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NATURAL ENVIRONMENT RESEARCH COUNCIL

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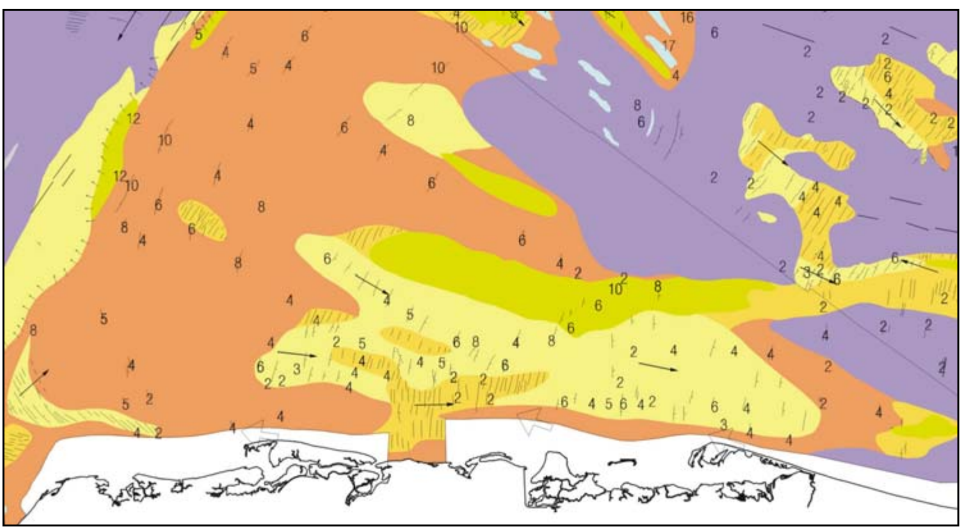
J.W.C. James

British Geological Survey
Commissioned Report CR/01/18



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Cover Illustration: Sea bed sediment and facies off the north Norfolk coast

Keyworth, Nottingham, British Geological Survey, 2002

FIGURES

Acronyms

AGDS	Acoustic ground discrimination system
BGS	British Geological Survey
BIOMÔR	Benthic Biodiversity in the Southern Irish Sea project
BMP	Broadscale Mapping Project (SeaMap Group, Newcastle University)
CEFAS	The Centre for Environment, Fisheries & Aquaculture Science
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EUNIS	European Nature Information System
GSC	Geological Survey of Canada
ICES	International Council for the Exploration of the Seas
ICES-SGMHM	Study Group on Marine Habitat Mapping under ICES
INTERREG	European Union Inter-Region programme
MPA	Marine Protected Area
NOAA	National Oceanic & Atmospheric Administration
OSPAR	Oslo-Paris convention for the protection of the marine environment
SAC	Special Area of Conservation
SMP	Shoreline Management Plan
SWISS	South west Irish Sea Survey
UKHO	United Kingdom Hydrographic Office

1 Introduction

The development of UK marine environmental policy is being pursued with regard to a number of international initiatives including the 1992 OSPAR Convention for the Protection of the Marine Environment of the north-east Atlantic, the North Sea Ministerial Conference and the European Union Habitats and Species Directive.

A strategy recently adopted under OSPAR is the protection and conservation of ecosystems and biodiversity. This requires the identification of processes and impacts on ecosystems that may affect their natural structure, biological diversity and productivity. A primary step in this process is to identify and describe ecosystems in terms, which include their physical, chemical and biological character. This requires a systematic approach if it is to be of value in, for example, the identification of marine protected areas. Such an approach is being advanced with the development of marine habitat classifications and their implementation in mapping habitats in the coastal, shelf and ocean environment.

The aim of this report is to identify and briefly describe a number of marine habitat classification systems an examples of marine habitat mapping and to examine the use and application of geological data, maps and interpretation to the assessment and mapping of marine habitats.

2 British Geological Survey data, maps and interpretation.

Since the mid 1960's the British Geological Survey (BGS) has undertaken regional geological surveys in UK designated waters. During the 1970's and 80's this involved a systematic programme of sampling and coring of the sediment and rock at and beneath the sea bed and culminated in the acquisition of over 30,000 sea bed samples (Figure 1). These samples were examined, described and curated, and the majority of them were sieved and classified on their particle size distribution. This data set is held in ORACLE data bases at BGS and has been augmented over the years by similar data from commercial and academic sources, not only in UK designated waters, but also in adjacent Irish and Continental waters, enhancing the BGS database to over 80,000 sample stations. This is an extensive and comprehensive set of sediment data with a regional scale density, averaging around a sample per 2 - 5 km^2.

Geophysical surveys were run in parallel with this sampling and coring programme. A suite of geophysical equipment was deployed, principally airgun, sparker and sidescan, to acquire high-resolution seismic profiles and records. These systems provide information and data for geological interpretation of both the sea bed and the shallow sub-surface.

BGS has systematically acquired over 200,000 km of seismic data across UK designated waters and adjacent waters (Figure 2). In common with the sediment data held by BGS the seismic data is extensive and comprehensive but its density is on a regional scale with average line spacing of 5 – 10 km. The interpretation of this BGS seismic data has been augmented in some areas by the interpretation of widespread bathymetric and sidescan sonar surveys acquired by the UK Hydrographic Office (UKHO).

2.1 1:250,000 Map Series

The primary products of the regional geological surveys undertaken by BGS were a series of published maps of UK designated waters and adjacent areas at a scale of 1:250,000 (Figure 3). In all, 62 sheets have been published and each sheet may comprise up to six map themes. Three of these themes are related to the gravity and magnetics of the earth and are not relevant to the mapping of marine habitats. The three map themes that are relevant to the mapping of marine habitats are: -

1. Sea Bed Sediments - distribution of sediments at the sea bed, some of which may be mobile and subject to erosion and transport. This theme would be the primary source for integrating geological data into habitat maps.

2. Quaternary Geology - distribution and form of sediment associated with recent glacial and climatic events at or beneath the sea bed. Important because the limit of glaciations and their influence on the sea bed around the UK has an impact on the form and character of sediment at the sea bed and therefore habitat.

3. Solid Geology - distribution and form of rock at or beneath the sea bed. Influential because the nature of habitat on rock will be different to habitat on sediment.

These themes may be published as individual sheets, although in some cases the sea bed sediments and Quaternary Geology may be amalgamated and published together as one sheet. BGS is currently undertaking a programme to digitise the solid geology and sea bed sediments themes from the 1:250,000 map series and make the digital products available for sale.

2.2 Inshore sea bed characterisation

Understanding sedimentary processes in the inshore/nearshore zone, which covers the area from the coast to 20 km offshore, is essential to a number of coast related issues including

- Marine aggregate policy on licencing and resources
- Impacts of aggregate dredging within and outside licenced dredging areas
- Implementation of Shoreline Management Plans (SMPs)
- Coastal erosion, flooding and impact of climate change
- Fisheries policy and resources.
- Marine conservation policy

The geological and sediment data depicted on the 1:250,000 maps produced by BGS were not on a large enough scale to address local coast related issues. In the mid 90's the Inshore Sea Bed Characterisation Project was initiated to collate and interpret geological and sediment data at a more appropriate and detailed level in the inshore/nearshore zone.

This was a BGS core programme project which was co-funded between 1996 and 2002 by the Department of the Environment, Transport and the Regions (DETR) with the Ministry of Agriculture, Fisheries and Food (MAFF) providing additional funds for the first sector examined.

BGS used three principal data sources for the project

- Sediment and seismic data from the BGS offshore database
- Bathymetry and sidescan interpretations from UKHO data
- Dredging industry data and commercial and academic reports

These datasets range from broad, regional scale surveys to detailed, total cover of relatively small areas. Some are available on open access whilst others are commercially sensitive. The collation of these data and making them available within a coherent digital format was a major aim of the project.

During the course of the project, particular emphasis has been placed on the interpretation of side scan sonar data to produce bedform and facies maps. These are important in mapping the distribution of sediment and rock at the sea bed and understanding sedimentary processes from the scale and structure of bedforms. They are also a primary dataset on which to base the mapping of marine habitats.

The project has been designed to produce digital data for a series of themes, up to 30 in all, including

- Solid geology
- Sea bed sediments
- Bedforms and facies
- Sediment transport
- Bathymetry

The digital themes have been captured using Microstation and are available in MapInfo and ArcView format. The project comprises six sectors covering the inshore from Flamborough Head in Yorkshire to the Deben Estuary in Suffolk, and Dungeness on the Kent coast to Portland Bill (Figure 4). A report has been produced to describe the themes which have been compiled for the these six sectors (Evans and others, 1998).

