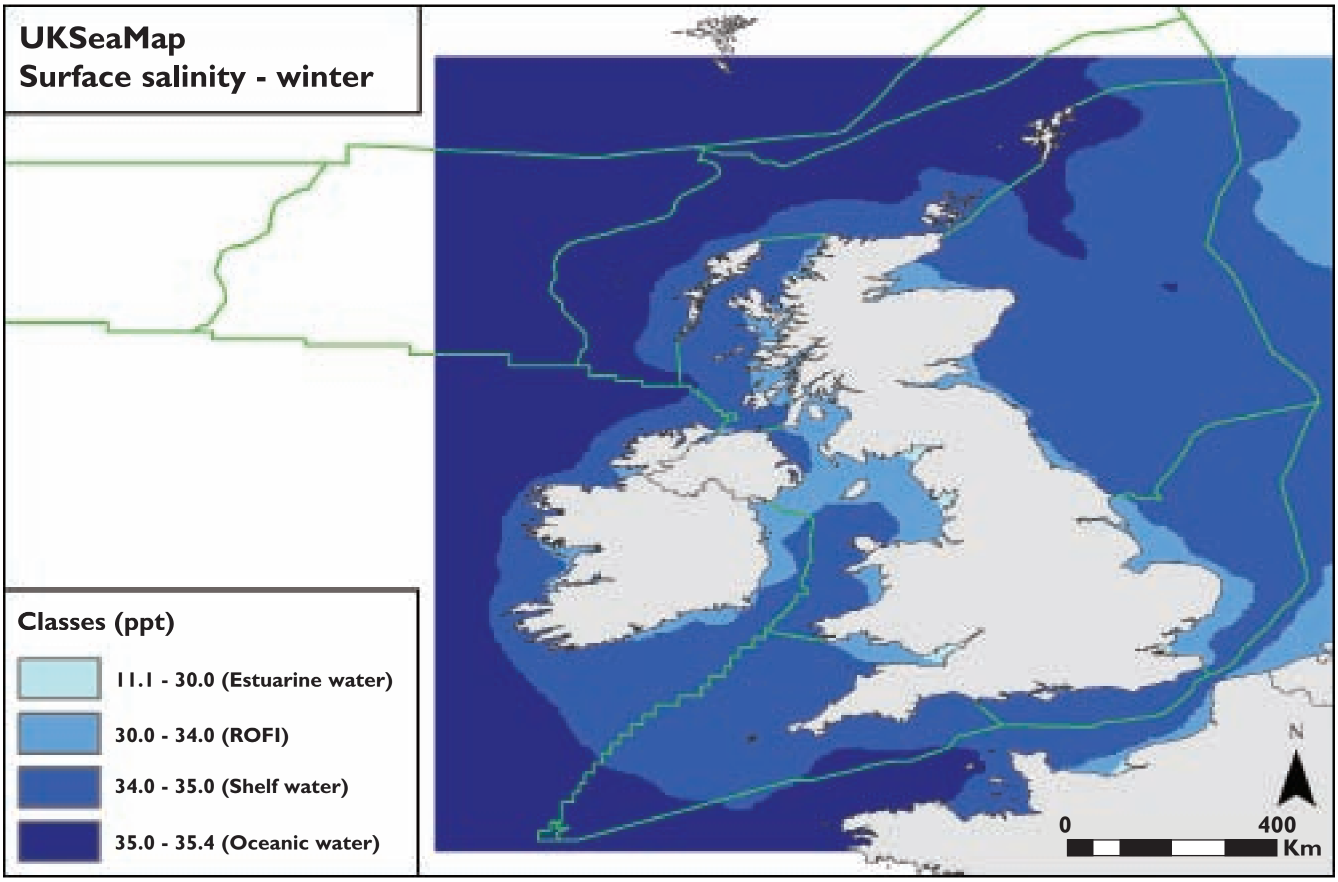


Figure 23. Winter sea surface salinity (source data from POL)

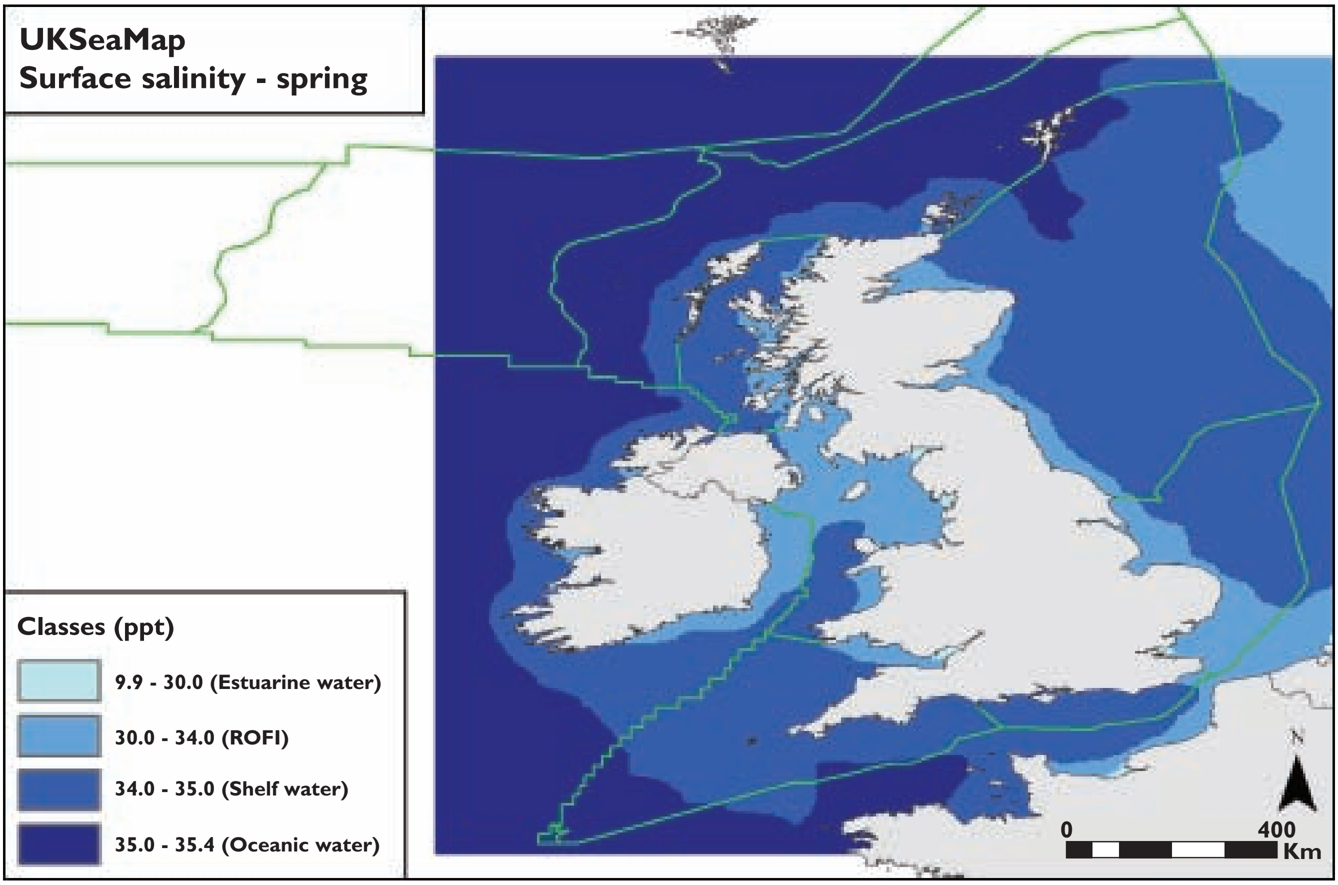


Figure 24. Spring sea surface salinity (source data from POL)

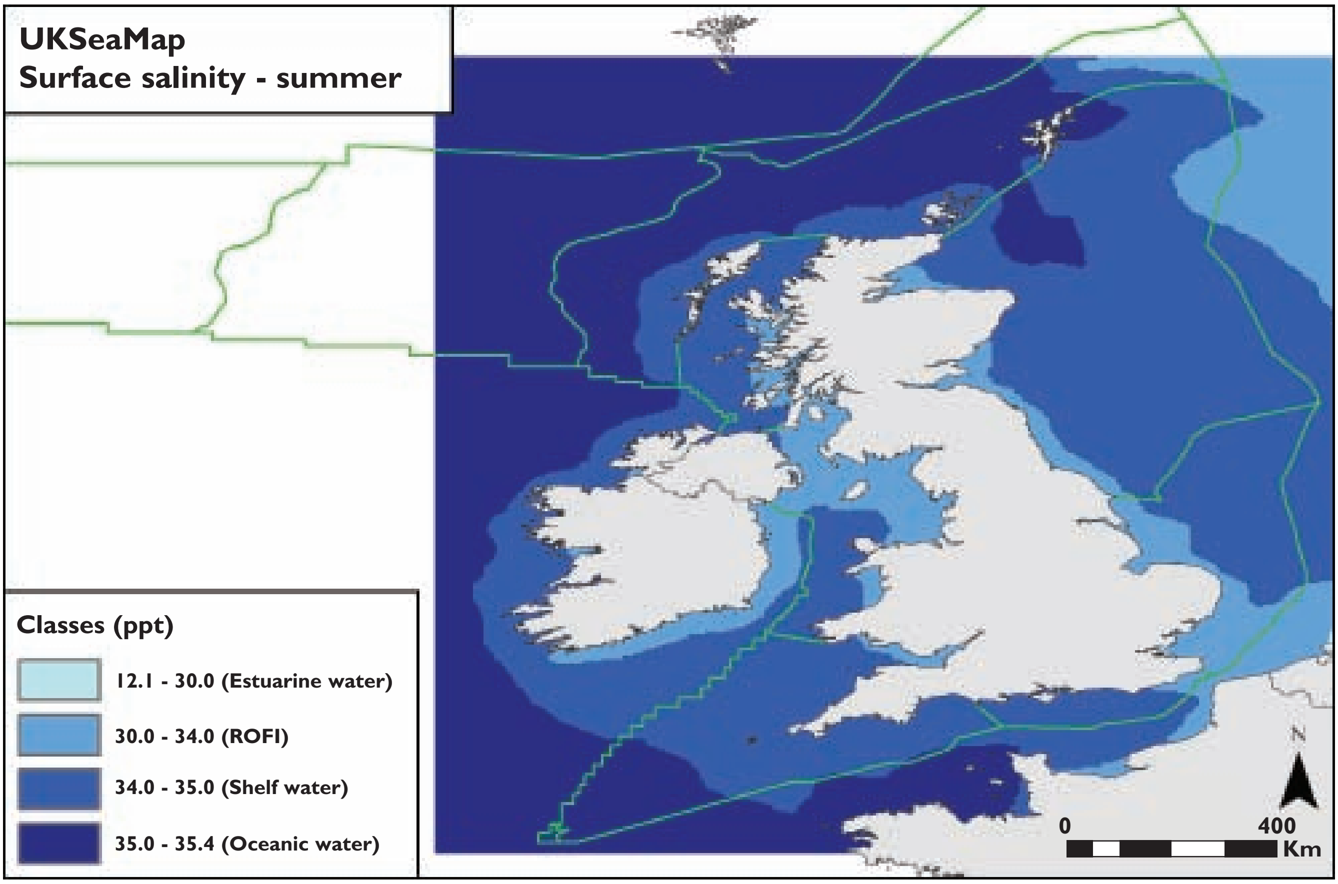


Figure 25. Summer sea surface salinity (source data from POL)

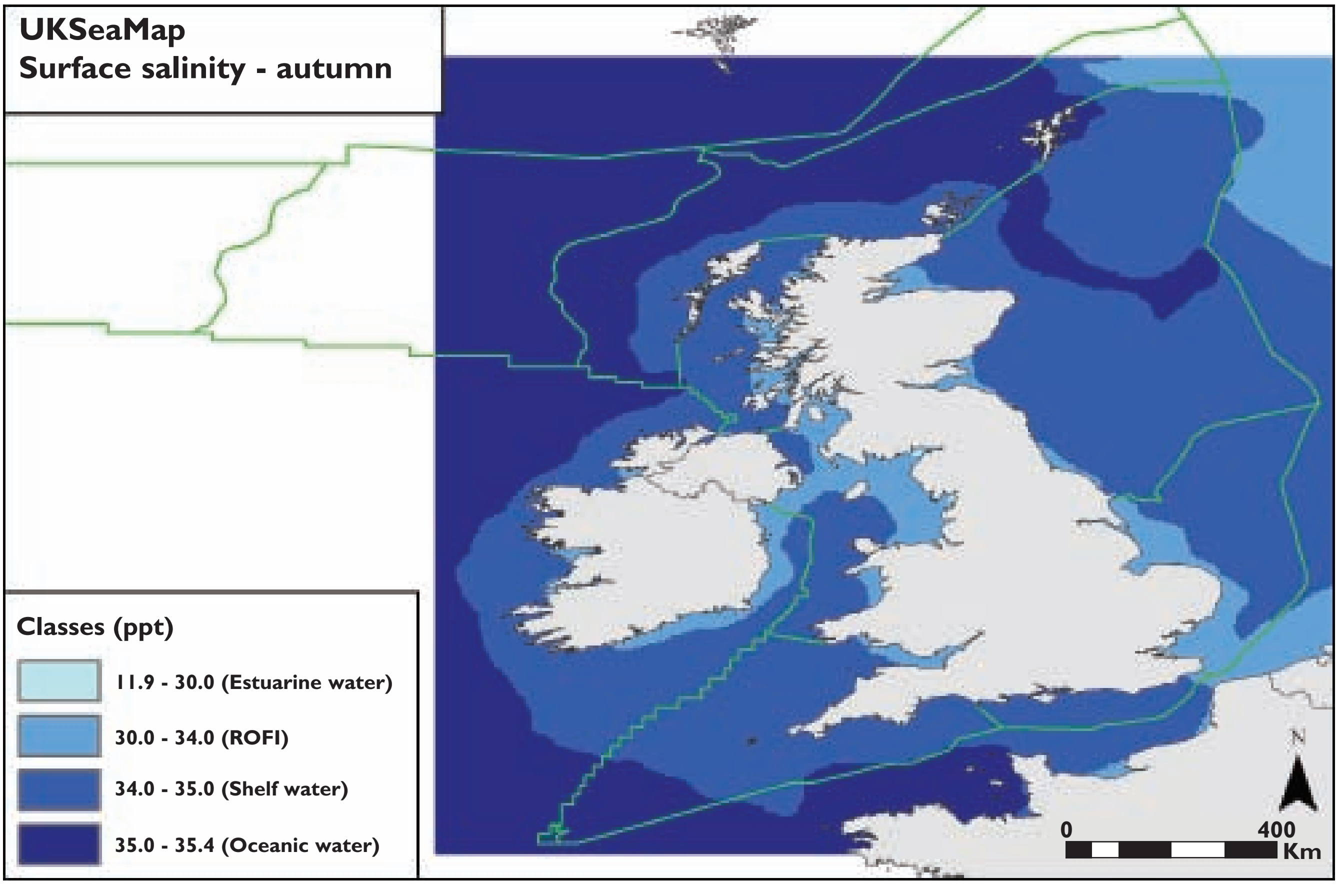


Figure 26. Autumn sea surface salinity (source data from POL)

5.2.2 Surface to seabed temperature difference

Surface to seabed temperature difference data has been used to distinguish three classes which reflect the degree of stability in the water column, namely thermally stratified and well-mixed waters on the continental shelf, together with an intermediate transition zone (shown as frontal on the maps) (Figures 27-30).

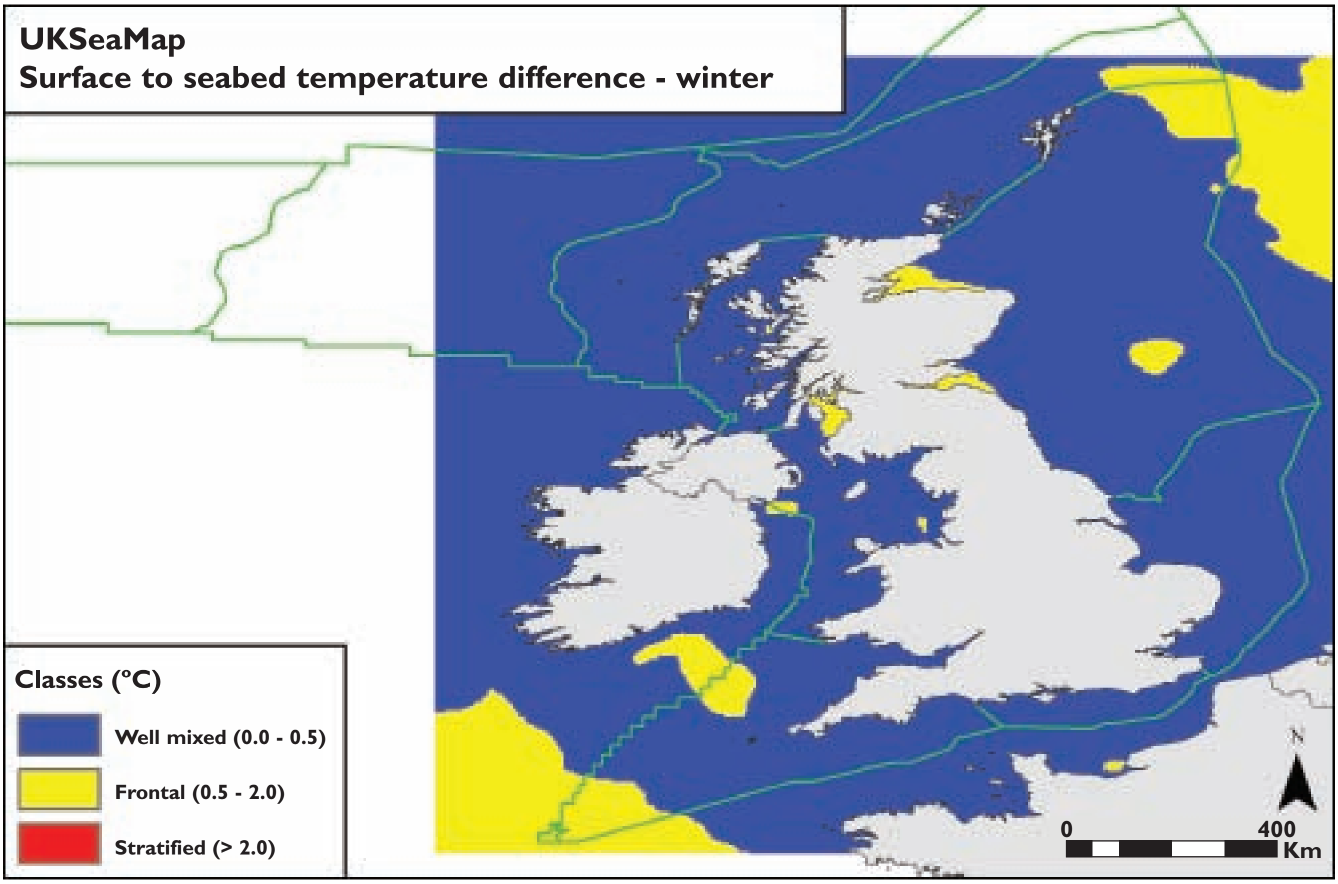


Figure 27. Winter surface to bed temperature difference (source data from POL)

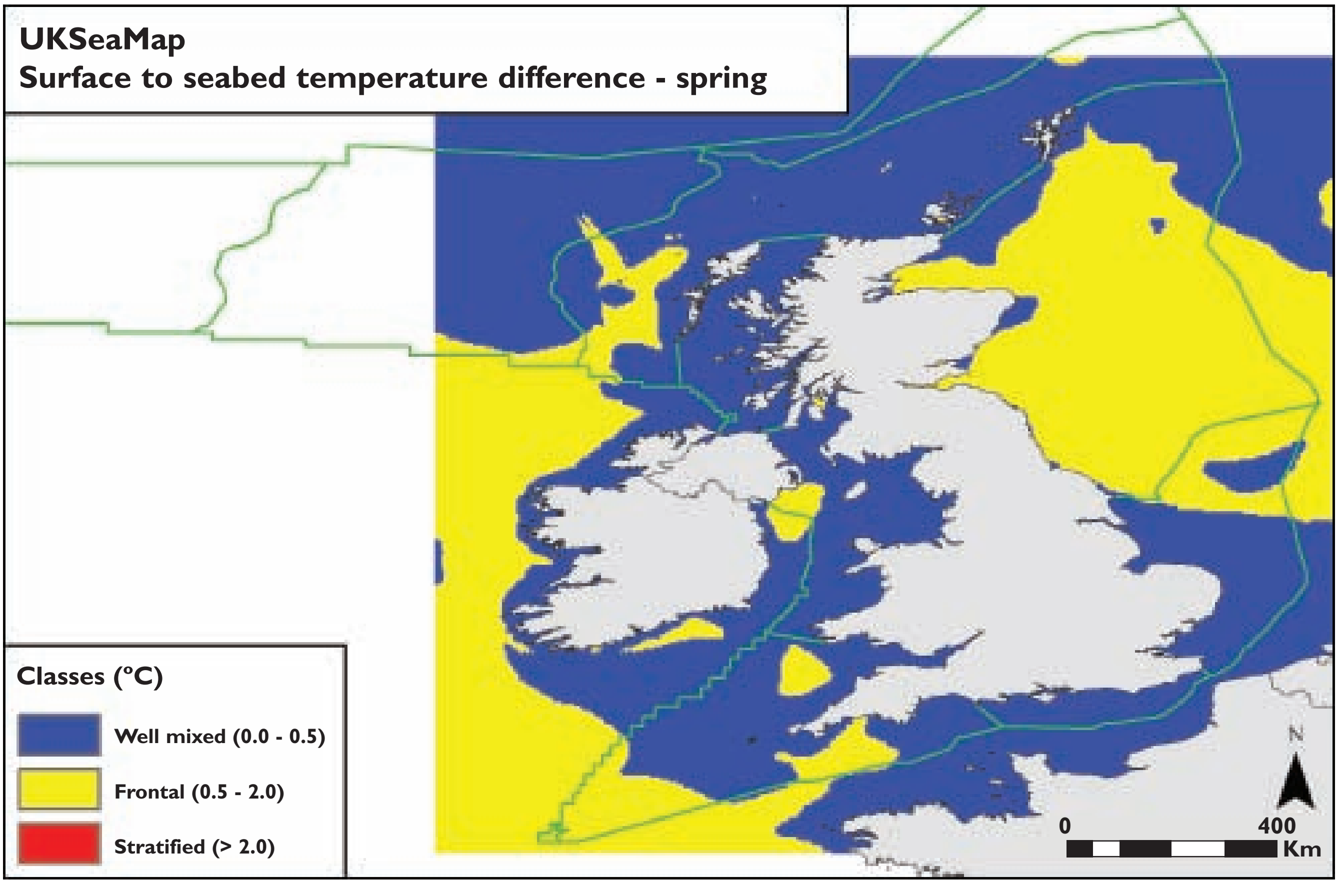


Figure 28. Spring surface to bed temperature difference (source data from POL)

