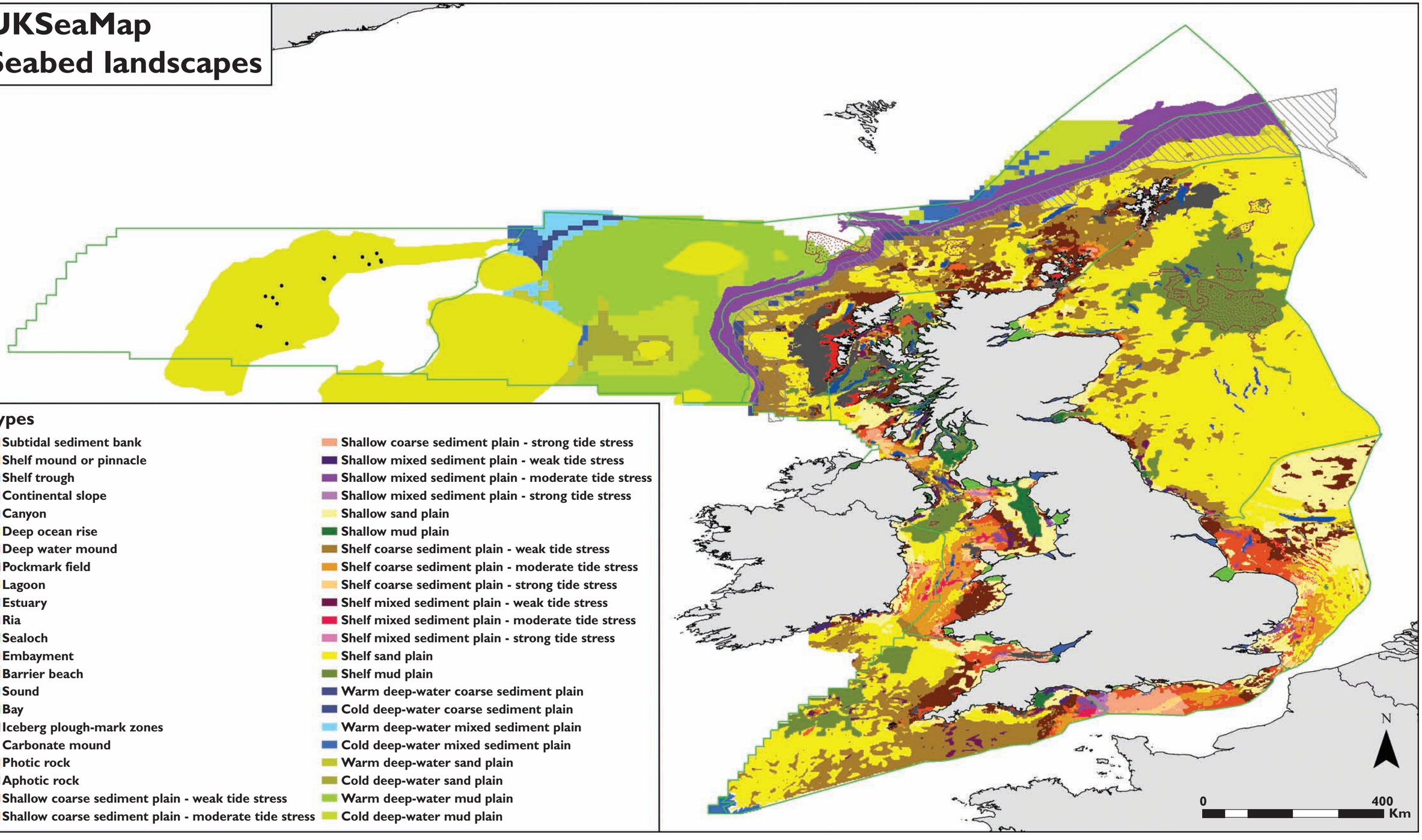
JOINT NATURE CONSERVATION COMMITTEE

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

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October 2006

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Cyngor Cefn Gwlad Cymru
Countryside Council for Wales

THE CROWN ESTATE

defra
Department for Environment Food and Rural Affairs

dti

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MESH MAPPING EUROPEAN SEABED HABITATS

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

nwe eno INTERREG IIIB NORTH WEST EUROPE

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 Methodology - an overview

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