A further sector from Dungeness to the Deben Estuary is also available and a report has been completed (Evans & Slater, 2000) but at the time of writing the bedform and facies themes have not been completed. Their inclusion as a digital theme awaits a review of the use of UKHO side scan sonar data.

Both of these major BGS marine and coastal datasets could be incorporated into habitat mapping schemes. Their relevance would depend on the scale and detail required. The classifications and schemes described below indicate that geological and sediment data, and interpretations of the type held by BGS can be incorporated successfully into habitat mapping programmes.

The Joint Nature Conservation Committee (JNCC) is currently in discussions with BGS with regard to a project to map, on a regional scale, the extent of Special Areas of Conservation (SAC) marine habitats in UK designated waters out to the 200 mile limit.

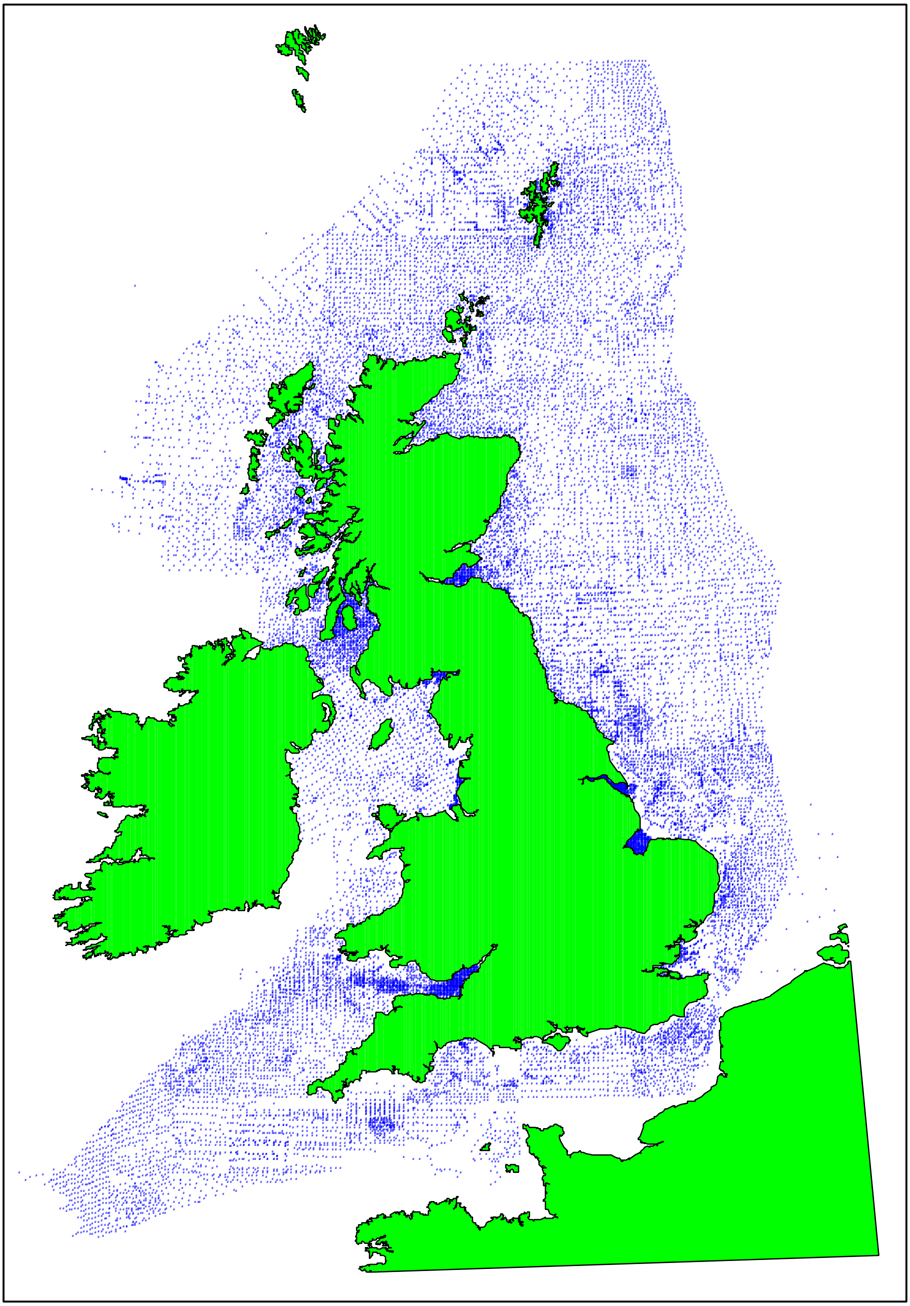

Figure 1 BGS offshore sample stations

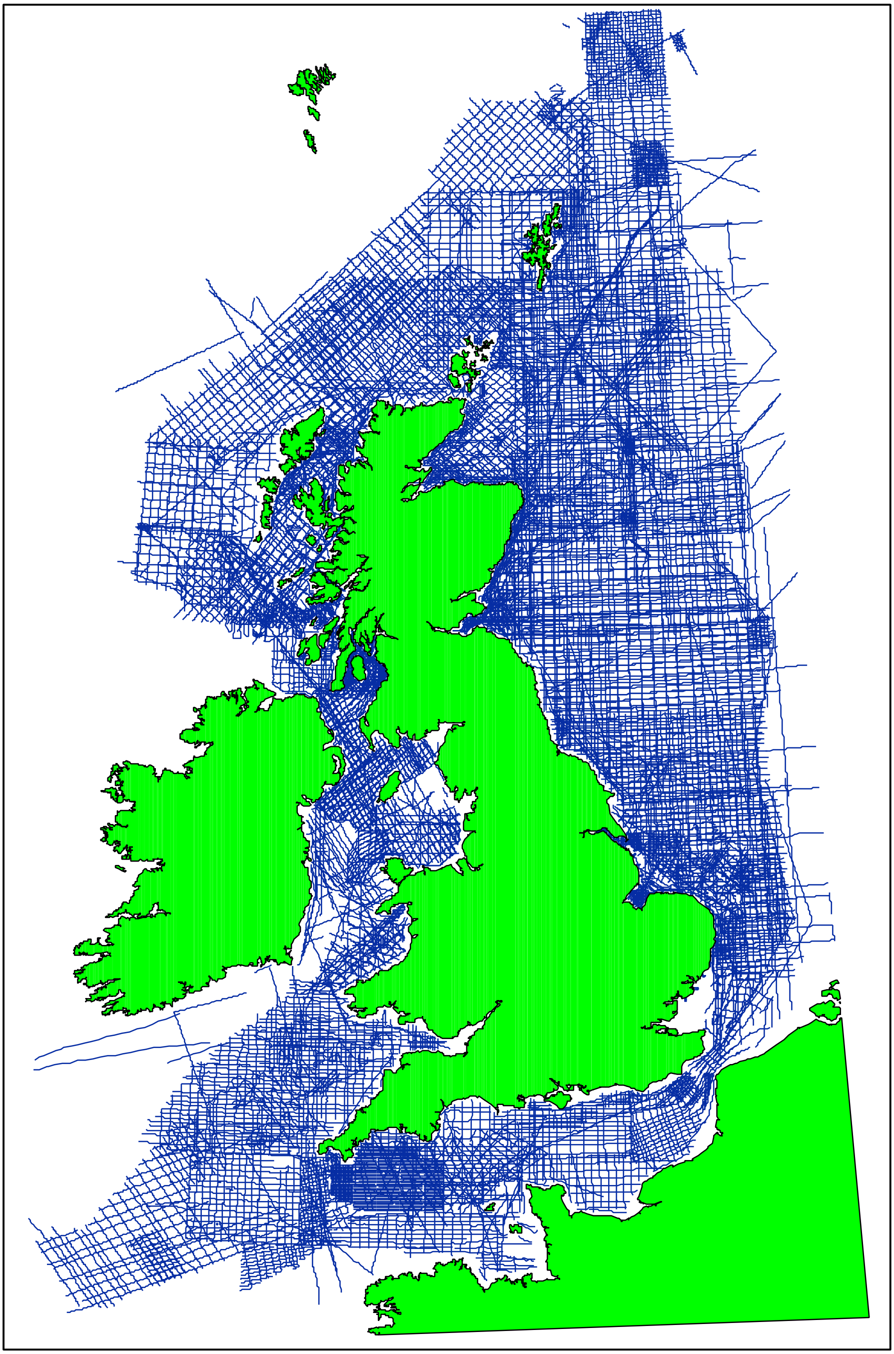

Figure 2 BGS geophysical survey tracks

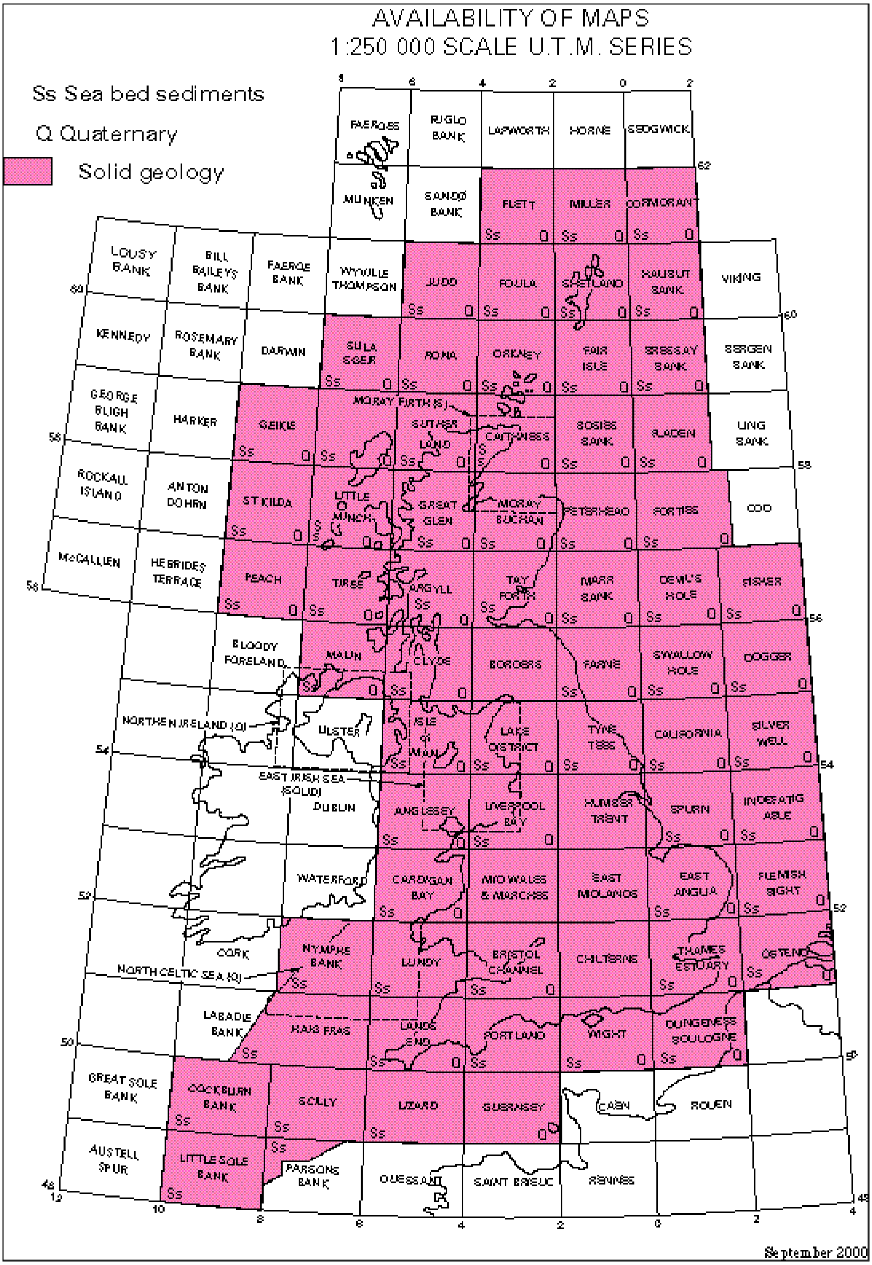

Figure 3 Availability of published BGS 1:250,000 maps

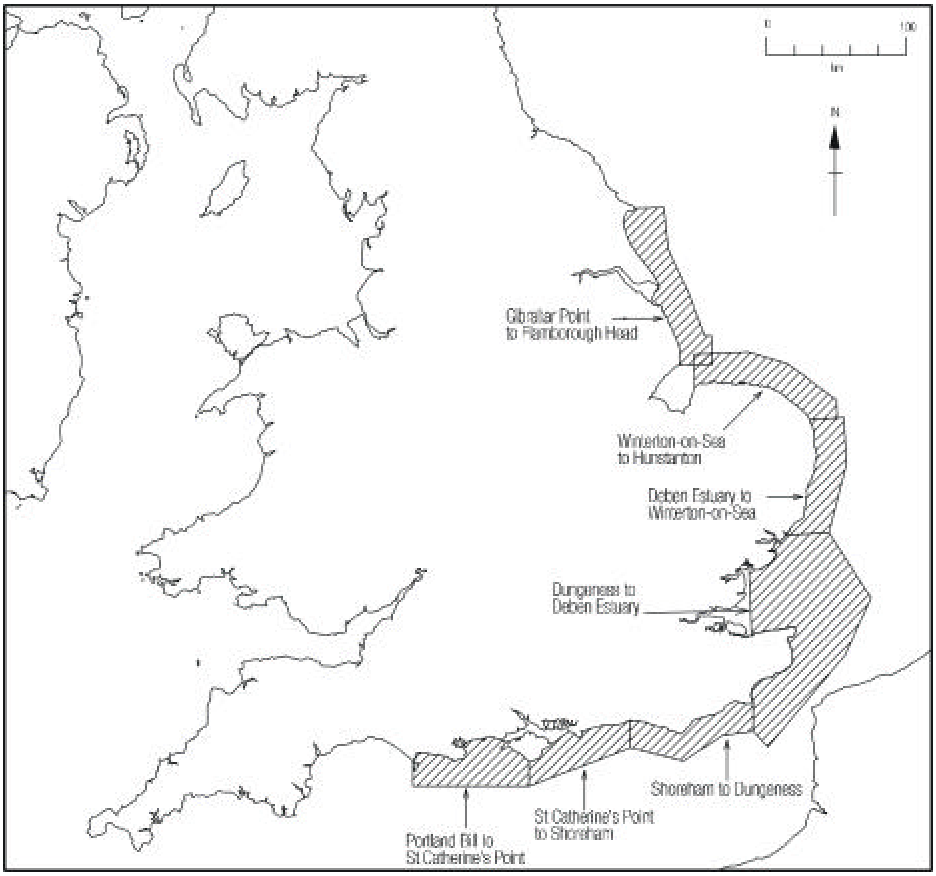

Figure 4 BGS Inshore Sea Bed Characterisation Project sectors

3 The use of geological data and interpretations in marine habitat mapping

Day and Roff (2000) are clear in their understanding that physiographic features which include geology, sediment and morphology of the sea bed greatly influence the distribution and range of species and biological communities. It is self evident there are vast differences between communities which live on hard rocky substrates and those which dwell on and in soft muddy substrates. The beauty of physiographic features such as geology and sediment is they are generally more readily mapped than biological or oceanographic features, especially through the use of modern geophysical techniques such as multi-beam, sidescan sonar and AGDS (acoustic ground discrimination system). They are ideally suited to act as the primary building blocks of marine habitat classifications. This has been recognised in the inclusion of sediment and substrate at primary levels in the European, Canadian and American habitat classifications described below.