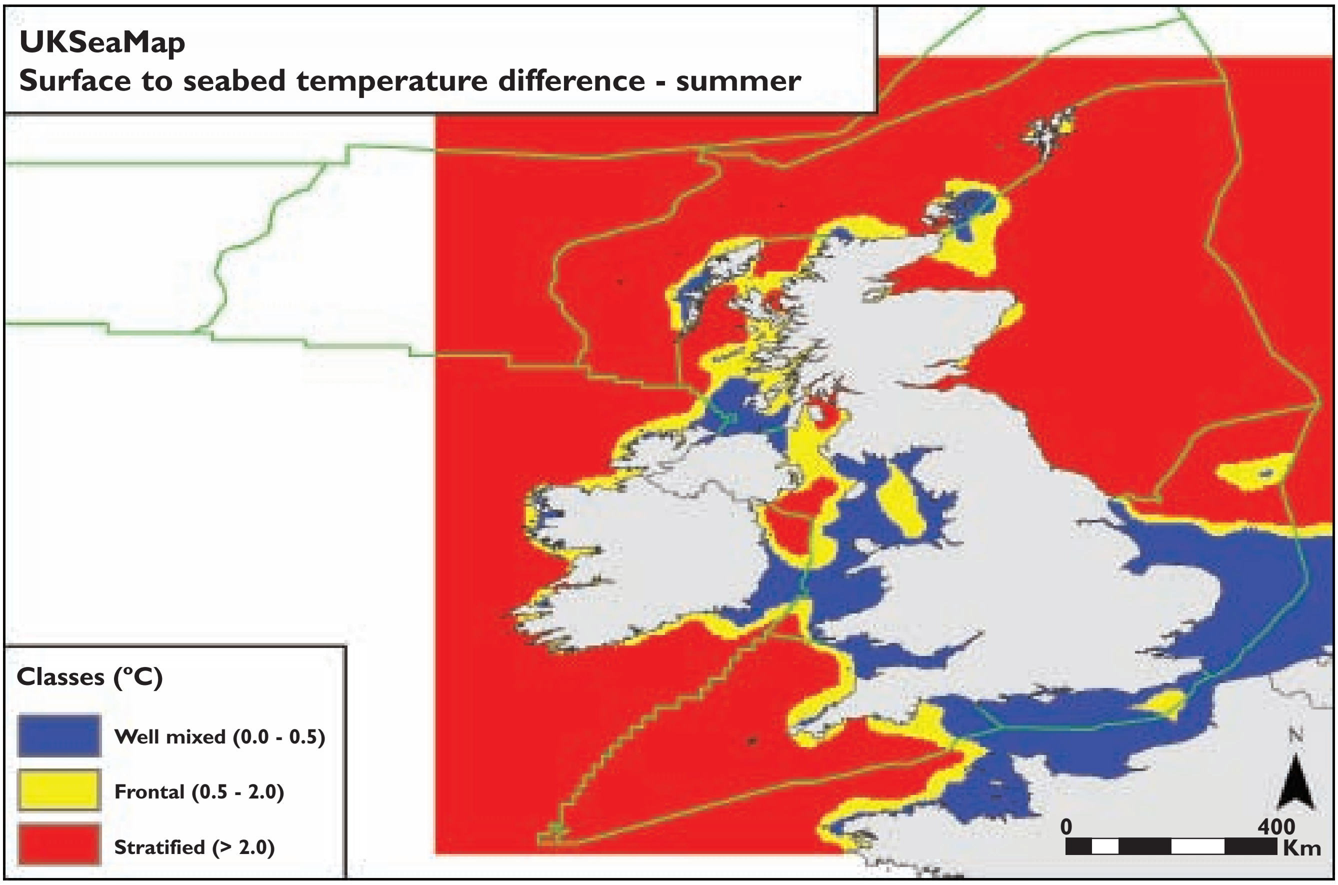


Figure 29. Summer surface to bed temperature difference (source data from POL)

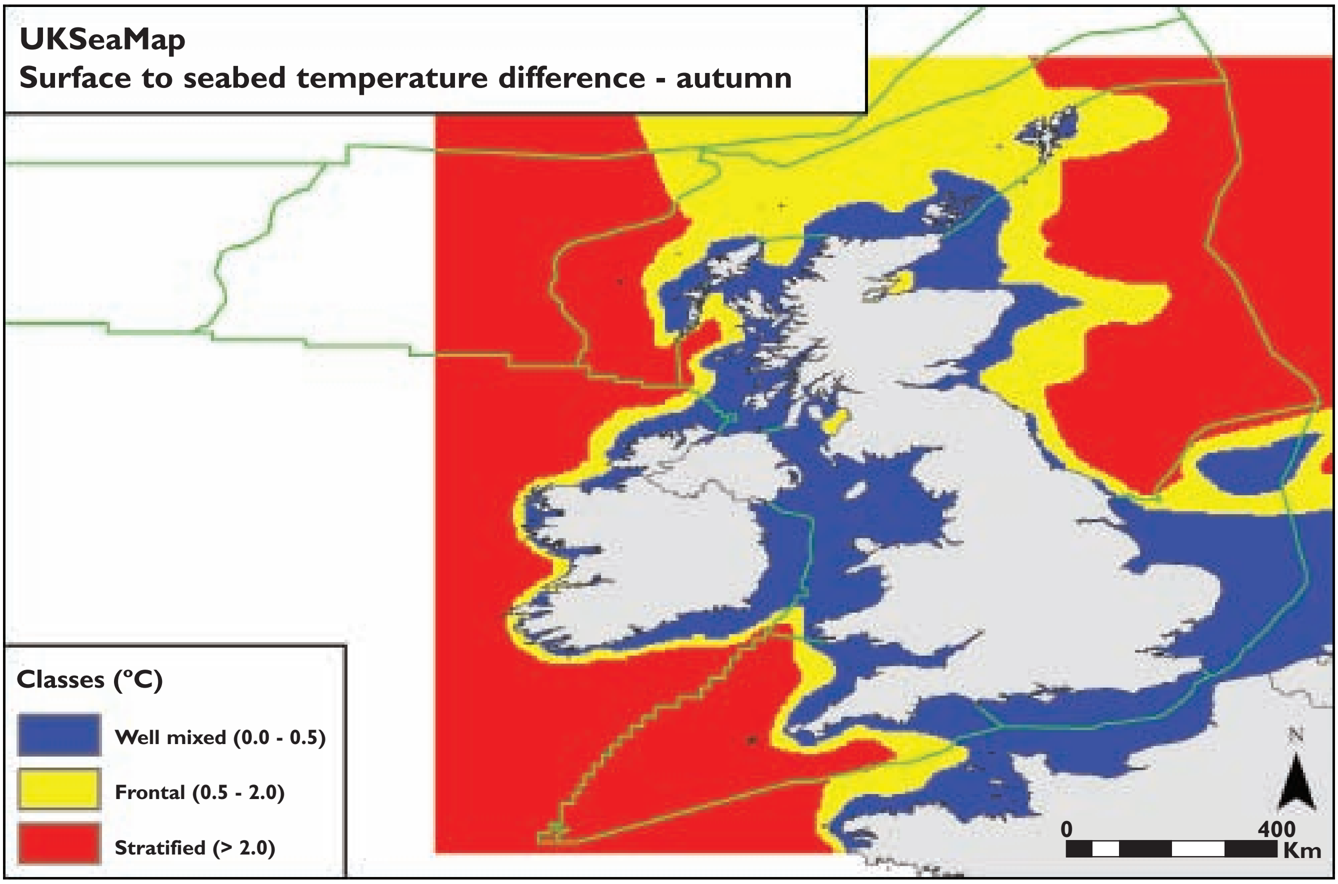


Figure 30. Autumn surface to bed temperature difference (source data from POL)

5.2.3 Front probability

Fronts are an important zone of rapid change in hydrographic and biological character, often separating shelf sea regions from the open ocean. Front probability data has therefore been included in the water column classification process to illustrate the likelihood of a front being present within a particular area.

The front probability density function is defined as the number of days the horizontal temperature difference between neighbouring modelled locations exceeds 0.5°C, divided by the number of days in this season over the 10-year run. Figures 31-34 illustrate the location of fronts in the UKSeaMap area.

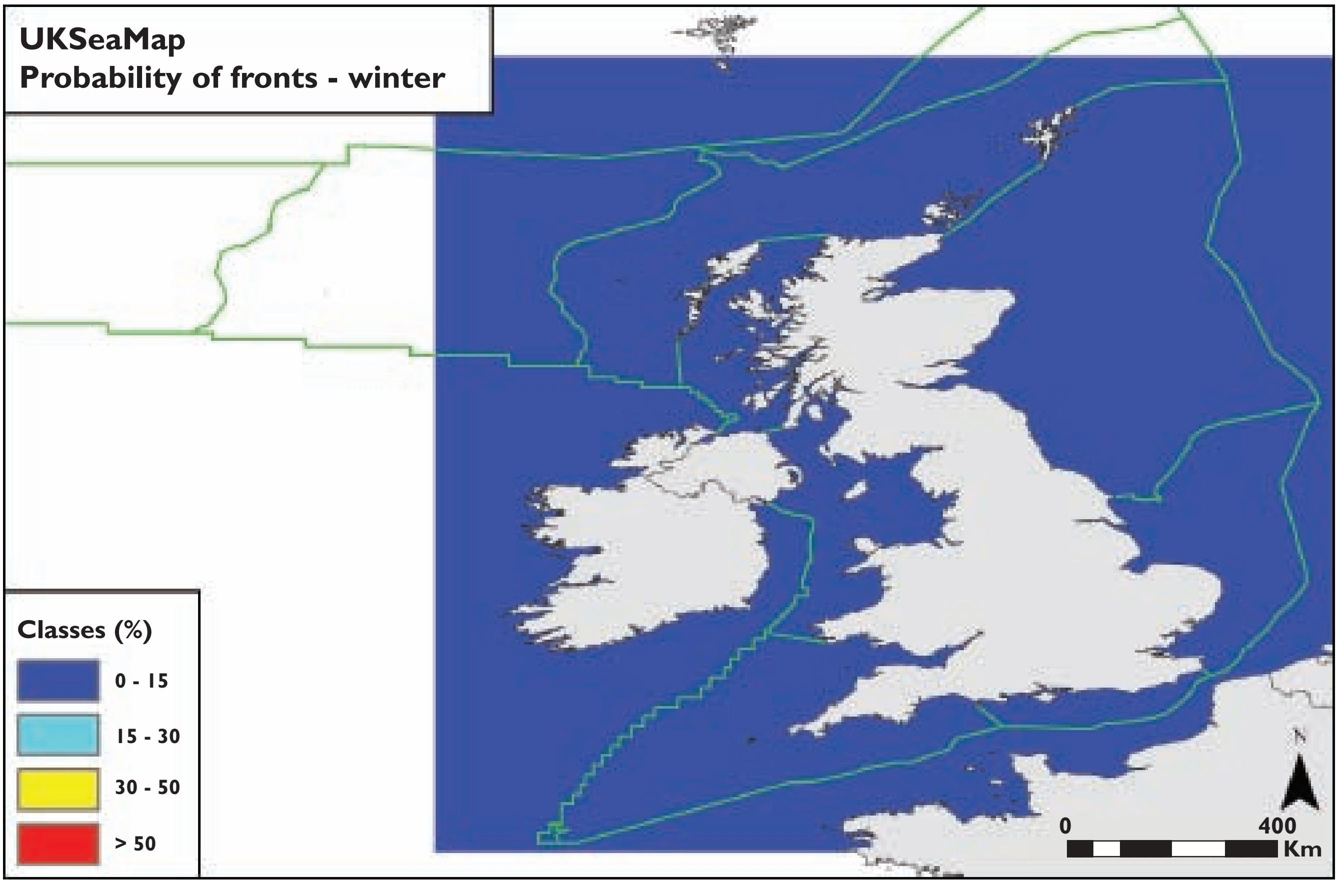


Figure 31. Winter front probability (source data from POL).

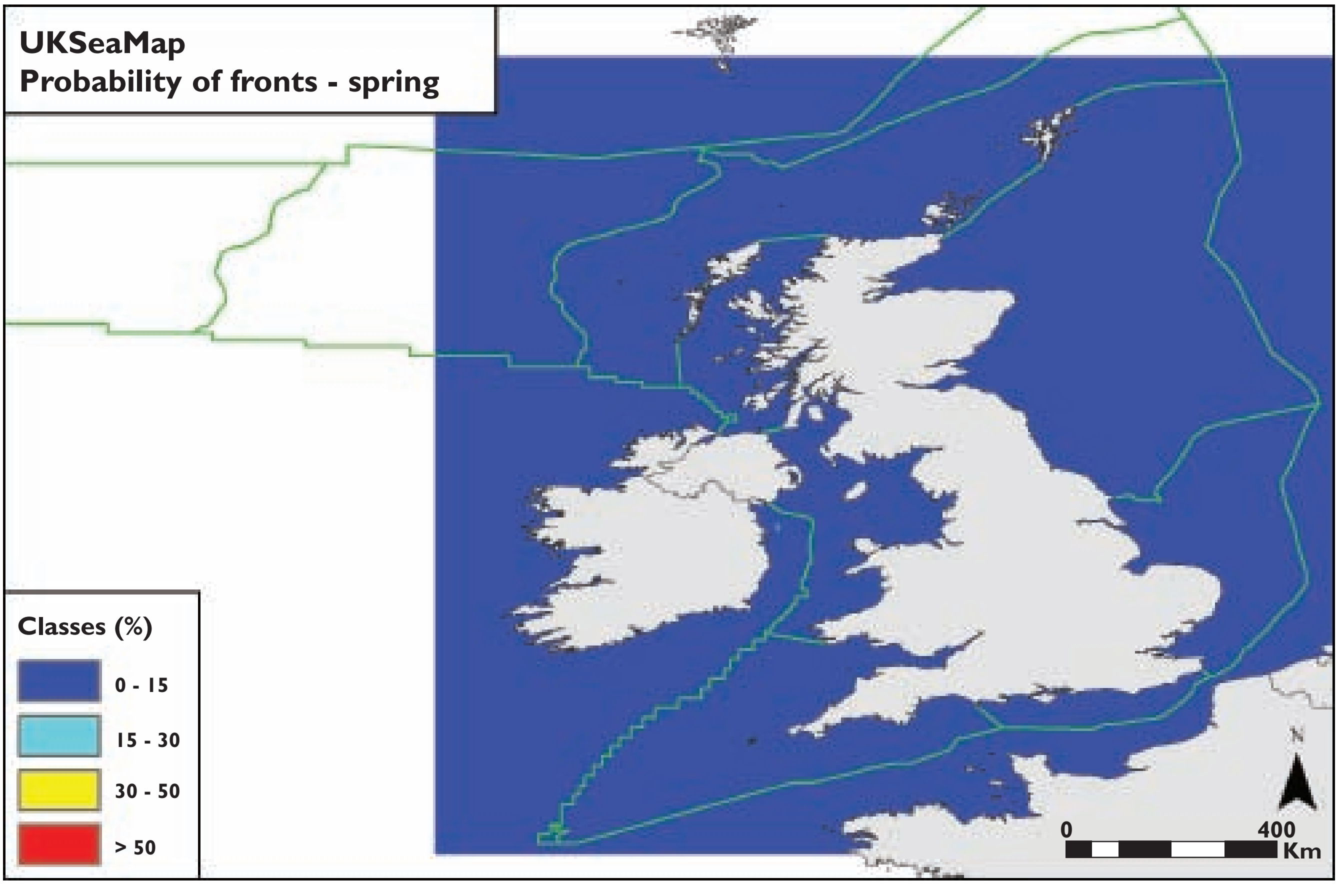


Figure 32. Spring front probability (source data from POL).

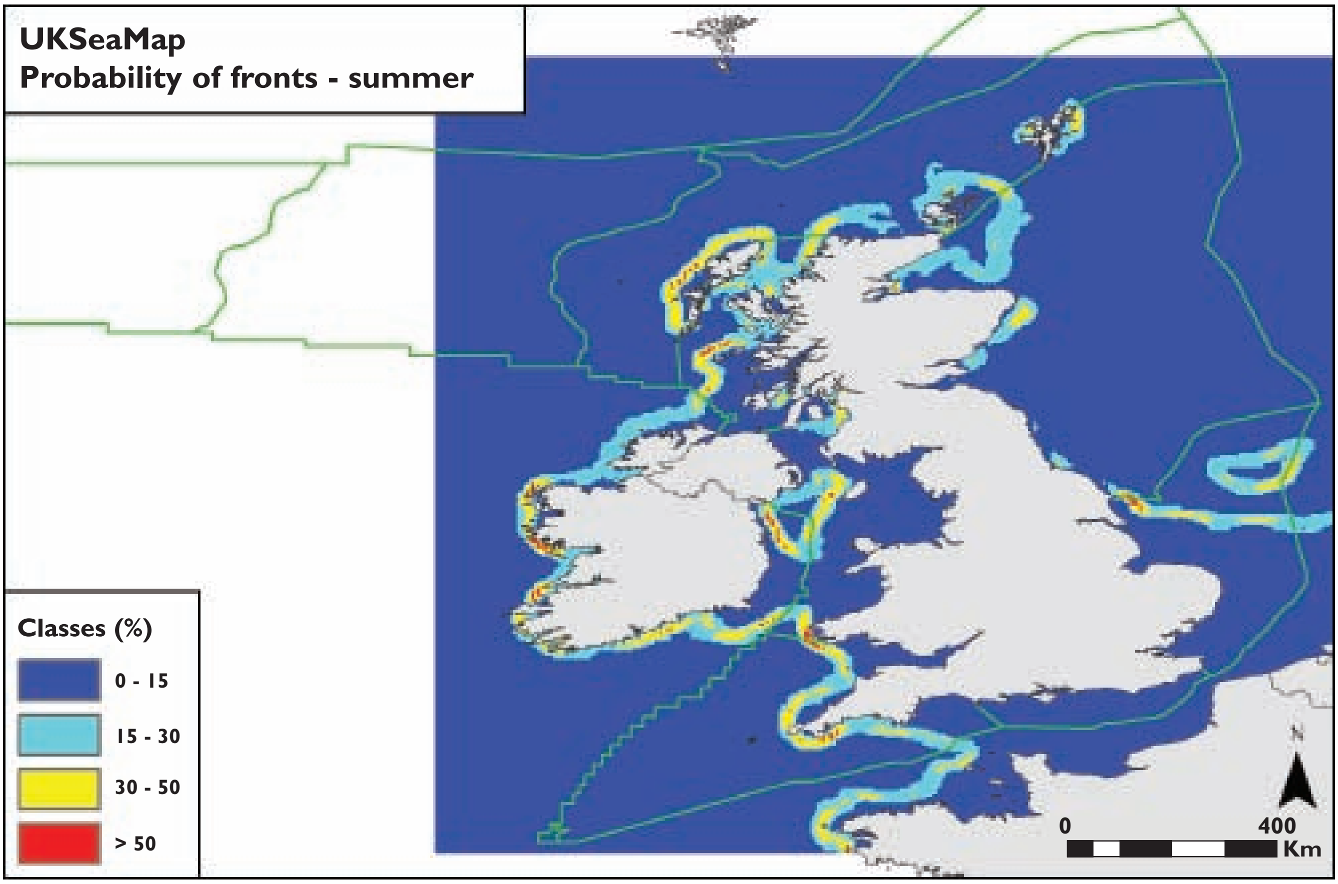


Figure 33. Summer front probability (source data from POL).

