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A study into marine landscapes applied to habitat mapping

Continental Shelf and Margins Programme

Internal Report IR/03/132

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/03/132

A study into marine landscapes applied to habitat mapping

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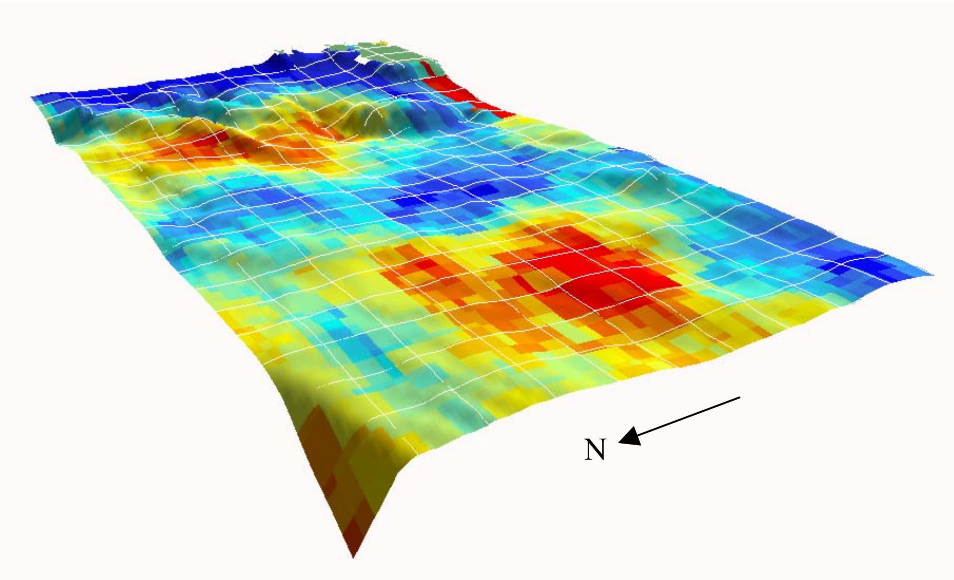
Key words

Habitat mapping; sediment; marine geology; GIS.

Front cover

The relative concentrations of zinc in seabed samples draped over a 3D view illustrating the bathymetry of a study area located to the north and west of the Orkney Islands.



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Executive Summary

In recent years there have been many new seabed-mapping programmes carried out around the world using the latest data acquisition techniques. The need for these maps is driven by the recognition that an ecosystem-based approach to the management of national Exclusive Economic Zones (EEZs), as required by the Convention on Biological Diversity (CBD) adopted at the Rio Earth Summit in 1992, requires both detailed bathymetry and maps of the physical properties of the sea floor.

In Europe, the implementation of the CBD is through the Habitats and Birds Directives, which require the identification of Special Areas of Conservation (SACs) and Special Protected Areas (SPAs). A network of SACs and SPAs will be set up across Europe known as *Natura 2000.* In addition, the International Council for the Exploration of the Seas has developed the concept of the ecosystem-based approach in the context of fisheries management, subsequently adopted by the European Union in its review of the Common Fisheries Policy; the World Wildlife Fund for Natures' marine policy has developed the concept of Marine Protected Areas (MPAs); the OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic is also working to promote networks of MPAs and Ecological Quality Objectives (EcoQOs).

In the UK, the Department of Environment, Fisheries and Rural Affairs (DEFRA) major reports on Marine Stewardship*,' Safeguarding our Seas: A Strategy for the Conservation and Sustainable Development of our Marine Environment'* published in 2002 and followed by a consultation paper *' Seas of Change',* form the basis for developing a practical application of the ecosystem-based approach. The DEFRA Review of Marine Nature Conservation (RMNC) produced an interim report in 2001, which recommended that a pilot scheme at a regional scale to test a proposed framework for nature conservation. This has led to the Irish Sea Pilot Study managed by the Joint Nature Conservation Committee (JNCC), which has adopted the concept of 'marine landscapes', first developed in Canadian waters, based on geophysical features recognising that their importance in determining the nature of biological communities.

As a result of these national and international initiatives, a number of habitat classification schemes have been introduced in different parts of the world. Since 2001, a group of geologists with interests in the application of geological data to habitat mapping have met each year to present their views and mapping programmes and to discuss their ideas with scientists from other disciplines, mainly biologists and oceanographers. The GeoHab (Geological Mapping of Habitats for Marine Resources and Management) group have provided the impetus for this review of BGS geological data in the context of habitat mapping classification schemes, and proposes ways in which our BGS data may be applied automatically, within a Geographical Information System, to the selection of relevant sources of information.

1 Introduction

The study of marine habitats and their classification is a developing area of research world-wide. The British Geological Survey (BGS) has participated in several habitat-related projects already, and there is potential for even greater involvement in the future. James (2001a) described emerging marine habitat classification schemes and the application of marine geological datasets in mapping habitats. This report updates and develops the report of James (2001a) by reviewing existing marine habitat classification schemes, describing how BGS datasets relate to such schemes and testing the feasibility of using GIS techniques to automatically generate habitat sea-floor maps for different schemes using BGS data sources. Many of the existing schemes are either project specific or restricted to particular habitats and do not utilise geological information in a systematic manner or to its full potential.

Habitat mapping is defined as the process by which seafloor geological characteristics are integrated with biological information (Todd et al., 1999). This type of mapping is necessary for sustainable ecosystem-based management of the marine environment, such as fisheries management and the monitoring of essential fish habitats, biological resource management, Special Areas of Conservation (SAC) management, risk assessment, pollution monitoring, long-term monitoring programmes, geohazard identification and resource validation (Marine Habitat Committee, 2001). A close relationship exists between the physical environment and its associated biological community. The management of the marine environment requires mapping of the physical environment and classification of its biotopes (Urbański and Szymelfenig, 2003). A biotope combines the habitat and its associated biological community into the smallest defined unit supporting a homogenous group of species (Urbański and Szymelfenig, 2003).

In the United States a prototype Marine and Estuarine Ecosystem and Habitat Classification (Allee et al., 2000) has been developed, combining existing global and regional systems to form a hierarchical classification containing both biological and physical information. Work has also been carried out on marine habitat mapping by the Geological Survey of Canada (GSC), centring on the Gulf of Maine, and the United States Geological Survey (USGS) who have studied areas such as Georges Bank, off New England. In European waters, progress has been made through joint programmes between OSPAR, the International Council for the Exploration of the Seas (ICES) and the European Environment Agency (EEA). The EEA has developed a classification system which will form the basis for habitat mapping within the OSPAR area (James, 2001a). This system, the European Nature Information System (EUNIS) habitat classification, has developed and evolved from a number of systems including the CORINE, BioMar and EMERALD classifications. The Joint Nature Conservation Committee (JNCC) has developed a national marine habitat classification for Britain and Ireland. This habitat classification has been developed as a tool to aid the management and conservation of marine habitats and is structured to align with the EUNIS habitat classification scheme (Connor et al., 2003).

The application of marine geophysics and Geographic Information System (GIS) techniques are powerful tools for habitat mapping of the deep ocean and shallow continental shelves. Examples of datasets used for marine habitat mapping include sidescan sonar data, backscatter data, multibeam bathymetric data, seabed samples, aerial and seabed photographs and acoustic ground discrimination systems (AGDS).

High-resolution sidescan sonar data can be used to determine the extent of different habitats. The use of backscatter values, in conjunction with other geophysical data and samples, provides an insight into seafloor sediment processes (Todd et al., 1999). Unique backscatter patterns are controlled by lithology, density of rock unit and topographic expression (McRea et al., 1999). A study conducted on Browns Bank off Nova Scotia revealed that in general, areas with high backscatter values indicated areas of gravel, whereas areas of low backscatter values indicated areas of fine-grained sand and areas of sandwaves (Todd et al., 1999). Multibeam images have provided a fresh insight into morphological and textural seabed attributes, which have led to the identification of new features and processes. There have been many papers describing AGDS methods of habitat mapping in recent years. Two systems, namely QTC-View and RoxAnn, are commonly used. It has been argued that a close relationship exists between the acoustic patterns and the main sedimentary and biological groups, however, the accuracy of the classification produced by AGDS systems is reliant on the calibration of the equipment, as classification is based on the closest correlation with one of the calibration types (Anderson et al., 2002). It is therefore important to collect a representative selection of calibration files to avoid spurious results. It has also been suggested that AGDS systems such as RoxAnn can be over-sensitive (Greenstreet et al., 1997).

Several authors have recognised the need to integrate geological data with other available data when considering the distribution of biological communities. For example, Pickrill and Todd (2003) report the value of high-resolution mapping of the physical environment, coupled with the mapping of benthic species and their distribution in realising the relationship between the sea floor and the benthic community. Urbański and Szymelfenig (2003) noted that the distribution of biological communities is dependent on the physiology of the seabed and its composition. A study in the western coastal shelf area of Portugal has found that the distribution of benthic groups follows the same distribution pattern shown by sedimentary units (Freitas et al., 2003).

The distribution of cold-water coral reefs is also closely related to the substrate. Coral mounds composed of *Lophelia pertusa* have been found in the Sula Ridge area, on the Mid-Norwegian Shelf, existing preferentially along the escarpment, glacial flutes and iceberg ploughmarks (Thorsnes, 2003). These cold-water coral habitats consequently sustain high levels of biodiversity due to their structural complexity, which provides a habitat for many other species (Roberts et al., 2003). Due to increasing activity at the continental shelf edge by hydrocarbon and fishing industries, the extent of cold-water corals must be mapped and monitored in order to assess their distribution; it seems likely that trawling activities have already reduced their extent in the north-east Atlantic (Roberts et al., 2003).

In recent years there has been increasing use of BGS 1:250 000 scale thematic maps in habitat mapping. BGS has been involved in several projects with organisations such as English Nature and the JNCC, which have incorporated BGS data into habitat mapping databases. The marine geological data acquired by BGS over the last 30 years includes seismic and acoustics, sediment particle size, geochemistry and geotechnical data. Digital data derived from bathymetry, seabed sediment, Quaternary geology and solid geology maps as well as other data sources have been used to develop the BGS Offshore GIS using ArcGIS.

The aim of this report is to present a description of marine habitat classification systems presently in use or development. The report will also propose a framework within which BGS data and interpretations can be applied to the most commonly-used classifications.

2 Activities in Habitat Mapping

2.1 GEOHAB

GeoHab (Marine **Geo**logical **Hab**itat Mapping) was established in 2001 to bring together scientists worldwide who are working on the development of maps linking acoustic mapping and geological sampling to marine biology in a GIS environment. GeoHab does not endorse a particular habitat mapping classification scheme but recognises that schemes will continue to develop and the habitat mapping community will use the most universal and easily applied schemes.

GeoHab is an international forum that meets annually and is designed to:

- maintain awareness of technological developments and survey standards
- identify existing metadata sources relevant to marine habitat mapping
- develop new thematic maps useful for fisheries management, biodiversity management and the assessment of future Marine Protected Areas (MPAs)
- encourage standardisation of maps by creating a habitat mapping glossary and building links to marine mapping around the world
- apply and evaluate habitat classification systems using real-world examples

The first meeting of the GeoHab group took place in Dartmouth, Nova Scotia in May 2001. Moss Landing Marine Laboratories, California, hosted the second meeting of GeoHab in May of 2002. At this meeting, Gary Greene and his team presented their GIS attribute code for Deep-Water Marine Benthic Habitat Classification (see chapter 3). The scheme presented at GeoHab 2002 followed on from work published in 1999 (Greene et al., 1999), which presented a standard classification scheme for deep-water habitats.

The third GeoHab meeting was co-convened by Geoscience Australia and CSIRO Marine Laboratories in Hobart, Tasmania, from the 30th April to 2nd May 2003. The main themes of the 2003 meeting were the impact of fishing gear on habitats based on the understanding of geological attributes, the use of surrogates for biodiversity distribution in MPA design and visualisation tools for presenting data to managers.

Many presentations and abstracts centred on the vast amount of current research into the integration of biology and geology. Discussion also highlighted the continuing debate as to whether a standard habitat mapping scheme is possible or required due to its need to be sufficiently flexible to adapt to individual researchers or organisations' requirements. Habitat mapping tools presented at the Hobart conference included:

- the use of foraminifera in benthic habitat mapping
- the use of Recent fossil planktonic foraminifera as a guide to determine how persistent the distribution of habitats has been through time
- the ecosystem's response to climate change
- the use of aerial photography in shallow water seabed mapping.

The importance of multibeam, sonar, bathymetric and backscatter data, which can be manipulated within a GIS environment, was also a common theme.

The forth GeoHab meeting will be held in Galway, Ireland, in May 2004. Dr. Anthony Grehan of the University of Galway will host this meeting.

2.2 IRISH SEA PILOT PROJECT

The UK Department of Environment, Fisheries and Rural Affairs (DEFRA) have funded a project to test a new framework for marine nature conservation developed by the UK Conservation Agencies for the Review of Marine Nature Conservation (RMNC). The framework is designed to apply the two principles of using *a whole ecosystem approach* and *managing the sea at a regional scale*.

The Irish Sea was chosen because of its important habitats and species populations, such as sea birds and fish; it is also the summer feeding area for basking sharks and leatherback turtles. The whole ecosystem approach of this project will promote the sustainable development of a number of activities ranging from tourism to commercial fish stocks, while maintaining a balance with wildlife protection.

The study area covers an area from Linney Head, Wales to Mine Head, Ireland in the south to the Mull of Kintyre, Scotland to Fair Head, Northern Ireland in the north (Figure 1). The project will consider the sea at four scales:

a. *The whole sea* from the high water mark to the limits of UK jurisdiction;

b. *Regional seas* of which the Irish Sea is one of nine regional seas around the UK;

c. *Ecological Units/Marine Landscapes* within regional seas;

d. *Specific areas of national importance*.

Datasets from several sources, including the BGS, were compiled into a GIS and used to characterise marine landscape features. The interim report of the Irish Sea Pilot (Golding et al., 2003) reports on the set of ecological units or physiographic units used to identify marine landscapes for the Irish Sea (Figure 1). The 15 ecological units comprise 6 sediment categories and 9 physiographic features. The ecological units form the basis for the identification of associated habitats. Knowing whether a particular habitat is associated with a particular ecological unit can be used to predict the natural biodiversity resources of a regional sea.

2.3 AUSTRALIA

Geoscience Australia have a Seabed Mapping and Characterisation Project which aims to provide an improved understanding of the relationships between oceanographic processes, marine geology, benthic habitats and the ocean environment. This will help in the designation of protected areas and marine management.

The project collects and interprets data on solid geology, seabed sediments, sedimentary processes and morphology, as well as other aspects of seabed geology, allowing ‘bioregions’ to be identified. These aim to help with the conservation of the marine environment and give an insight into the stability and nature of the seafloor.

Geoscience Australia has also produced the most recent version of a database containing information for over 1000 Australian coastal waterways (Harris and Heap, 2003). This database, the Australian Estuarine Database (AED), has classified each waterway as wave- or tide-dominated estuaries, wave- or tide-dominated deltas, lagoons, strand plains or tidal flats.