In this context a considerable amount of data on physiographic features are already available in the UK marine environment through published Admiralty charts for bathymetry and morphology and BGS maps and interpretations on the distribution of rock and sediment at and beneath the sea bed. The development of oil and gas fields over the last 30 years has provided a wealth of data which could be utilised for habitat mapping in UK designated waters.

Given that the physiography of the sea bed is so influential in determining the form and variability of biological communities, then it is necessary for biologists, ecologists and managers of marine resources to understand the principal factors and attributes which control the form of the geology and sediment at the sea bed.

3.1 Geological History

The events of the geological past have a profound influence on the present. For example, the present distribution of sediment and rock at the sea bed on the UK Continental Shelf has been greatly affected by the movement and extent of ice during the last glaciation and the deposition of sediment associated with its melting and retreat. Ice during the last glaciation did not cover much of southern England and was also absent from the English Channel and this has controlled the form of sediment and rock on the sea bed in the English Channel. In areas such as the Irish Sea, which were covered by ice, the sediments at the sea bed may be underlain by thick glacial sediments.

The effect of the glaciations continue in the present day. Many of the coasts which are being actively eroded in the UK, such as North Norfolk and Holderness, are formed of unconsolidated glacial sediment and these continue to be a source of sediment for sand banks and sand waves in the adjacent seas.