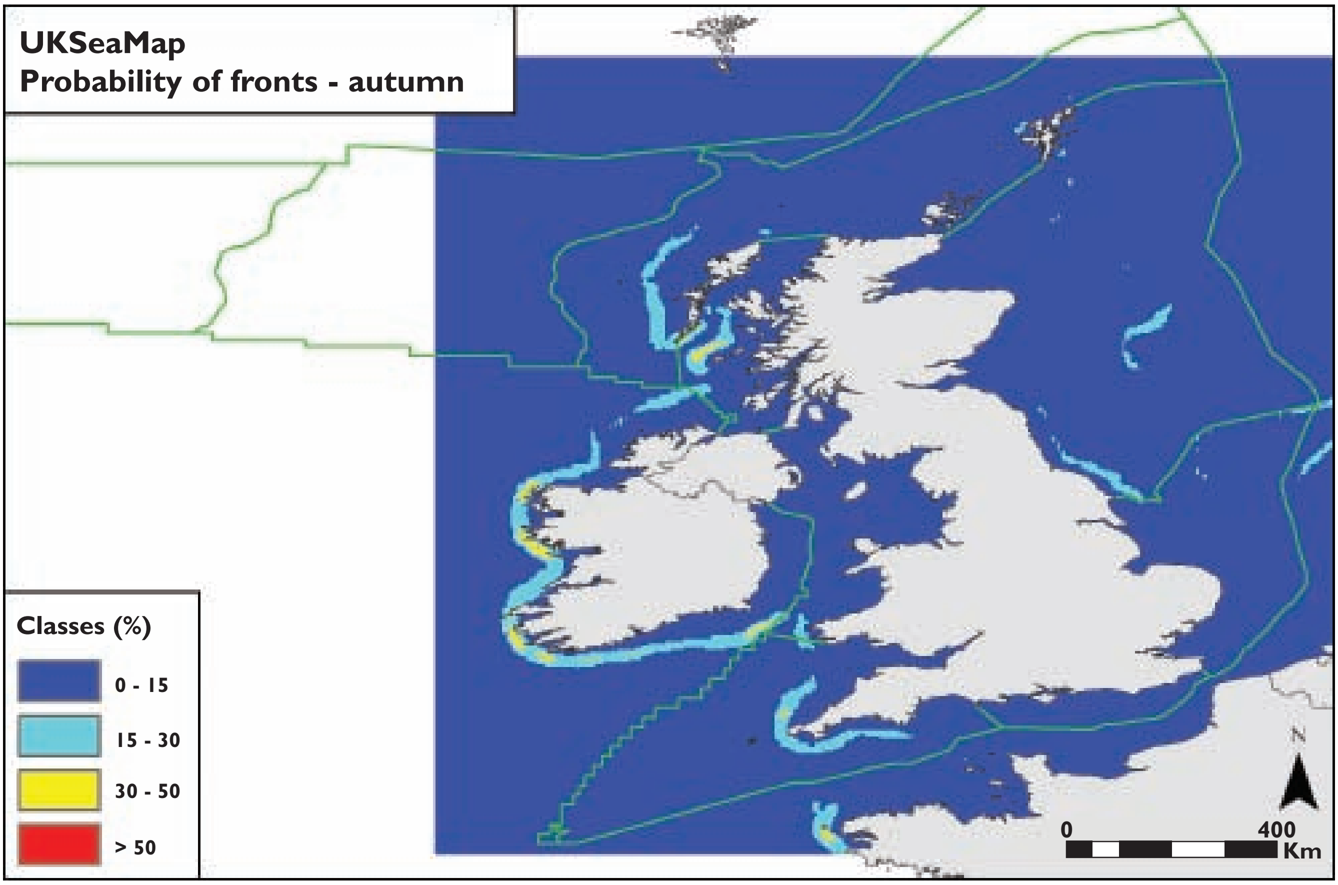


Figure 34. Autumn front probability (source data from POL).

5.3 Water column analysis

Using a similar methodology to that implemented for the seabed modelling (Section 4.3), a classification tree was developed, as shown in Table 9, to enable a supervised classification of the water column data sets to be undertaken. The analysis used data sets on salinity, surface to bed temperature difference and the probability of fronts.

Surface to bed temperature difference was used to distinguish between well mixed, frontal and temperature stratified areas. Areas identified as frontal from the surface to bed temperature difference data were then subdivided using the front probability data.

Four maps were produced (winter, spring, summer, autumn) to illustrate the seasonal variability in the pelagic environment (Figures 35-38).

Table 9. Water column features analysis

Salinity (‰)	Surface to seabed temperature difference (°C)	Fronts (% probability)	Water column type
Estuarine (<=30)			Estuarine water
ROFI (>30 and <=34)	Well-mixed (<=0.5)		Well-mixed ROFI
	Frontal (>0.5 and <=2.0)	No Front (<15%)	Weakly-stratified ROFI
		Front (>15%)	Frontal ROFI
	Stratified (>2.0)		Stratified ROFI
Shelf (>34 and <=35)	Well-mixed (<=0.5)	0	Well-mixed shelf water
	Frontal (>0.5 and <=2.0)	No Front (<15%)	Weakly-stratified shelf water
		Front (>15%)	Frontal shelf water
	Stratified (>2.0)		Stratified shelf water
Oceanic (>35)	Well-mixed (<=0.5)	0	Well-mixed oceanic water
	Frontal (>0.5 and <=2.0)	No Front (<15%)	Weakly-stratified oceanic water
		Front (>15%)	Frontal oceanic water
	Stratified (>2.0)		Stratified oceanic water

5.4 Water column classification and maps

The classification of water column features, resulting from the supervised analysis, is presented in Table 10 and illustrated, by season, in Figures 35-38.

Table 10. Classification of water column features and their main characteristics

Water column type	Salinity (‰)	Surface to seabed temperature difference (°C)	Fronts (% probability)
Estuarine water	Estuarine (<=30)		
Well-mixed ROFI	ROFI (>30 and <=34)	Well-mixed (<=0.5)	
Weakly-stratified ROFI	ROFI (>30 and <=34)	Frontal (>0.5 and <=2.0)	No Front (<=0.15)
Frontal ROFI	ROFI (>30 and <=34)	Frontal (>0.5 and <=2.0)	Front (>0.15)
Stratified ROFI	ROFI (>30 and <=34)	Stratified (>2.0)	
Well-mixed shelf water	Shelf (>34 and <=35)	Well-mixed (<=0.5)	0

Water column type	Salinity (‰)	Surface to seabed temperature difference (°C)	Fronts (% probability)
Weakly-stratified shelf water	Shelf (>34 and <=35)	Frontal (>0.5 and <=2.0)	No Front (<=0.15)
Frontal shelf water	Shelf (>34 and <=35)	Frontal (>0.5 and <=2.0)	Front (>0.15)
Stratified shelf water	Shelf (>34 and <=35)	Stratified (>2.0)	
Well-mixed oceanic water	Oceanic (>35)	Well mixed (<=0.5)	0
Weakly-stratified oceanic water	Oceanic (>35)	Frontal (>0.5 and <=2.0)	No Front (<=0.15)
Frontal oceanic water	Oceanic (>35)	Frontal (>0.5 and <=2.0)	Front (>0.15)
Stratified oceanic water	Oceanic (>35)	Stratified (>2.0)	

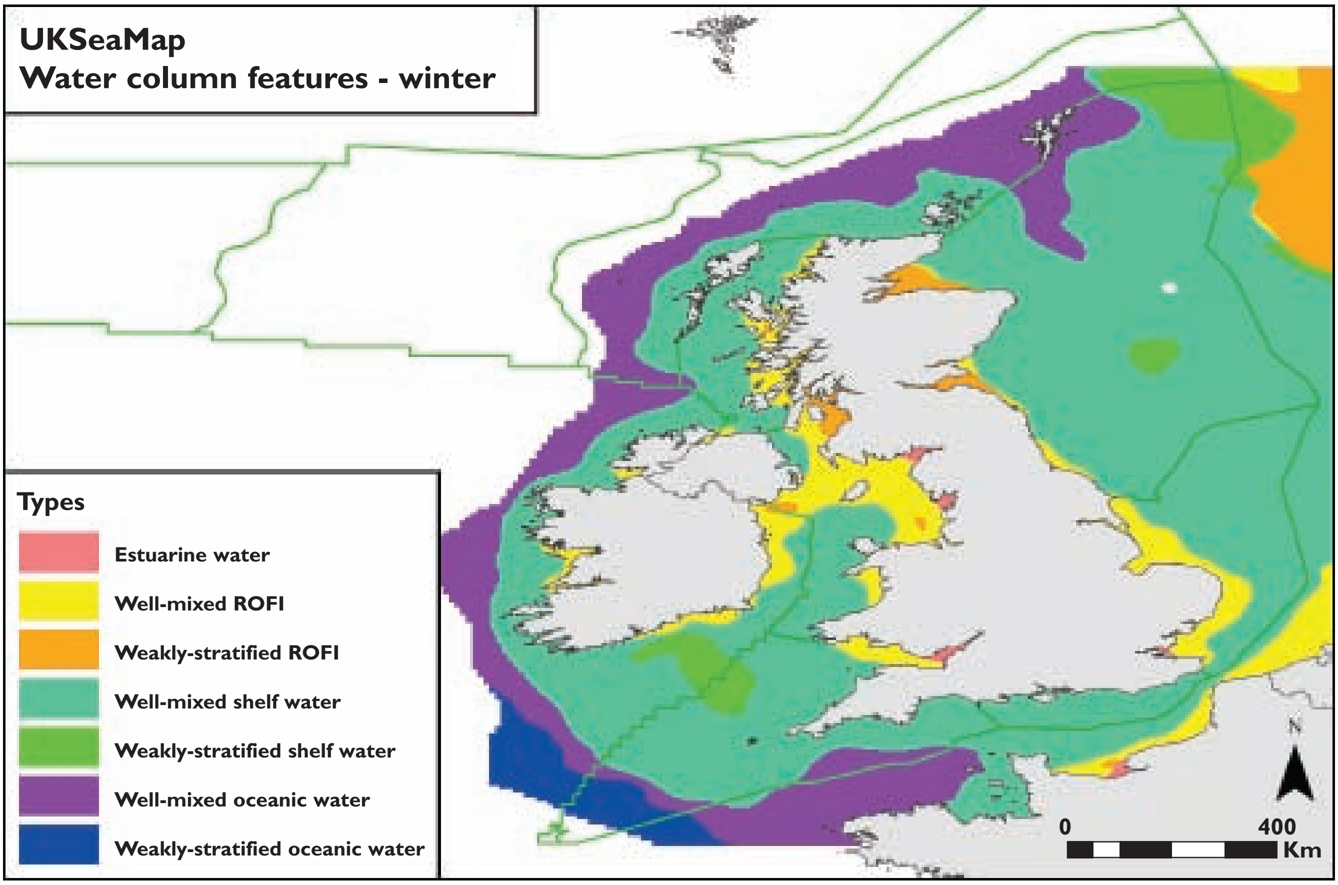


Figure 35. Winter water column features.

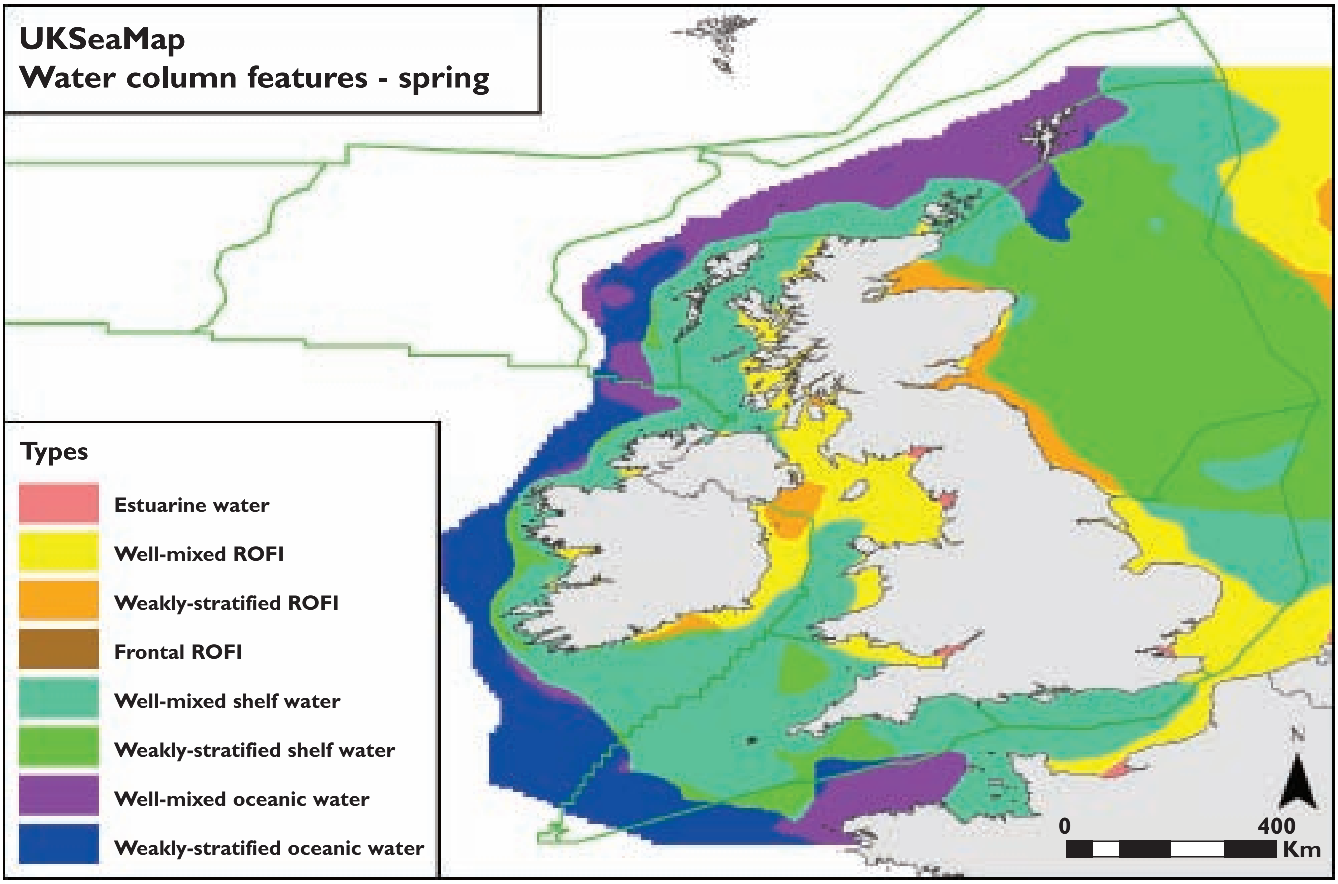


Figure 36. Spring water column features.

5.5 Biological validation

5.5.1 Data used

The water column maps were compared with plankton distribution data prepared by SAHFOS (Sir Alister Hardy Foundation for Ocean Science). These data showed the annual mean distribution of the following plankton taxa in the north-east Atlantic: the copepods *Calanus finmarchicus, Calanus helgolandicus* and *Metridia lucens*, decapod larvae and total dinoflagellate abundance. The data for these five plankton indicators were supplied as log transformed abundance per sample (per $3m^3$). Phytoplankton colour as an index of total phytoplankton biomass was also provided. Further information on the origin and development of these data sets, and their use in helping to classify and delineate water column features can be found in Edwards and Johns (2005). In contrast to the biological validation of the seabed landscapes, where it was possible to define the expected biological character of each type (in terms of its expected habitat composition), this was not possible for the water column as a detailed habitat classification for the water column is not available for UK waters.

5.5.2 Data analysis

The plankton distribution data were interfaced with the seasonal water column maps in a GIS using Spatial Analyst to determine a mean abundance of each plankton indicator for each water column type on a season by season basis.

5.5.3 Results – validity and characterisation of water column types

The results from the water column biological validation are shown in Tables 11-15. The grey shaded rows indicate the water column features which were not indicated in the analysis as being present during that particular season. In the 'relative contribution' tables, the figures given show the highest mean annual abundance as 100, with the remaining figures represented as a proportion of that highest figure (e.g. for Spring data, *Calanus finmarchicus* has its highest abundance as 0.458 per $3m^3$ for *Well-mixed oceanic waters*. The value of 0.254 per $3m^3$ for *Weakly-stratified oceanic waters* represents 55% of this maximum value. The relative contribution figures enable easier comparison of relationship of each taxon to one or more water column types.

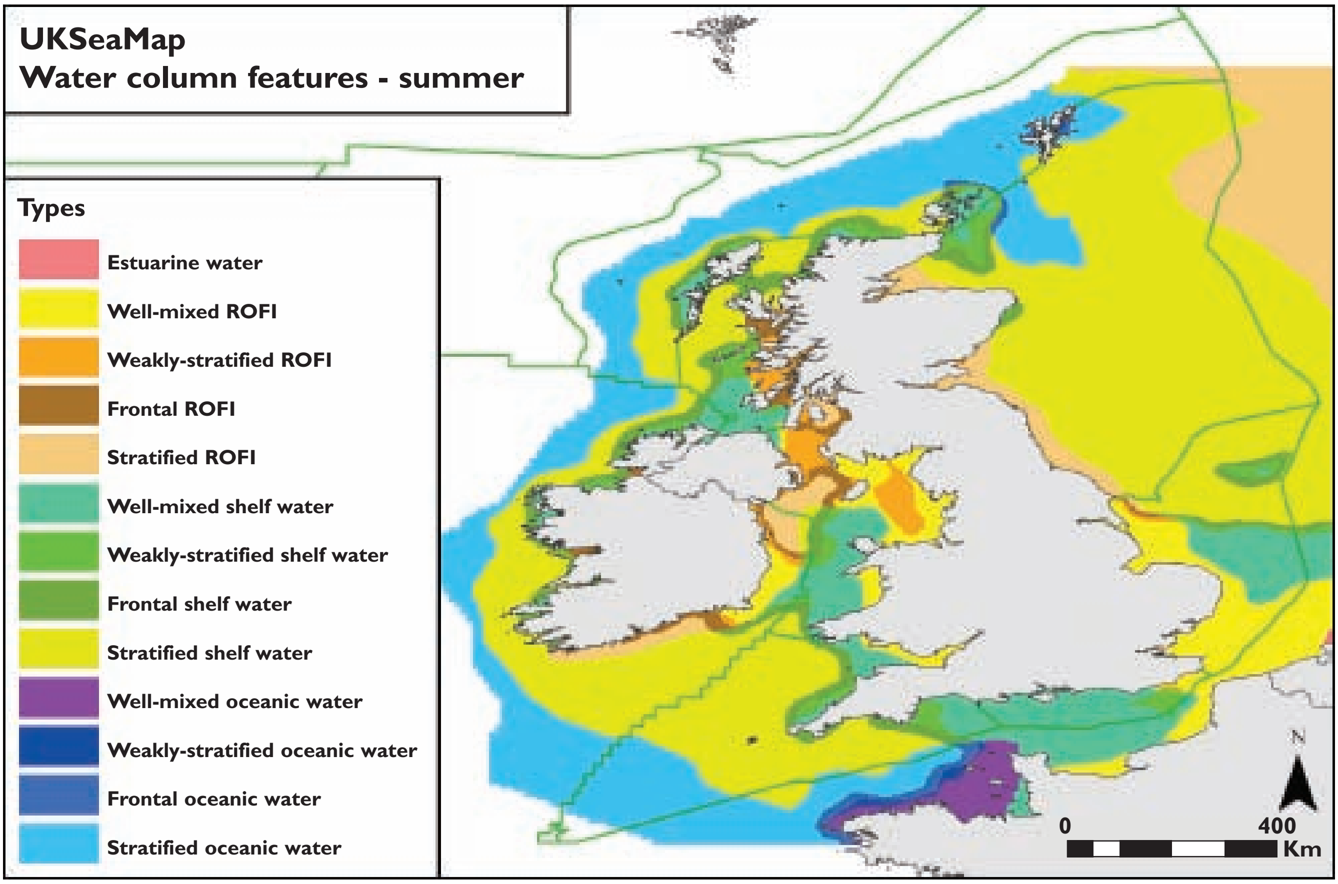


Figure 37. Summer water column features.