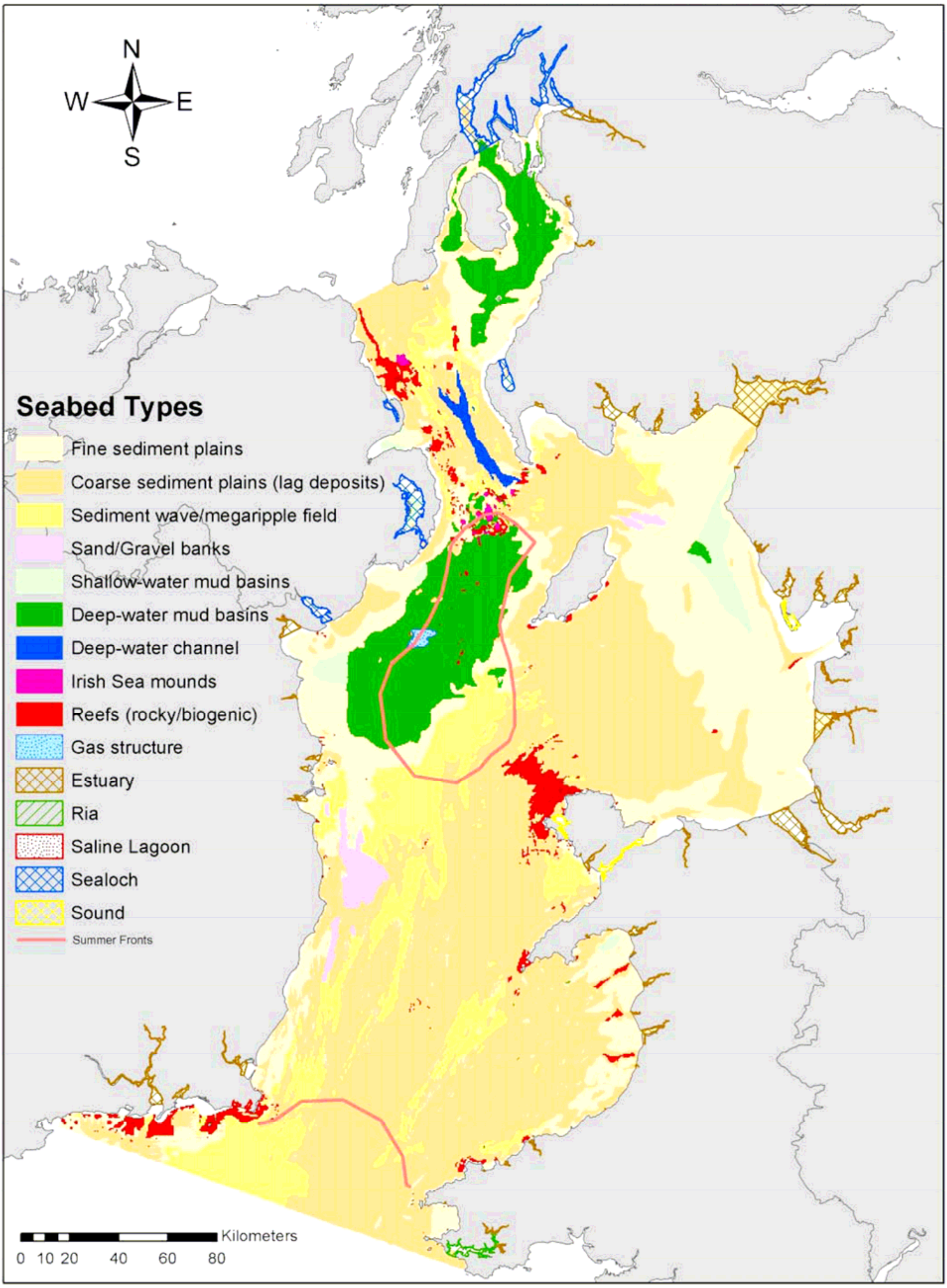


Figure 1 Set of ecological units for the Irish Sea (Golding et al, 2003).

2.4 NORWAY

The Norwegian Geological Survey (NGU) has long realised the importance of Norway's coastal and shelf areas. As a result, NGU along with a number of other national organisations has embarked on compiling a database, detailing the topography of the seafloor. As part of this database the geotechnical properties of the seafloor, the distribution of seabed sediments and geological resources are also being mapped. These all contribute to creating the seabed habitats that provide breeding grounds for fish stocks in Norwegian waters.

Cold-water coral reef habitats have also been discovered on the Mid-Norwegian Shelf. These are known to be important breeding grounds for commercially significant fish stocks and their preservation is vital. By mapping out these coral reefs and other marine habitats, Norwegian scientists realise that through their understanding of these environments, the effects of human activities can be determined and effective fisheries management and preservation of the environment can be developed. The Sula Reef (Figure 2) located at 300m water depth in the Norwegian Sea is a reef complex consisting of more than 500 individual coral mounds (Thorsnes, 2003). The distribution of these cold-water corals, predominantly *Lophelia pertusa*, is closely related to the substrate on which the corals are situated. The corals are preferentially located on glacial ridges formed when ice eroded the bedrock of Paleocene sandstones overlying Cretaceous shales.

The MAREANO Project[1] is an initiative coordinated by the NGU, the Institute of Marine Research and the Norwegian Hydrographic Service. MAREANO is a large-scale seabed mapping project aimed at collecting new as well as historical data on the physical, chemical and biological characteristics of the mid-Norwegian shelf and the Norwegian Sea. This will provide the basic framework in terms of bathymetry, geology, habitats and pollution, embedded in a virtual database system accessed by a web-based GIS system.

The MAREANO Project is currently moving its focus northwards, away from the Norwegian Sea to the Barents Sea, covering an area of approximately 135,000km^2. This is in response to strong emphasis on ecosystem-based area management in the Barents Sea by the Norwegian Government.

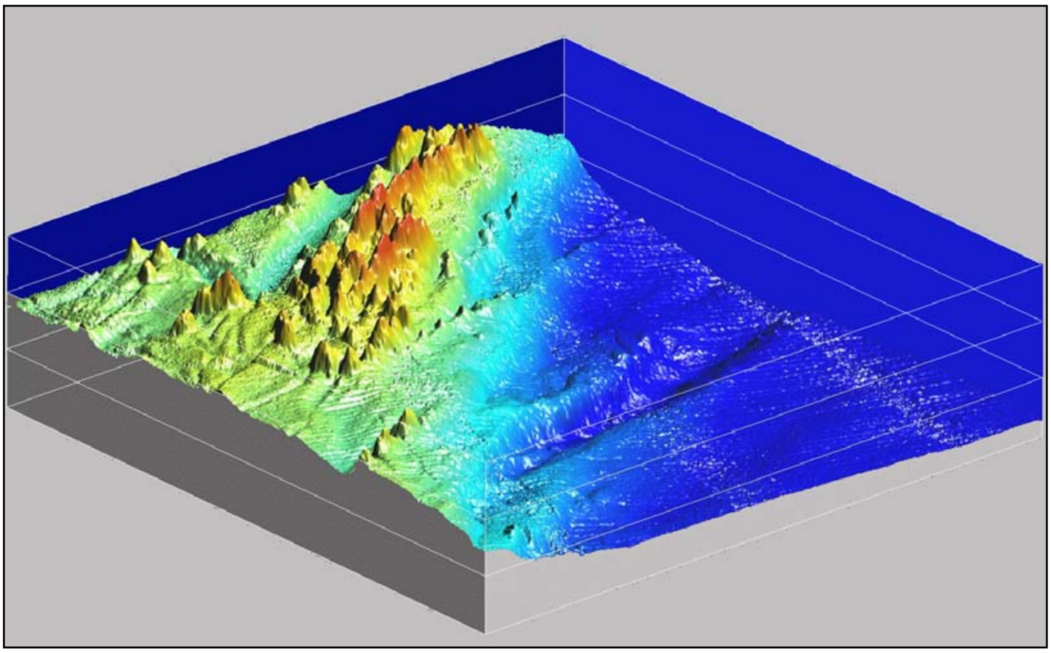


Figure 2 Coral reefs on glacial ridges form a special habitat having vast ecological importance in Norwegian waters. These mounds are from the Sula Ridge, and were mapped using multibeam bathymetry.

[1] For further information on MAREANO please contact Terje Thorsnes of the Norwegian Geological Survey (terje.thorsnes@ngu.no).

2.5 GEOLOGICAL SURVEY OF CANADA

2.5.1 Benthic Habitat Mapping

The Gulf of Maine Digital Atlas has been compiled by B J Todd, J L Strang and W A Rainey. The project illustrates the distribution of habitats, surficial geology, image locations, seismic lines and bathymetry of the Browns Bank area, home to important scallop beds on the western Scotian Shelf. Browns Bank is located on the glaciated continental shelf off southern Nova Scotia, Canada. The digital atlas habitat classification of the Browns Bank area is:

1. **Soft coral and sea cucumber habitat** – sand, gravel, high energy environment
2. **Barren habitat** – sand, shallow water, high energy environment
3. **Barren habitat** – sand, deep water, low energy environment
4. **Terrebratulina (brachiopod) habitat** – sand, gravel, and boulders, high diversity and abundance of megafauna
5. **Terrebratulina (brachiopod) habitat** – tunicates and sponges predominate
6. **Scallop habitat** – sand, gravel, high energy, low diversity
7. **Deposit feeders habitat** – gravel, silt, low energy environment.

Several areas of multibeam data are outlined (including the Browns Bank study area) and several have been converted into detailed shaded-relief images. These compliment the larger more regional scale USGS shaded-bathymetry image.

In this study, habitats were defined using geophysical and sedimentological characteristics, water depth and dominant benthos types (Todd et al., 2000a). The aim of this study was to integrate geological, biological and dynamic conditions in order to understand the ecology of the Browns Bank area (Todd et al., 2000a); this is an important step towards effective fisheries management. It was determined that sediment grain size alone does not control species distribution. Transport processes, current and wave activity, the interaction of benthic and pelagic realms and grain size should all be considered together if a detailed benthic mapping project is to be undertaken in a particular area (Todd et al., 2000a).

The data gathered during the course of the habitat mapping on Browns Bank has also been used to understand the Quaternary geological history as a framework for modern sedimentary processes (Todd et al., 1999).

The success of the Browns Bank study, and the collaboration between the fishing industry and the government, has resulted in similar mapping projects over Georges Bank and German Bank (Pickrill and Todd, 2003). The results of these studies have had a positive effect on the fishing industry. These include improved stock assessment and management as a result of the better understanding of scallop habitats, vulnerable or barren habitats being avoided by the dredgers, new lighter rakes being developed and a reduction in the time spent dredging in order to collect quotas (Pickrill and Todd, 2003).

2.5.2 Juan de Fuca Atlas

The Juan de Fuca Atlas (Mosher et al., 2000) is a combined GSC and USGS publication. The main features of the atlas are the shaded-bathymetry images, sandbar locations and surficial geology. No interpretation of marine habitats is included in the CD-ROM but conclusions can be drawn from the detailed bathymetric data and the distribution of seabed sediments.

2.6 MONTEREY BAY AQUARIUM RESEARCH INSTITUTE (MBARI)

In 1998, MBARI completed bathymetric surveys of selected areas located offshore four of the Hawaiian Islands, offshore Santa Barbara and the central coast of California. These multibeam surveys have been distributed on CD-ROM to be used by ocean scientists and students. The surveys have produced bathymetric images of the seafloor and no interpretation of marine habitat, however, the images could be used in the classification and identification of seafloor features or marine landscapes.

MBARI currently has an ongoing seafloor-mapping project with three main aims:

- to develop their ability for high-resolution mapping of the deep-ocean floor.
- to continue developing software for the processing and display of swath data; this is in collaboration with the Lamont–Doherty Earth Observatory.
- continue developing tools aimed at incorporating seafloor mapping into existing GIS environments.

2.7 SCOTTISH SUSTAINABLE MARINE ENVIRONMENT PROJECT

A new study into Scotland's marine environment began in October 2002 funded by a £250,000 grant from the Scottish Executive. The project is managed by a steering committee of representatives involved in the marine environment, members from the Scottish Executive Environment and Rural Affairs Department (SEERAD), Scottish Natural Heritage (SNH), Scottish Coastal Forum, Federation of Scottish Aquaculture Producers, Scottish Environment LINK, Convention of Scottish Local Authorities (CoSLA), Scottish Environment Protection Agency (SEPA) and the British Ports Authority (BPA). The study will investigate an ecosystem-based approach to the management of marine resources and will develop a framework to involve local communities in new approaches to sustainable management of the marine environment.

The project will be carried out in three phases:

- Conceptualisation of the project and data and information gathering. Completed in April 2003;
- Developmental phase, undertaking background work to launch and run pilot management schemes that will be ready to start at the end of this phase in March 2004;
- Beginning in April 2004, implementation of the pilot management project, which will require new partnership funding, established under phase 2.

This project is seen to be complementary to the Irish Sea Pilot Project. The two projects are expected to work closely and liase with each other, bringing about mutually added value.

2.8 CEFAS

The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) has been funded by DEFRA to investigate the factors that control the distributions of marine biological communities. CEFAS mapped four areas in the English Channel to investigate gravel biotopes and to assess different surveying methods. BGS contributed geological expertise and data to the project to test the value and practicality of integrating geological and biological interpretations (James, 2001b). The main conclusion of the report was that a significant relationship existed between the gravel biotopes and seabed facies as mapped by side-scan sonar. The report also made several recommendations on survey methodology and the analysis/interpretation of seabed facies data in relation to habitats.

2.9 JOINT NATURE CONSERVATION COMMITTEE

The JNCC has developed a national marine habitat classification for Britain and Ireland. This habitat classification has been developed as a tool to aid the management and conservation of marine habitats and is structured to align with the EUNIS habitat classification scheme (Connor et al., 2003).

An improved understanding of the distribution, extent and status of marine habitats is required for the assessment of the marine environment and consequently the better use of habitats during spatial and strategic planning of activities (Connor et al., 2003). This habitat classification provides an ecologically-based system for classification of the seashore and seabed features. These include marine, estuarine and brackish-water habitats, rock and sediment habitats, upper shore to coastal waters and biological communities throughout Britain and Ireland.

A hierarchical system has been developed consisting of six levels equal to the levels in the EUNIS classification:

1. Level 1: Environment (marine)
2. Level 2: Broad habitats
3. Level 3: Main habitats
4. Level 4: Biotope complexes
5. Level 5: Biotopes
6. Level 6: Sub-biotopes

This approach allows classification to be undertaken either through habitat attributes such as substratum, topography, geology, salinity or strength of tidal currents, or through information about the biological community (Connor et al., 2003). The framework of this classification system is flexible enough to be extended to the offshore continental shelf and other European seas, in keeping with the EUNIS classification.

3 Review of Existing Marine Habitat Classification Schemes

During recent years many marine habitat classification schemes have been developed. However, these schemes have often been developed for specific projects and are not applicable to wider areas; have been created with the objective of mapping the habitat of a specific species or have been written from a terrestrial viewpoint. Recent collaborations between organisations and programmes of work centred on marine habitat mapping have established the need for a consistent habitat classification system in which all those involved can "speak the same language". A practical and accommodating classification scheme would require to be scientifically based, comprehensive, flexible enough to allow the addition of new information and provide a common language for description and communication within an international forum.

Within this chapter, four existing classification schemes are described.

3.1 EUROPEAN NATURE INFORMATION SYSTEM (EUNIS)

The European Environment Agency (EEA) has developed a comprehensive habitat classification system[2] encompassing all types of habitat found in Europe. The European Nature Information System (EUNIS) has evolved from a number of different systems including CORINE and BioMar, from which the classification of marine habitats is largely based. EUNIS includes terrestrial, marine, freshwater, natural and artificial habitats within its eleven categories.

- A Marine habitats
- B Coastal habitats
- C Inland surface water habitats
- D Mire, bog and fen habitats
- E Grassland and tall forb habitats
- F Heathland, scrub and tundra habitats
- G Woodland and forest habitats and other woodland land
- H Inland unvegetated or sparsely vegetated habitats
- I Regularly or recently cultivated agricultural, horticultural and domestic habitats
- J Constructed, industrialised and other artificial habitats
- X Habitat complexes

The habitat system is hierarchical based on five levels. In section A the marine environment, these have only been verified down to level 3 (see below), with the remaining two levels yet to be agreed upon. The EUNIS classification system is scientifically based, comprehensive and applicable at a number of levels depending on the information available. It provides a common language for the description of marine habitats and is flexible to allow the admission of new information.

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention 1992) came into force on the 25th March 1998, superceding the 1972 Oslo

[2] See http://mrw.wallonie.be/dgrne/sibw/EUNIS/home.html for the EUNIS habitat classification system.

Convention and the 1974 Paris Convention. The EUNIS habitat classification is the system OSPAR have decided will form the basis for habitat mapping within its areas (James, 2001a).