The lowering of sea levels during glacial periods created incised channels and valleys on the emergent continental shelf. Many of these buried channels subsequently filled with sediment as sea level rose after the glaciations. These buried valleys may support unique habitats and therefore it is important to understand the processes which formed them and the methods which can be utilised to map them. These would require seismic reflection techniques to look at the 2D picture of the sediment and rock beneath the sea bed. In mapping habitats understanding the underlying structure of the sea bed can be just as important as the sea bed surface itself. The form and type of rocks can be determined from seismic reflection surveys.

The mapping of marine habitats requires a knowledge and understanding of the long term processes on a geological scale which have controlled the form of the sea bed as well as the modern contemporary processes which influence the sea bed and its biota.

3.2 Morphology and Relief.

Changes in relief can have profound influence on habitat. Areas of high relief may be rich in biomass and very diverse, they can also be very irregular and 'rough', especially in areas where rock is exposed at the sea bed. Relief can also influence the direction and focus of tidal currents and waves which in turn can influence erosion and deposition and the form of the substrate.

Sediment stability to some degree is controlled by slope and this may be very important on the continental margins where mass movement down the continental slope is a significant mechanism of sediment transport. On the coast the slope angle of

the shoreface can influence the form of the coast with steep slopes commonly associated with exposed rock.
Regional morphological features such as bays, estuaries and shoals can control the character of habitats. Tidal range and currents, wave energy and direction may be focused within these regional features and produce variations in depositional and erosional regimes.

3.3 Sediment grain size and distribution

Sediment grain size is a dominant influence on benthic and demersal communities (Day and Roff , 2000). The nature of the substrate from mud to gravel, as well as rock in all its forms is a powerful determinant of the type of organisms and benthic community which form its inhabitants. For example, few burrowing species will be found on most rock exposed at the sea bed but they dominate muddy soft habitats.

Sediment mobility and transport depends on current velocity and grain size. Currents can fashion sediment into bedforms such as megaripples, sand waves and sand banks. These types of environment experience change because of sediment mobility, the largest changes may be associated with storms. Mobile bedform environments tend to support lower species numbers and diversity compared to rock and mud environments.

3.4 Rock geology and structure

Day and Roff (2000) believe that, unlike the terrestrial environment where local geology can have a significant effect on habitat in terms of vegetation and animal communities, in the marine environment the type of rock exposed at the sea bed is not significant in the development of habitat communities. They do concede that rock character has an influence through its erosion and release of sediment into the marine environment.

However, further research is required to understand the relationships between rock and habitats in UK waters. It is unlikely that Chalk at the sea bed will support the same biological community as an igneous rock such as granite. Rock attributes such as bedding and roughness, porosity, density, mineralogy, sorting, alkalinity and acidity are also likely to provide some control on habitats.

4 Marine Habitat Classification

OSPAR in its 'Strategy on the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area' indicates that assessment by OSPAR of habitats which need protection will require inventories of marine habitats. It has indicated that implementation will require co-operation between scientists and institutions. This has already begun with joint initiatives on habitats being undertaken by OSPAR, the International Council for the Exploration of the Seas (ICES) and the European Environment Agency (EEA). ICES has a Study Group on Marine Habitat Mapping (ICES-SGMHM) which recently reported at a meeting in The Hague in April 2000. The EEA has developed the European Nature Information System (EUNIS) habitat classification and it is this system that OSPAR believes can be used as the basis for habitat assessment and mapping within its area.

The development of a habitat classification for the OSPAR area based on the EUNIS classification has been pursued at two workshops convened under a joint OSPAR/ICES/EEA umbrella. The first was at Oban in September 1999 and the second at Southampton in September 2000.

4.1 EUNIS Habitat Classification

The EEA has published a draft final report describing the EUNIS habitat classification (Davies & Moss, 1999) and the classification is available on the world-wide web www.mrw.walloniw.be/dgrne/sibw/EUNIS/home.html.

The report states that the aims and requirements of the habitat classification are to

- provide a common and easily understood language for the description of all marine, freshwater and terrestrial habitats throughout Europe
- be objective and scientifically based, with clear definitions and principles
- be comprehensive, but applicable at a number of hierarchical levels of complexity in recognition of the variety of its applications
- be flexible so as to evolve and allow the admission of new information, but also sufficiently stable to support users of its predecessors.

The report also suggests it is important to seek, as far as possible, the achievement of a consensus amongst those concerned with habitat classification as developers or users. The EUNIS classification has developed from a number of systems (Figure 5). The classification of marine habitats is largely derived from the BioMar project (Connor et al., 1997).

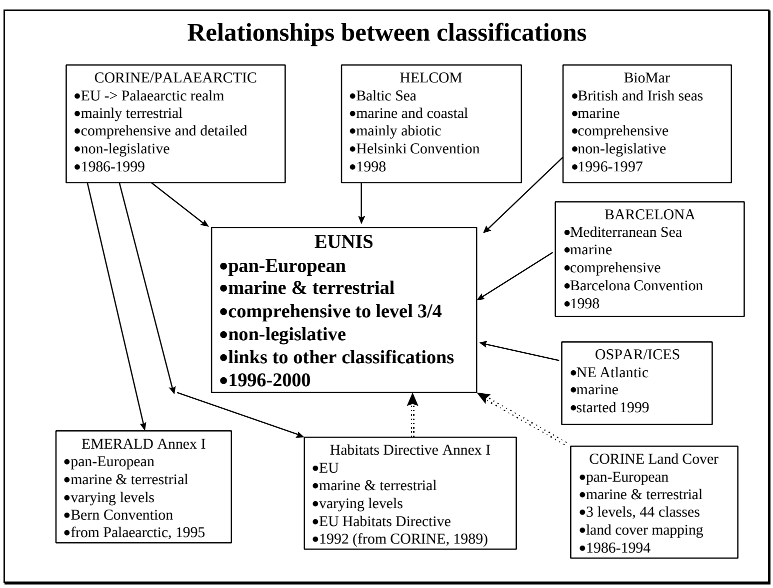

Figure 5 Relationships between classifications (from ICES, 2000)

The EUNIS classification is a hierarchical system based on five levels. In the marine environment they are currently specified down to Level 3 and these are listed below. The more detailed levels of functional groups (Level 4) and species (Level 5) remain to be classified and agreed.

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 mixed 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

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 Caves and overhangs in the circalittoral zone
A3.9 Deep circalittoral rock habitats
A3.A 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 mixed sediments
A4.5 Shallow-water sediments dominated by angiosperms (other than [Posidonia])
A4.6 [Posidonia] beds
A4.7 Deep circalittoral sediment habitats
A4.8 Seeps and vents in sublittoral sediments

Level 2
A5 Bathyal zone
Level 3
A5.1 Bathyal zone hard substrates
A5.2 Bathyal zone mixed substrates
A5.3 Bathyal zone sand

A5.4 Bathyal zone muddy sand
A5.5 Bathyal zone mud
A5.6 Seeps in the bathyal zone
A5.7 Caves in the bathyal zone

Level 2
A6 Abyssal zone
Level 3
A6.1 Hard substrates on the abyssal plain
A6.2 Soft substrates on the abyssal plain
A6.3 Tectonic ridges
A6.4 Seamounts
A6.5 Abyssal hills
A6.6 Hadal zone (deep ocean trenches)
A6.7 Caves in the abyssal zone
A6.8 Anoxic deep seabed habitats below anoxic water

Level 2
A7 Pelagic water column
Level 3
A7.1 Enclosed coastal saline or brackish water
A7.2 Partially enclosed coastal water
A7.3 Unenclosed mixed shallow water
A7.4 Unenclosed seasonally stratified coastal water
A7.5 Euphotic zone in non-coastal water
A7.6 Reduced-salinity water below the euphotic zone
A7.7 Water over continental shelf below euphotic zone
A7.8 Water below euphotic zone over seabed beyond continental slope break
A7.9 Ice-dominated marine habitats
A7.A Open ocean habitats with currents and eddies
A7.B Anoxic water column

Down to level 3 the classification is primarily based on physiographic and hydrographic features with sedimentological and geological components as important elements. The geological maps and data held by BGS would appear to be a primary source in any attempt at validation of the EUNIS-level 3 classification.

The workshop at Oban concluded that mapping of the OSPAR area at level 3 would be an important test for the consistency of the classification. This was expanded into a proposal for habitat mapping of the OSPAR area placed before the ICES-SGMHM meeting in the Hague in April 2000 (ICES, 2000). The UK is currently considering ways of taking this proposal forward. Certainly the BGS 1:250,000 maps of UK designated waters could be used within any UK contribution to mapping of the OSPAR area. The Dutch currently have a proposal within ICES-SGMHM to produce an Ecotope/Habitat Map of the Southern North Sea down to EUNIS Level 3.