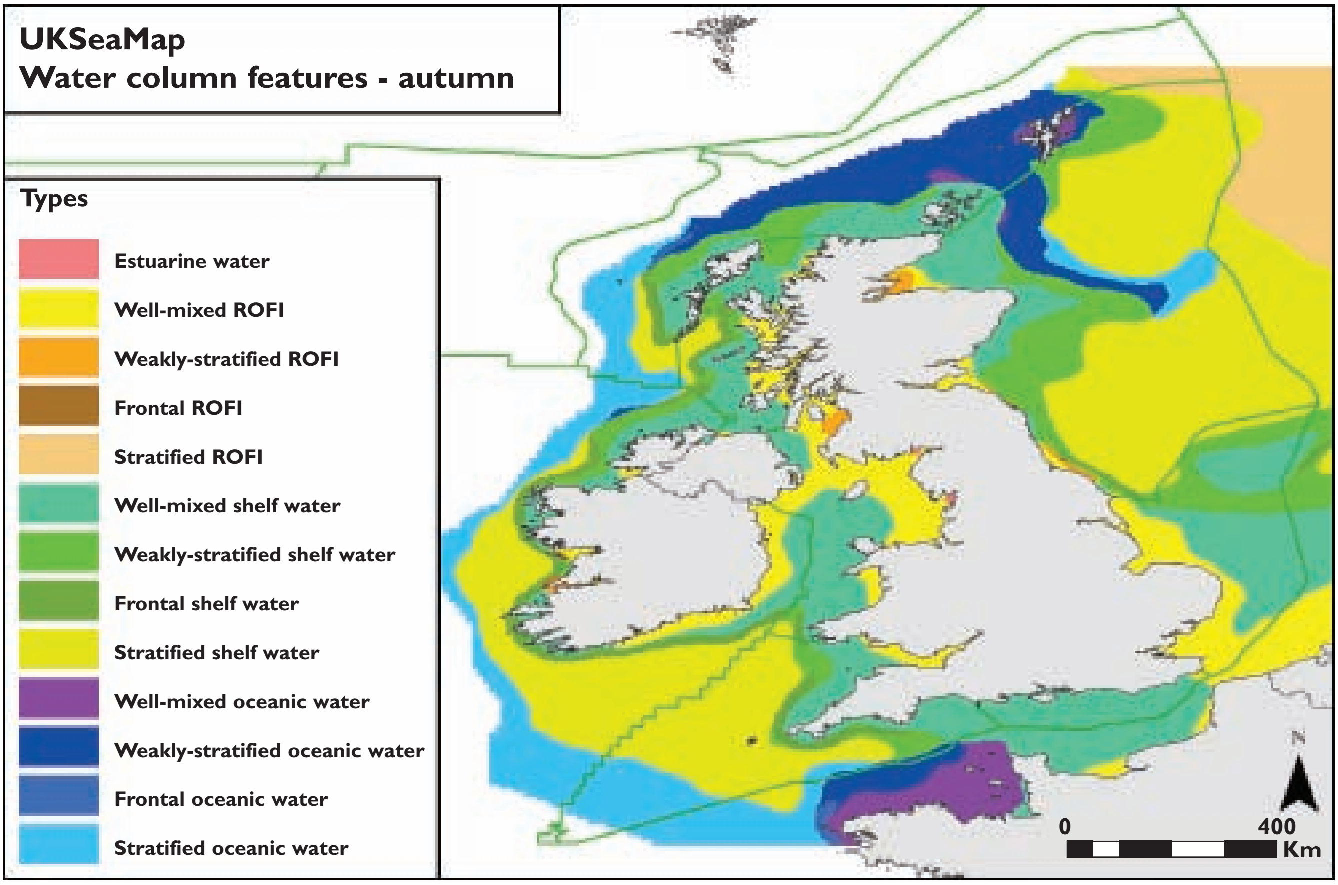


Figure 38. Autumn water column features.

Table 11. Water column features for Spring showing mean annual abundance (per 3m³) of the six plankton indicators and their relative contribution across the features for each indicator.

Mean annual abundance:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI						
Stratified ROFI						
Weakly stratified ROFI	0.194	0.307	0.246	0.093	1.570	0.911
Well mixed ROFI	0.118	0.297	0.320	0.070	1.558	1.060
Shelf frontal water						
Shelf stratified water						
Weakly stratified shelf water	0.401	0.302	0.182	0.100	1.856	1.030
Well-mixed shelf water	0.266	0.423	0.261	0.147	1.669	0.978
Oceanic stratified water						
Weakly stratified oceanic water	0.254	0.466	0.161	0.229	1.642	0.867
Well-mixed oceanic water	0.458	0.283	0.146	0.182	1.646	0.980

Relative contribution across water column features for each taxon:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI						
Stratified ROFI						
Weakly stratified ROFI	42	66	77	41	85	86
Well mixed ROFI	26	64	100	31	84	100
Shelf frontal water						
Shelf stratified water						
Weakly stratified shelf water	88	65	57	44	100	97
Well-mixed shelf water	58	91	82	64	90	92
Oceanic stratified water						
Weakly stratified oceanic water	55	100	50	100	88	82
Well-mixed oceanic water	100	61	46	79	89	92

Table 12. Water column features for Summer showing mean annual abundance (per $3m^3$) of the six plankton indicators and their relative contribution across the features for each indicator.

Mean annual abundance:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI	0.223	0.334	0.254	0.132	1.510	0.862
Stratified ROFI	0.440	0.258	0.164	0.121	1.705	0.821
Weakly stratified ROFI	0.187	0.262	0.306	0.089	1.525	0.960
Well mixed ROFI	0.081	0.287	0.339	0.052	1.587	1.171
Shelf frontal water	0.200	0.418	0.310	0.113	1.701	1.091
Shelf stratified water	0.380	0.362	0.188	0.134	1.794	0.980
Weakly stratified shelf water	0.213	0.295	0.360	0.061	1.861	1.403
Well-mixed shelf water	0.111	0.353	0.375	0.069	1.568	1.078
Oceanic stratified water	0.372	0.358	0.147	0.199	1.634	0.903
Weakly stratified oceanic water						
Well-mixed oceanic water						

Relative contribution across water column features for each taxon:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI	51	80	68	67	81	61
Stratified ROFI	100	62	44	61	92	59
Weakly stratified ROFI	43	63	82	45	82	68
Well mixed ROFI	18	69	90	26	85	83
Shelf frontal water	45	100	83	57	91	78
Shelf stratified water	86	87	50	68	96	70
Weakly stratified shelf water	48	71	96	30	100	100
Well-mixed shelf water	25	84	100	35	84	77
Oceanic stratified water	84	86	39	100	88	64
Weakly stratified oceanic water						
Well-mixed oceanic water						

Table 13. Water column features for Autumn showing mean annual abundance (per 3m³) of the six plankton indicators and their relative contribution across the features for each indicator.

Mean annual abundance:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI						
Stratified ROFI	0.702	0.223	0.084	0.201	1.807	0.769
Weakly stratified ROFI						
Well-mixed ROFI	0.122	0.293	0.320	0.072	1.547	1.033
Shelf frontal water	0.143	0.514	0.317	0.118	1.693	0.987
Shelf stratified water	0.397	0.394	0.173	0.145	1.792	0.922
Weakly stratified shelf water	0.360	0.274	0.203	0.111	1.807	1.094
Well-mixed shelf water	0.176	0.349	0.323	0.089	1.643	1.110
Oceanic stratified water	0.295	0.452	0.156	0.215	1.670	0.852
Weakly stratified oceanic water	0.473	0.261	0.139	0.174	1.650	0.973
Well-mixed oceanic water	0.463	0.300	0.159	0.159	1.594	1.005

Relative contribution across water column features for each taxon:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI						
Stratified ROFI	100	43	26	93	100	69
Weakly stratified ROFI						
Well-mixed ROFI	17	57	99	33	86	93
Shelf frontal water	20	100	98	55	94	89
Shelf stratified water	57	77	54	68	99	83
Weakly stratified shelf water	51	53	63	51	100	99
Well-mixed shelf water	25	68	100	41	91	100
Oceanic stratified water	42	88	48	100	92	77
Weakly stratified oceanic water	67	51	43	81	91	88
Well-mixed oceanic water	66	58	49	74	88	91

Table 14. Water column features for Winter showing mean annual abundance (per 3m³) of the six plankton indicators and their relative contribution across the features for each indicator.

Mean annual abundance:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI						
Stratified ROFI						
Weakly stratified ROFI						
Well-mixed ROFI	0.127	0.300	0.311	0.076	1.540	0.962
Shelf frontal water						
Shelf stratified water						
Weakly stratified shelf water	0.575	0.302	0.107	0.175	1.797	0.805
Well-mixed shelf water	0.309	0.360	0.230	0.120	1.742	1.022
Oceanic stratified water						
Weakly stratified oceanic water	0.095	0.603	0.165	0.235	1.523	0.682
Well-mixed oceanic water	0.427	0.309	0.161	0.187	1.680	0.992

Relative contribution across water column features for each taxon:

Water column feature	*Calanus finmarchicus*	*Calanus helgolandicus*	Decapod larvae	*Metridia lucens*	Total dinoflagellate	Phytoplankton colour index
Frontal ROFI						
Stratified ROFI						
Weakly stratified ROFI						
Well-mixed ROFI	22	50	100	32	86	94
Shelf frontal water						
Shelf stratified water						
Weakly stratified shelf water	100	50	34	75	100	79
Well-mixed shelf water	54	60	74	51	97	100
Oceanic stratified water						
Weakly stratified oceanic water	17	100	53	100	85	67
Well-mixed oceanic water	74	51	52	80	94	97

The copepod *Metridia lucens* appears to correlate well with the oceanic water column features; although it occurred in all water column features, it was recorded at highest abundance in the oceanic water column features such as *Weakly stratified oceanic water* (its relative contribution value to oceanic features was >70, whilst for shelf and ROFI features it was nearly always <70). This concurs with the use of *M. lucens* as a salinity indicator, indicating areas of high salinity.

The copepod *Calanus finmarchicus* is predominantly a boreal (cold-water) species whereas the copepod *Calanus helgolandicus* is predominantly a temperate (warm-water) species. These two plankton taxa were used to examine the distribution of bio-geographical boundaries and whether they coincided with water column feature boundaries. While *C. finmarchicus* generally occurred at higher abundances in stratified water column features, there were no clear patterns evident linking these two taxa with particular water column types. This may be due to the fact that a direct measurement of sea temperature was not used in UKSeaMap to develop the water column features.

A difference between summer stratified waters and tidally mixed waters was observed in the densities of decapod larvae, which were used as an indicator to represent the meroplanktonic fauna. This correlation was reflected in certain water column features across all seasons, where decapod larvae were recorded in their highest abundances in *Well mixed shelf water* but particularly in the *Well mixed ROFI* type.

Phytoplankton colour index (PCI) was consistently highest in well-mixed water column features, likely due to the increased availability of nutrients which tend to be limiting under stratified conditions.

The *total dinoflagellate* group occurred at the highest abundance of all six plankton indicators used across all four seasonal water column maps. The *Well mixed ROFI* in particular consistently contained the highest abundance of *total dinoflagellate* compared to all other water column types. Again, this may be due to the increased availability of nutrients in a well mixed water column.

In order to assess further the validity of the water column features using plankton data, it would be necessary to use plankton data split according to the same seasonal categories as used in the water column feature maps. The use of annual mean biological data appears to have reduced the ability to discriminate and validate trends occurring within each seasonal water column map. Nevertheless, certain plankton taxa, such as *Metridia lucens,* displayed trends in distributional abundance which was observed within the water column feature maps. Validation of the water column features on a cell by cell basis, rather than at a water column feature scale, could also be of merit. This may highlight more subtle trends across the water column features which were lost during the amalgamation process.

6 Web-based dissemination of the maps

A web-based GIS mapping facility has been developed to disseminate the underlying data sets and the resultant maps. The application was developed as part of the MESH programme (**www.searchMESH.net**), but the UKSeaMap results are made available as a separate output, via the JNCC web site at **www.jncc.gov.uk/UKSeaMap**.

7 Relationships to other ‘habitat’ schemes and data sources

In using the outputs of UKSeaMap, and when considering them in more technical discussions, readers should be aware of the relationship to other ways of classifying the marine environment. There are differences between these, such as the way in which the same feature might be classified or the scale at which classifications operate. Such differences do not necessarily mean any one classification is preferred over another, but rather they reflect the different purpose behind each classification. It is thus important to be aware of these differences when trying to interpret them individually and collectively. The following sections outline key differences between UKSeaMap and a number of other classifications that are currently of importance to marine management and protection.

7.1 Relationship to Habitats Directive Annex I types

The relationship between Annex I habitats and the marine landscape types is given in Table 15.

Table 15. Relationship between Annex I habitat types and marine landscape types.

Annex I habitat type	Equivalence	Marine landscape type
Sandbanks which are slightly covered by sea water all the time	Includes some of	Subtidal sediment banks
Estuaries	Equals	Estuary
Mudflats and sandflats not covered by seawater at low tide	Included within	Shallow sand plains, or Shallow mud plains
Lagoons	Equals	Lagoons
Large shallow inlets and bays	Includes some of	The following, where the specific site meets the EC definition: Rias Sealochs Embayments Bays
Reefs	Includes some of	Photic rocks, and Aphotic rocks
Submerged or partially submerged sea caves	Occur within	Photic rocks, and Aphotic rocks

Where possible the landscape types have been directly linked with Annex I features; the landscape maps therefore provide an initial overview of Annex I distribution in the UK. However, as the Annex I habitats are specifically defined in EC guidance (European Commission 1999), and are subject to modification, the landscape maps should not be taken to encompass all areas that might qualify as Annex I habitat. For instance, the areas of *Reef* habitat are significantly under represented in the maps (due to the lack of coastal rock in the substratum data set). Conversely only a portion of the sealochs, embayments and bays in the landscape map will meet the EC definition (which is interpreted in the UK to have a particular depth limit).

7.2 Relationship to OSPAR habitats

Most of the habitats on the OSPAR List are at a finer level of detail than marine landscape types and are better equated to habitats within the EUNIS classification (see correlation table at **www.jncc.gov.uk/page-3365**). However, the OSPAR habitat *Seamounts* equates to the marine landscape type *Deep ocean rise* and *Carbonate mounds* are also a marine landscape type.

7.3 Relationship to EUNIS habitat classification

The relationship to the habitat classification scheme of EUNIS is given in Annex 7. Broadly, the modelled seabed and water column types can be directly related to one or more EUNIS broad habitat types. The seabed types, defined by sediment type and depth, are most readily equated to particular EUNIS types. However, as these features may occur within some of the topographically-defined marine landscape types, there may not always be a simple 1:1 relationship to EUNIS.

7.4 Access to more detailed habitat and species data

The UKSeaMap project is intended to provide only a broadscale suite of seabed and water column types for UK seas; more detailed maps on marine habitats can be found at **www.searchMESH.net**. These data are primarily presented as polygon data, but point sample biological data referenced to the national habitat classification are also presented. The National Biodiversity Network Gateway (**www.searchNBN.net**) holds a similar set of point sample biological data, with facilities to search and map at the species level.

8 Limitations and lessons learned

Some overall limitations of the maps developed within the project are outlined in Section 2.6. These and further considerations are outlined below:

- The relative coarseness of the grid used, particularly for the areas beyond the Continental Slope, means that the maps are not suitable for fine-scale management and advisory uses. The associated MESH project is collating fine-scale data, where this is available, and is thus better suited to fine-scale management issues.
- Some areas have no data or insufficient data and remain unmapped.
- In view of the need to use relatively coarse DEMs which provide full UK coverage, it has not been possible to identify more fine-scale topographic and bed-form 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.
- In some coastal areas there is considerable under representation of rock in the seabed substratum data set, which has had a significant effect on the biological validation and confidence assessment in the coastal zone (see Section 4.8).
- Section 4.6.6 highlights further aspects resulting from the biological validation process that have indicated areas of uncertainty in either the seabed landscape map or in the biological validation data.
- There is generally a paucity of biological validation data for offshore and deep-water habitats which has led to insufficient data to validate the landscape types for these regions. Additionally limitations in the modelling data for these regions, particularly for deep-water, and the lack of a detailed deep-water habitat classification, yield a lower level of confidence in the maps for these areas.

Despite having gained the practical experience of developing a marine landscape map for the Irish Sea Pilot, undertaking the UKSeaMap project has provided a number of additional challenges which were not anticipated at the start of the project. The highlighting of these issues may provide guidance to others wishing to embark on a similar modelling process, as well as to those with a strategic interest in such issues, such as government:

- The scale of the area to be mapped and its variation in character from small coastal features, such as lagoons, through to the extensive deep-water zones beyond the continental shelf, requires significant additional effort to coordinate the data required at this scale. With multiple options for data storage, manipulation and processing, the final data and methodology used were the result of a significant number of trials, each of which had to be evaluated within the context of the available data, technical expertise and time.
- Acquisition of suitable data sets which covered the entirety (or majority) of the UK waters. The data sets for physical and hydrographic parameters often had limitations in terms of geographical coverage, resolution or format, and the final data sets used were sometimes a compromise of these aspects (for instance, the best data may not have had sufficiently wide geographical coverage).
- Where suitable data were available, they often required considerable additional processing to get them into a suitable GIS format and to define categories which related directly to ecological character.
- Whilst the physical and hydrographic data sets used were mostly sourced from single organisations able to provide a UK-wide data set, access to biological seabed sample data was via a wide range of organisations. As was encountered with the Irish Sea Pilot, acquiring such data proved very time consuming as many organisations do not yet have the data fully archived to facilitate its rapid provision.
- Overall, the project has raised considerable interest amongst stakeholders who wish to use the final maps and the web-GIS. Stakeholder expectations have sometimes needed to be managed in relation to the level of detail achievable, or the amount of data that could be acquired for certain parts of the project. This has necessarily led to lowering their expectations as to how much the project could achieve in the time available or its suitability for their intended use.

9 Future development of UKSeaMap

The maps resulting from the UKSeaMap project have started to be used by others who have developed some aspects of the uses identified in Section 2.5. For example, a Defra-funded project by the University of Wales at Bangor has undertaken a preliminary scoping study to identify a network of marine protected areas that represent the range of marine landscapes defined by UKSeaMap (Richardson *et al.* 2006). Ongoing work at CEFAS is examining the relationship between the marine landscape types and the distribution of human activities, such as fishing (see Eastwood *et al.* in prep.).

The work undertaken to produce the seabed and water column maps and to validate them with biological data has led to maps with varying levels of quality or confidence, as might be expected from a methodology using data over this scale and complexity. To ensure the maps remain useful into the future there is a need to work towards improving and maintaining their overall quality (confidence). This work can be achieved under a number of themes:

- Quality and completeness of the underlying data sets
    - Incorporation of data on substratum type from the ground-truth data – this is particularly important for rock habitats close to the coast.
    - Use of higher resolution substratum data, where available, such as the coastal characterisation data being produced by BGS.
    - Addition of finer-scale data where available, such as for rocky mounds and outcrops from SEA surveys, additional pockmark and carbonate features in the Irish Sea, diapers in the Faroe-Shetland Channel, moraines, drowned cliff lines and peat beds.
    - Improvement in the modelled data set for near-bed stress to take account of known areas of strong tidal currents, particularly around Scotland.
    - Development of a Data Management Plan – to improve documentation of each data set used, and track updates as they become available.
- Modifications to the models
    - Consideration of using temperature for the water column model, further differentiation of bottom temperature (e.g. below 0°C in Faroe-Shetland Channel), and consideration of the importance of annual variation of bottom temperatures.
    - Consideration of modelling the water column in 3D to reflect known differences in water mass with depth (e.g. because of temperature).
    - Validation of the water column features on a cell by cell basis, rather than at a water column feature scale, may highlight subtle trends across the water column features which are lost in the present analysis.
    - Consideration of the use of internal wave data which is known to have a significant influence on ecological character of the seabed in some areas (e.g. slope west of Shetland).
    - Assessment of whether oxygenation (anoxia, hypoxia) and nutrient loading (oligotrophic, eutrophic) should be added to the seabed model (both parameters are important in determining ecological character at various scales).
- Quality and completeness of the biological validation data
    - The seabed biological validation for offshore areas needs further analysis to confirm the habitat types identified using the Habitat Matching Program, as the habitat standards are limited in this area; additionally more detailed assessment of the mis-matches between seabed substrata and biological validation data for the modelled landscape types are needed, as well as further assessment of the validity of the bed-stress sub-types. This work should help improve the validation for the relevant landscape types.
    - There remain significant offshore areas for which validation has not been possible. Of particular note is the use of SEA data for deep water, which needs classification (into habitat types) before assessment against the landscape map.
    - Use of plankton data at the seasonal level rather than annual averages, to better coincide with the seasonal water column maps.
- Refinement of the landscape classification, through more detailed analysis
    - Some coastal physiographic types, in particular sealochs, estuaries and lagoons, are quite broad in character, and a more in-depth analysis would lead to a more refined classification of these features. Whilst there are existing classifications available, these are mostly based on their physical characteristics; an analysis of their ecological character is required to produce more ecologically relevant classifications of these features.
- Maintenance of the webGIS facility
    - The UKSeaMap webGIS data sets will be uploaded to the MESH web site, but both projects will run for a limited period and consideration needs to be given as to how both the MESH and UKSeaMap data sets can be maintained, and where possible added to and improved, beyond the end of the two projects.
    - Development of a 3D 'fly through' bathymetric model for UK waters over which the landscape types are draped, to provide a much more powerful visual display of the maps for end-users.

- Integration of the UKSeaMap broadscale maps with finer scale habitat maps
  - UKSeaMap provides a broadscale modelled characterisation of the UK seas based on a series of thematic data sets, often at relatively course resolution. Ultimately, it should be the intention to improve the quality of the maps with improved data; this can be achieved through integration of more high resolution data as it becomes available. For instance, using high quality multibeam acoustic data and other more detailed habitat maps to update the present landscape maps (i.e. replace the broader scale modelled landscape types with real data) so that confidence in the map can be further improved. Consideration needs to be given here to both the classification system used (landscapes versus habitats) and the scale at which the maps are presented (aggregation of finer scale data).
- Assessment of the relationship between water column and seabed types
  - Assessment of the relationship between the seabed types and the water column types would be valuable as the character of seabed communities relies heavily on the influences of the water column, both in relation to its hydrographic properties (salinity, temperature, water quality), and its plankton (many benthic species have planktonic larval stages). Additionally, pelagic and demersal fish species might be expected to show a relationship to seabed types, which could be useful both in fisheries management and environmental protection.
- Development of a strategy and process for incorporating new data
  - Further new information will become available over time and a process is needed to enable it to be incorporated so that the underlying data sets and resultant landscape maps can be periodically updated.
- Re-evaluation of the regional seas boundaries
  - The collation of information on a series of physical and hydrographic data layers provides the relevant information to assess the appropriateness of the current (draft) regional seas boundaries and to recommend modifications if appropriate.