Level 1
A MARINE HABITATS

Level 2
A1 Littoral rock and other hard substrata
Level 3
A1.1 Littoral rock very exposed to wave action
A1.2 Littoral rock moderately exposed to wave action
A1.3 Littoral rock sheltered from wave action
A1.4 Rock habitats exposed by action of wind (e.g. hydrolittoral)
A1.5 Rockpools
A1.6 Littoral caves and overhangs

Level 2
A2 Littoral sediments
Level 3
A2.1 Littoral gravels and coarse sands
A2.2 Littoral sands and muddy sands
A2.3 Littoral muds
A2.4 Littoral combination sediments
A2.5 Habitats with sediments exposed by action of wind (e.g. hydrolittoral)
A2.6 Coastal saltmarshes and saline reedbeds
A2.7 Littoral sediments dominated by aquatic angiosperms
A2.8 Biogenic structures on littoral sediments

Level 2
A3 Sublittoral rock and other hard substrata
Level 3
A3.1 Infralittoral rock very exposed to wave action and/or currents and tidal streams
A3.2 Infralittoral rock moderately exposed to wave action and/or currents and tidal streams
A3.3 Infralittoral rock sheltered from wave action and currents and tidal streams
A3.4 Caves, overhangs and surge gullies in the infralittoral zone
A3.5 Circalittoral rock very exposed to wave action or currents and tidal streams
A3.6 Circalittoral rock moderately exposed to wave action or currents and tidal streams
A3.7 Circalittoral rock sheltered from wave action and currents including tidal streams
A3.8 Deep circalittoral rock habitats exposed to strong currents
A3.9 Deep circalittoral rock habitats exposed to moderately strong currents
A3.A Deep circalittoral rock habitats exposed to weak or no currents
A3.B Caves and overhangs below the infralittoral zone
A3.C Vents and seeps in sublittoral rock

Level 2
A4 Sublittoral sediments
Level 3
A4.1 Sublittoral mobile cobbles, gravels and coarse sands
A4.2 Sublittoral sands and muddy sands
A4.3 Sublittoral muds

A4.4 Sublittoral combination sediments
A4.5 Shallow sublittoral sediments dominated by angiosperms
A4.6 Biogenic structures over sublittoral sediments
A4.7 Deep shelf sediment habitats
A4.8 Seeps and vents in sublittoral sediments

Level 2
A5 Deep-sea bed

Level 3
A5.1 Deep-sea rock and artificial hard substrates
A5.2 Deep-sea combination substrates
A5.3 Deep-sea sand substrates
A5.4 Deep-sea muddy sand substrates
A5.5 Deep-sea muds
A5.6 Deep-sea bioherms
A5.7 Canyons, channels, slope failures and slumps on the continental slope
A5.8 Deep-sea trenches
A5.9 Deep-sea reducing habitats
A5.A Deep-sea bed influenced by hypoxic water column

Level 2
A6 Isolated 'oceanic' features: seamounts, ridges and the submerged flanks of oceanic islands

Level 3
A6.1 Permanently submerged flanks of oceanic islands
A6.2 Seamounts, knolls and banks
A6.3 Oceanic ridges
A6.4 Isolated oceanic features influenced by hypoxic water column
A6.5 Vents in the deep sea

Level 2
A7 Pelagic water column

Level 3
A7.1 Neuston
A7.2 Completely mixed water column with reduced salinity
A7.3 Completely mixed water column with full salinity
A7.4 Partially mixed water column with reduced salinity and medium or long residence time
A7.5 Unstratified water column with reduced salinity
A7.6 Vertically stratified water column with reduced salinity
A7.7 Fronts in reduced salinity water column
A7.8 Unstratified water column with full salinity
A7.9 Vertically stratified water column with full salinity
A7.A Fronts in full salinity water column

Level 2
A8 Ice-associated marine habitats

Level 3
A8.1 Sea ice
A8.2 Freshwater ice
A8.3 Brine channels
A8.4 Under-ice habitat

The EUNIS classification pays close attention to the area extending from the coast (splash zone) out to between 50-70m water depth (circalittoral zone), however, little attention is made to sediments in deeper shelf waters. Levels A4.1-A4.6 subdivide the sea bed sediments located between the splash and circalittoral zones into particle size ranges and proportions of sediment grades. However, only one level encompasses deep shelf sediment habitats located in 50-70m to approximately 200m water depth (level A4.7). Sediments lying in water depths greater than 200m are catered for in level A5, but not in as much detail as those in shallower water.

3.2 DEEP WATER MARINE BENTHIC HABITAT CLASSIFICATION SYSTEM

The Deep-Water Marine Benthic Habitat Classification System is a hierarchical GIS attribution code created to make marine benthic habitats easier to recognise and assist the use of GIS systems (Greene et al., 2002). This habitat attribute code is based on the deep-water habitat characterisation scheme developed by Greene et al. (1999). The aim was to create a universal scheme which could be accurately applied in many scientific disciplines. Greene et al. (1999) established their classification scheme principally for the identification of the benthic habitats of rockfish assemblages in deep water using geology, geophysics and direct observations (including biological observations).

The following categories refer directly to habitat interpretation: megahabitat (physiographic and size related features >10km), seafloor induration (substrate hardness), meso/macro habitat (feature size between 1km and 1m), modifier (describes the textural and lithological relationship), slope and seafloor complexity. Additional categories exist based on video, photographic or direct observations and relate to scales of 10m to centimetres, but these are not listed below. The classification scheme is as follows:

Megahabitat

A Aprons, continental rise, deep fans and bajadas. (3000-5000m of water)
B Basin floors, Borderland types. (Floors at 1000-2500m depth)
F Flanks, continental slope, basin/inland-atoll flanks. (2000-3000m depth)
I Inland seas, fjords. (0-200m water depth)
P Plains, abyssal. (Greater than 5000m water depth)
R Ridges, banks and seamounts. (Crests at 200-2500m water depth)
S Shelf, continental and island shelves. (0-200m water depth)

Seafloor Induration

h Hard bottom, rock outcrop, relic beach rock or sediment pavement.
m Mixed (hard and soft bottom).
s Soft bottom, sediment covered.
Subdivided:
(b)=boulder
(c)=cobble
(g)=gravel
(h)=halimeda sediment, carbonate
(m)=mud, silt, clay
(p)=pebble
(s)=sand

Meso/Macrohabitat

a atoll
b beach, relic
c canyon
d deformed, tilted and folded bedrock
e exposure, bedrock
f flats
g gully, channel
i ice-formed feature or deposit, moraine, drop-stone depression
k karst, solution pit, sink
l landslide
m mound, depression

n	enclosed waters, lagoon
o	overbank deposit (levee)
p	pinnacle
r	rill
s	scarp, cliff, fault or slump
t	terrace
w	sediment waves
y	delta, fan
z	zooxanthellae hosting structure, carbonate reef. Subdivided: 1=barrier reef 2=fringing reef 3=head, bommie 4=patch reef

Modifier (letter is subscript)

a	anthropogenic (artificial reef/breakwall/shipwreck)
b	bimodal (conglomeratic, mixed [includes gravel, cobbles and pebbles])
c	consolidated sediment (includes claystone, mudstone, siltstone, sandstone, breccia or conglomerate)
d	differentially eroded
f	fracture, joints-faulted
g	granite
h	hummocky, irregular relief
i	interface, lithologic contact
k	kelp
l	limestone or carbonate
m	massive
p	pavement
r	ripples
s	scour (current or ice, direction noted)
u	unconsolidated sediment
v	volcanic rock

Seafloor Slope

1	Flat (0-1º)
2	Sloping (1-30º)
3	Steeply sloping (30-60º)
4	Vertical (60-90º)
5	Overhang (>90º)

Seafloor Complexity

A	Very low complexity (-1 to 0)
B	Low complexity (0 to 1)
C	Moderate complexity (1 to 2)
D	High Complexity (2 to 3)
E	Very High Complexity (3+)

Geologic Unit (When possible, the associated geological unit is identified for each habitat type)

For the designation of small-scale marine habitats it is recommended that the macro/microhabitats, seafloor slope and seafloor complexity are determined not only from remote sensing imagery but also from direct observations and ground-truth data.

The Deep-Water Marine Benthic Habitat Classification Scheme provides a good general guide for the mapping of marine habitats. Sections on seafloor slope and seafloor complexity are not covered in any detail by the other classification schemes examined in this chapter, neither is the Geological Unit.

However, the letter codes allocated to each descriptor listed above, when combined as part of a description, leads to a complex code.

Example: The code Shp_d1D(Q/R) gives the interpretation – Continental shelf megahabitat; flat, highly complex hard seafloor with pinnacles differentially eroded. Geologic unit = Quaternary/Recent.

This code becomes more complex if the classification scheme for direct observations (not listed in this document) is included, as many of the letters and numbers are used with parentheses, brackets, or are preceded by an asterisk.

3.3 NATURA 2000 IN UK OFFSHORE WATERS

The selection of marine special areas for conservation (SAC's) under Annex I of the Habitats and Birds Directive[3] (see below), known as the Habitats Directive, has been limited in UK waters to those within 12 nautical miles of the coast. The Offshore Natura 2000 Project, managed by the JNCC, has been established to provide advice necessary for the selection of SAC's (Special Areas of Conservation) in the offshore area under the Habitats Directive. DEFRA sit on the steering committee of Natura 2000 and have recently stated that they are consulting on the regulations to extend the Habitats Directive beyond the 12 nautical mile limit (Department for Environment, Food and Rural Affairs, 2002). The aim of the project is to ensure that the work carried out in the offshore area interfaces with that already completed for inshore waters. Together, terrestrial and marine sites of protection are intended to form a coherent ecological network of sites of European importance. However, the only sub-groups of Annex I within the marine environment are listed below, and have little practical application in the offshore environment of the UK. The Habitats Directive was written from a terrestrial perspective and its application in the marine environment has proved difficult (Hiscock et al., 2003).

1 COASTAL AND HALOPHYTIC HABITATS
11 Open sea and tidal areas
- **1110 Sandbanks which are slightly covered by seawater all the time**
- 1120 **Posidonia* beds (*Posidonion oceanicae*)
- 1130 Estuaries
- 1140 Mudflats and sandflats not covered by seawater at low lide
- 1150 *Coastal lagoons
- 1160 Large shallow inlets and bays
- **1170 Reefs**
- **1180 Submarine structures made by leaking gases**

12 Sea cliffs and shingle or stony beaches
- 1210 Annual vegetation of drift lines
- 1220 Perennial vegetation of stony banks
- 1230 Vegetated sea cliffs of the Atlantic and Baltic Coasts
- 1240 Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp.
- 1250 Vegetated sea cliffs with endemic flora of the Macaronesian coasts

13 Atlantic and continental salt marshes and salt meadows
- 1310 *Salicornia* and other annuals colonising mud and sand
- 1320 *Spartina* swards (*Spartinion maritimae*)
- 1330 Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)

[3] See http://europa.eu.int/comm/environment/nature/hab-an1en.htm for Annex I of the Habitats and Birds Directive.

1340 *Inland salt meadows
14 Mediterranean and thermo-Atlantic salt marshes and salt meadows
1410 Mediterranean salt meadows (*Juncetalia maritimi*)
1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticiosi*)
1430 Halo-nitrophilous scrubs (*Pegano-Salsoletea*)
15 Salt and gypsum inland steppes
1510 *Mediterranean salt steppes (*Limonietalia*)
1520 *Iberian gypsum vegetation (*Gypsophiletalia*)
1530 *Pannonic salt steppes and salt marshes
16 Boreal Baltic archipelago, coastal and landupheaval areas
1610 Baltic esker islands with sandy, rocky and shingle beach vegetation and sublittoral vegetation
1620 Boreal Baltic islets and small islands
1630 *Boreal Baltic coastal meadows
1640 Boreal Baltic sandy beaches with perennial vegetation
1650 Boreal Baltic narrow inlets

The numerical code corresponds to the NATURA 2000 code
Bold indicates levels populated as part of a commissioned report for the JNCC (Graham et al., 2001)

Identification and determining the extent of the habitats listed in Annex I of the Habitats Directive was undertaken by BGS, under contract, as part of the Natura 2000 report (Johnson et al., 2000; Graham et al., 2001). Much of the data to populate Annex I was taken from existing BGS map interpretations of sample and geophysical data and mapped within a GIS. Only the three habitat types indicated in 'Open Sea and Tidal Areas' were mapped, however limitations regarding the use of the existing definitions were encountered. For example, the definition of the term 'sandbanks' applies to features in water depths rarely greater than 20m, however, it was found that parts of sandbanks and sandbank systems often extend into water deeper than 20m, such as the flanks and channels between individual banks. Sandbanks have also been identified in waters much deeper than 20m in the UK offshore area. Sandbanks are a broad habitat type, can have a large extent and character and are therefore difficult to determine precisely.

The term 'reef' refers to bedrock, rocky substrate and biogenic concretions arising from the seafloor (Johnson et al., 2000). BGS found it easy to extract areas of bedrock and rocky substrates but ran into complications regarding areas of gravel to be included as reefs. Areas of gravel as defined by BGS were included as Annex I reef habitats, as no division of the gravel into boulders and cobbles (reef structures), and pebbles and granules (non-reef structures) could occur at this time; further refinement of gravel reefs will occur as more information is gathered about areas of gravel.

BGS mapping of Annex I habitats in offshore waters highlighted the fact that the definitions given in Annex I need to be refined. It highlights that Annex I of the Habitats Directive is a legislative list of habitat types selected on account of their conservation requirements, not a comprehensive classification scheme such as EUNIS.

English Nature also commissioned the BGS to identify selected seabed habitats between mean low water and the 12 nautical mile limit off the English coast (British Geological Survey, 2003). A GIS was created for English Nature as part of the European Habitats Directive for the selection of SAC's, containing physical seabed features using the distribution of bedrock and sediment at the seabed as well as biological information (Poulton et al., 2002).

3.4 MARINE AND ESTUARINE ECOSYSTEM AND HABITAT CLASSIFICATION

This proposed classification system has been developed as part of a joint initiative between the Ecological Society of America and NOAA's Offices of Habitat Conservation and Protected

Resources. Together, these organisations sponsored a workshop to review existing classification systems, develop the framework for a national classification and propose a plan to expand the framework into an all-encompassing classification system.

As a result of the workshop a classification system (Allee et al., 2000, see below) has been created covering all marine and estuarine ecosystem types. The system has also been designed to interface with existing U.S. schemes for terrestrial and freshwater systems. It is also equipped to handle additions to the scheme resulting from new technologies and information.

The system consists of 13 levels encompassing both broad-scale and detailed-scale features. The classification is structured to allow aggregation at different levels depending on the amount or quality of data available on a particular ecosystem.

Level 1 – Life Zone

1a Temperate
1b Tropical
1c Polar

Level 2 – Water/Land

2a Terrestrial
2b Water

Level 3 – Marine/Freshwater

3a Marine/Estuarine
3b Freshwater

Level 4 – Continental/Non-Continental

4a Continental
4b Non-Continental

Level 5 – Bottom/Water Column

5a Bottom (Benthic)
5b Water (Column)

Level 6 – Shelf, Slope, Abyssal

6a Shallow – on or over the continental shelf; <200 metres
6b Medium – on or over the continental slope; 200-1000 metres
6c Deep – on or over the rise and deeper features; >1000 metres

Level 7 – Regional Wave/Wind Energy

7a Exposed/Open – open to full oceanic wave or wind energies
7b Protected/Bounded – protected from full wave or wind energies

Level 8 – Hydrogeomorphic or Earthform Features

8a Continental – Nearshore (surfzone); Inshore (rest of shelf); Straight or partially enclosed shorelines; Lagoons; Fjords; Embayments; Estuaries – shore zone; Off shore zone; Delta; Carbonate settings; Outer continental shelf; Upper continental slope; Upper submarine canyon
8b Non-Continental – Island (Volcanic; Low); Atoll; Submerged reef types

Level 9 – Hydrodynamic Features

9a Supratidal – above high tides
9b Intertidal – extreme high to extreme low water
9c Subtidal – below extreme low water
9d Circulation features – for example eddies

Level 10 – Photic/Aphotic

10a Photic
10b Aphotic

Level 11 – Geomorphic Types or Topography

Cliff; Bench, Flat, Reef flat; Spur-and-groove; Sand bar; Crevice; Slump; Rockfall; Terrace; Ledge; Overhang; Steeply sloping; Riverine; Fringe; Inland; Beach face; Dunes

Level 12 – Substratum and Eco-type

12a Substratum (not limited to this list) – Cobble; Pebble; Sand; Silt; Mud; Bedrock; Peat; Carbonate; Boulder; Biogenic; Organic; Anthropogenic

12b Eco-type (not limited to this list) – Coastal; Soft bottom; Hard bottom; Water column; Beach; Mangrove; Wetland; Seagrass bed; Coral reef; Kelp bed; Mud flat

Level 13 – Local Modifiers and Eco-unit

13a Modifiers (not limited to this list) – Temperature; Local energy regimes – waves, tides, current; Salinity; Nutrients; Alkalinity; Roughness/relief; Dynamism; Edge effects – from adjacent areas; Anthropogenic disturbances; Biological interactions; Extreme events – history

13b Eco-units – Unlimited representation of species resulting from modifiers applied at the above hierarchical levels

The classification system begins with the most geographically broad level, level 1, which is based on climate instead of biotic provinces. Following this are levels 2 and 3 which divides the Earth into land and water realms and then consequently subdivides water into freshwater or marine/estuarine. These two levels were inserted to allow this system to link into land and freshwater classification systems. Level 4 highlights the importance of the land masses and their influence on marine environments, for example controlling the volume of pollutants input into the system and the volume of freshwater runoff, which affects salinity. Level 5 separates the bottom-dwelling from those living within the water column and consequently what influences the two; for example, particle size and topography influence the bottom, whereas current and tides influence the water column. The two do interact to a degree and should not be considered independently. Levels 6 and 7 examine depth and energy at a large scale and Level 8 examines broad indicators of structure in the marine environment, such as hydromorphological and geomorphological features of the earth’s water and crust.

The classification system begins to examine more habitat types at a more local or regional scale in level 9. Sections 9a-c generally apply to benthic habitats and 9d applies to habitats located within the water column. Level 10 refers to both benthic and water-column habitats and the water depth to which photosynthesis can occur. Level 11 categorises features at a smaller scale than those identified in level 8. Some possible divisions are shorelines – cliff, bench, flat etc; reefs – reef flat, spur-and-groove, sand bar etc (Allee et al., 2000). Level 12 hosts two related elements, eco-type (broad description of the biological community) and substratum (follows the Wentworth scale for sediment size class divisions and can be an indicator of the local energy regime and substrate stability). The final level, level 13, further refines the eco-types of level 12 by describing particular locations or characteristic types (eco-unit) using local modifiers.