5 Habitat Mapping

5.1 Broadscale Mapping Project (BMP)

This three year project has been completed by the SeaMap research group of Newcastle University. It has developed methodologies for broad scale mapping of sub-littoral habitats and biota based on acoustic remote sensing. It was funded by a consortium which included the Crown Estate, the Countryside Council for Wales (CCW), English Nature, Scottish Natural Heritage (SNH) and the SeaMap research group.

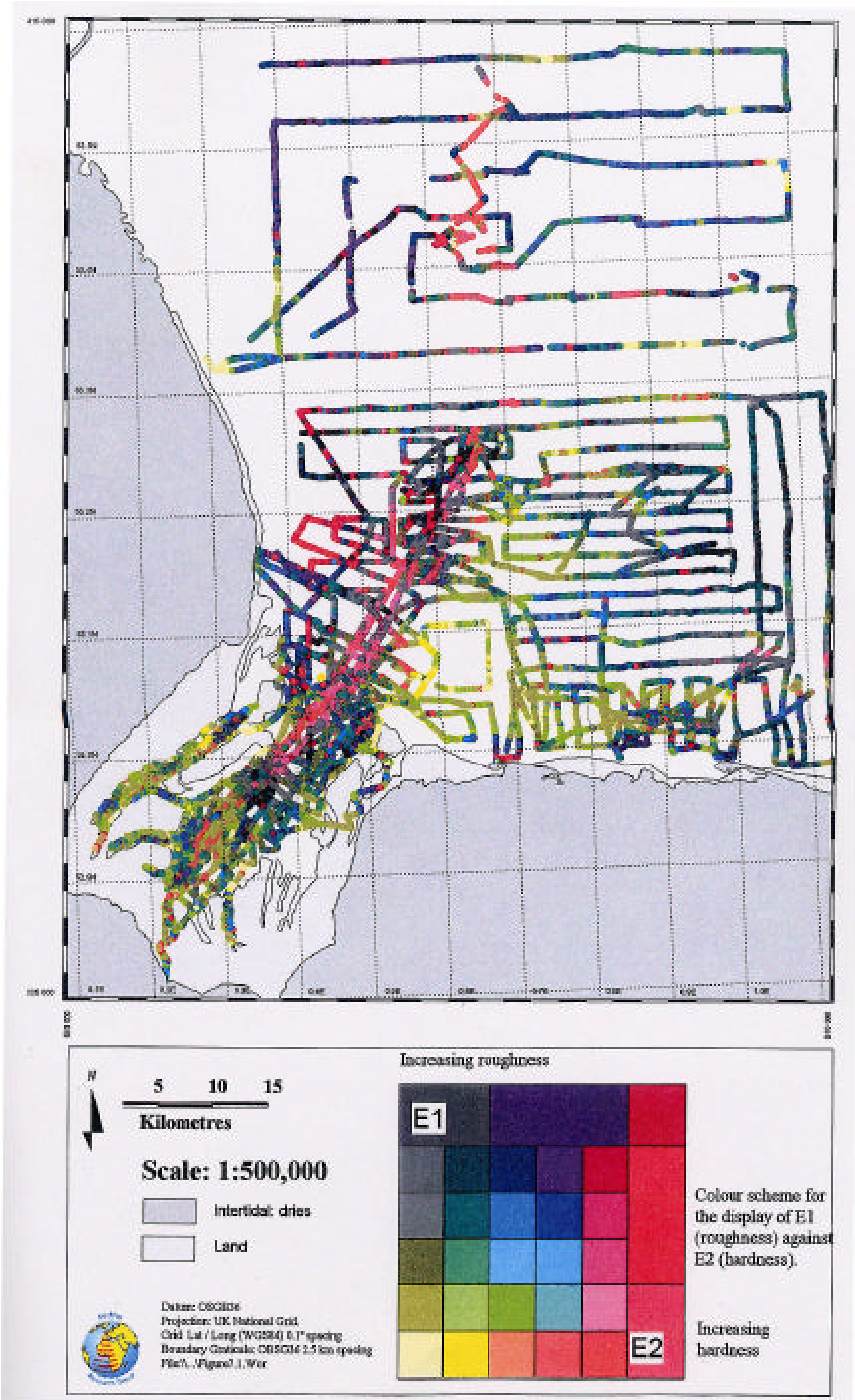

Figure 6 AGDS track data displaying roughness against hardness (from Foster-Smith & Sotheran, 1999) © English Nature 1999

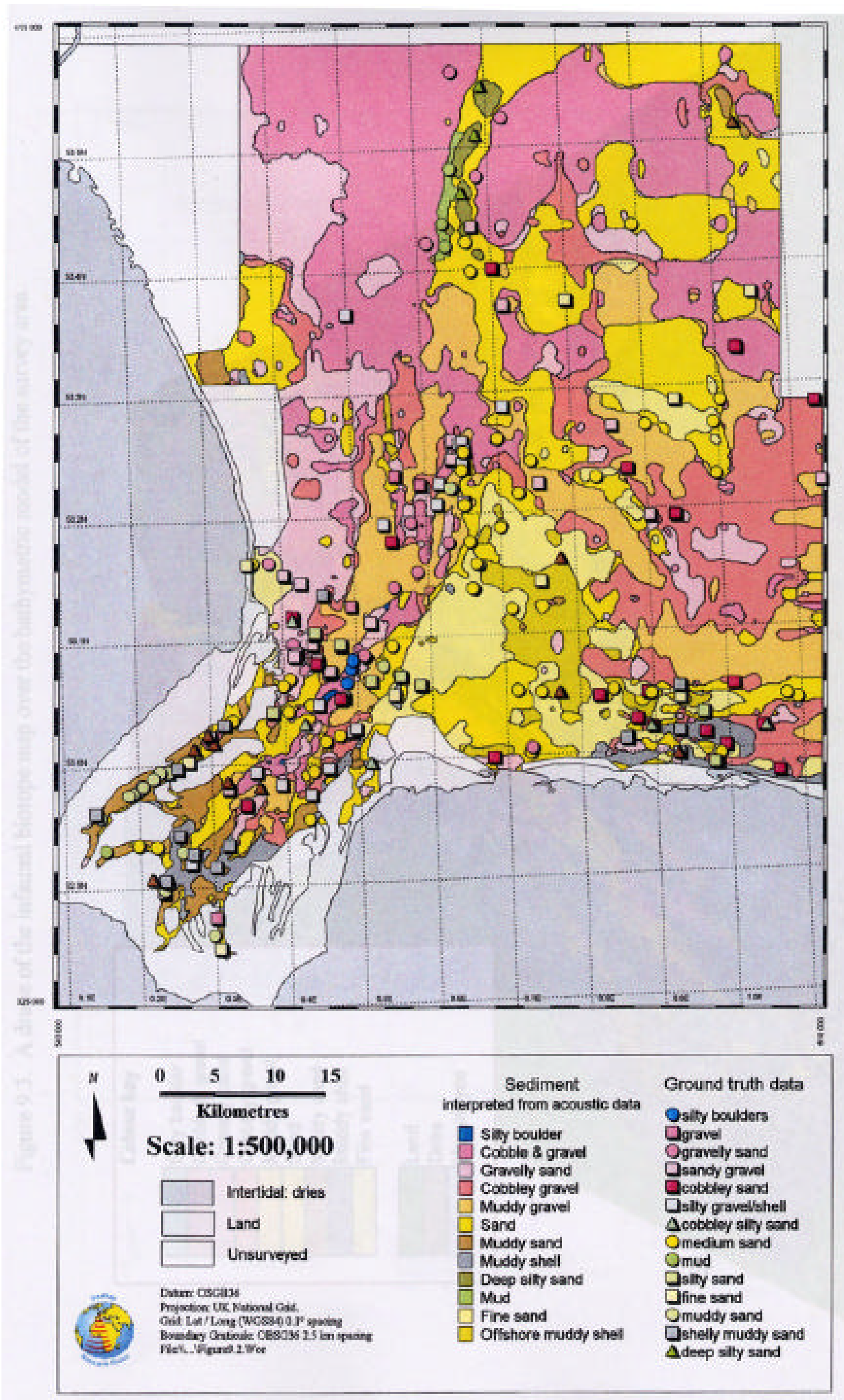

Figure 7 Distribution of sediments predicted from acoustic and ground truth data (from Foster-Smith & Sotheran, 1999) © English Nature 1999