10 References

Ahlqvist, O., Keukelaar, J. & Oukbir, K. (2000). Rough Classification and accuracy assessment. *International Journal of Geographical Information Science*, **14(5)**: pp 475-496.

British Geological Survey. 1987. *Sea bed sediments around the United Kingdom (2 sheets). 1:1,000,000*. Keyworth, British Geological Survey.

Chapman, N. 2006. *Habitat Matching Program: guidance manual. v2*. Peterborough, Joint Nature Conservation Committee.

Comber, A. J., Fisher, P. F. & Wadsworth, R. A. (2004). Assessment of a semantic statistical approach to detecting land cover change using inconsistent data sets. *Photogrammetic Engineering and Remote Sensing*, **70**(8): pp 931-938.

Connor, D.W., Brazier, D.P., Hill, T.O., & Northen, K.O. 1997. *Marine Nature Conservation Review: marine biotope classification for Britain and Ireland. Volume 1. Littoral biotopes. Volume 2. Sublittoral biotopes. Version 97.06*. JNCC Report, nos. 229 & 230.

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L. Lieberknecht, L.M., Northen, K.O. & Reker, J.B. 2004. *The Marine Habitat Classification for Britain and Ireland. Version 04.05 (internet version: **www.jncc.gov.uk/MarineHabitatClassification**)*. Peterborough: Joint Nature Conservation Committee.

Connor, D.W., & Hiscock, K. 1996. Data collection methods (with Appendices 5 - 10). *In: Marine Nature Conservation Review: rationale and methods*, ed. by K. Hiscock, 51-65, 126-158. Peterborough: Joint Nature Conservation Committee. (Coasts and seas of the United Kingdom. MNCR series.)

Cooper, R., Henni, P., Long, D., & Pickering, A. 2005. *Report explaining BGS data input to the UKSeaMap project – broadscale mapping of the seas around the UK*. Edinburgh: British Geological Survey.

Davidson, N.C., Laffoley, D.d'A., Doody, J.P., Way, L.S., Gordon, J., Key, R., Pienkowski, M.W., Mitchell, R., & Duff, K.L. 1991. *Nature conservation and estuaries in Great Britain*. Peterborough: Nature Conservancy Council.

Defra. 2001. *Review of Marine Nature Conservation – Interim report, March 2001*. London: Department for Environment, Food and Rural Affairs.

Defra. 2002. *Safeguarding our Seas: a strategy for the conservation and sustainable development of our marine environment*. London: Department for Environment, Food and Rural Affairs.

Defra. 2004. *Review of Marine Nature Conservation: Working Group report to Government*. London: Department for Environment, Food and Rural Affairs.

Defra. 2005. *Charting Progress: An Integrated Assessment of the State of the UK Seas*. London: Department for Environment, Food and Rural Affairs.

Dinter W.P. 2001. *Biogeography of the OSPAR Maritime Area*. Bonn: Bundesamt for Naturschutz. 167 pp.

Dunton, K.H. 1990. Growth and production in *Laminaria solidungula*: relation to continuous underwater light levels in the Alaskan High Arctic. *Mar. Biol.* **106**: 297-304.

Eastwood, P.D., Houghton, C.A., Rogers, S.I., Mills, C.M., & Aldridge, J.N. In prep. *Human activities in UK offshore waters: an assessment of pressure on the seabed*. Paper by Cefas, Lowestoft.

Edwards, M., & Johns, D.G. 2005. *Biogeographical provinces of the northeast Atlantic based on plankton data*. Plymouth: Sir Alister Hardy Foundation for Ocean Science. 3pp.

European Commission. 1999. *Interpretation manual of European Union habitats. EUR 15/2*. Brussels: European Commission.

Glémarec, M. 1973. The benthic communities of the European North Atlantic continental shelf. *Oceanography and Marine Biology: An Annual Review*, **11**: 263-289.

Gilliland, P.M., Connor, D.W., Golding, N., Laffoley, D. d'A., Burt, J., Baxter, J., Hamer, J. & Breen, J. 2004. *A 'countryside map' for the sea (CMap): Outline project proposal.*, Peterborough: English Nature (Unpublished).

Golding, N., Vincent, M. & Connor, D.W. 2004. *Irish Sea Pilot - Report on the development of a marine landscape classification for the Irish Sea*. Peterborough: Joint Nature Conservation Committee (and online at **www.jncc.gov.uk/irishseapilot**).

Graham, C, Campbell, E, Cavill, J, Gillespie, E, & Williams, R.. 2001. *JNCC Marine Habitats GIS Version 3: its structure and content.* Edinburgh: British Geological Survey (Commissioned Report, CR/01/238) 45pp.

Holt, J.T., Allen, J.L., Proctor, R. & Gilbert, F. 2005. Error quantification of a high resolution coupled hydrodynamic-ecosystem coastal-ocean model: part 1 model overview and assessment of the hydrodynamics. *Journal of Marine Systems*, **57**: 167-188.

Holt, J.T. & James, I.D. 2001. An s-coordinate density evolving model of the North West European Shelf. Part 1 Model description and density structure. *Journal of Geophysical Research*, **106(C7)**: 14015-14034.

Howson, C.M., Connor, D.W., & Holt, R.H.F. 1994. *The Scottish sealochs. An account of surveys undertaken for the Marine Nature Conservation Review*. (Contractor: University Marine Biological Station, Millport.) JNCC Report, no. 164. (Marine Nature Conservation Review Report, No. MNCR/SR/27.)

Jackson, D.L. & McLeod, C.R. (Eds) (2000, revised 2002) *Handbook on the UK status of EC Habitats Directive interest features: provisional data on the UK distribution and extent of Annex I habitats and the UK distribution and population size of Annex II species.* JNCC Report, no. 312.

Joint Nature Conservation Committee. 1996. *Guidelines for selection of biological SSSIs: intertidal marine habitats and saline lagoons.* Peterborough: Joint Nature Conservation Committee.

Laffoley, D. d'a., Baxter, J., Bines, T., Bradley, M., Connor, D.W., Hill, M., Tasker, M. & Vincent, M. 2000. *An implementation framework for conservation, protection and management of nationally important marine wildlife in the UK.* (Report to the DETR Working Group on the Review of Marine Nature Conservation by the statutory nature conservation agencies, Environment Heritage Services (Northern Ireland) and JNCC). Peterborough: English Nature Research Reports, No. 394 (29 pp).

Richardson, E.A., Kaiser, M.J., Hiddink, J.G., Galanidi, M., & Donald, E.J. 2006. *Developing scenarios for a network of Marine Protected Areas*. Report to Defra, Bristol. Bangor: School of Ocean Sciences, University of Wales (Research and Development Contract CRO 0348).

Roff, J.C., & Taylor, M.E. 2000. Viewpoint: national frameworks for marine conservation a hierarchical geophysical approach. *Aquatic Conserv: Mar. Freshw. Ecosyst.* **10**: 209-223.

Rogers, S., Allen, J., Balson, P., Boyle, R., Burden, D., Connor, D., Elliott, M., Webster, M Reker, J., Mills, C., O'Connor, B., & Pearson, S. 2003. *Typology for the Transitional and Coastal Waters for UK and Ireland.* (Contractors: Aqua-fact International Services Ltd, BGS, CEFAS, IECS, JNCC). Funded by Scotland and Northern Ireland Forum for Environmental Research, Edinburgh and Environment Agency of England and Wales. SNIFFER Contract ref: WFD07 (230/8030)). 146 pp.

Simpson, J.H. & Bowers, D. 1981. Models of stratification and frontal movement in shelf seas. *Deep Sea Research*, **28**: 727-738.

Vincent, M.A., Atkins, S.M., Lumb, C.M., Golding, N., Lieberknecht, L.M. & Webster, M. 2004. *Marine nature conservation and sustainable development - the Irish Sea Pilot.* (Report to Defra). Peterborough: Joint Nature Conservation Committee.

11 Acknowledgements

This project has only been possible through the valuable contributions of many individuals and organisations on a variety of aspects.

The members of the PSG, chaired initially by Dominic Whitmee (Defra) and then by Paul Gilliland (English Nature) have supported the project throughout and provided valuable guidance as the project has progressed:

British Geological Survey – Dave Long

CCW – John Hamer, Andrew Hill, Kirsten Ramsay

Crown Estate – Mike Cowling

English Nature – Paul Gilliland, Dan Laffoley

Defra –Naomi Keeble, Jo Myers, Dominic Whitmee

DTI – Kevin O'Carroll, Ollie Whitehead

ODPM – Brian Marker

RSPB – Annie Smith

Scottish Executive – Evanthia Karpouzli, David Mallon, John Tait, John McIvor

WWF – Alison Champion

Considerable technical input was received both from data suppliers and reviewers of the draft maps, and via the Technical workshop in January 2006, all of which has made the end results more scientifically robust and ensured the final maps are of wide value, including from:

Cefas – Paul Eastwood

CCW – Karen Robinson

Defra – Beth Greenaway

English Heritage – Chris Pater

FRS – Simon Greenstreet, Bill Turrell

Hartley Anderson Ltd – John Hartley

JNCC – Natalie Coltman, Kirsteen McKenzie, Malcolm Vincent

MBA – Keith Hiscock

PML – Mike Kendal, Kirsten Richardson

Proudman Oceanographic Lab. – Jason Holt

SEPA – Mark Williams

SMRU – Ian Boyd

SNH – George Lees, Colin Stewart

SAHFOS – David Johns

University of Liverpool – Chris Frid

Annex 1: Examples of the need for, and potential benefits of, UKSeaMap outputs

A geophysical spatially-based approach to marine ecosystems, available in the short to medium term, is necessary because, for example:

- Enhanced stewardship of the marine environment based on an ecosystem approach would be impossible without a basic understanding of the physical location and scale of major components of marine ecosystems, on the seabed and in the water column;
- It enables a move to be made away from reactive management to proactive management of marine ecosystem components;
- It provides a framework to improve the capacity to address and manage risk and uncertainty associated with the marine environment;
- It rapidly provides an essential part of the framework needed to support the implementation of internationally agreed commitments and targets, such as halting decline in biodiversity by 2010, applying the ecosystem approach by 2010, implementing MPA networks by 2012, and recovering and sustaining fish stocks by 2015;
- Through information on the distribution of marine ecosystem components, it provides a fundamental basis for marine spatial planning and the benefits this could provide, such as more effective reduction in conflict between different activities and between activities and the environment. It is important that such information is available in the short term to support likely pilot projects to explore the role of marine spatial planning. Spatial planning is recognised at UK, OSPAR and EU levels as a potentially key tool to achieve better integration and regulation in the management of human activities;
- It provides an essential spatial context for assessment of rapidly evolving sectors of use, such as aggregate extraction and wind farms, and cumulative effects across all sectors. It also provides an essential layer of information to support implementation of the Strategic Environmental Assessment Directive (being considered now but required from 2004) and potentially the Environmental Liability Directive;
- It rapidly provides a more informed basis to help focus future spatially-based research and survey requirements, and in so doing helps to maximise cost-effectiveness and reduce possible replication of effort.

Annex 2: Recommendations from the RMNC and Irish Sea Pilot

The Irish Sea Pilot (Vincent *et al.* 2004) included the following recommendations:

R14 The marine landscape approach should be adopted as a key element for marine nature conservation and utilised in the spatial planning and the management of the marine environment. The approach should take account of broadscale marine habitat information, as this information becomes available over time. In coastal and estuarine waters the approach should seek to complement that taken under the Water Framework Directive (in relation to typology and reference conditions) at a more detailed level.

R15 A list of internationally-agreed marine landscapes for the North-East Atlantic should be developed. 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. Work to complete the mapping of these marine landscapes in the North-East Atlantic should be undertaken in collaboration with other countries.

The Review of Marine Nature Conservation (Defra 2004) included the following recommendations:

Key recommendation 3:

Government should refine the process for identifying Marine Landscapes, and agree and map them in all UK waters.

Supporting recommendations:

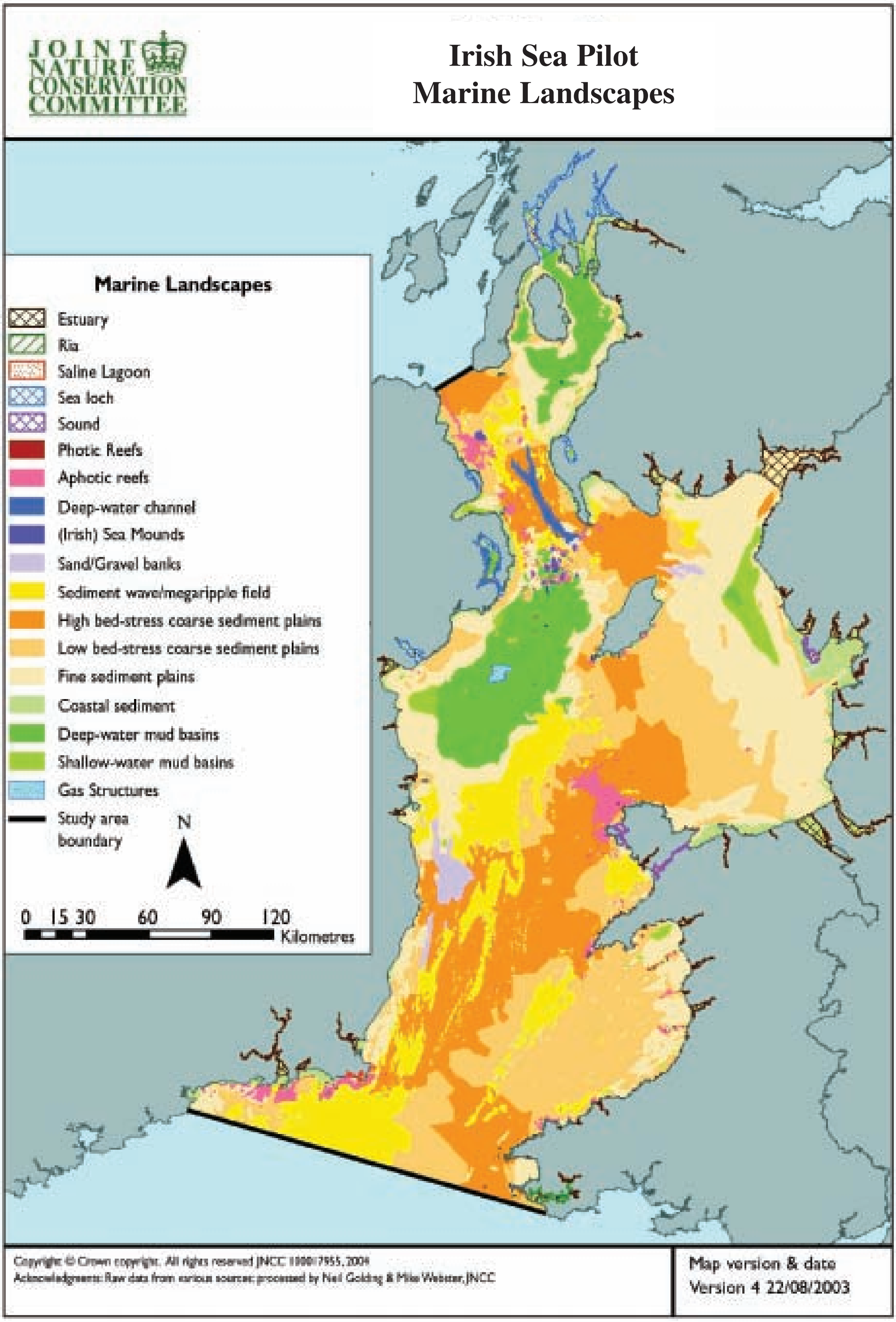
3.1 A list of agreed Marine Landscapes should be developed for UK waters. The list identified for the Irish Sea should be expanded to include landscapes not found in the Irish Sea and further refined as necessary, in particular in relation to the water column. Work should be initiated to complete the mapping of these Marine Landscapes for UK waters.

3.2 Further work should be undertaken to determine the degree of correlation between Marine Landscapes and adult populations of vertebrate (i.e. pelagic fish, seabirds and sea mammals) and invertebrate species.

3.3 Work should be initiated to develop a list of internationally agreed landscapes for the North-east Atlantic and work to map these should be undertaken in collaboration with other countries.

3.4 The methodology for sensitivity and vulnerability of Marine Landscapes should be further developed and refined.

Annex 3: Irish Sea Pilot marine landscape map



Annex 4: Detailed considerations about project methodology

Analysis process

Unsupervised classification approach

An unsupervised approach uses algorithms to cluster multivariate data based solely on the values of the inputs, without any training. Clusters produced by the analysis must then be related to real world features in order to be described. The advantage of this method is that almost all subjectivity is removed from the process. However, the disadvantage of using this method is that it could produce a very 'messy' picture (because of the large number of possible combinations, based on the number of data sets and the number of categories within each), which could need significant additional scientific interpretation into suitable mapping units (classes). A commonly used algorithm for this type of analysis is a Maximum Likelihood Classifier (MLC) and the use of this was investigated. The MLC, however, assumes a normal distribution of data values whilst the inputs for the seabed analysis (see Section 4.3) are a combination of continuous and categorical data types, thus making the MLC an inappropriate technique for the project. Non-parametric unsupervised techniques are also available within the field of data mining. Software to carry out such methods, developed by the University of Waikato, New Zealand, were examined but it was not considered feasible to use this technique within the current project timescale.

Supervised classification approach

A supervised approach relies on a degree of guidance being provided by the mapping scientist. This guidance draws upon expert judgement and prior knowledge, which means that the process, and often the output, can be more intuitive and less abstract in nature. Although this method may be criticised on the basis of being subjective, it would seem short sighted to not apply the wealth of knowledge and understanding we have about marine ecosystems to the classification process in this project. This method relies on developing broad definitions for each marine landscape type prior to the data analysis stage (i.e. supervising the classification of marine landscape types), recognising that criteria used to define each landscape type have ecological relevance. After applying these criteria to the data sets, the validity of the resulting units can be tested with biological data.

GIS data type

Vector

Vector data type refers to the storage of spatial data in the form of points, lines and polygons. All of these are specific locations, or nodes, which in the case of lines and polygons are joined together by arcs. Vector data types were used to develop the Marine Landscapes classification for the Irish Sea Pilot, so it is a valid method to adopt. In order to do this all the input data sets need to be converted to polygons, representing areas of each class, and then overlaid. Problems created by this approach include the creation of very small sliver polygons, which must be dealt with in a consistent way, and also if the situation were to arise that thresholds need to be changed then the input data set must be recreated and the analysis re-run. Running the 'union' command in ArcGIS (the command that overlays data sets) is also very time consuming and demanding on computer processor power.

Raster

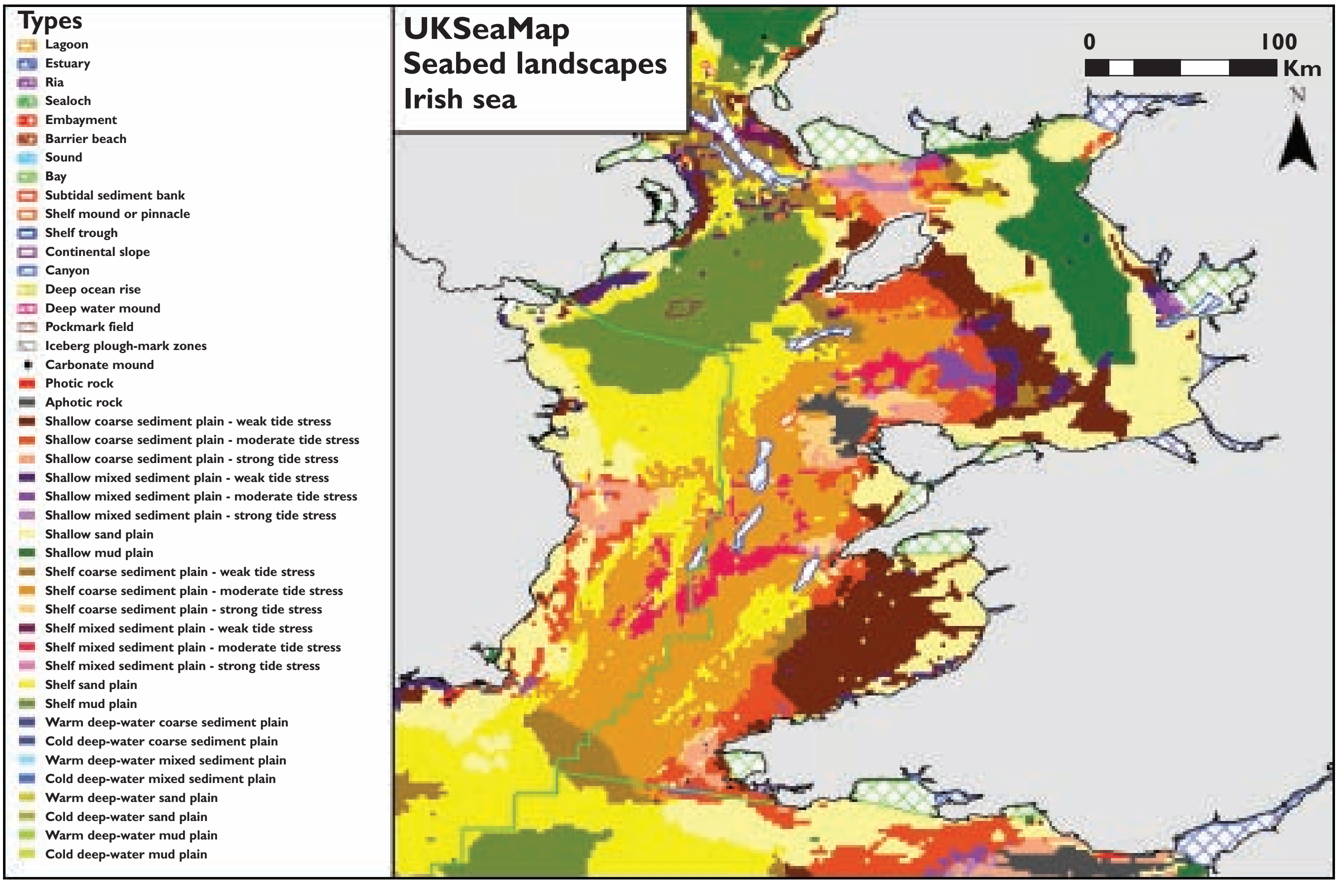
Raster data refers to the storage of spatial data in the form of a continuous field of uniform cells (i.e. a grid layer), each with an associated value. Although analysing and combining raster data in ArcGIS is quicker than vector data, it has the disadvantage of not containing any attribute information, which can store additional information about the data layer.