This proposed system differs from the EUNIS system in that the EUNIS system includes land, freshwater and marine-based habitats. For example, section A (Marine Habitats) of the EUNIS system is equivalent to level 3a of this proposed system. Another difference between the two systems is that depth (level 6) and exposure (level 7) are subdivisions in the marine and estuarine system, whereas in the EUNIS classification the two are linked and considered together (Allee et al., 2000). The EUNIS system also lacks equivalents to levels 10, 13 and 12b.

4 Incorporating BGS Data into Existing Classification Schemes

This chapter aims to examine three existing classification systems and ways in which BGS data can be incorporated them. A study by James (2001) into various schemes for habitat mapping indicates that the geological and sediment data and interpretations held by BGS are of a format suitable for successful inclusion into many habitat mapping schemes.

4.1 EUROPEAN NATURE INFORMATION SYSTEM (EUNIS)

				Description (EUNIS) and BGS source
Level 1				
A	MARINE HABITATS			Directly connected to oceans, can be mostly saline, brackish or almost fresh waters. BGS Source: Outline of UKCS waters.
Level 2				
A1	Littoral rock and other hard substrata			Includes habitats of bedrock, boulders and cobbles that occur in the intertidal zone (the area of the shore between high and low tides) and the splash zone. BGS Source: Since this level only considers the intertidal zone only a small proportion of the information from the Inshore Seabed Characterisation (ISC) project will be applicable so data could also be taken from Poulton et al. (2002) for English coastal waters. Crop the data to only include areas of rock, and gravel (Folk: G) not sediments.
	Level 3			
	A1.1	Littoral rock very exposed to wave action		Extremely exposed to exposed bedrock and boulder shores. BGS Source: Use areas of rock outcrop and gravel (Folk: G) taken from the ISC project and from Poulton et al. (2002) for English coastal waters, and cross check with areas of strong currents and wave energy (digitised from Pantin, 1991).
	A1.2	Littoral rock moderately exposed to wave action		Moderately exposed rocky shores (bedrock, boulders and cobbles). BGS Source: Use areas of rock outcrop and gravel (Folk: G) taken from the ISC project and from Poulton et al. (2002) for English coastal waters, and cross check with areas of moderate currents and wave energy (digitised from Pantin, 1991).
	A1.3	Littoral rock sheltered from wave action		Sheltered rocky shores, of bedrock or stable boulders and cobbles. BGS Source: Use areas of rock outcrop and and gravel (Folk: G) taken from the ISC project and from Poulton et al. (2002) for English coastal waters, and cross check with sheltered areas and weak current and wave energy (digitised from Pantin, 1991).
	A1.4	Rock habitats exposed by action of wind (e.g. hydrolittoral)		BGS Source: This level can be populated using data from the Foreshore Representation Project[4] of the Coastal Geoscience and Global Change Impacts Programme (CGGCI) of BGS.

[4] For more information contact J W C James, jwcj@bgs.ac.uk

			Description (EUNIS) and BGS source
	A1.5	Rockpools	Rockpools occur where the topography of the shore allows seawater to be retained within depressions in the bedrock producing 'pools' on the retreat of the tide. BGS Source: BGS cannot populate.
	A1.6	Littoral caves and overhangs	A community of marine animals and lower plants colonizing mediolittoral overhangs and crevices, and the mediolittoral level of sea-caves. BGS Source: BGS cannot populate.
Level 2			
A2	Littoral sediments		Includes habitats of shingle (mobile cobbles and pebbles), gravel, sand and mud (or a combination) in the intertidal zone. BGS Source: Since this level considers the intertidal zone only a small proportion of the information from the Inshore Seabed Characterisation (ISC) project will be applicable so data could also be taken from Poulton et al. (2002) for English coastal waters. Crop the data to only include areas of sediment, not rock outcrop.
	Level 3		
	A2.1	Littoral gravels and coarse sands	Clean sand and/or gravel 16-0.063mm in diameter including shingle shores comprising mobile cobbles, pebbles and coarse gravel. Mud (particle diameter less than 0.063mm) does not exceed 10%, and is usually totally absent. BGS Source: Use cropped area of intertidal sediments and cross reference with Folk classification to get only the areas occupied by clean sand and/or gravel (G, sG, gS).
	A2.2	Littoral sands and muddy sands	Shores of muddy sand, typically consisting of particles less than 4mm in diameter, where the mud fraction (less than 0.063mm diameter particles) makes up between 10% and 30% of the sediment. Typically, the sand fraction is medium (particle diameter 0.25-1mm) or fine (particle diameter 0.063-0.25mm) sand. BGS Source: Use cropped area of intertidal sediments and cross reference with Folk classification to get only the areas occupied by muddy sand of the above size and proportion mud ((g)mS, (g)S, S, mS).
	A2.3	Littoral muds	Shores of fine sediment less than 0.063mm in diameter. Also included in this higher division are sandy muds which have between 20% and 70% sand, the remainder being made up of mud with a particle size less than 0.063mm. Small amounts of gravel or pebbles may be found within mud. BGS Source: Use cropped area of intertidal sediments and cross reference with Folk classification to get only the areas occupied by muds ((g)M, (g)sM, M, sM).
	A2.4	Littoral combination sediments	Shores of mixed sediment (pebbles-mud sized sediment) predominantly <64mm in diameter and poorly sorted. BGS Source: This level can be populated using data from the Foreshore Representation Project of CGGCI.
	A2.5	Habitats with sediments exposed by action of wind (e.g. hydrolittoral)	BGS Source: This level can be populated using data from the Foreshore Representation Project of CGGCI.

<table>
<tr><td colspan="3"></td><td colspan="2">Description (EUNIS) and BGS source</td></tr>
<tr><td></td><td>A2.6</td><td>Coastal saltmarshes and saline reedbeds</td><td colspan="2">Angiosperm-dominated stands of vegetation, occurring on the extreme upper shore of sheltered coasts and periodically covered by high tides
BGS Source: This level can be populated using data from the Foreshore Representation Project of CGGCI.</td></tr>
<tr><td></td><td>A2.7</td><td>Littoral sediments dominated by aquatic angiosperms</td><td colspan="2">BGS Source: This level can be populated using data from the Foreshore Representation Project of CGGCI.</td></tr>
<tr><td></td><td>A2.8</td><td>Biogenic structures on littoral sediments</td><td colspan="2">BGS Source: This level can be populated using data from the Foreshore Representation Project of CGGCI.</td></tr>
<tr><td colspan="3">Level 2</td><td colspan="2"></td></tr>
<tr><td>A3</td><td colspan="2">Sublittoral rock and other hard substrata</td><td colspan="2">Includes habitats of bedrock, boulders and cobbles that occur in the sublittoral zone (the area between the intertidal zone out to a depth of 200m or the edge of the continental shelf).
BGS Source: Use bathymetry data to crop <u>JNCC rock theme</u> and <u>JNCC gravel theme</u> to include only those from 0-200m water depth (will also need for all of section A4).</td></tr>
<tr><td></td><td colspan="2">Level 3</td><td colspan="2"></td></tr>
<tr><td></td><td>A3.1</td><td>Infralittoral rock very exposed to wave action and/or currents and tidal streams</td><td>Rocky habitats in the infralittoral zone subject to exposed to extremely exposed wave action or strong tidal streams.</td><td rowspan="4">BGS Source: The Infralittoral zone is the zone only exposed at extreme low tides. This level can be populated using data from the Foreshore Representation Project of CGGCI.</td></tr>
<tr><td></td><td>A3.2</td><td>Infralittoral rock moderately exposed to wave action and/or currents and tidal streams</td><td>Infralittoral rock subject to moderate wave exposure, or moderately strong tidal streams on more sheltered coasts.</td></tr>
<tr><td></td><td>A3.3</td><td>Infralittoral rock sheltered from wave action and currents and tidal streams</td><td>Infralittoral rock in wave and tide-sheltered conditions.</td></tr>
<tr><td></td><td>A3.4</td><td>Caves, overhangs and surge gullies in the infralittoral zone</td><td>Caves situated under the sea or opened to it, at least at high tide.</td></tr>
<tr><td></td><td>A3.5</td><td>Circalittoral rock very exposed to wave action or currents and tidal streams</td><td colspan="2">Circalittoral rocky habitats subject to strong wave action or tidal currents.
BGS Source: Cross reference the areas of rock (see A3 for method to find areas of rock) with bathymetry data to isolate only rock between 0 and 50m then compare with current data, select only areas of rock subjected to high energy waves/strong currents (digitised from Pantin, 1991).</td></tr>
<tr><td></td><td>A3.6</td><td>Circalittoral rock moderately exposed to wave action or currents and tidal streams</td><td colspan="2">Circalittoral rock subject to moderate wave exposure or some degree of tidal currents in more sheltered conditions.
BGS Source: Cross reference the areas of rock (see A3 for method to find areas of rock) with bathymetry data to isolate only rock between 0 and 50m then compare with current data, select only areas of rock subjected to moderate wave energy/moderate currents (digitised from Pantin, 1991).</td></tr>
</table>

			Description (EUNIS) and BGS source
	A3.7	Circalittoral rock sheltered from wave action and currents including tidal streams	Circalittoral rock or mixed substrata, sheltered from wave action and from significant tidal currents. BGS Source: Cross reference the areas of rock (see A3 for method to find areas of rock) with bathymetry data to isolate only rock between 0 and 50m then compare with current data, select only areas of rock sheltered from strong wave and current energies (digitised from Pantin, 1991).
	A3.8	Deep circalittoral rock habitats exposed to strong currents	BGS Source: Cross reference the areas of rock (see A3 for method to find areas of rock) with bathymetry data to isolate only rock between 50 and 200m then compare with current data, select only areas of rock subjected to high energy waves/strong currents (digitised from Pantin, 1991).
	A3.9	Deep circalittoral rock habitats exposed to moderately strong currents	BGS Source: Cross reference the areas of rock (see A3 for method to find areas of rock) with bathymetry data to isolate only rock between 50 and 200m then compare with current data, select only areas of rock subjected to moderate wave energy/moderate currents (digitised from Pantin, 1991).
	A3.A	Deep circalittoral rock habitats exposed to weak or no currents	BGS Source: Cross reference the areas of rock (see A3 for method to find areas of rock) with bathymetry data to isolate only rock between 50 and 200m then compare with current data, select only areas of rock sheltered from strong wave and current energies (digitised from Pantin, 1991).
	A3.B	Caves and overhangs below the infralittoral zone	Sea caves situated entirely below sea level. BGS Source: This level can be populated using data from the Foreshore Representation Project of CGGCI.
	A3.C	Vents and seeps in sublittoral rock	BGS Source: Highlight areas of pockmarks and pockmark fields that exist between 0 and 200m (JNCC pockmarks and pockmark fields theme) and cross reference with areas of rock identified in the sublittoral zone (see A3 for method to find areas of rock) and pick areas of overlap.
Level 2			
A4	Sublittoral sediments		Sediment habitats in sublittoral nearshore zone (i.e. covering the infralittoral and circalittoral zones) extending from extreme lower shore down to about 200 metres. BGS Source: Use bathymetry to crop seabed sediments (Folk classification) to include only those lying in water depths between 0 and 200m.
	Level 3		
	A4.1	Sublittoral mobile cobbles, gravels and coarse sands	Gravel or course sand >1mm diameter (including shingle and mobile cobbles). BGS Source: Use the cropped area from A4 then use bathymetric data to crop further to include only sediments from 0-70m water depth. Then extract all areas of sediment with Folk values of G, sG gM and gS.
	A4.2	Sublittoral sands and muddy sands	Fine sand or muddy sand less than or equal to 1mm diameter with 30% silt (<0.063mm diameter). BGS Source: Use the cropped area from A4 then use bathymetric data to crop further to include only sediments from 0-70m water depth. Then extract all areas of sediment with Folk values of (g)mS, (g)S, S and mS.

			Description (EUNIS) and BGS source
	A4.3	Sublittoral muds	>30% components <0.063mm diameter. BGS Source: Use the cropped area from A4 then use bathymetric data to crop further to include only sediments from 0-70m water depth. Then extract all areas of sediment with Folk values of (g)M, (g)sM, M and sM.
	A4.4	Sublittoral combination sediments	Intimate mixture of above, mosaics and veneers. BGS Source: BGS cannot populate.
	A4.5	Shallow sublittoral sediments dominated by angiosperms	Habitats dominated by aquatic angiosperms versus animal communities. BGS Source: BGS cannot populate.
	A4.6	Biogenic structures over sublittoral sediments	BGS Source: Highlight areas of *Lophelia pertusa* and *Sabellaria spinulosa* that exist between 0 and 200m using bathymetric data (JNCC *Lophelia* location theme and get location data for *Sabellaria* from the database accompanying Poulton et al., 2002).
	A4.7	Deep shelf sediment habitats	Sublittoral sediments in offshore circalittoral zone (below 50-70 metres) on an open coast. BGS Source: Use the cropped area from A4 then use bathymetric data to crop further to include only sediments from 70-200m water depth.
	A4.8	Seeps and vents in sublittoral sediments	Habitats specific to sublittoral sources of seeping or bubbling gases or liquids through sediments. BGS Source: Highlight areas of pockmarks and pockmark fields that exist between 0 and 200m (JNCC pockmarks and pockmark fields theme) and check these areas to ensure none of the seeps and vents are located in areas of rock.
Level 2			
A5	Deep-sea bed		Combined Bathyal and abyssal areas. BGS Source: Use bathymetry to crop seabed sediments (Folk classification) to include only those lying in water depths >200m.
	Level 3		
	A5.1	Deep-sea rock and artificial hard substrates	BGS Source: Use bathymetry to crop JNCC rock theme to include only those lying in water depths >200m (BGS do not hold data on deep-sea artificial hard substrates such as shipwrecks).
	A5.2	Deep-sea combination substrates	Includes combination substrates in the abyssal zone. BGS Source: BGS cannot populate.
	A5.3	Deep-sea sand substrates	BGS Source: Use the cropped area from A5. Then extract all areas of sediment with Folk values of S and (g)S.
	A5.4	Deep-sea muddy sand substrates	Includes part of soft substrates in the abyssal zone. BGS Source: Use the cropped area from A5. Then extract all areas of sediment with Folk values of mS and (g)mS.
	A5.5	Deep-sea muds	Benthic communities of continental slope developed on blue, coral, green or red oceanic muds. Relatively high diversity. BGS Source: Use the cropped area from A5. Then extract all areas of sediment with Folk values of (g)M, (g)sM, M and sM.
	A5.6	Deep-sea bioherms	BGS Source: Highlight areas of *Lophelia pertusa* and *Sabellaria spinulosa* that exist in water depths >200m using bathymetric data (JNCC *Lophelia* location theme and get location data for *Sabellaria* from the database accompanying Poulton et al., 2002).

			Description (EUNIS) and BGS source
	A5.7	Canyons, channels, slope failures and slumps on the continental slope	BGS Source: Use bathymetry data to allow an interpreter to identify areas of canyons, channels, slides and slumps and overlap with cropped seabed sediments (A5) to pick the areas of overlap. The continental slope is a relatively steeply-sloping surface extending from the continental shelf to the continental rise.
	A5.8	Deep-sea trenches	Benthic communities of these deep elongated subduction troughs typically greater than 6000m depth. BGS Source: Use bathymetry data to allow an interpreter to identify areas of elongated, usually asymmetric depressions and overlap with cropped seabed sediments (A5) to pick the areas of overlap.
	A5.9	Deep-sea reducing habitats	New unit to accommodate seeps and other reducing habitats. BGS Source: Take existing JNCC pockmarks and pockmark fields theme and the existing JNCC other seeps theme and crop to depths >200m. Also use the colour of sediment samples as a guide to areas of reducing environments. Green/olive colours indicate reduction whereas yellows/orange/brown indicate oxidation, requires an interpreter (? or can we do a function in GIS).
	A5.A	Deep-sea bed influenced by hypoxic water column	Includes all the deep-sea. BGS Source: BGS cannot populate (refers to the water column).
Level 2			
A6	Isolated 'oceanic' features: seamounts, ridges and the submerged flanks of oceanic islands		BGS Source: Requires an interpretation of bathymetry data to identify the isolated oceanic features.
	Level 3		
	A6.1	Permanently submerged flanks of oceanic islands	BGS Source: Requires an interpretation of bathymetry data to identify submerged flanks of oceanic islands.
	A6.2	Seamounts, knolls and banks	Isolated elevated area close enough to the sea surface to create neritic conditions. BGS Source: Requires an interpretation of bathymetry data to identify seamounts, knolls and banks whose crests lying in 200m of water or less (neritic zone).
	A6.3	Oceanic ridges	Raised ridges of deep sea floor with elongated topography associated with boundary of 1 or more tectonic plates. BGS Source: Requires an interpretation of bathymetry data to isolate linear positive topographic features.
	A6.4	Isolated 'oceanic' features influenced by hypoxic water column	Habitats on isolated features of significant elevation, influenced by hypoxic and/or anoxic conditions. BGS Source: BGS cannot populate (refers to the water column).
	A6.5	Vents in the deep sea	Communities in the vicinity of oceanic hydrothermal vents, mainly centralised on mid oceanic ridges and central rifts. BGS Source: BGS has no hydrothermal vent data at this time but it is a geological feature and in the future if we had location data then we could populate this level.
Level 2			
A7	Pelagic water column		BGS Source: BGS cannot populate any of the level 3 sections of the 'pelagic water column' level.
Level 2			

		Description (EUNIS) and BGS source
A8	Ice-associated marine habitats	BGS Source: BGS cannot populate any of the level 3 sections of the 'ice-associated marine habitats' level.