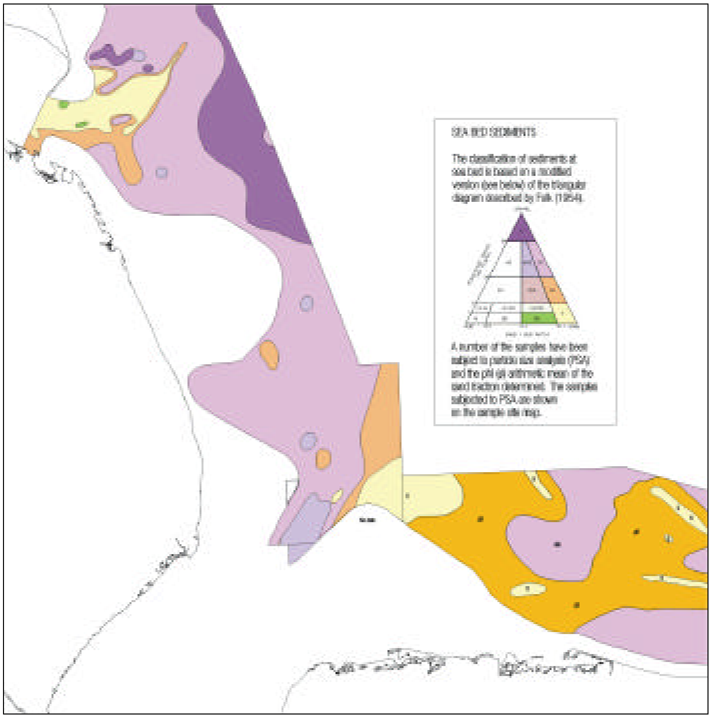

Figure 8 Distribution of sediments from BGS 1:250,000 maps

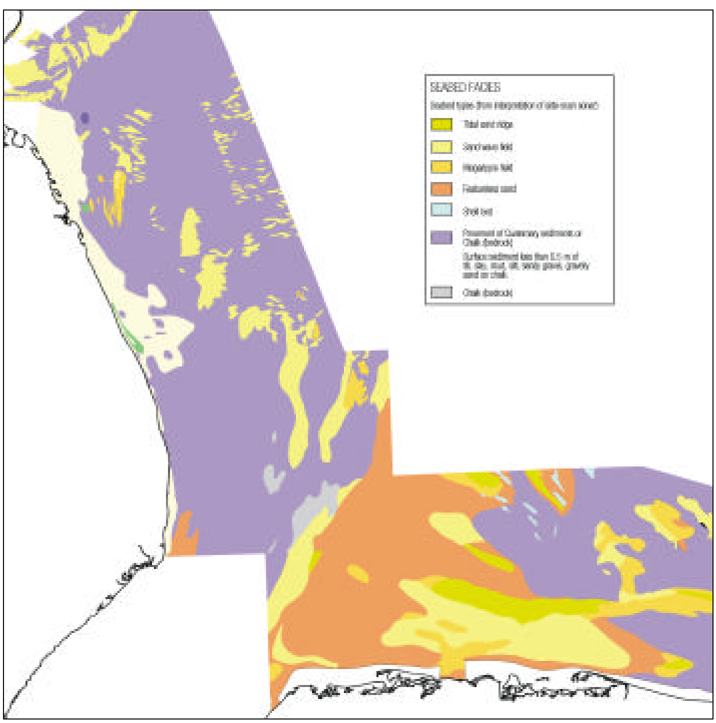

Figure 9 Sea bed facies from BGS Inshore Sea Bed Characterisation

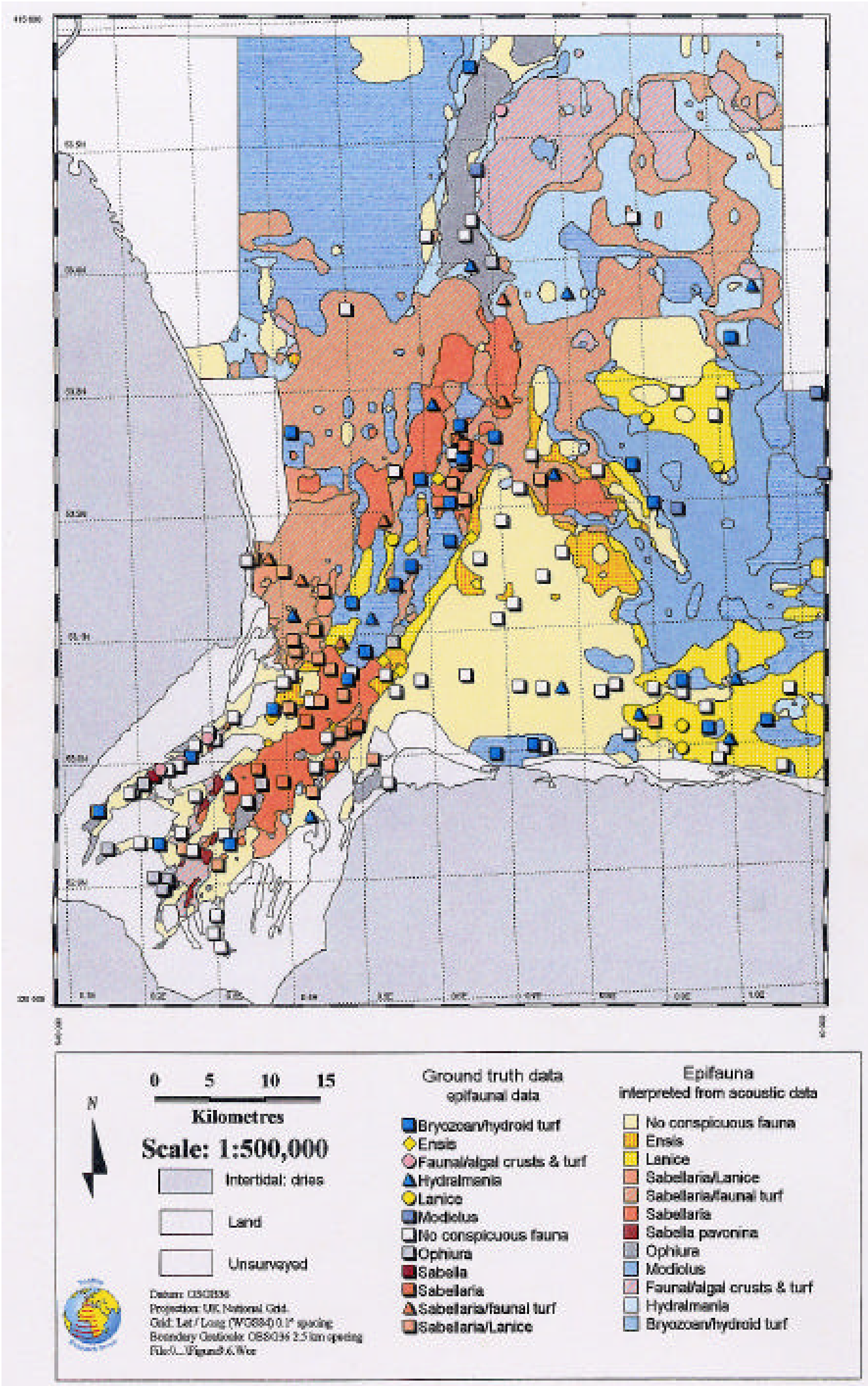

Figure 10 Distribution of epifaunal biota predicted from acoustic and ground truth data (from Foster-Smith & Sotheran, 1999) © English Nature 1999)

BMP surveys had two overall objectives

- Contribute to the development of a general methodology for broadscale habitat mapping.
- Provide broadscale spatial description of areas for use, with other relevant data, in the management of the marine environment.

One of three trial areas where mapping was completed was The Wash and the Lincolnshire and North Norfolk coasts (Foster-Smith & Sotheran, 1999). The SeaMap Research Group have done similar surveys and mapping around other areas of the UK coast.

The methodology is based on a propriety acoustic ground discrimination system (AGDS) called Roxann. The system analyses the return echo from a single beam echo sounder. Variations in the return echo indicate variations in the acoustic reflectance of the sea bed. These variations are believed to be directly applicable to variations in the physical properties of the sea bed such as its hardness and roughness which can mirror the grain size of the sediments or the nature of rock (Figure 6).

The return echo is digitally recorded and allows image processing of the pixel data created. Ground truthing of the processed images is an essential element of the methodology. The biota and habitats of the sea bed are sampled with a variety of techniques including physical sampling and remote methods such as video. The latter is particularly useful in the context of image processing. This process produces an acoustic signature for each habitat or biotope type which is recognised. This is followed by a stage called **maximum likelihood classification** which is an automated process and assigns each pixel to the most likely (probable) class of habitat or biotope. In this survey the pixel size is 100 m and the authors indicate that the intended scale for display is 1:250,000. The same scale as the BGS regional offshore maps.