Annex 5: Identification of coastal physiographic types in a GIS

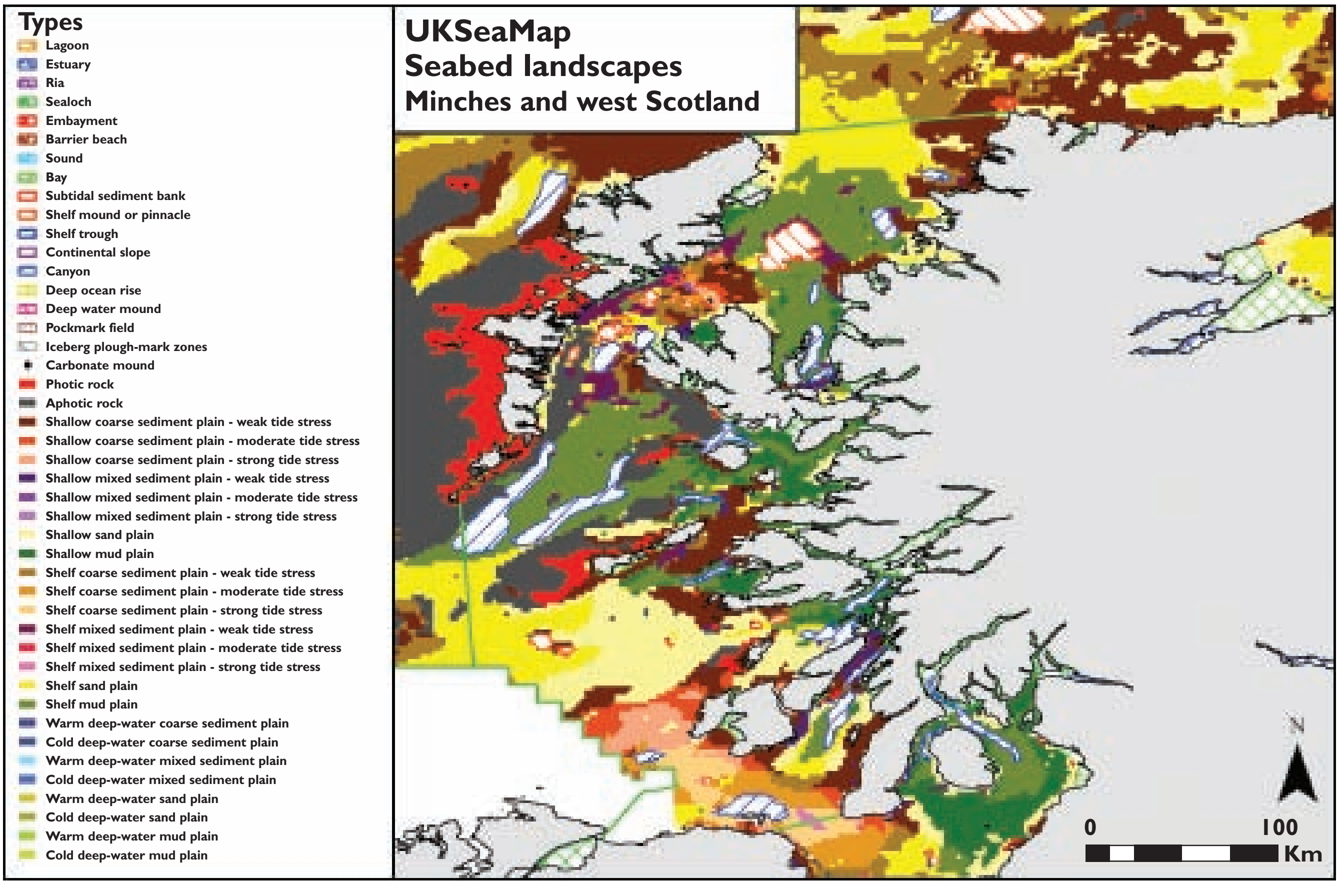
To define, in a GIS, which parts of the coast could be classified as a coastal physiographic feature, a set of rules was established which were used to distinguish the features from the adjacent 'open coast'. These rules were applied to an Ordnance Survey 1:25,000 coast line. As lagoons are generally very small features, these have mostly been identified from specific studies (e.g. MNCR survey of Scottish lagoons) rather than via the following approach.

	Application
Landward Seaward	Normal Tidal Limit, as indicated on the OS map. Some rias and bays may have an estuary on their boundary landward side.
Seaward boundary	Line between headlands at the mouth of the estuary, inlet or bay (if necessary, including islands in the mouth) where it opens to open coast (or into a bay). Where several estuaries, inlets or bays share a mouth, the outer-most limit was used to encompass a 'system'. Where unclear (i.e. there are no distinct headlands), a line was drawn from the point on the coast where orientation changes to predominantly an open coast aspect.
Height boundary	OS High Water.
Physiographic type	Separated according to overall shape and depth profile characteristics, exposure to onshore winds and salinity input: Estuaries (coastal plain, bar-built and complex, as defined by Davidson *et al.* 1991). Marine features which generally have a large riverine input (from one or several rivers).Rias in south-west Britain (excluding significant estuarine areas at their heads). Embayments – predominantly enclosed features, lacking large riverine input and the typical elongated estuary structure (typically broad inside a narrow entrance). Sealochs and Shetland voes – glacially-derived features. Bays – indentations of the open coast, bounded by headlands which provide some shelter from along-shore winds (but which are predominantly open to onshore winds). Generally length (from mouth to head of bay) at least half width (at mouth).
Depth	No depth limit; vary from predominantly intertidal to over 200m deep. Specific coastal types, however, have typical depth profiles.
Size	Upper limit – The Wash (62,000 ha) Lower limit – 200 ha for open coast bays; 100 ha for enclosed coast rias, voes, embayments and sealochs. Very small estuaries sometimes included as part of larger bay/inlet. Note that no lower size limit has been applied to lagoons. Working size limits have been adopted to exclude both very small and very large areas of (open) coast that might, at some scales, be considered to meet the definitions applied above (e.g. for bays).

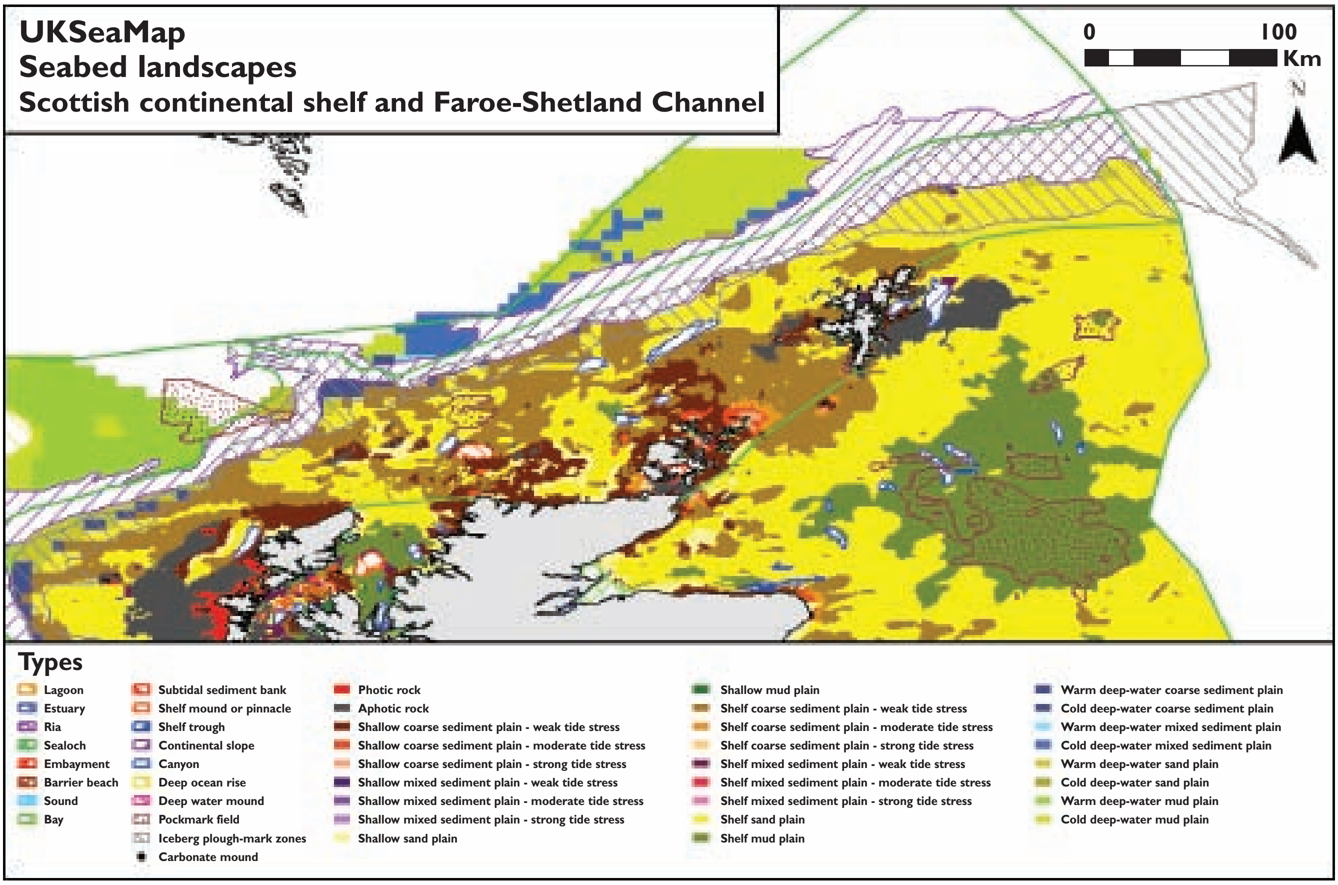
Annex 6: Seabed landscape maps for UK regions



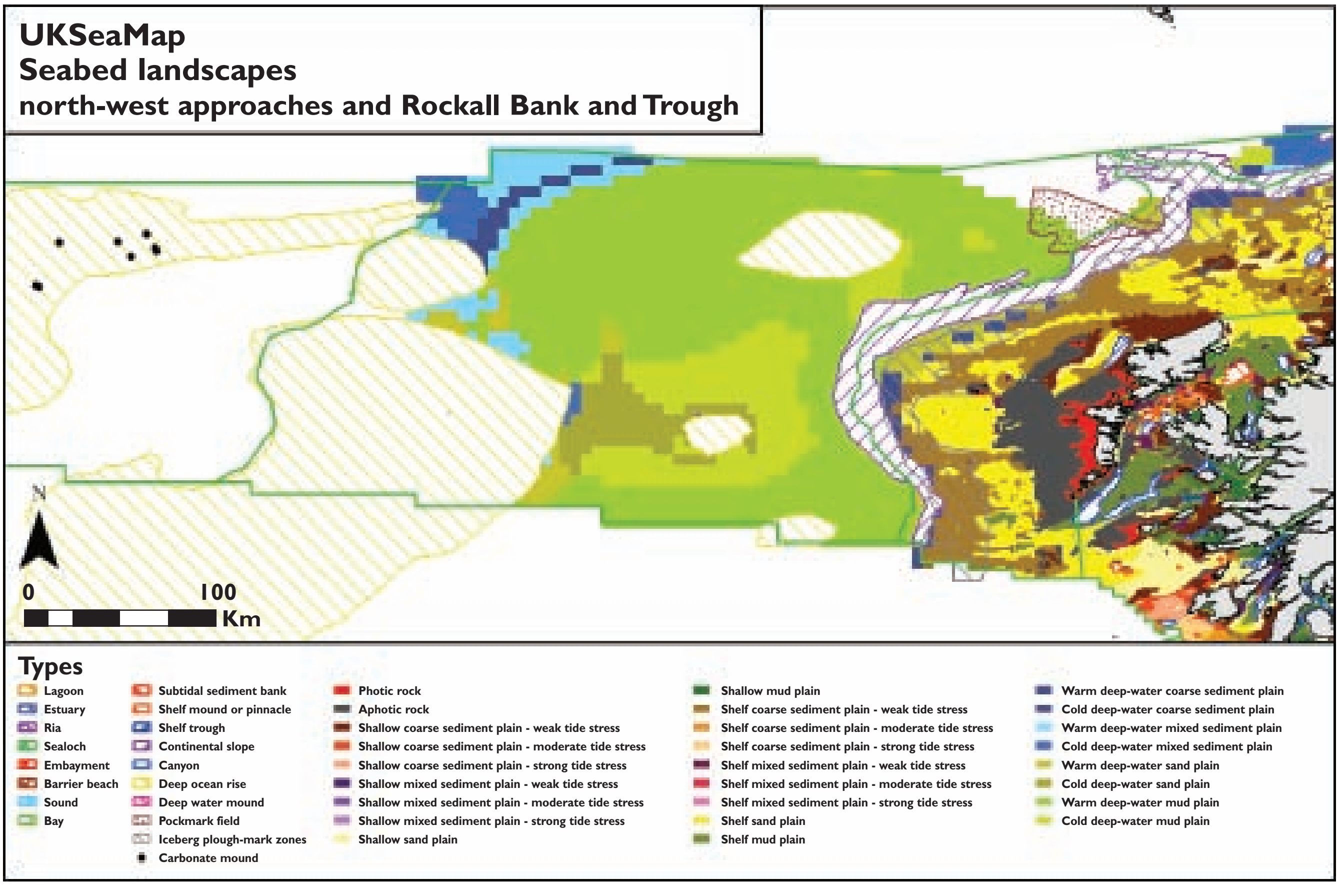
Marine landscape map for the Irish Sea



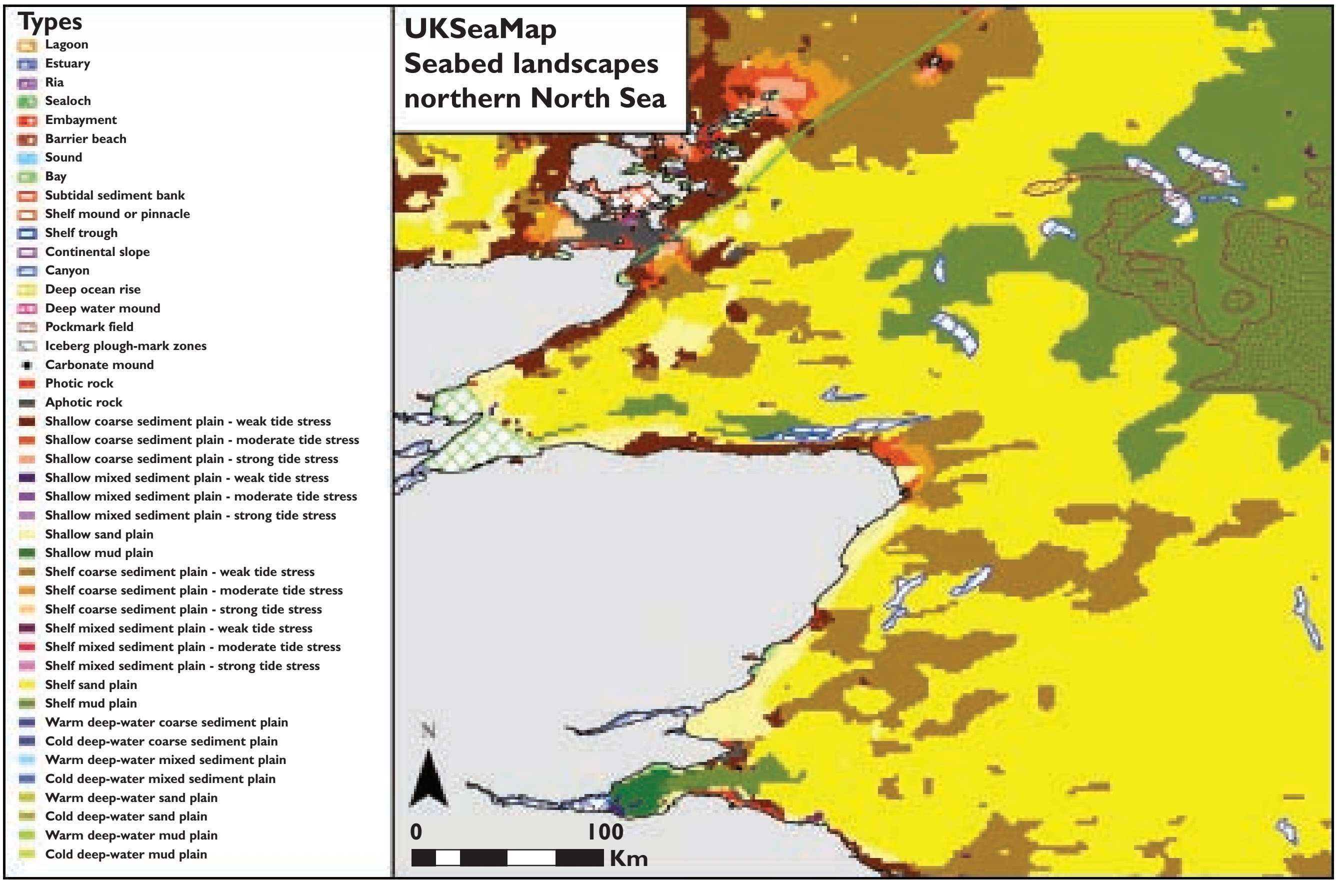
Marine landscape map for the Minches and west Scotland



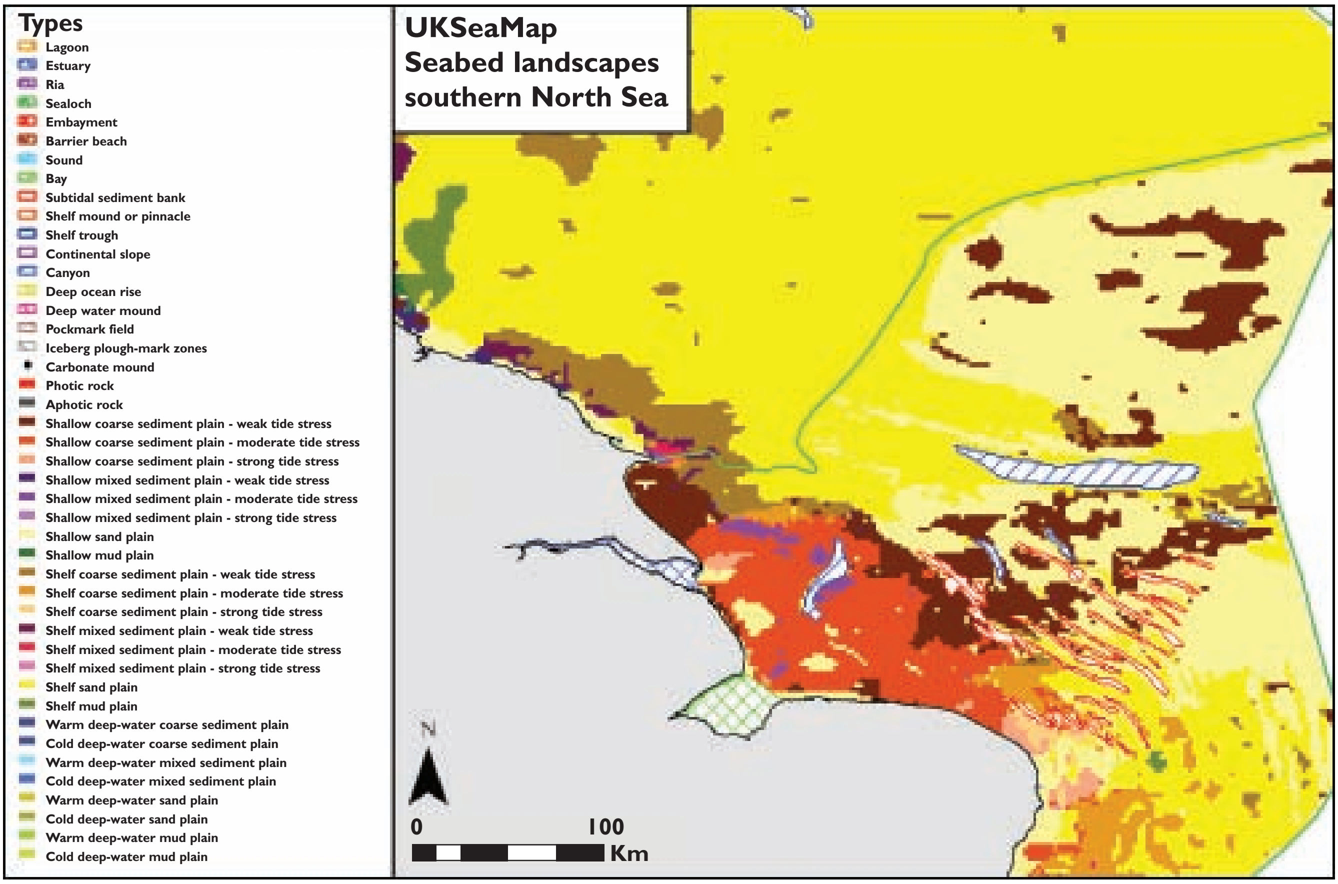
Marine landscape map for the Scottish Continental Shelf and the Faroe-Shetland Channel