The EUNIS classification is considered by many European agencies to be a comprehensive classification system, unlike Annex I of the Habitats Directive, which is considered a legislative list. Initial impressions are that the scheme covers all major aspects of the marine environment from the intertidal zone to abyssal areas. However, once it is examined with a view to incorporate existing data, such as that held by BGS, problems are encountered and gaps in the classification noticed.

There are obviously aspects that BGS will not be able to populate such as those that are biologically based or relate to the water column. Some areas of the classification that are based on geology cannot be populated by BGS data as the features are too small-scale, such as areas of rock outcrop exposed to hydrolittoral activity, areas of rockpools and caves. Furthermore, areas of combination sediments cannot be populated as typically combination sediments indicate a complicated seabed. As a result of sample density in deep waters, the distribution of sediment appears simplified to a degree, therefore it is not appropriate to populate the combination sediments levels of the EUNIS classification.

The eight main subdivisions presented above concentrate primarily on the nearshore area and coastal zone. It is hoped that much of the data and interpretation required to populate sections A1-A4 of the classification will come from reports written by Evans et al. (1998) and Poulton et al. (2002). The first is a report prepared for the Department of the Environment, Transport and the Regions on the *Inshore Seabed Characterisation Project*. This project is aimed at increasing knowledge and understanding of the geology of the inshore seabed, its sediment transport regime and its sand and gravel resource potential. The focus of the *Inshore Seabed Classification Project* has been bedform and facies maps, interpreted from side-scan sonar data. These maps illustrate the distribution of sediment and rock at the seabed. The Inshore Seabed Characterisation project concentrates on the inshore/nearshore zone (coast to 20km) and only covers six sectors extending from Flamborough Head to Portland Bill. The report by Poulton et al. (2002) describes the structure and content of a GIS and associated database identifying seabed habitats and features within nearshore English waters to 12 nautical miles, which was developed for English Nature by the BGS.

There are also a few classification levels that BGS cannot populate, as they are not based on geology, for example levels A2.7 littoral sediments dominated by aquatic angiosperms, and A4.5 shallow sublittoral sediments dominated by angiosperms. Level A7 (pelagic water column) cannot be populated by BGS because it refers to the water column; BGS data pertains only to the seabed and substratum below it. Neither can level A8 as it refers to ice-associated marine habitats.

BGS data could be used to more accurately define some levels of the EUNIS classification. For example, level 4.1 could be refined to read "clean gravels and clean coarse sand >1mm diameter (including shingle and cobbles)". Similarly, BGS data could be used to subdivide deep-shelf sediments in level A4.7 (70-200m), as EUNIS have done for sediments located on the rest of the shelf (0-70m), would be a better use of available data.

4.2 DEEP-WATER MARINE BENTHIC HABITAT CLASSIFICATION SCHEME

	Description and BGS Source
Megahabitat	Based on depth and general physiographic boundaries BGS Source: All BGS offshore data.

		Description and BGS Source
A	Aprons, continental rise, deep fans and bajadas.	3000-5000m of water BGS Source: Requires an interpretation of bathymetry data to 'ink' in this boundary.
B	Basin floors, Borderland types.	Floors at 1000-2500m depth BGS Source: Requires an interpretation of bathymetry data to 'ink' in this boundary.
F	Flanks, continental slope, basin/inland-atoll flanks.	200-3000m depth BGS Source: Requires an interpretation of bathymetry data to 'ink' in this boundary.
I	Inland seas, fjords.	0-200m water depth BGS Source: Requires an interpretation of bathymetry data to 'ink' in this boundary and check if some of these areas have been accidentally classified as 'S'.
P	Plains, abyssal	Greater than 5000m water depth BGS Source: Requires an interpretation of bathymetry data to 'ink' in this boundary.
R	Ridges, banks and seamounts.	Crests at 200-2500m water depth BGS Source: Requires an interpretation of bathymetry data to 'ink' in this boundary.
S	Shelf, continental and island shelves.	0-200m water depth BGS Source: Requires an interpretation of bathymetry data to 'ink' in this boundary.
Seafloor Induration		The author believes that this section is not subdivided into shelf and deep-sea sediments. BGS Source: All BGS sea bed sediment data.
h	Hard bottom, rock outcrop, relic beach rock or sediment pavement.	BGS Source: use the JNCC rock theme to populate this section.
m	Mixed (hard and soft bottom).	BGS Source: BGS cannot populate.
s	Soft bottom, sediment covered. Subdivided: (b)=boulder (c)=cobble (g)=gravel (h)=halimeda sediment, carbonate (m)=mud, silt, clay (p)=pebble (s)=sand	BGS Source: Using the entire seabed sediment dataset, crop to make: i combined theme for (b), (c), (g) and (p) = all gravel dominated sediments (Folk G, mG, msG and sG) ii (h) = digitise areas of high carbonate production (e.g. from Pantin, 1991) iii (m) = all mud dominated sediments (Folk gM, (g)M, (g)sM, sM and M) iv (s) = all sand dominated sediments (Folk gmS, gS, (g)S, mS and S)
Meso/Macrohabitat		
a	atoll	Ring-shaped reef enclosing a lagoon, and is surrounded by open sea. BGS Source: Requires a scientist to interpret data.
b	beach, relic	BGS Source: BGS cannot populate.
c	canyon	BGS Source: Requires an interpretation of bathymetry data to identify canyons.

		Description and BGS Source
d	deformed, tilted and folded bedrock	BGS Source: Use the JNCC rock theme and overlay with Solid/Quaternary Geology map sheets. Simplify interpretation by selecting anything older than Mesozoic as being structurally affected.
e	exposure, bedrock	BGS Source: Populate with the JNCC rock theme.
f	flats	BGS Source: BGS cannot populate.
g	gully, channel	BGS Source: Requires an interpretation of bathymetry data to identify gullies and channels.
i	ice-formed feature or deposit, moraine, drop-stone depression	BGS Source: Use existing JNCC Iceberg Ploughmark theme and also use Quaternary Geology maps to identify limits of glacial deposits (most of UKCS has glacio-marine deposits).
k	karst, solution pit, sink	BGS Source: BGS cannot populate.
l	landslide	BGS Source: Merge ‘s’ and ‘l’.
m	mound, depression	BGS Source: Use existing JNCC mound theme to populate and disregard depressions.
n	enclosed waters, lagoon	BGS Source: BGS cannot populate.
o	overbank deposit (levee)	BGS Source: BGS cannot populate.
p	pinnacle	BGS Source: Requires an interpretation of bathymetry data to identify pinnacles.
r	rill	Narrow channels caused by fluvial surface runoff, small-scale features. BGS Source: BGS cannot populate.
s	scarp, cliff, fault or slump	BGS Source: Merge ‘s’ and ‘l’. Requires an interpretation of bathymetry data to identify scarps, cliffs, faults with a topographic expression on the seafloor, slump features and slides forming a topographic expression on the seafloor (i.e. not buried, for example the Afen Slide).
t	terrace	BGS Source: Requires an interpretation of bathymetry data to identify terraces (steps on the seafloor topography).
w	sediment waves	BGS Source: Use JNCC sandbanks theme to populate this section, however, this only includes shallow water sediment waves therefore require to digitise areas of sediment waves from diagrams within BGS offshore regional reports.
y	delta, fan	BGS Source: Requires an interpretation of bathymetry data to identify deltas and fans.
z	zooxanthellae hosting structure, carbonate reef. Subdivided: 1=barrier reef 2=fringing reef 3=head, bommie 4=patch reef	BGS Source: BGS cannot populate.
Modifier (letter is subscript)		The modifier describes the texture or lithology of the seafloor. Several can be used.
a	anthropogenic (artificial reef/breakwall/shipwreck)	BGS Source: BGS cannot populate.
b	bimodal (conglomeratic, mixed [includes gravel, cobbles and pebbles])	BGS Source: Use the sea bed sediment data to extract all areas of sediment with Folk values of G, mG, msG and sG.

		Description and BGS Source
c	consolidated sediment (includes claystone, mudstone, siltstone, sandstone, breccia or conglomerate)	BGS Source: See Geologic Unit below.
d	differentially eroded	BGS Source: BGS cannot populate.
f	fracture, joints-faulted	
g	granite	BGS Source: See Geologic Unit below.
h	hummocky, irregular relief	BGS Source: BGS cannot populate unless have access to swath bathymetry to map the topographic expression.
i	interface, lithologic contact	BGS Source: BGS cannot populate.
k	kelp	BGS Source: BGS cannot populate.
l	limestone or carbonate	BGS Source: See Geologic Unit below.
m	massive	BGS Source: BGS cannot populate.
p	pavement	BGS Source: BGS cannot populate.
r	ripples	BGS Source: BGS cannot populate. See meso/macrohabitat 'w'. Already have sediment waves classified, which often occur in conjunction with ripples. Sediment waves can also be termed megaripples so must watch terminology.
s	scour (current or ice, direction noted)	BGS Source: BGS cannot populate.
u	unconsolidated sediment	BGS Source: BGS cannot populate. Covered in seafloor induration above.
v	volcanic rock	BGS Source: See Geologic Unit below.
Seafloor Slope		Calculated for survey area from x-y-z multibeam data.
1	Flat (0-1º)	BGS Source: GEBCO-97 dataset. Relative slope maps (presented as simple 'hot to cold' maps) can be produced for large areas. Absolute slope values generally require high-resolution data and smaller areas of interest.
2	Sloping (1-30º)	
3	Steeply sloping (30-60º)	
4	Vertical (60-90º)	
5	Overhang (>90º)	
Seafloor Complexity		Calculated for survey area from x-y-z maximum slope data using neighbourhood statistics and reported in standard deviation units.
A	Very low complexity (-1 to 0)	BGS Source: 2D filter of several points is performed, if all the points are the same then low complexity, if all the points are different then high complexity. This definition is very generalised and the calculated result would be heavily dependant on the resolution of the data used to perform the function.
B	Low complexity (0 to 1)	
C	Moderate complexity (1 to 2)	
D	High Complexity (2 to 3)	
E	Very High Complexity (3+)	
Geologic unit		When possible, the associated geological unit is identified for each habitat type. BGS Source: Use JNCC rock theme and overlap with Solid/Quaternary Geology map sheets to determine geological unit (and hence lithology therefore no need to populate c, g, l and v above).

The meso/macrohabitat section and modifiers, in which both depositional features and erosional features are considered together at the same level, may be more appropriately separated into two categories. Likewise, in the meso/macrohabitat section both bedrock exposure, and deformed, tilted and folded bedrock are all at the same level of detail, however, bedrock exposure could be defined at a level above deformed, tilted and folded bedrock as the latter is a description of the areas of exposure.

Some of the levels in the modifier section are repetitive. Four of the proposed modifiers refer to lithology, however the Geologic Unit is described in a later section and encompasses the lithology, therefore populating ‘c’, ‘g’, ‘l’ and ‘v’ would replicate information already included in the classification.

Other aspects of this scheme provide clearer and more concise descriptions of geological features than the other classifications considered in this chapter. For example, the section on ‘megahabitat’, provides such descriptions for large-scale features including seamounts, basin floors and shelf areas.

4.3 MARINE AND ESTUARINE ECOSYSTEM AND HABITAT CLASSIFICATION

Description		BGS Source
Level 1 – Life Zone – regional divisions based on climate		
1a	Temperate	BGS Source: BGS cannot populate.
1b	Tropical	
1c	Polar	
Level 2 – Water/Land – these divisions allow this classification to be linked to terrestrial and freshwater classifications		
2a	Terrestrial	BGS Source: Use BGS land data.
2b	Water	BGS Source: All BGS offshore data in this level.
Level 3 – Marine/Freshwater – these divisions allow this classification for marine and estuarine habitats to be linked to freshwater classifications		
3a	Marine/Estuarine	BGS Source: All BGS offshore data in this level.
3b	Freshwater	BGS Source: Use BGS land data.
Level 4 – Continental/Non-Continental – these divisions allow for the importance of the land masses influence on the marine environment		
4a	Continental	BGS Source: Use BGS land data.
4b	Non-Continental	BGS Source: All BGS offshore data in this level as the UKCS is epicontinental.
Level 5 – Bottom/Water Column		
5a	Bottom (Benthic)	BGS Source: All BGS offshore data in this level.
5b	Water (Column)	BGS Source: BGS cannot populate.
Level 6 – Shelf, Slope, Abyssal – addresses depth at a large scale		
6a	Shallow – on or over the continental shelf; <200 metres	BGS Source: Use bathymetric data to crop seabed sediments to include only those lying in water between 0 and 200m deep.
6b	Medium – on or over the continental slope; 200-1000 metres	BGS Source: Use bathymetric data to crop seabed sediments to include only those lying in water between 200 and 1000m deep.
6c	Deep – on or over the rise and deeper features; >1000 metres	BGS Source: Use bathymetric data to crop seabed sediments to include only those lying in water over 1000m deep.
Level 7 – Regional Wave/Wind Energy – their influence on the stability of a system considered at a large scale		

	Description		BGS Source
7a	Exposed/Open – open to full oceanic wave or wind energies		BGS Source: Requires a scientist to interpret seabed sediment data in conjunction with current and tidal data (digitised from Pantin, 1991). Crop the sea bed sediments into two sections either heavily influenced by currents and tides or sheltered from them.
7b	Protected/Bounded – protected from full wave or wind energies		
Level 8 – Hydrogeomorphic or Earthform Features			
8a	Continental – Nearshore (surfzone); Inshore (rest of shelf); Straight or partially enclosed shorelines; Lagoons; Fjords; Embayments; Estuaries – shore zone; Off shore zone; Delta; Carbonate settings; Outer continental shelf; Upper continental slope; Upper submarine canyon		BGS Source: Require a scientist to interpret bathymetric data to include everything from the upper continental slope to the shore (8a), and to include isolated oceanic features such as islands and atolls and also submerged reefs (8b). An interpreter is necessary as few of the features in both 8a and 8b are easily defined in terms of bathymetric extent.
8b	Non-Continental – Island (Volcanic; Low); Atoll; Submerged reef types		
Level 9 – Hydrodynamic Features			
9a	Supratidal – above high tides	Benthic	BGS Source: BGS cannot populate.
9b	Intertidal – extreme high to extreme low water		
9c	Subtidal – below extreme low water		
9d	Circulation features – for example eddies		
Level 10 – Photic/Aphotic			
10a	Photic		The photic zone lies between 0 and 50-100m water depth BGS Source: Use bathymetric data to crop seabed sediments to include only those lying in water between 0 and 100m deep.
10b	Aphotic		BGS Source: Use bathymetric data to crop seabed sediments to include only those lying in water greater than 100m deep.
Level 11 – Geomorphic Types or Topography – Cliff; Bench, Flat, Reef flat; Spur-and-groove; Sand bar; Crevice; Slump; Rockfall; Terrace; Ledge; Overhang; Steeply sloping; Riverine; Fringe; Inland; Beach face; Dunes			BGS Source: Use bathymetric data to interpret the location and extent of these features.
Level 12 – Substratum and Eco-type			
12a	Substratum (not limited to this list) – Cobble; Pebble; Sand; Silt; Mud; Bedrock; Peat; Carbonate; Boulder; Biogenic; Organic; Anthropogenic		BGS Source: BGS can populate some of these subdivisions using the existing seabed sediments GIS theme. Group together cobble, boulder and pebble and populate with the JNCC gravel theme. Silt and Mud can be populated by cropping the sea bed sediments theme and selecting areas covered by Folk classification (g)M, (g)sM, M, gM and sM. Anthropogenic substratum cannot be populated by BGS.
12b	Eco-type (not limited to this list) – Coastal; Soft bottom; Hard bottom; Water column; Beach; Mangrove; Wetland; Seagrass bed; Coral reef; Kelp bed; Mud flat		BGS Source: BGS cannot populate.
Level 13 – Local Modifiers and Eco-unit			

Description		BGS Source
13a	Modifiers (not limited to this list) – Temperature; Local energy regimes – waves, tides, current; Salinity; Nutrients; Alkalinity; Roughness/relief; Dynamism; Edge effects – from adjacent areas; Anthropogenic disturbances; Biological interactions; Extreme events – history	BGS Source: BGS cannot populate.
13b	Eco-units – Unlimited representation of species resulting from modifiers applied at the above hierarchical levels	BGS Source: BGS cannot populate.