The biotope descriptions used in this BMP survey “differed somewhat” from those in the BioMar project (Connor et al., 1997) which forms the basis of the marine classification in the EUNIS classification. Obviously if the EUNIS Classification is to be widely adopted and accepted then data and surveys using methodologies like the BMP will have to be incorporated.

There are a number of factors which must be borne in mind when using offshore map data based on point sampling and narrow beam geophysical methods such as echosounders and seismic reflection profilers like boomers and sparkers. These factors are applicable to BGS maps as well as BMP and CEFAS maps

- Narrow beam geophysical methods have a footprint which is basically a line of closely spaced points across the sea bed. Therefore the lateral spacing of geophysical tracks is critical to the resolution and coverage of any interpretation. The more tracks the greater the resolution. This is especially true where image processing methods which rely on interpolation are adopted. The level of detail in the distribution of sediment maps (Figure 7) is greater in the areas where track and sample density is relatively high, such as the Wash and off the North Norfolk coast compared to the northern part of the project area where samples are few and the geophysical lines are over 5 km apart.

- Sampling methods vary in the scale of their sampling and the footprint of their coverage. The greater the density of sampling the greater the confidence and accuracy of the interpretation. Maximum particle size recovery of sediment or biota is restricted to the maximum jaw size of grab or dredge or the diameter of core barrel. Therefore biota or sediment larger than these maximum sampling dimensions will not be recovered. Ground truthing based on physical sampling may not provide a complete picture of the biotopes for any interpreted level or class of habitat. In that respect video evidence is important in providing visual non-destructive evidence of the nature of the epifauna and character of sediment and rock at the sea bed.

- In assigning biotopes to a particular level or class of habitat it cannot be assumed that these are unique or distinct to that habitat. The assigned biotopes may occur elsewhere in other habitats. It should also be assumed that sampling methods may not have recovered all biotopes present within any particular mapped habitat. In terms of accuracy of habitat classification those with a broader and less detailed description of biotopes may be relatively more accurate than those with numerous and detailed biotopes.

Figure 7 shows the distribution of sediments predicted by the BMP from their acoustic and ground truth data. The level of detail appears to reflect the density of survey. Larger areas covered by individual categories in the north where sample and line density is low, compared to the numerous and complex pattern of categories in The Wash and off North Norfolk where sample and line density is much higher (Figure 6).

The distribution of sediment from the BMP surveys indicates a generally broad sweep of coarse gravelly sediment off the Lincolnshire coast and in the north and east of the area broken by some patches of sand. A large triangular area of sand lies off the North Norfolk coast.

This distribution pattern is also seen in the BGS sediment maps of the area (Figure 8 & 9). The sea bed facies map (Figure 9) is based on high density side scan sonar coverage and there is a considerable amount of detail in terms of sand wave and sand patch distribution on the gravel substrate. This level of detail is not seen on the BGS 1:250,000 sediment map (Figure 8) because the survey data is at a much lower density. These sand wave features off the Lincolnshire coast are also not picked up in detail on the BMP map because of the low density of BMP survey tracks in this area.

A useful exercise would be to marry the BMP acoustic, sediment and biota data to the BGS sea bed facies and sediment data. The integration of both datasets should lead to improvements in ground truthing and in the relationships between biotopes and bedforms, sea bed geology and morphology. Ultimately producing a more comprehensive habitat map of the area.

In undertaking any integration of diverse datasets from associated disciplines such as geology and biology it would be important to record and explain the methodologies adopted by each discipline, and also the limits and benefits of integration.

5.2 CEFAS HABITAT RESEARCH

CEFAS scientists are currently undertaking a number of research projects at their Burnham and Lowestoft laboratories into the management of fisheries and the conservation of marine habitats based on an understanding of all the major elements, physical, chemical and biological which control marine systems. Factors such as sediment and geology and their impact on sea bed substrates and associated biota are recognised as being important in understanding marine habitats.

An example of this type of research is an on-going project being conducted under contract for DETR (formerly DETR) entitled 'Comparison: Value of Marine Benthic Faunas' (Freeman,1999). One of its tasks is to evaluate different methods of sampling the sea bed during fish and benthos surveys and compare the best methods with data presented on geological and sediment maps from the BGS Inshore Sea Bed Characterisation Project. The aim is to describe the link between the animals collected at each sample site and the sediment or rock on which they are found and then evaluate the credibility of using BGS map interpretations as the basis for habitat maps.

Freeman (1999) compared these BGS map interpretations with results from physical sampling by Day grabs and an acoustic ground discrimination system (AGDS) called QTC VIEW, which is similar in principle to the RoxAnn system run for the BMP.

The initial conclusions from this research indicates

- A weak correlation between the BGS map interpretations and QTC data. This may be due to the 'supervised mode' in which the QTC survey was conducted. Further QTC surveys are planned in an 'unsupervised mode' where the parameters of the QTC system are set and controlled by the operator and greater accuracy is expected

- Grab sampling and associated particle size assessment (PSA) classifications were the most accurate means of ground truthing sea bed sediments

- Broad-scale categories of substrate based on QTC, grab and PSA interpretations can be constructed which indicate a relationship between CEFAS fish sampling stations and BGS sea bed sediment data

- CEFAS annual groundfish surveys in the eastern English Channel and southern North Sea over areas covered by BGS interpretations, indicate the scale of these BGS datasets is appropriate to the spatial and temporal analysis of finfish and macro-benthic faunas collected by CEFAS.

BGS 1:250,000 sea bed sediment maps have been used in other attempts at ground-truthing (Greenstreet and others, 1997; Kaiser and others, 1998) and a reasonably strong relationship has been indicated from the research.

Another current CEFAS project (A0908) with a habitat mapping emphasis is 'Mapping of gravel biotopes and an examination of the factors controlling the distribution, type and diversity of their biological communities'. One of the objectives of this MAFF funded project is to assess the utility of sea bed mapping techniques. It also intends to incorporate biological, sedimentological and hydrographic data with

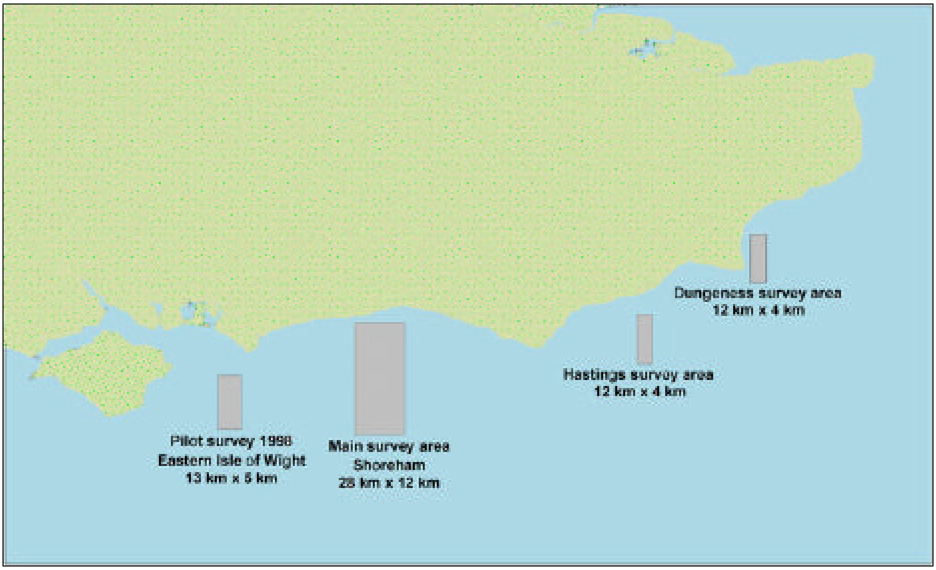

Figure 11 Survey areas for CEFAS Project A0908, eastern English Channel. (From Brown, 2000)

environmental and fisheries information into a GIS. Four areas are being surveyed between the Isle of Wight and Dungeness (Figure 11). These areas have been covered by BGS surveys and the Inshore Sea Bed Characterisation Project and these data have been given to the CEFAS project for comparison with their own survey data. Discussions have taken place between BGS and CEFAS researchers with regard to the geology and sediments of the research areas. This research project is proceeding (Brown, 2000).