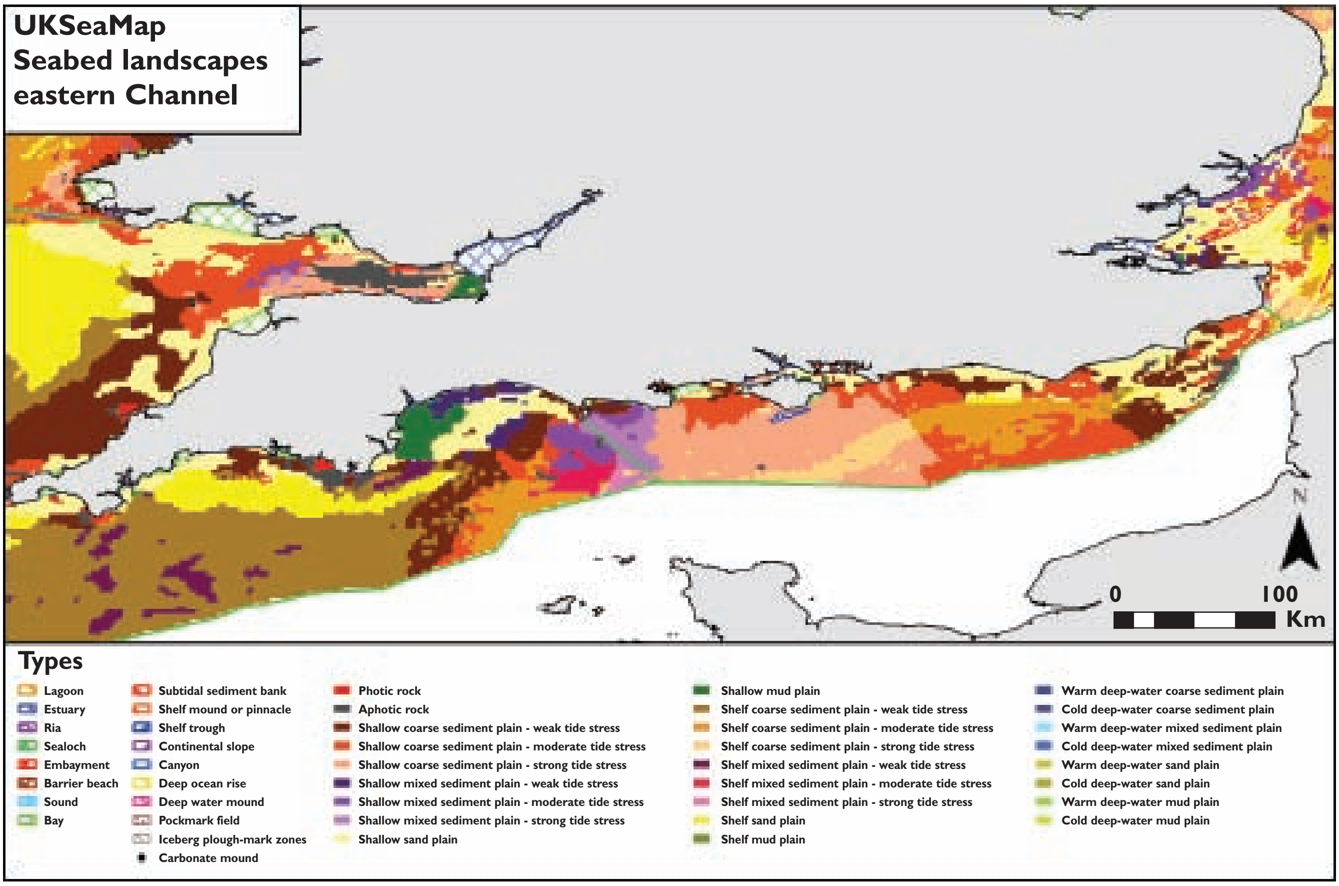
Marine landscape map for the north west approaches and Rockall Bank and Trough



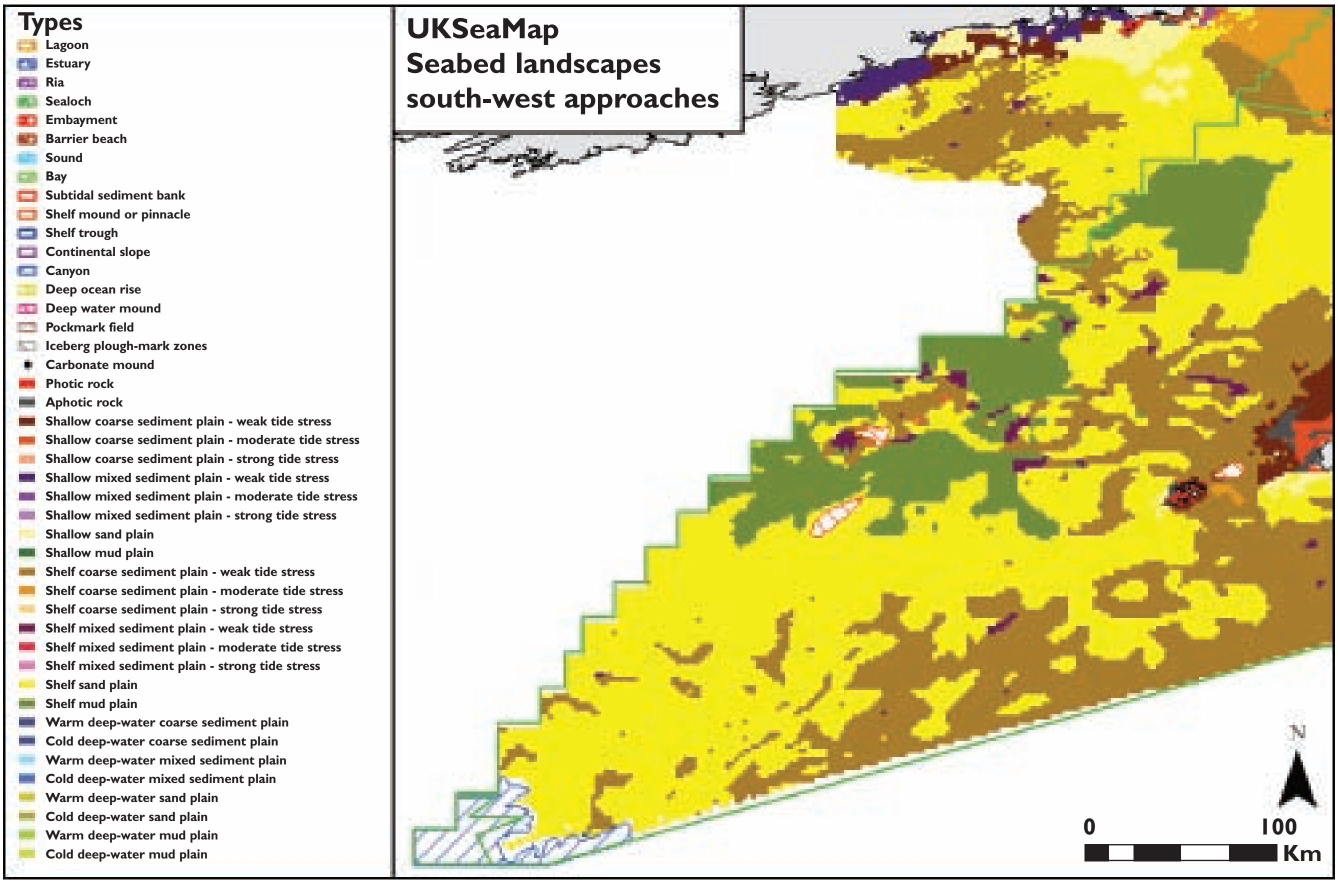
Marine landscape map for the northern North Sea



Marine landscape map for the southern North Sea



Marine landscape map for the eastern Channel



Marine landscape map for the south west approaches

Annex 7: Relationship between marine landscape types and the EUNIS habitat classification

To prepare for the biological analysis, those EUNIS Level 4 habitats that appear to fall within the expected definition of the landscape type were identified. These relationships are based upon the expected character or definition of each modelled seabed type, coastal physiographic feature and topographic feature (particularly substratum and depth zone) and are summarised below within a semantic Look-Up Table (LUT) which is a way to define relationships between two different classification schemes. In this case it is required to define how a marine habitat relates to a marine landscape as these are two different concepts. 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)

A semantic LUT is required to carry out this analysis as the two data sets cannot be compared directly, one data set being landscape features, the other being habitat types. Such a comparison is unavoidable as the concept of marine landscape features is both recent and novel, and as a consequence there are no similar data with which to compare the new map. The only data available for the comparison are point sample biological data, which can be identified to a habitat type (within EUNIS), but it would not be possible to directly assign such a sample to a landscape feature as the latter is a concept related to a broader scale than that represented by a single point. The semantic LUT therefore allows a comparison to be made between the two classification systems based on expert opinion of the relationship between the two classification systems. Such techniques have been used recently with considerable success in research comparing different land cover classification schemes in terrestrial environments (Comber *et al* 2004).

Using three values in the semantic LUT allows the analysis to utilise a rough set approach in comparing the two classifications (Ahlqvist *et al*. 2000). This technique moves away from the more traditional Boolean comparison (where something is either a member of a set or it is not) by allowing an uncertain membership function (given the value 0 above). In a Boolean analysis, the relationship is very clear, such that certain habitats should occur, for example, in the landscape type *Shallow mud plain*, and all others should definitely not. Using a rough set approach, however, there may be other habitats that while not specifically related to a *Shallow mud plain*, could possibly be found in such locations. This technique allows the production of a maximum (including definite and uncertain relationships) and a minimum (including definite relationships only) approximation of the relationship between the two data sets; it also recognises that not all such relationships in biology are clear-cut.

In this way, it was possible to assess whether each sample had an 'expected' 'unexpected' or 'uncertain' relationship with the underlying landscape type and thus both a conservative (minimum) (the proportion of data falling into expected definitions only) and an optimistic (maximum) (the proportion of data falling into either expected or uncertain definitions) estimate of correlation was made for each landscape type.

The following table provides (in two parts) a provisional correlation between EUNIS habitat types (levels 1-3) and the marine landscape types, indicating that many landscape types may include multiple habitat types. Note that the table only shows a summary of the full LUT, showing EUNIS types only down to level 3, whilst the biological sample data were assigned to the more detailed EUNIS level 4 (biotope complex level). Greyed out cells in the table indicate the habitat is not expected to occur in UK waters (as these are defined as Baltic or Mediterranean types).

Part 1: Enclosed coast, open coast and shelf features

EUNIS level	EUNIS code	EUNIS name	Enclosed coast: Lagoon	Enclosed coast: Estuary	Enclosed coast: Ria	Enclosed coast: Sealoch/Voe	Enclosed coast: Embayment	Open coast and shelf seas – Semi-enclosed coastal features: Barrier beach	Semi-enclosed coastal features: Sound or strait	Semi-enclosed coastal features: Bay	Shallow coastal plain features: Photic rock	Shallow coastal plain features: Aphotic rock	Shallow coastal plain features: Weak tide stress shallow coarse sediment plain	Shallow coastal plain features: Moderate tide stress shallow coarse sediment plain	Shallow coastal plain features: Strong tide stress shallow coarse sediment plain	Shallow coastal plain features: Weak tide stress shallow mixed sediment plain	Shallow coastal plain features: Moderate tide stress shallow mixed sediment plain	Shallow coastal plain features: Strong tide stress shallow mixed sediment plain	Shallow coastal plain features: Shallow sand plain	Shallow coastal plain features: Shallow mud plain	Shelf plain features: Weak tide stress shelf coarse sediment plain	Shelf plain features: Moderate tide stress shelf coarse sediment plain	Shelf plain features: Strong tide stress shelf coarse sediment plain	Shelf plain features: Weak tide stress shelf mixed sediment plain	Shelf plain features: Moderate tide stress shelf mixed sediment plain	Shelf plain features: Strong tide stress shelf mixed sediment plain	Shelf plain features: Shelf sand plain	Shelf plain features: Shelf mud plain	Coastal and shelf bed-form features: Subtidal sediment bank	Coastal and shelf bed-form features: Shelf mound or pinnacle	Coastal and shelf bed-form features: Shelf trough	Coastal and shelf bed-form features: Pockmark field
1	A	Marine habitats	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
2	A1	Littoral rock and other hard substrata	I	I	I	I	I	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I
3	A1.1	High energy littoral rock	I	0	0	I	0	0	0	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I
3	A1.2	Moderate energy littoral rock	0	I	I	I	0	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I
3	A1.3	Low energy littoral rock	I	I	I	I	0	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I
3	A1.4	Features of littoral rock	I	I	I	I	0	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I
2	A2	Littoral sediment	I	I	I	I	I	I	I	I	-I	-I	I	I	I	I	I	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.1	Littoral coarse sediment	0	I	0	0	0	0	0	0	-I	-I	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.2	Littoral sand and muddy sand	I	I	I	I	I	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.3	Littoral mud	I	I	I	I	I	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.4	Littoral mixed sediments	I	I	I	I	I	0	I	0	-I	-I	-I	-I	-I	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.5	Coastal saltmarshes and saline reedbeds	0	I	I	I	I	0	0	0	-I	-I	-I	-I	-I	-I	-I	-I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.6	Littoral sediments dominated by aquatic angiosperms	0	I	I	I	I	I	I	I	-I	-I	0	0	0	0	0	0	I	0	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.7	Littoral biogenic reefs	0	I	I	I	0	I	0	I	I	-I	I	I	I	I	I	I	0	0	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A2.8	Features of littoral sediment	0	I	I	I	0	0	I	I	-I	-I	0	0	0	0	0	0	0	0	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
2	A3	Infralittoral rock and other hard substrata	I	I	I	I	I	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I
3	A3.1	Atlantic and Mediterranean high energy infralittoral rock	0	0	0	I	0	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I
3	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	0	I	I	I	0	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I		0	-I	-I
3	A3.3	Atlantic and Mediterranean low energy infralittoral rock	I	I	I	I	0	0	0	0	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I
3	A3.4	Baltic exposed infralittoral rock																														
3	A3.5	Baltic moderately exposed																														
3	A3.6	Baltic sheltered infralittoral rock																														
3	A3.7	Features of infralittoral rock	I	I	I	I	0	0	I	I	I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	-I	0	-I	-I

EUNIS level	EUNIS code	EUNIS name	Enclosed coast: Lagoon	Enclosed coast: Estuary	Enclosed coast: Ria	Enclosed coast: Sealoch/Voe	Enclosed coast: Embayment	Open coast and shelf seas – Semi-enclosed coastal features: Barrier beach	Sound or strait	Bay	Shallow coastal plain features: Photic rock	Aphotic rock	Weak tide stress shallow coarse sediment plain	Moderate tide stress shallow coarse sediment plain	Strong tide stress shallow coarse sediment plain	Weak tide stress shallow mixed sediment plain	Moderate tide stress shallow mixed sediment plain	Strong tide stress shallow mixed sediment plain	Shallow sand plain	Shallow mud plain	Shelf plain features: Weak tide stress shelf coarse sediment plain	Moderate tide stress shelf coarse sediment plain	Strong tide stress shelf coarse sediment plain	Weak tide stress shelf mixed sediment plain	Moderate tide stress shelf mixed sediment plain	Strong tide stress shelf mixed sediment plain	Shelf sand plain	Shelf mud plain	Coastal and shelf bed-form features: Subtidal sediment bank	Shelf mound or pinnacle	Shelf trough	Pockmark field
2	A4	Circalittoral rock and other hard substrata	1	0	1	1	0	0	1	1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	0	-1
3	A4.1	Atlantic and Mediterranean high energy circalittoral rock	-1	0	0	1	0	0	1	0	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	0	-1
3	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	0	0	0	1	0	0	1	0	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	0	-1
3	A4.3	Atlantic and Mediterranean low energy circalittoral rock	1	0	1	1	0	0	0	0	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1
3	A4.4	Baltic exposed circalittoral rock																														
3	A4.5	Baltic moderately exposed circalittoral rock																														
3	A4.6	Baltic sheltered circalittoral rock																														
3	A4.7	Features of circalittoral rock	0	0	0	1	0	0	1	1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1
2	A5	Sublittoral sediment	1	1	1	1	1	1	1	1	-1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	A5.1	Sublittoral coarse sediment	1	0	0	0	0	0	0	0	-1	-1	1	1	1	-1	-1	-1	-1	-1	1	1	1	-1	-1	-1	-1	-1	1	0	1	-1
3	A5.2	Sublittoral sand	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	1	-1	1	1	1	0
3	A5.3	Sublittoral mud	1	1	1	1	1	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	1	0	0	1	1
3	A5.4	Sublittoral mixed sediments	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	1	1	1	-1	-1	-1	-1	-1	1	1	1	-1	-1	0	0	1	-1
3	A5.5	Sublittoral macrophyte-dominated sediment	1	1	1	1	1	1	1	1	-1	-1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	0	0	-1
3	A5.6	Sublittoral biogenic reefs	0	1	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
3	A5.7	Features of sublittoral sediments	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1
2	A6	Deep-sea bed	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.1	Deep-sea rock and artificial hard substrata	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.2	Deep-sea mixed substrata	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.3	Deep-sea sand	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.4	Deep-sea muddy sand	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.5	Deep-sea mud	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.6	Deep-sea bioherms	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

			Enclosed coast					Open coast and shelf seas																											
								Semi-enclosed coastal features			Shallow coastal plain features										Shelf plain features								Coastal and shelf bed-form features			
EUNIS level	EUNIS code	EUNIS name	Lagoon	Estuary	Ria	Sealoch/Voe	Embayment	Barrier beach	Sound or strait	Bay	Photic rock	Aphotic rock	Weak tide stress shallow coarse sediment plain	Moderate tide stress shallow coarse sediment plain	Strong tide stress shallow coarse sediment plain	Weak tide stress shallow mixed sediment plain	Moderate tide stress shallow mixed sediment plain	Strong tide stress shallow mixed sediment plain	Shallow sand plain	Shallow mud plain	Weak tide stress shelf coarse sediment plain	Moderate tide stress shelf coarse sediment plain	Strong tide stress shelf coarse sediment plain	Weak tide stress shelf mixed sediment plain	Moderate tide stress shelf mixed sediment plain	Strong tide stress shelf mixed sediment plain	Shelf sand plain	Shelf mud plain	Subtidal sediment bank	Shelf mound or pinnacle	Shelf trough	Pockmark field
3	A6.7	Raised features of the deep-sea bed	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.8	Deep-sea trenches and canyons, channels, slope failures and slumps on the continental slope	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.9	Vents, seeps, hypoxic and anoxic habitats of the deep sea	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A7	Pelagic water column	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A7.1	Neuston	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A7.2	Completely mixed water column with reduced salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A7.3	Completely mixed water column with full salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A7.4	Partially mixed water column with reduced salinity and medium or long residence time																																	
3	A7.5	Unstratified water column with reduced salinity																																	
3	A7.6	Vertically stratified water column with reduced salinity																																	
3	A7.7	Fronts in reduced salinity water column																																	
3	A7.8	Unstratified water column with full salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A7.9	Vertically stratified water column with full salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A7.A	Fronts in full salinity water column	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A8	Ice-associated marine habitats																																	
3	A8.1	Sea ice																																	
3	A8.3	Brine channels																																	
3	A8.4	Under-ice habitat																																	

Part 2: Continental slope, deep sea and water column features

			Continental slope and deep sea														Water column												
			Continental slope and deep sea topographic and bed-form features						Continental slope and deep sea plain features								Estuarine	ROFI				Shelf				Oceanic			
EUNIS level	EUNIS code	EUNIS name	Continental slope	Iceberg plough mark zone	Canyon	Deep ocean rise	Carbonate mound	Deep-water mound	Warm deep-water coarse sediment plain	Cold deep-water coarse sediment plain	Warm deep-water mixed sediment plain	Cold deep-water mixed sediment plain	Warm deep-water sand plain	Cold deep-water sand plain	Warm deep-water mud plain	Cold deep-water mud plain	Estuarine water	Well-mixed ROFI	Weakly-stratified ROFI	Frontal ROFI	Stratified ROFI	Well-mixed shelf water	Weakly-stratified shelf water	Frontal shelf water	Stratified shelf water	Well-mixed oceanic water	Weakly-stratified oceanic water	Frontal oceanic water	Stratified oceanic water
1	A	Marine habitats	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	A1	Littoral rock and other hard substrata	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A1.1	High energy littoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A1.2	Moderate energy littoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A1.3	Low energy littoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A1.4	Features of littoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A2	Littoral sediment	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.1	Littoral coarse sediment	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.2	Littoral sand and muddy sand	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.3	Littoral mud	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.4	Littoral mixed sediments	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.5	Coastal saltmarshes and saline reedbeds	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.6	Littoral sediments dominated by aquatic angiosperms	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.7	Littoral biogenic reefs	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A2.8	Features of littoral sediment	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A3	Infralittoral rock and other hard substrata	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A3.1	Atlantic and Mediterranean high energy infralittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A3.3	Atlantic and Mediterranean low energy infralittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A3.4	Baltic exposed infralittoral rock																											
3	A3.5	Baltic moderately exposed infralittoral rock																											
3	A3.6	Baltic sheltered infralittoral rock																											