The marine and estuarine ecosystem and habitat classification system is not well suited, in many respects, for the incorporation of existing BGS data. Level 1 does not refer to geological information, therefore cannot be populated, and levels 2-5 are on such a scale as to include all BGS offshore and inshore data in one section. However, it must be noted that levels 2 and 3 exist to allow interaction with both terrestrial and freshwater classification systems. From a geological perspective, there are some levels that host a variety of different features, all of which relate to a different scale; for example, inshore is listed as a feature but lagoon, fjord, embayment and estuary are also listed as features. However, lagoons etc can occur within the inshore zone, therefore are in effect features within features. Perhaps more sublevels should exist within level 8 that reflect a decrease in scale at each sublevel.

The term ‘substratum’ used in level 12 may be misleading. To the biologist, the term ‘substratum’ could refer to the surface on which organisms are living, be it unconsolidated sediment or bedrock. However the term ‘substratum’ to the geologist could refer to what exists below the seabed, not the seabed surface.

5 Test GIS Implementation

The scope of this test was to determine the ease with which BGS data could be incorporated into existing marine habitat classification schemes. This was to be achieved through the use of quick and simple methods, and to identify further, more sophisticated, GIS development work that could be undertaken.

Four habitat layers were selected from both the EUNIS and Deep-Water Marine Benthic Habitat classifications to be populated, two examined data at a regional scale and two at a localised scale (Table 1).

Table 1 Description of the four habitat layers used in this test and the four study areas used. See also Figure 3 for location.

Study Area	Location	Habitat Layer	Scale
(A) North Atlantic/Europe Region	60º W to 60º E and 20º N to 90º N	Area considered for GIS based habitat mapping within which the study areas B-D were selected	Regional
(B) UKCS Study Area	30º W to 10º E and 40º N to 70º N	Megahabitat (Deep-Water Marine Benthic Habitat Classification)	Regional
(B) UKCS Study Area	30º W to 10º E and 40º N to 70º N	Seafloor Slope (Deep-Water Marine Benthic Habitat Classification)	Regional
(C) Habitat Local Study Area 1	08º W to 04º W and 58º N to 60º N	Sublittoral Sediments (EUNIS classification, level A4)	Localised
(C) Habitat Local Study Area 1	08º W to 04º W and 58º N to 60º N	Geologic Unit (Deep-Water Marine Benthic Habitat Classification)	Localised
(D) Habitat Local Study Area 2	05º W to 03º W and 59º N to 60º N	Area used for the creation of three 3D views.	Localised

These habitat layers were created and manipulated in ArcGIS 8.3. The completed layers are stored within the BGS Offshore GIS, and contain data derived from BGS seabed sediment, Quaternary geology, solid geology map series and other digital data sources.

5.1 DISCUSSION

5.1.1 Megahabitat

The megahabitat layer is based on water depth and general physiographic boundaries. The layer could be partially populated by performing a function on a dataset but still requires manual interpretation of data.

In the test, a megahabitats GIS layer was created for an area extending from 40º N to 70º N and from 30º W to 10º E (Figure 4). This extended offshore area hosts all except one of the megahabitat sub-divisions proposed in the classification of Greene et al. (2002). Category I, inland seas and fjords (0-200m water depth), was not identified in the study area as it was considered that the megahabitat scale, identifying features on a scale of 10s of kilometres to kilometres, was too broad to accurately identify these features.

The GEBCO-97 bathymetric dataset was used to form the basis of the geological interpretation. Boundaries were identified from appropriately filtered depth contour values and digitised to polygons in ArcGIS 8.3, creating a regional scale habitat map (Figure 4). Problems encountered included the identification of basin floors and the continental rise. The depth range provided as part of the proposed classification of Greene et al. (2002) for basin floors (1000-2500m) does not include the floors of deep basins such as the Rockall Basin that lies in water depths over 2500m.

5.1.2 Sublittoral Sediments

Sublittoral sediments describe the sediment habitats existing in the sublittoral nearshore zone extending from the extreme lower shore down to approximately 200m. The study area for the sublittoral sediments layer extends from 58º N to 60º N and from 04º W to 08º W, offshore northwest Scotland, encompassing the Sula Sgeir, Rona, Lewis and Sutherland BGS 1:250 000 map sheets (Figure 3).

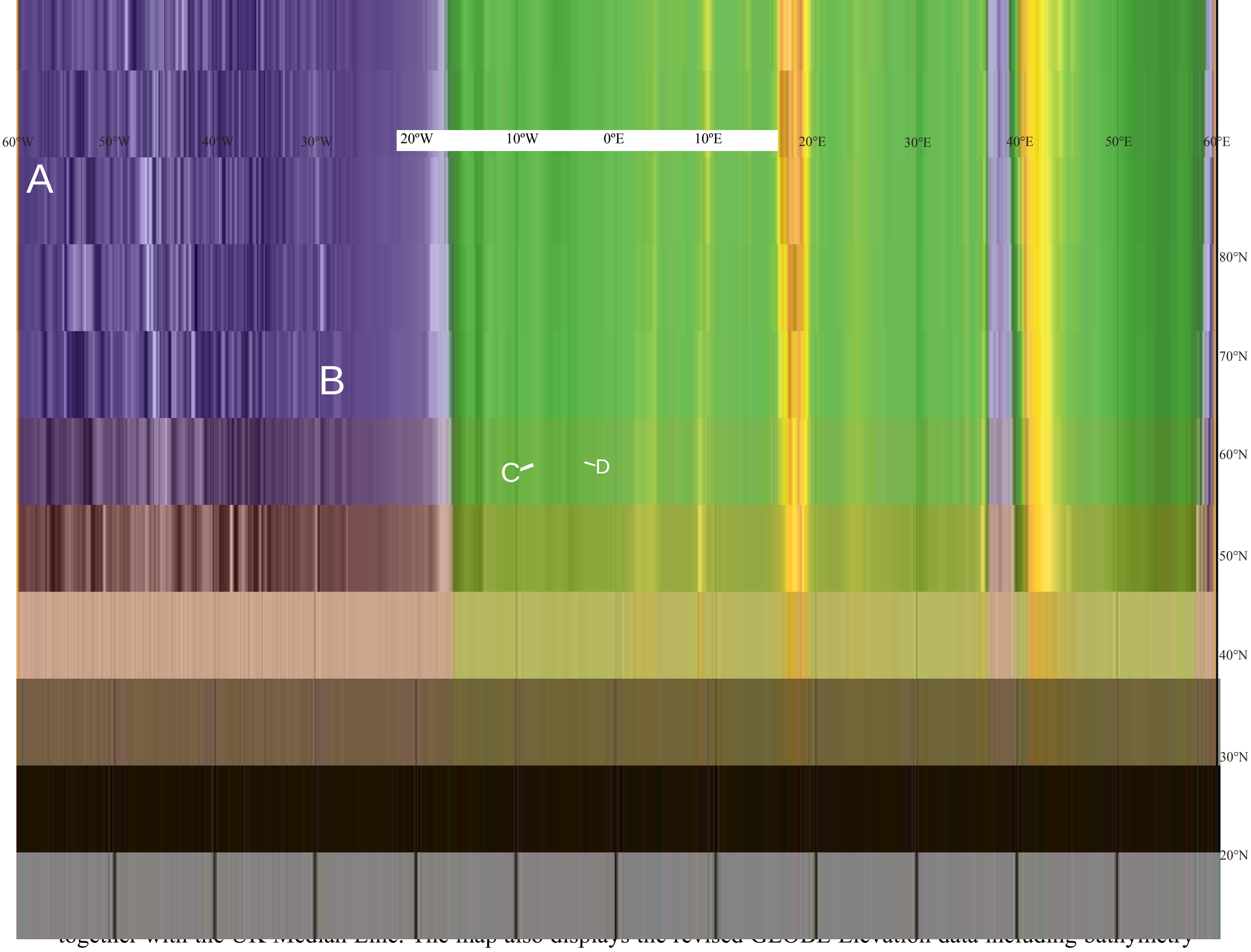
The following method was used to create the habitat layers:

1. Create general sublittoral sediments for subsequent cropping:
    a. Crop DigBath (polyline dataset) to study area (C);
    b. Use existing cropped DigSed (polygon dataset);
    c. Join DigBath polylines to create new polygons for cropping the existing DigSed dataset. Check for dangling nodes before generating polygons.
    d. Use new DigBath derived polygons to crop DigSed and therefore create the 'Sublittoral Sediments' theme (section A4 of EUNIS).
2. Create three cropping polygons from DigBath (0-200m, 0-70m and 70-200m water depths:
    a. Filter two depth contours from DigBath polylines;
    b. Join ends of potentially incomplete polygons;
    c. Clean the polylines (setting: default fuzzy tolerance) and remove dangling nodes (setting: closest node snap and a tolerance of 1);
    d. Convert the polylines to polygons;
    e. Remove all polygons within major polygon(s) using an advanced merge (setting: 'erase' (-1)). This creates a final version for clipping DigSed.

NOTE: Steps 2c-e used the ETGeowizards add-in. See discussion below for problems encountered and method.

The 0-70m and 70-200m water depth polygons required a review process to identify any smaller areas above and below the 70m contour. This was to determine whether a feature represented an isolated bathymetric depression (of interest – Option B in Figure 5 below) or a localised bathymetric high (not of interest – Option A in Figure 5 below). If the 70m feature contour has no internal contour to help determine the relief, it was treated as of no interest (insufficient data – Option C in Figure 5 below). Examples of this review process are illustrated in Figures 6 and 7.

The three cropping polygons from DigBath used to produce the sublittoral sediments GIS layer are shown in Figure 8. These polygons were used to crop the BGS DigSed product (Figure 9). Levels A4.1-A4.3 and A4.7 were populated (Figure 10), as was level A4.8. Levels A4.4 and A4.5 cannot be populated by BGS (see chapter 4). By using the existing JNCC *Lophelia pertusa* location theme, only two occurrences of the cold water coral were documented in study area C in water depths between 0 and 200m.



together with the UK Median Line. The map also displays the revised GLOBE Elevation data including bathymetry from Sandwell and Smith (see www.ngdc.noaa.gov/seg/topo/globega2.shtml)

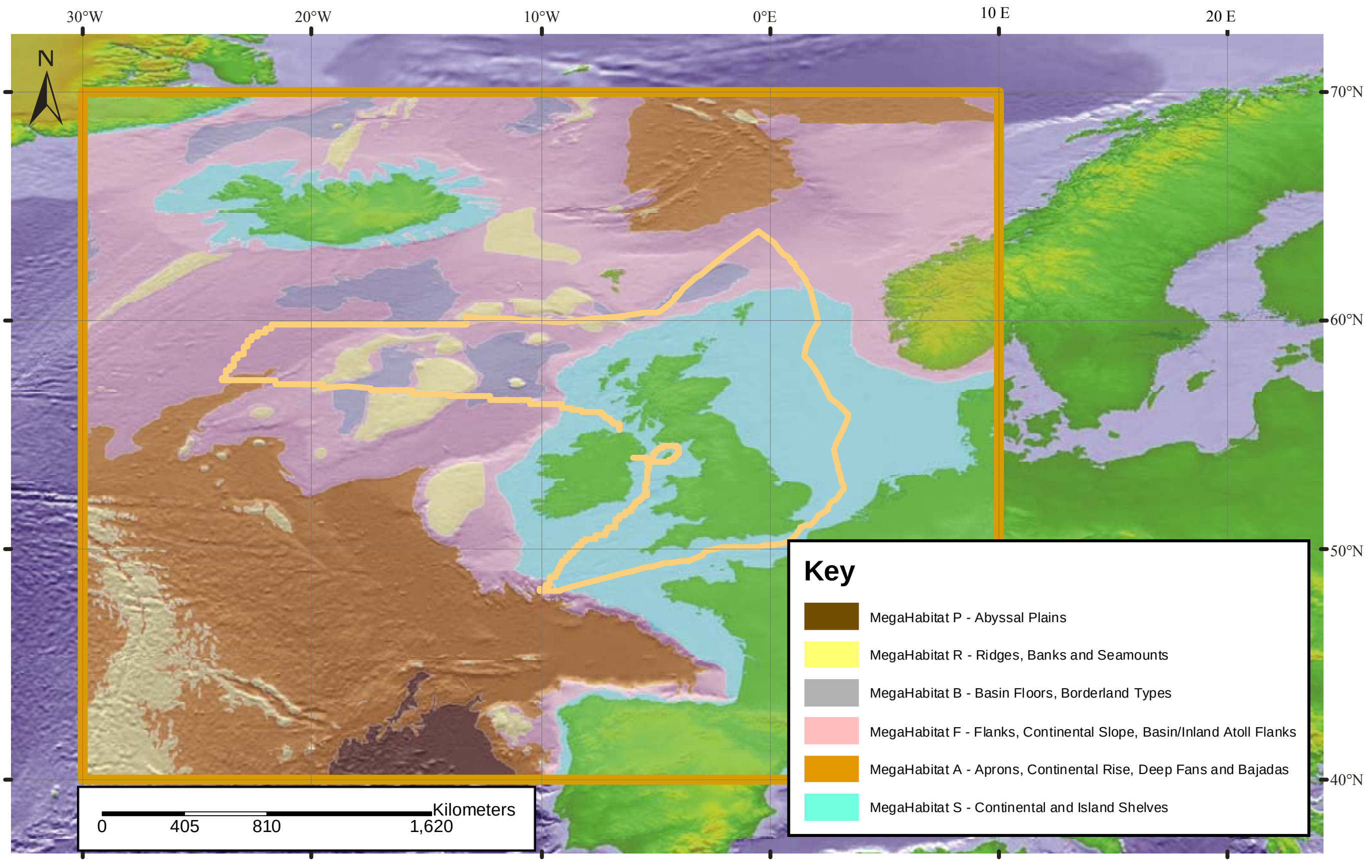


Figure 4 A draft of the Megahabitat GIS layer for study area (B). The polygons have been overlain on the revised GLOBE Elevation data.

5.1.3 Seafloor Slope

The slope layer created here was derived from the GEBCO-97 dataset for a large area and was therefore plotted only as a relative-slope map (Figure 11). Both the size of the area covered and the resolution of the bathymetric grid used can have an influence on the slope values that are derived. General, relative-slope values can be mapped as simple 'hot to cold' colour maps showing where the slope is greater within a given area. Absolute-slope values, for example in degrees, generally require high-resolution data and smaller areas of interest.

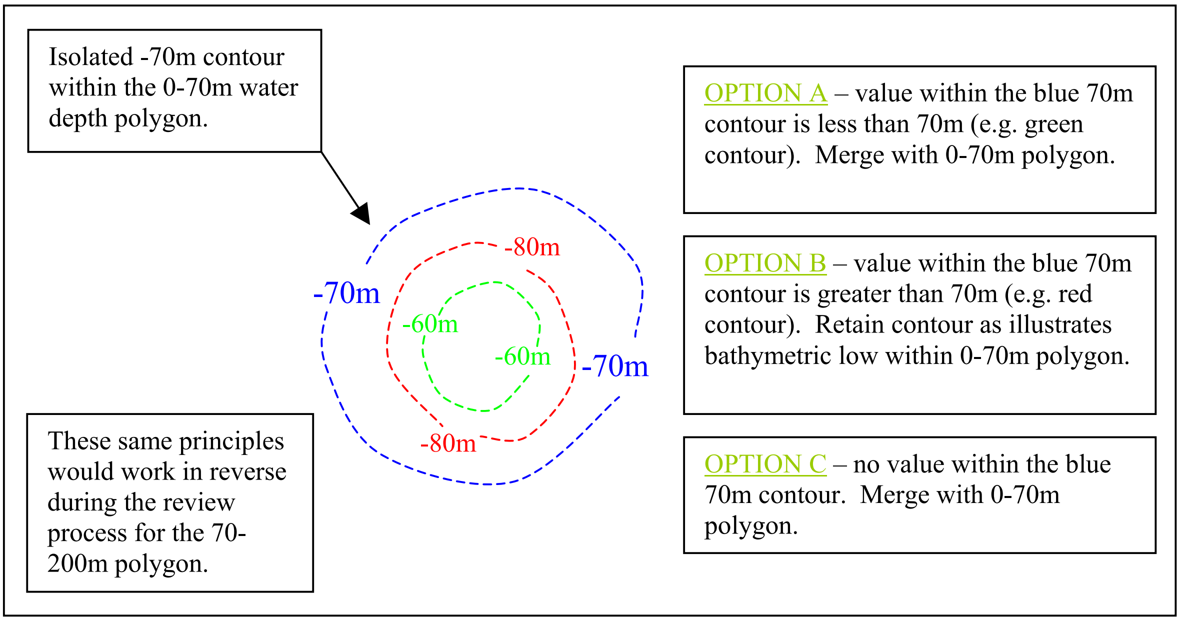


Figure 5 Polygon options. During the manual review process of the DigBath contours, those not considered to be of interest (Options A and C) would be removed. Some polygons can be merged if part of a contiguous area.