			Continental slope and deep sea														Water column												
			Continental slope and deep sea topographic and bed-form features						Continental slope and deep sea plain features								Estuarine	ROFI				Shelf				Oceanic			
EUNIS level	EUNIS code	EUNIS name	Continental slope	Iceberg plough mark zone	Canyon	Deep ocean rise	Carbonate mound	Deep-water mound	Warm deep-water coarse sediment plain	Cold deep-water coarse sediment plain	Warm deep-water mixed sediment plain	Cold deep-water mixed sediment plain	Warm deep-water sand plain	Cold deep-water sand plain	Warm deep-water mud plain	Cold deep-water mud plain	Estuarine water	Well-mixed ROFI	Weakly-stratified ROFI	Frontal ROFI	Stratified ROFI	Well-mixed shelf water	Weakly-stratified shelf water	Frontal shelf water	Stratified shelf water	Well-mixed oceanic water	Weakly-stratified oceanic water	Frontal oceanic water	Stratified oceanic water
3	A3.7	Features of infralittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A4	Circalittoral rock and other hard substrata	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A4.1	Atlantic and Mediterranean high energy circalittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A4.3	Atlantic and Mediterranean low energy circalittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A4.4	Baltic exposed circalittoral rock																											
3	A4.5	Baltic moderately exposed circalittoral rock																											
3	A4.6	Baltic sheltered circalittoral rock																											
3	A4.7	Features of circalittoral rock	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A5	Sublittoral sediment	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A5.1	Sublittoral coarse sediment	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A5.2	Sublittoral sand	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A5.3	Sublittoral mud	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A5.4	Sublittoral mixed sediments	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A5.5	Sublittoral macrophyte-dominated sediment	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A5.6	Sublittoral biogenic reefs	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A5.7	Features of sublittoral sediments	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A6	Deep-sea bed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.1	Deep-sea rock and artificial hard substrata	0	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.2	Deep-sea mixed substrata	0	1	0	0	-1	0	-1	-1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.3	Deep-sea sand	0	0	0	0	-1	0	-1	-1	-1	-1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.4	Deep-sea muddy sand	0	0	0	0	-1	0	-1	-1	-1	-1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.5	Deep-sea mud	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

EUNIS level	EUNIS code	EUNIS name	Continental slope and deep sea														Water column												
			Continental slope and deep sea topographic and bed-form features						Continental slope and deep sea plain features								Estuarine	ROFI				Shelf				Oceanic			
			Continental slope	Iceberg plough mark zone	Canyon	Deep ocean rise	Carbonate mound	Deep-water mound	Warm deep-water coarse sediment plain	Cold deep-water coarse sediment plain	Warm deep-water mixed sediment plain	Cold deep-water mixed sediment plain	Warm deep-water sand plain	Cold deep-water sand plain	Warm deep-water mud plain	Cold deep-water mud plain	Estuarine water	Well-mixed ROFI	Weakly-stratified ROFI	Frontal ROFI	Stratified ROFI	Well-mixed shelf water	Weakly-stratified shelf water	Frontal shelf water	Stratified shelf water	Well-mixed oceanic water	Weakly-stratified oceanic water	Frontal oceanic water	Stratified oceanic water
3	A6.6	Deep-sea bioherms	0	1	1	1	1	1	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.7	Raised features of the deep-sea bed	0	0	0	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.8	Deep-sea trenches and canyons, channels, slope failures and slumps on the continental slope	0	0	1	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A6.9	Vents, seeps, hypoxic and anoxic habitats of the deep sea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	A7	Pelagic water column	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	A7.1	Neuston	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	A7.2	Completely mixed water column with reduced salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	?	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	A7.3	Completely mixed water column with full salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	0	-1	-1	1	0	-1	-1	1	0	-1	-1
3	A7.4	Partially mixed water column with reduced salinity and medium or long residence time																											
3	A7.5	Unstratified water column with reduced salinity																											
3	A7.6	Vertically stratified water column with reduced salinity																											
3	A7.7	Fronts in reduced salinity water column																											
3	A7.8	Unstratified water column with full salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	?	0	-1	-1	?	-1	-1	-1	?	-1	-1	-1
3	A7.9	Vertically stratified water column with full salinity	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	0	1	-1	1	0	1	-1	1	0	1
3	A7.A	Fronts in full salinity water column	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	1	-1	-1	-1	1	-1
2	A8	Ice-associated marine habitats																											
3	A8.1	Sea ice																											
3	A8.2	Freshwater ice																											
3	A8.3	Brine channels																											
3	A8.4	Under-ice habitat																											

Annex 8: Biological validation of the seabed features

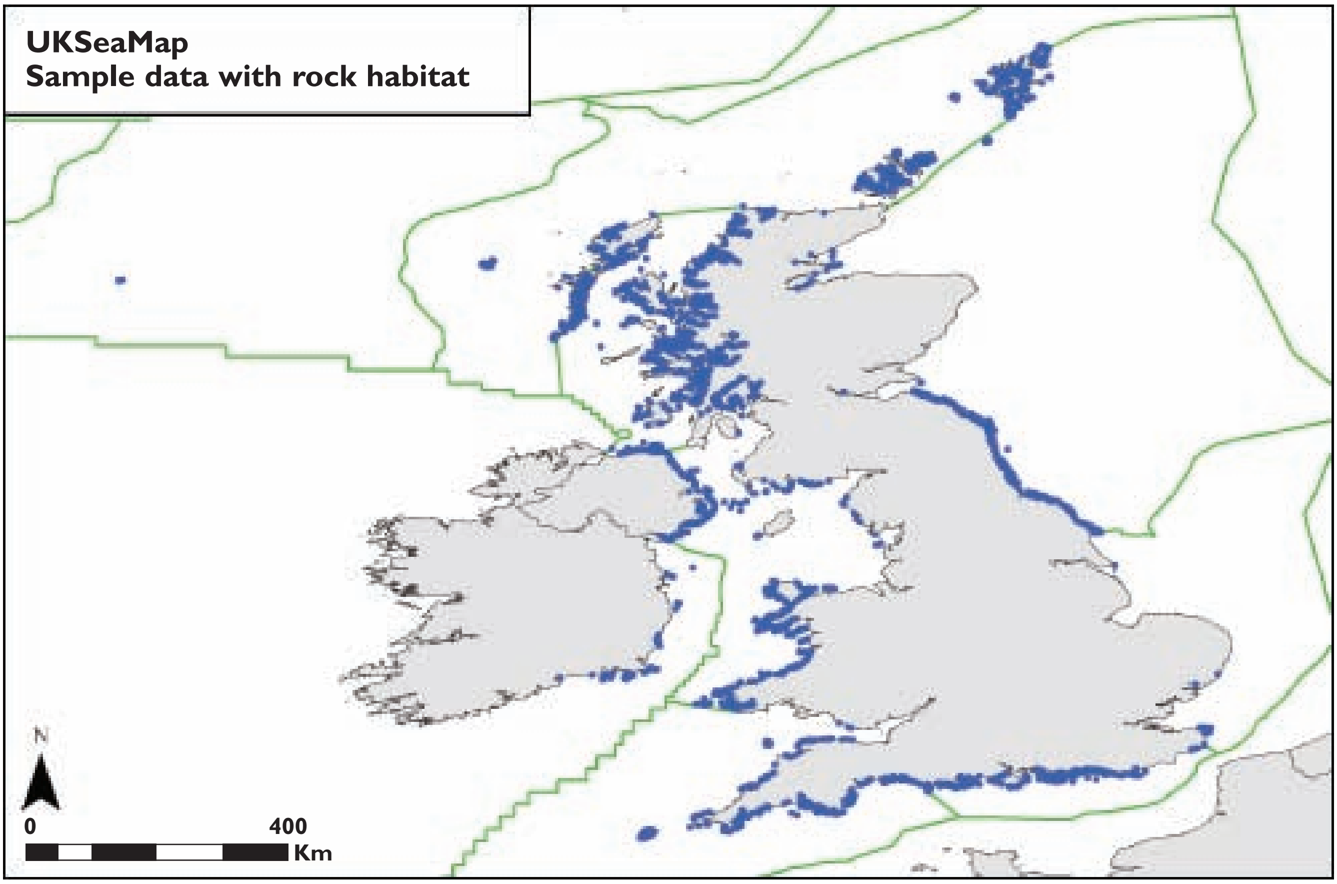
The following table provides further detail on the results of the seabed biological validation process. This information is provided in summary in Table 7.

	By Cell				By Landscape type							
Landscape type	**Total no. of cells**	**No. of cells not validated**	**No. of cells validated**	**% cells validated**	**Total no. of samples**	**Not expected**	**Uncertain**	**Expected**	**Min. % correlation (expected)**	**Max. % correlation (expected + uncertain)**	**Habitat types not matching**	**Comments**
Enclosed coast												
Lagoon	27	2	25	93	137	6	39	92	67	96		
Estuary	539	3	536	99	3697	20	1556	2121	57	99		
Ria	78	2	76	97	965	27	309	629	65	97		
Sealoch	1101		1101	100	6640		449	6191	93	100		
Embayment	138	2	136	99	861	32	423	406	47	96		
Open coast and continental shelf												
Semi-enclosed coastal features												
Barrier Beach	0											
Sound	36		36	100	410	13	199	198	48	97		
Bay	510	1	509	100	1459	10	559	890	61	99		
Shallow coastal plain features												
Photic rock	284	90	194	68	1637	640	5	992	61	61	CR; SS.SMp; SS.SCS	Lack of 'rock' data within BGS data set
Aphotic rock	51	31	20	39	225	145		80	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	556	237	30	2747	2126	20	601	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	385	440	53	3293	2067	116	1110	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	150	109	42	1104	820	18	266	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	153	51	25	653	492	19	142	22	25	Rock types; Infralittoral sands	
Shallow mixed sediment plain - moderate tide stress	39	27	12	31	303	225	6	72	24	26	Rock types; SS.SCS	
Shallow coarse sediment plain - strong tide stress	15	9	6	40	109	88	2	19	17	19	Rock types; SS.SCS	

	By Cell				By Landscape type							
Landscape type	Total no. of cells	No. of cells not validated	No. of cells validated	% cells validated	Total no. of samples	Not expected	Uncertain	Expected	Min. % correlation (expected)	Max. % correlation (expected + uncertain)	Habitat types not matching	Comments
Shallow sand plain	1127	648	479	43	4063	2669	229	1165	29	34	Rock types; SS.SCS	% Correlation improves outside coastal buffer, but still ~350 samples were assigned to SS.SCS
Shallow mud plain	256	132	124	48	658	446	59	153	23	32	Rock types	% validated increases to 80% when the area outside the buffer is examined
Shelf plain features												
Shelf coarse sediment plain - weak tide stress	90	84	6	7	226	219	7		0	3	SS.SCS.ICS	Poor distinction between shallow/shelf landscapes; HMP problem
Shelf coarse sediment plain - moderate tide stress	174	164	10	6	433	420	12	1	0	3	SS.SCS.ICS	Poor distinction between shallow/shelf landscapesl; HMP problem
Shelf coarse sediment plain - strong tide stress	19	17	2	11	55	52	3		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	10	7	41	58	50	6	2	3	14		Sample size too low for results to be reliably interpreted
Shelf mixed sediment plain - moderate tide stress	6	3	3	50	7	4	1	2	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	713	54	7	2029	1945	72	12	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	128	66	446	199	194	53	12	55	Rock types; Muddy sands; Infralittoral muds	Many rock samples found in mud within coastal buffer - % validated increases to 70% when the area outside the buffer is examined
Coastal and shelf bed-form features												
Subtidal sediment bank	9		9	100	16	2	9	5	31	88		
Shelf mound or pinnacle	13		13	100	53		18	35	66	100		
Shelf trough	33	2	31	94	137	51	58	28	20	63	IR types	
Pockmark field	0											

	By Cell				By Landscape type							
Landscape type	Total no. of cells	No. of cells not validated	No. of cells validated	% cells validated	Total no. of samples	Not expected	Uncertain	Expected	Min. % correlation (expected)	Max. % correlation (expected + uncertain)	Habitat types not matching	Comments
Continental slope and deep sea												
Continental slope and deep sea topographic and bed-form features												
Continental slope	2	2		0	17	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 validate feature	2	2		0	27	27			0	0		No types in LUT to
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	1		0	1	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

Annex 9: Map illustrating distribution of benthic sample data for rock habitats



Consideration was given as to whether these data could be used to modify the seabed substratum data set prior to undertaking the modelling analysis. However, the significant differences in scale of the two data sets meant that it was inappropriate to combine the data.

Annex 10: Data sets used in UKSeaMap

Parameter	Data set	Date	Source	Processing	Boundaries (categories)
Bottom temperature	Minimum bottom temperature	1973-1999	ICES	Spline interpolation	4°C isotherm (Warm deep water, Cold deep water)
Fronts	Front probability	10 year simulation of POLCOMS	POL	Inverse distance weighted interpolation	0.15 (Non-frontal and Frontal)
Photic depth	Annual mean light attenuation	1998-2004 for January to August and 1997-2003 for September to December	Data supplied by POL, derived from SeaWiFS.	Inverse distance weighted interpolation	1% of light reaches seabed (Photic and Aphotic zones)
Salinity	Sea surface salinity	10 year simulation of POLCOMS	POL	Inverse distance weighted interpolation	30 ppt, 34 ppt and 35 ppt (Estuarine, ROFI, Shelf and Oceanic)
Seabed disturbance (tides)	Maximum seabed tide stress	2000-2004	POL	Inverse distance weighted interpolation	1.8 Newtons/m^2 and 4.0 Newtons/m^2 (Weak, Moderate and Strong)
Seabed disturbance (waves)	Maximum wave length	Over 10-year period	POL	Inverse distance weighted interpolation	Wave base (Shallow and Shelf)
Stratification	Surface to seabed temperature difference	10 year simulation of POLCOMS	POL	Inverse distance weighted interpolation	0.5°C and 2.0°C (Well mixed, Frontal and Stratified)
Substrata	DigSBS250 seabed sediments	NA	British Geological Survey	Simplification of the Folk categories; supplemented with other data	Mud and sandy mud, Sand and muddy sand, Mixed sediment, Coarse sediment and Rock
Topography	Digital Elevation Models and bathymetric contour data (DigBath250)	NA	Gebco, SeaZone, BGS	Slope calculation	Various topographic features

Annex 11: Other water column data sets

The following data sets were not used in the water column analysis.

Surface sea temperature

Temperature is an important parameter for many biological processes which ultimately determine biological community characteristics and can be used to describe biogeographic changes. It was considered that maximum and minimum temperatures may be the most biologically meaningful aspect of temperature, as species are influenced by low temperature through mortality and their inability to reproduce and by high temperatures which influence breeding and larval survival. This includes benthic species which often have a larval stage.

Sea surface temperature (SST) data, based on 8-day composites on an equal angle grid (~9km resolution) from the NASA/NOAA pathfinder Advanced High Resolution Radiometer were obtained (see **http://podaac.jpl.nasa.gov/products/product102.html**). The 15 years (1985-1999) of satellite measurements were averaged to give seasonal means and standard deviation.

Unfortunately there is no simple relationship between temperature and biology as some species distributions are influenced by lowest temperature and some by highest. The UK is in the middle of major biogeographic provinces: most species extend further north and south than the British Isles in the north-east Atlantic so there are few clear boundaries.

Stratification data sets

These data are extracted from a 10-year simulation of the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS; Holt and James 2001) applied to the north-west European Shelf. This is the 'Medium Resolution Continental Shelf' domain described by Holt *et al.*, (2005) and run operationally at the Met. Office in a 7-day hind cast mode (see **http://www.metoffice.gov.uk/research/ncof/mrcs/browser.html**).

Stratification probability

The stratification probability density function is defined as the number of days the surface to bed temperature difference at this cell exceeds 0.5°C divided by the number of days in this season over the 10-year run. The stratification data set has not been incorporated into the classification process as the front probability and the surface to bed temperature difference data sets provide a more detailed description of water column stratification.

Potential energy anomaly

The potential energy anomaly is a measure of the energy required to overcome stable stratification and completely mix the water column (see Simpson and Bowers 1981). Potential energy anomaly were not used within the water column classification analysis as both surface to bed temperature difference and front probability have been used to describe the level of stratification in the water column.

Mixed layer depth

Mixed layer depth (i.e. the depth to which surface waters are mixed) replicates categories described above using surface to bed temperature difference data and does not appear to bring anything extra to the water column type classification so it has not been included.

Annex 12: Glossary

ArcGIS Spatial Analyst – A set of spatial modelling and analysis tools produced by ESRI.

Classification Tree – A table of decisions and their possible consequences used to create a plan to reach a goal.

Digital Elevation Model (DEM) – A digital file, usually in raster form, describing the terrain and elevation of a given area.

Data layer – A collection of similar geographic features, such as estuaries, carbonate mounds and rock, referenced together for display on a map.

Geographic Information System (GIS) – A collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. The UKSeaMap project was undertaken using ESRI's ArcGIS 8.3 software application.

Highest Astronomical Tide (HAT) – The highest level to which the tide can be expected to occur under average meteorological conditions.

Inverse distance weighted interpolation - Within ArcGIS data points can be interpolated into continuous raster layers using a set of Spatial Analyst functions that predict values for a surface from a limited number of data points. Inverse distance weighted interpolation estimates values by averaging the values of sample data points in the vicinity of each cell. The closer a point is to the centre of the cell being estimated the more influence it has in the averaging process. A minimum number of measured points, to use within each neighbourhood, need to be defined. When there are fewer measured points than the specified minimum, the search radius will increase until it can encompass the minimum number of points. The power function used in the algorithm controls the weighting of known points on the interpolated values based on their distance from the output point. A power of two was used in UKSeaMap to ensure a balance between weightings of near and distant points, and results in a relatively smooth surface.

Mean High Water Datum – The average of the high water heights over a period.

Metadata – Structured, encoded data that describe characteristics of information-bearing entities to aid in the identification, discovery, assessment, and management of the described entities.

North Atlantic Drift – An ocean current in the North Atlantic, which is a branch of the Gulf Stream.

Photoperiodism – The physiological reaction of organisms to the length of day or night.

Raster Calculator – A Spatial Analyst function that provides a powerful tool for performing mathematical calculation.

Raster Data – Raster data refers to the storage of spatial data in the form of a continuous field of uniform cells, each with an associated value.

Shapefile – A set of files that contain a set of points, arcs, or polygons (or features) that hold tabular data and a spatial location.

Slope Function – The slope function calculates the maximum rate of change between each cell and its neighbour. Every cell in the output raster has a slope value. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. The output can be calculated as a percentage or degree.

Spline method - an interpolation method in GIS in which cell values are estimated using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points.

Supervised Classification – A classification system that allows the specialist to choose and set up discrete classes thus supervising the selection and assigning them category names.

Unsupervised Classification – A classification system that uses algorithms to cluster multivariate data based solely on the values of the inputs, without any training.

Vector Data – Vector data type refers to the storage of spatial data in the form of points, lines and polygons.

The Joint Nature Conservation Committee (JNCC) is the statutory adviser to Government on UK and international nature conservation. Its work contributes to maintaining and enriching biological diversity, conserving geological features and sustaining natural systems.

JNCC delivers the UK and international responsibilities of the Council for Nature Conservation and the Countryside (CNCC), the Countryside Council for Wales (CCW), Natural England, and Scottish Natural Heritage (SNH).

The functions that arise from these responsibilities are principally to:

- advise Government on the development and implementation of policies for, or affecting, nature conservation in the UK and internationally;
- provide advice and disseminate knowledge on nature conservation issues affecting the UK and internationally;
- establish common standards throughout the UK for nature conservation, including monitoring, research, and the analysis of results;
- commission or support research which it deems relevant to these functions.

The Committee comprises 14 members: a Chairman and five independent members appointed by the Secretary of State; the Chairman of CNCC; the Chairmen or deputy Chairmen of CCW, Natural England and SNH; and one other member from each of these bodies.

JNCC, originally established under the Environmental Protection Act 1990, was reconstituted by the Natural Environment and Rural Communities Act 2006. Support is provided to the JNCC by a company limited by guarantee (JNCC Support Co) that the Committee established in 2005.

Details of publications produced by JNCC are available from:
Communications Team, JNCC, Monkstone House, City Road,
Peterborough PE1 1JY, UK.
Telephone 01733 562626
Fax 01733 555948
Email communications@jncc.gov.uk

Website: www.jncc.gov.uk

Designed and printed by statusdesign.co.uk, 1M

ISBN-13: 978 1 86107 590 1