The following figures illustrate the application of the sublittoral sediment review procedure described in section 5.1.2.

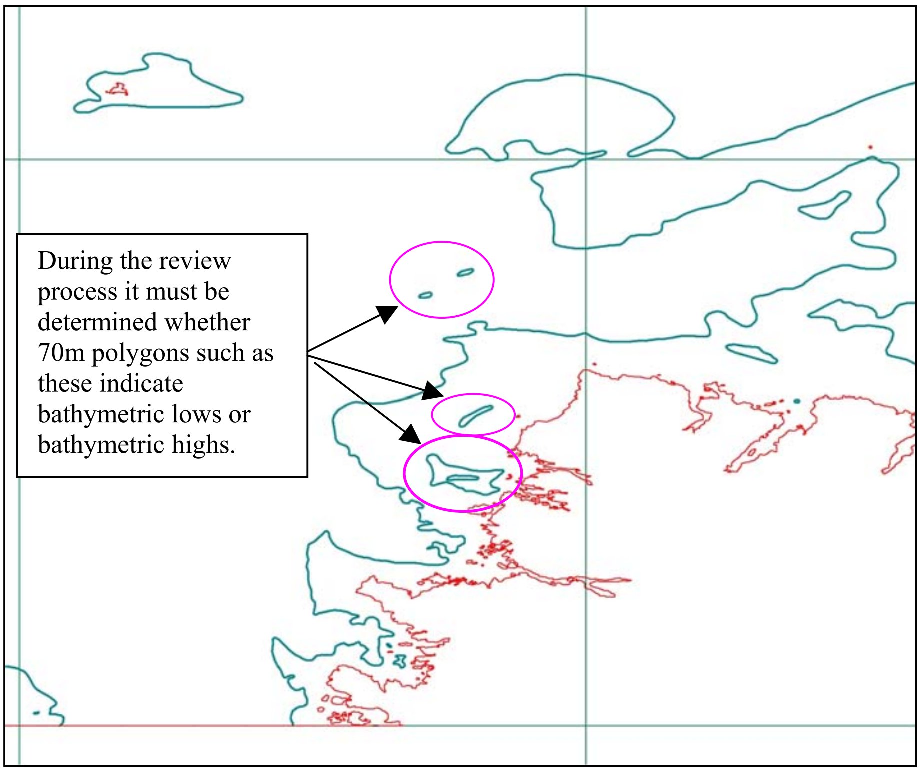


Figure 6 DigBath bathymetry –70m contour (blue) and 0m contour (red) within the Cape Wrath area.

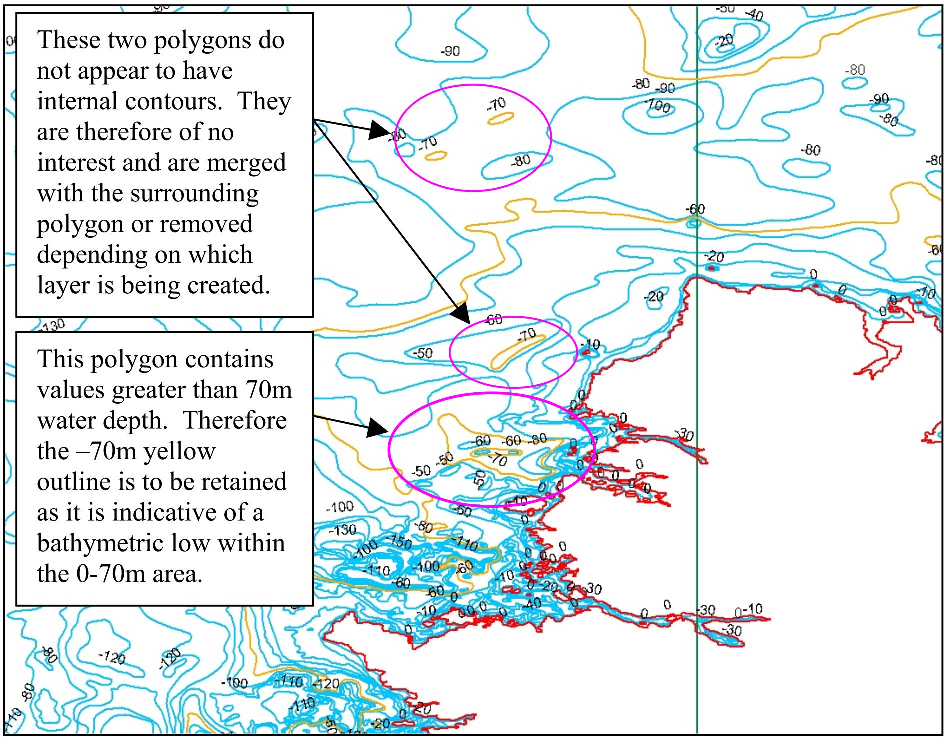


Figure 7 DigBath bathymetry within the Cape Wrath area. The –70m contour is this time highlighted in orange with the 0m contour again highlighted in red.

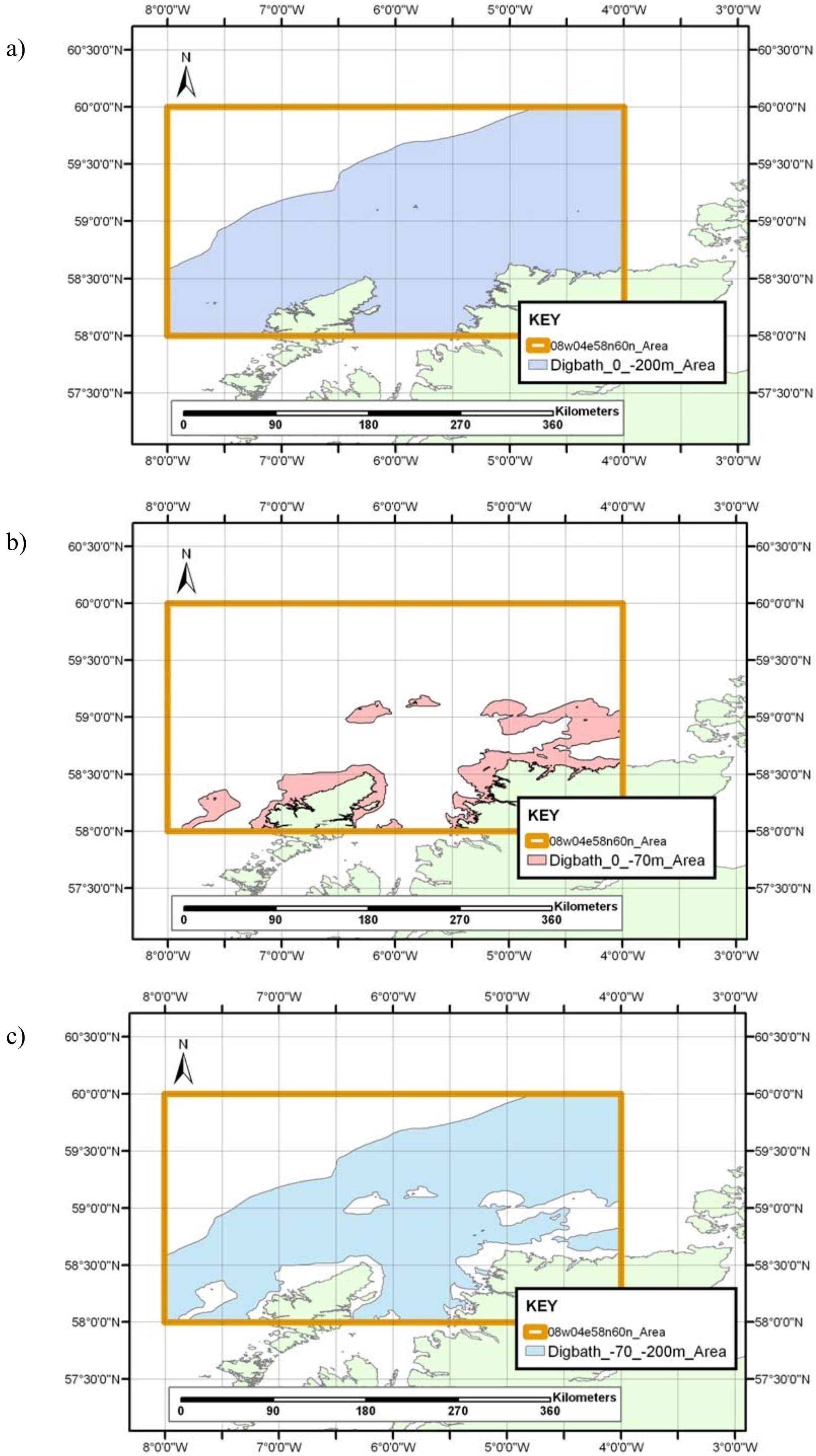


Figure 8 The three DigBath cropping polygons for a) 0-200m water depth, b) 0-70m water depth, and c) 70-200m water depth.

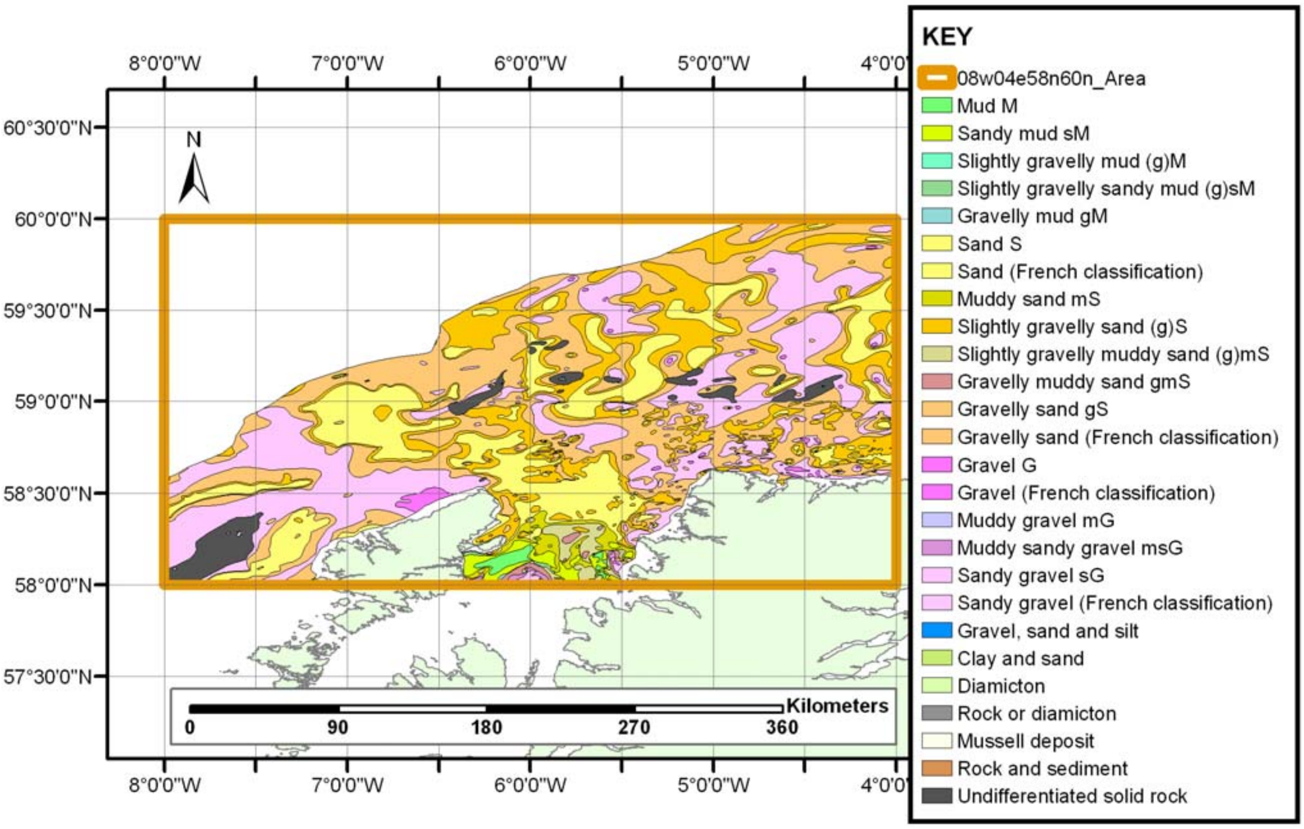


Figure 9 Figure illustrating the range of sediment types found within study area C in 0-200m water depth. The sediment classification system is based on that of Folk (1954).

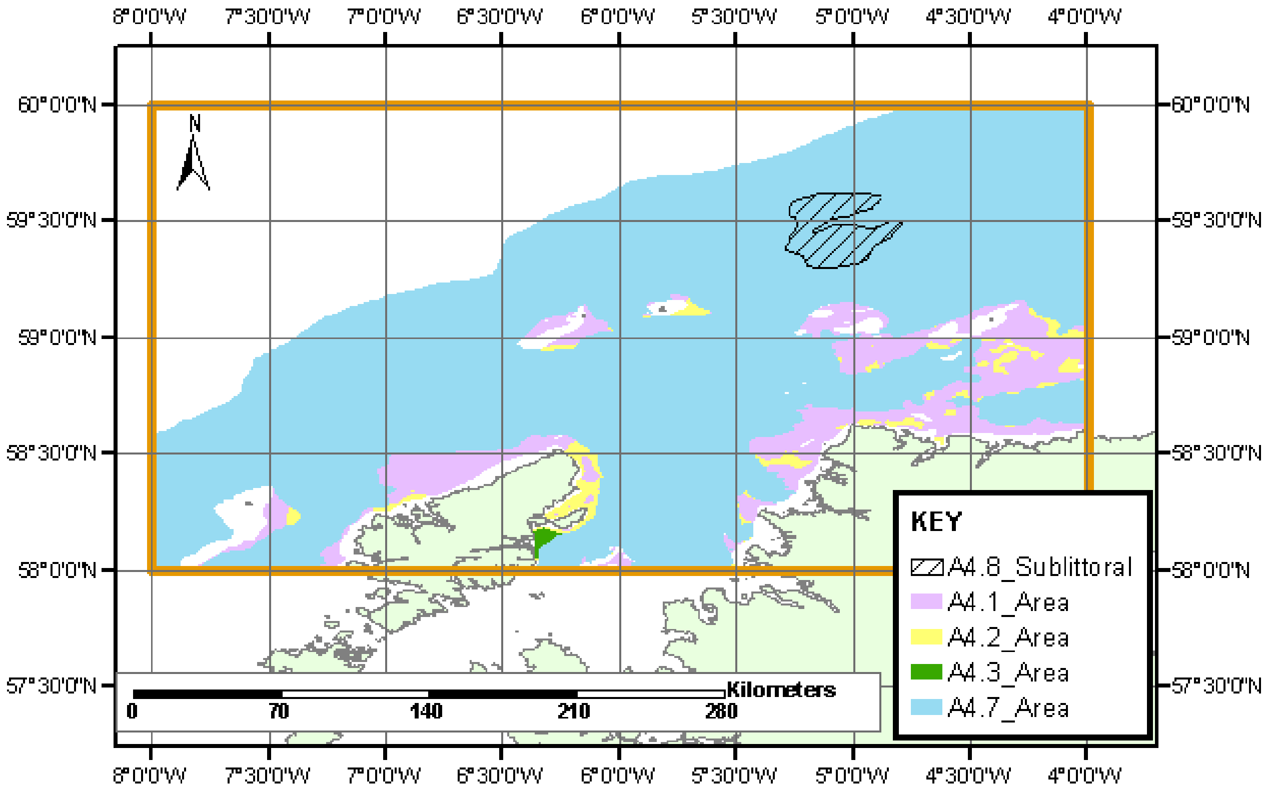


Figure 10 Figure showing the distribution of four sublittoral sediment levels: A4.1 (sublittoral mobile cobbles, gravels and coarse sands), A4.2 (sublittoral sands and muddy sands), A4.3 (sublittoral muds) and A4.7 (deep shelf sediment habitats). The figure also shows areas of A4.8 seeps and vents in sublittoral sediments (hatched area). Areas of rock exposed at the seabed are not shown here, but are discussed in section 5.1.4. As you can see in the Figure, the EUNIS sublittoral sediments level simplifies the seabed sediments considerably.

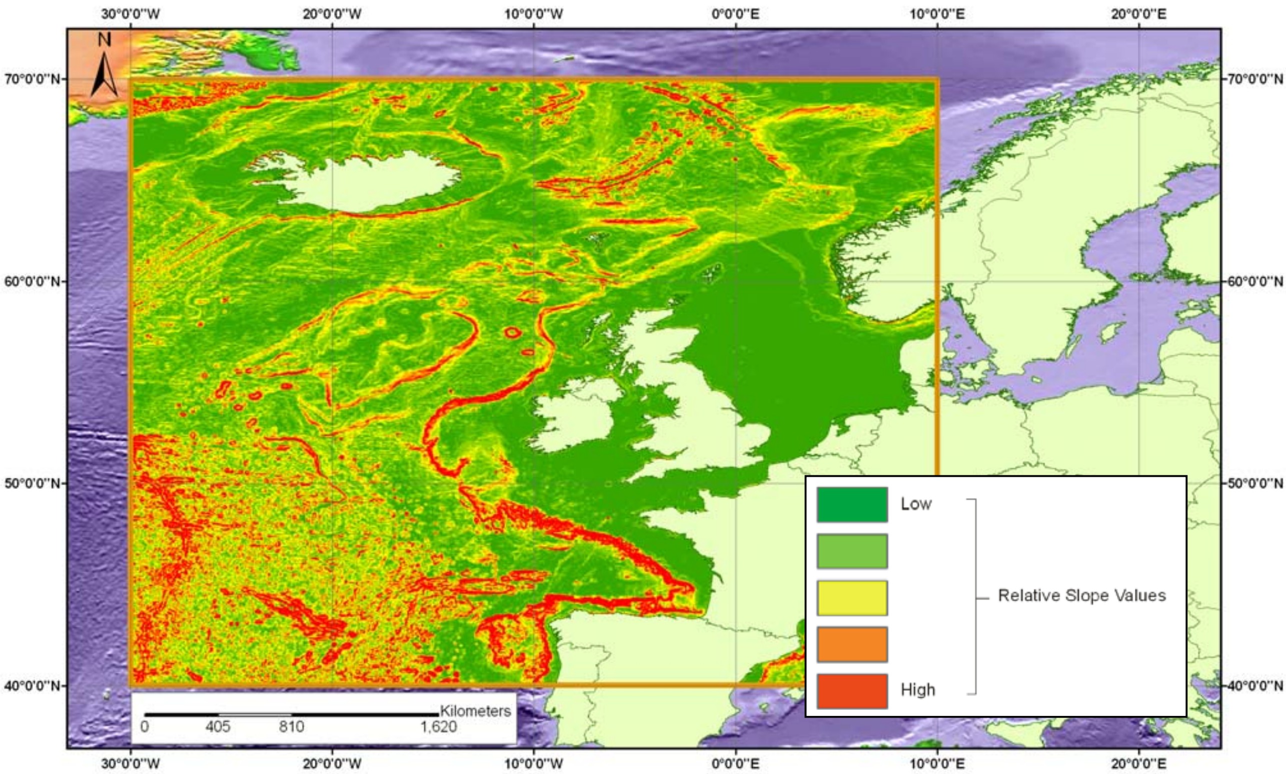


Figure 11 This figure shows broad scale relative slope values for area (B). The derivation of useful absolute slope values requires high-resolution data, such as the BGS Bathymetry (DigBath250) product, and may be inappropriate over large areas.

Table 2 Rock outcrop within the study area, the identified areas of bedrock listed under 'shape ID' are derived from an existing JNCC rock outcrop theme.

Shape ID	Bedrock Geology
R0001	Undifferentiated Lewisian metamorphic rock (Precambrian)
R0004	Undifferentiated Quaternary (Pleistocene) rock; usually <10m including ?some bedrock (undifferentiated Lewisian metamorphic rock)
R0005	Undivided Torridonian sedimentary rock
R0007	Undifferentiated Lewisian metamorphic rock (Precambrian) with an area of pre-Tertiary basic/ultra basic intrusion
R0266	Permo-Triassic sedimentary rock possibly including younger Mesozoic rocks
R0277	Lewisian metamorphic rock (Precambrian)
R0276	
R0275	
R0267	
R0265	
R0269	
R0270	
R0271	
R0268	Lewisian metamorphic rock (Precambrian) with areas of Permo-Triassic sedimentary rock.
R0272	
R0274	
R0273	

5.1.4 Geologic Unit

This layer holds data visible at a small scale rather than at a regional scale. The study area for this layer is the same as that for the sublittoral sediments GIS layer. Using the existing JNCC rock outcrop theme, the areas of rock are taken by a geologist and compared to existing Quaternary and solid geology maps at 1:250 000 scale (Table 2). This allows the geological unit to be identified and the information to be added to the existing JNCC theme. No significant problems have been encountered during the course of populating this theme.

5.2 GEOHAB 2003

The third GeoHab meeting (Marine **Geo**logical **Hab**itat Mapping) conference took place from the 30th April to the 2nd May 2003. BGS submitted both an abstract (Appendix 1) and a poster to the conference, centring on the BGS Offshore GIS and work undertaken as part of this report. As well as illustrating some of the GIS test layers such as megahabitats and slope, three additional 3D views were created for study region (D) (Figure 3) located to the north and west of the Orkney Islands.

A 3D view illustrating the bathymetry was created for the study area (Figure 12a). This showed the seafloor topography of the area to consist of a bathymetric high in the east and a relative bathymetric low in the west. The bathymetry then had alternative datasets draped over it (Figures 12b and c).

Figure 12b illustrates the relationship between marine landscape and seabed composition. Gravel, sandy gravel and gravelly sand are associated with the area of elevated seabed in the east, whereas fine-grained sediment composed of muddy sand and sand is located in the bathymetric low to the west. Throughout the Holocene, fine-grained sediment has been reworked and transported from areas of high energy, such as bathymetric highs, and redeposited where energy levels are lower.

The same bathymetric 3D view can also be draped with geochemical data, in this case the relative concentrations of zinc in seabed samples (Figure 12c). Areas of high relative zinc concentrations appear to coincide with the areas of fine-grained sediment located in the bathymetric low in the west of the study area (Figure 12b). High concentrations of metals such as zinc may be related to contaminants derived from industrial and agricultural practices. Contaminants can be held in suspension on the surface of fine-grained particles and deposited in 'pollutant sinks', such as areas of weak currents over bathymetric depressions (Stevenson, 2001). These types of data are important in determining how sediments and metals are transported and deposited in the marine environment.

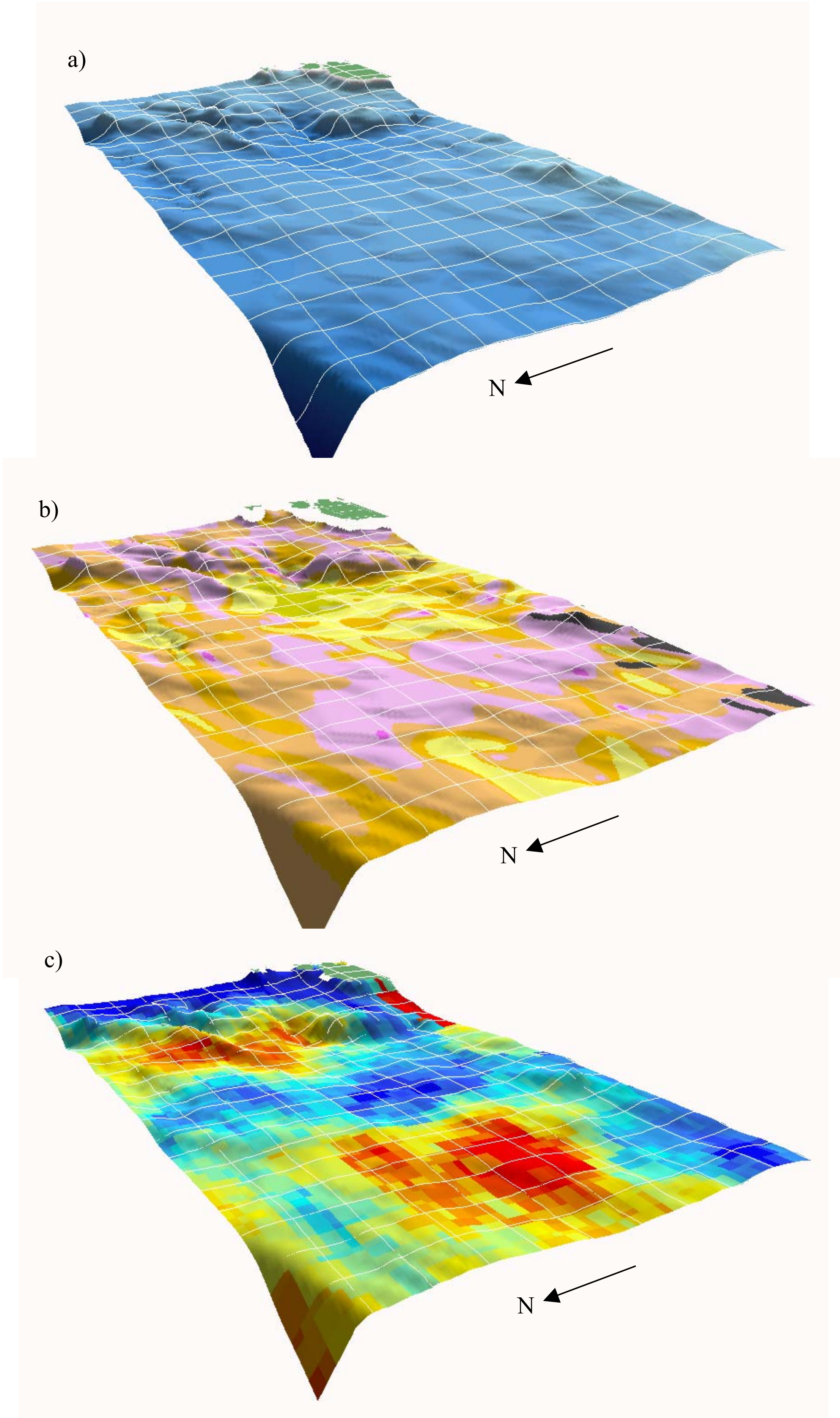


Figure 12 a) 3D view of the bathymetry of area (D) draped with alternative datasets: seabed sediments b) and relative concentrations of zinc c).

5.3 CONCLUSIONS

The purpose of this exercise was to determine the ease with which BGS data could be incorporated into existing marine habitat classification schemes. In the time available several GIS layers have been created, but for archiving purposes attribution and metadata will also be created. No custom programming has been undertaken during the course of this test, however doing so may decrease the time taken to create these layers in future. The issue of custom programming will be discussed further below.

With regard to the megahabitats GIS layer, a semi-automated GIS process would be efficient in creating an initial set of megahabitat polygons for manual review. This would require custom programming to create an automatically generated bathymetric-derived dataset using the defined depth-range for certain features as a guide. If undertaken, this method could be tested against the manual test results shown in Figure 4.

As with the megahabitats GIS layer, a semi-automated GIS process would be more efficient in creating an initial set of cropping polygons for creating the subsets of DigSed for the sublittoral sediments GIS layer. The usefulness of this is dependent on the size of the area of interest and the complexity (resolution) of the bathymetric dataset used. This would require custom programming. Again, if undertaken, this method could be tested against the manual test results shown in Figure 10.

Further work could be carried out to develop appropriate guide values for both scale of study area and resolution (density) of bathymetric data required when calculating seabed slope. This could be achieved through consultation with colleagues within BGS who routinely work with slope data. Consideration should also be given to the affects of smoothing on the results, which could perhaps be done through performing a test on a small localised area with a UTM projection, i.e. x, y and z (depth) all using the same unit of measurement, with high-resolution bathymetric data.

In order to semi-automate the process of identification of areas where rock is exposed at the seabed, areas of rock outcrop could be identified using the attribute fields of the BGS DigSed product. The consequent layer containing the location of rock at the seabed could be either at a regional or local scale. The population of lithology, formation name and other information could not be done through custom programming and would require the input of a geologist.

In conclusion, the work carried out during the course of this test has allowed the development of a set of basic steps needed to convert data held by BGS into pre-existing classification schemes. The four selected GIS layers coupled with the 3D views have given an insight as to the direction future habitat-mapping work within BGS should take.

These include aspects such as developing the knowledge BGS has on sediment bedform distribution and erosional features to be included in the Offshore GIS. Some of this information already exists in the GIS environment, however, a wealth of information is contained in BGS Offshore Regional Reports, which has yet to be transferred to a GIS. Other analyses should also be considered for future work such as rugosity analysis and topographic position index (TPI). Rugosity analysis is a measure of how rough the seabed is and can be calculated from high-resolution digital elevation data. TPI is related to the relative position of a location in the overall landscape, for example a hilltop, valley bottom, canyon or exposed ridge. Broad-scale TPI can be used to classify meso- and macro- scale habitats.

6 Conclusions and Recommendations

6.1 CONCLUSIONS

- There are many local and regional classification schemes in use, all of which use geological parameters to a greater or lesser extent.
- As yet there is no single scheme which matches all requirements, and it may be that it is not possible to create a single scheme with the flexibility to be applicable in different areas of the world and at different levels of resolution.
- In either scenario BGS needs to be able to 'package' its data in different ways to match existing schemes and future schemes as they develop. Procedures need to be defined that describe how particular scheme objects can be populated from BGS datasets.
- Some scheme objects can be populated directly from BGS data types that are held digitally. For others, the mapping is indirect and requires derivation from two or more BGS digital data types. In these cases, scheme objects can be populated either automatically (by developing a suitable processing algorithm) or semi-automatically (requiring the input of an interpreter), using GIS techniques to process the data.
- For some scheme objects, BGS does hold useful data, however, the data are not in digital form. Some effort is required to convert such data to digital formats, which can then be processed and mapped within the GIS.
- Existing habitat mapping schemes do not utilise geological information to its full potential. Continued contact with national and international organisations working on classification systems will address this problem.
- A 'neutral' sea-bed facies scheme should be developed as a geological base layer, which can then be integrated with oceanographic and biological parameters specific to any single classification.

6.2 RECOMMENDATIONS

- BGS should develop its role in habitat mapping, and be seen to be a source of data, expertise and research in this field, rather than just a data provider.
- Further collaboration with organisations that have the necessary oceanographic and biological knowledge.
- Non-digital datasets, which could help to populate habitat schemes, should be digitised and integrated with other data within the GIS environment.
- A 'Marine Landscape Lexicon' should be created, compiling a BGS standard glossary of terms to be used for the description of various elements making up a marine landscape.
- If a marine landscape is to be classified the following should be taken into consideration:
    - Location/geography – this would be a broad generic level that would set the context for the following sections.
    - Climate – if the broad climate is indicated, an idea of the environment and features found there can already be formed.
    - Tectonics – the tectonic setting of an area can also give an indication as to the type of features that can be found there.

- Physiography – this is based on topography and water depth and is used to distinguish large-scale features on a scale of tens of kilometres to kilometres.
- Bedforms – this section would describe and categorise all manner of features found in the marine environment, including active, moribund and decaying features. Particular attention should be made to placing the attributes of features and the processes forming them into their local and wider regional context. This section should contribute to the identification of areas of environmental concern and non-concern in relation to seabed geological processes.
- Composition or surface – the composition of the seafloor, and immediate subsurface, is important when considering the morphology and stability of the sea floor.

Appendix 1 – GeoHab 2003 Abstract

The British Geological Survey Offshore GIS and its application to marine habitat mapping

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The British Geological Survey is part of the UK Natural Environment Research Council with responsibility for geological mapping of the UK land area and continental shelf and margins. A wide range of marine geological data have been acquired over the last 30 years including seismic and acoustics, sediment particle size, geochemistry and geotechnical data, leading to the publication of a series of thematic maps at 1:250,000 scale.

In recent years there has been increasing interest in the use of these maps in the development of marine habitat classifications. Digital data derived from the seabed sediment, Quaternary geology and solid geology map series have been used to develop the BGS Offshore GIS using ArcMap 8.2.

A review of national and international habitat classification schemes has been carried out to assess which data and interpretations, presently held by the British Geological Survey, can be inserted into these classification systems. This assessment has mainly focussed on three classifications; the Marine and Estuarine Ecosystem and Habitat Classification (Allee et al., 2000); the European Nature Information System (EUNIS) habitat classification and the Deep-Water Marine Benthic Habitat Classification of Greene et al., which was presented at the GeoHab Conference in Monterey in 2002.

Work in progress will test the method of incorporating BGS data into existing classification schemes. Four GIS layers have been selected from the EUNIS and Deep-Water Marine Benthic Habitat classifications; two have been examined at a regional scale and two at a localised scale. These are Sublittoral Sediments (from the EUNIS classification) and Megahabitat, Seafloor Slope and Geologic Unit (Deep-Water Marine Benthic Habitat Classification). The work will conclude with a report on how the BGS Offshore GIS can be adapted to inform legislative demands that encompass both the coastal zone and the offshore area.

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Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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