5.3 BIOMÔR

The National Museum of Wales initiated a benthic sampling programme in the southern Irish Sea in 1989 with a second survey undertaken in 1991. The principal objectives of the two surveys were to

- Determine the faunal composition, diversity and extent of the benthic invertebrate assemblages of the southern Irish Sea and its approaches
- Examine factors influencing the faunal distributions
- Investigate the zoogeography of the area
- Obtain comprehensive reference material of marine invertebrates from the area
- Carry out and encourage taxonomic research on the material

The surveys were collectively grouped as the **BIOMÔR Project – Benthic Biodiversity in the Southern Irish Sea** and the results were published in a report of the National Museum and Galleries of Wales (Mackie and others, 1995). In terms of mapping at the habitat level, the determination of the species assemblages present was established through a number of procedures including cluster analysis, non-metric multidimensional scaling and assessments of characteristic species. The inclusion of species diversity with these procedures produced an overall assessment of biodiversity.

Sampling methods relied on grab, dredge and trawling. Geophysical surveys were not a primary focus of the project although RoxAnn was deployed in an area south west of Aberystwyth. The sampling strategy included sampling within known sediment types which had been determined through study of the available data on sediment distribution. This included published BGS sea bed sediment maps of the area.

The project produced a generalised sediment map of the study area based on the particle size analysis of 64 samples collected during the two surveys. The proportions of mud, sand and gravel were grouped into categories according to a triangular classification by Buchanan (1971) rather than the system used on BGS sediment maps which is based on Folk (1954). The Folk system was considered to be weighted towards the gravel component whilst the Buchanan system gives more weight to mud and sand, a feature which the report considered to be important in biological terms.

However, in comparing the sediment maps produced by BGS and BIOMÔR using these different sediment classifications there was a good agreement between them.

5.4 South west Irish Sea Survey (SWISS)

The SWISS project is complimentary to BIOMÔR and is designed to map the bio-sedimentary communities of the western side of the southern Irish Sea, an area not covered by BIOMÔR. The survey methodology adopted was similar to BIOMÔR, although RoxAnn, remote sensing images from SPI (Sediment Profile Imagery) and towed video were used as well as physical sampling with grabs and dredges. Fieldwork began in 1997 and over 100 sites have been sampled. Analysis of the results has largely been completed and a final report is in preparation.

The project was part of an EU INTERREG programme on the protection of the marine and coastal environment administered by the Marine Institute (Ireland) and the Welsh Office.

5.5 Geological Survey of Canada

Commercial fishery has been an important element of the economy of the Atlantic seaboard of Canada, (Pickrill, 2000). The three main components are groundfish, lobster and scallops and the resource is under considerable threat. The management and conservation of a sustainable fishery is a primary objective and science has a role in its achievement through identifying and understanding marine habitats which are critical to the health of these fisheries.

The Geological Survey of Canada (GSC) has been involved in collaborative projects with fisheries research scientists and the fishing industry to address some of the problems and pressures on fishing. These include

- sidescan sonar and high resolution seismic surveys to assess the impacts of trawling on groundfish habitat.

- development of a sidescan sonar system to map lobster habitat and identify spawning grounds as well as the exploration of sites for artificial reef formation for lobster farming.

- combined use of high resolution seismics, sidescan sonar, multibeam mapping, and seafloor characterisation to map the seafloor and benthic communities to distinguish the relationships between scallop catch returns and substrate. The results will be used to improve fisheries management and scallop harvesting techniques.

These relatively small scale projects have shown the benefit of a multi-disciplinary approach to the mapping of marine habitats involving biologists, geologists, geophysicists and hydrographers. This has stimulated a collaborative proposal from three government departments, Fisheries and Oceans (FO), Natural Resources Canada (NRC) and the Department of National Defence (DNF) to the Canadian Federal Government.

The proposal, which is called SEAMAP, addresses the need for data, information and knowledge in the effective integrated management of marine resources and habitats. It is a long term, systematic and interdisciplinary program of seabed mapping. It is designed to be national in scope and cover the entire Canadian EEZ. Data aquisition methods will include multibeam bathymetry, sidescan sonar, high resolution seismic reflection profiling, grab sampling and bottom photography to characterise sediments and biotopes. Data and interpretations will be held digitally and made available through GI Systems and electronic media. The concept paper for SEAMAP can be found at http://seamap.bio.ns.ca/seamapconcept.html.

5.6 World Wildlife Fund Canada

The conservation of biodiversity in the marine environment and the planning of representative marine protected areas (MPA) in Canada’s oceans has been studied in a report commissioned by the World Wildlife Fund Canada (Day & Roff, 2000) The full report can be downloaded from http://www.wwf.ca/en/res_links/ under Resources.

The study developed a hierarchical framework for MPA planning based on ecological principles and geophysical and oceanographic features of the marine environment. The classification uses physical attributes and essentially predicts species assemblages on the basis of geophysical characteristics. The range of conditions which influence the distribution of biota can be mapped as geographic units which the authors term “seascapes” and they regard these as the basic ecological unit of their classification. They define seascapes as basically being stable, recurrent or predictable in time and space, and generally not subject to human or natural disturbance. They considered physical characteristics alone as sufficiently reliable indicators of the major types of biological communities.

Marine environment planning and management requires that seascapes have to be mapped and defined. This is done through the WWF National Marine Classification System which includes specific parameters to define seascapes. The system is outlined below.

WWFCanada – A National Framework for Marine Classification

LEVEL 1 – Environment Type

Marine

LEVEL 2 – Geographic Range

Arctic Ocean Basin
Atlantic Ocean Basin
Pacific Ocean Basin

LEVEL 3 - Temperature

Arctic
Subarctic
Boreal
Temperate
Subtropical

LEVEL 4 – Sea-Ice Cover

Permanent
Seasonal
Variable
Absent

LEVEL 5 – Segregation of Pelagic and Benthic Realms

Pelagic
Benthic

LEVEL 6 – Vertical Segregation

Pelagic
- Epipelagic
- Mesopelagic
- Bathypelagic
- Abyssal/hadal

Benthic
- Euphotic
- Dysphotic/aphotic
- Bathyal
- Abyssal/hadal

LEVEL 7 – Mixing and Wave Action

Pelagic-Stratification
- Stratified epipelagic
- Non-stratified epipelagic
- Frontal epipelagic

Benthic-Exposure
- Exposed
- Moderately exposed
- Sheltered

Slope
- Low slope
- High slope

LEVEL 8 – Benthic Substrate

Benthic-Sediments

Clays/silts
Sand/pebbles
Cobble/boulders

The classification system has been designed to be adaptable. Data can be incorporated as and when available. The authors believe it provides an ecologically sound, consistent and transparent method. It has the advantage of using physiographic and oceanographic features which are, in general, readily available in the public domain and provide broad scale mapping of biodiversity. If a similar style of approach to habitat mapping was applied in the UK the type of map and sediment data held by BGS would be a primary source of information at Level 8 and inform interpretations at other levels.

A case study was undertaken on the Scotian Shelf of Canada to test the national marine classification system. The results are available in the same area of the WWF Canada web site as the main report. The maps from the case study have been reproduced in Appendix A of this report. The maps indicate the type and scale of information, and data available for each of the levels which are applicable to this area of the Canadian EEZ. These are brought together in one map to produce the distribution of seascapes and marine natural regions (Map 10). This is the completed marine habitat map produced through theWWFCanada system.

5.7 United States of America

The Ecological Society of America and NOAA's Offices of Habitat Conservation and Protected Resources sponsored a workshop in October 1999 to develop a national marine and estuarine ecosystem classification system for the USA (Allee, 2000).

The objectives were to:

- review existing global and regional classification systems
- develop the framework of a national classification system
- propose a plan to expand the framework into a comprehensive classification system

A draft classification system was developed which the developers describe as a blend of the theoretical and pragmatic with physical and biotic structural variables. It is designed to be flexible to allow for variables in the level of information and data available and for modification as data is added. It has many similarities in its structure to the system developed for WWFCanada and there are a number of levels at which geological and sedimentological data would be incorporated.

USA – Proposed Marine and Estuarine Ecosystem Classification System

1. Life Zone –

1a. Temperate
1b. Tropical
1c. Polar

2. Water/Land

2a. Terrestrial
2b. Water

3. Marine/Freshwater

3a. Marine/Estuarine
3b. Freshwater

4. Continental/Non-Continental

4a. Continental
4b. Non-Continental

5. Bottom/Water Column

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

6. Shelf, Slope, Abyssal

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

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

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

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 – e.g., eddies

10. Photic/Aphotic

10a. Photic
10b. Aphotic

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

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

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.

5.8 *ICES-SGMHM - Initiatives and Habitat Mapping Programmes*

A number of initiatives, proposals and examples of habitat mapping were described at the meeting of the ICES Study Group on Marine Habitat Mapping (SGMHM) at the Hague in April 2000 (ICES, 2000). These included

Marine Areal Database for the Norwegian Sea (MAREANO)

This is a proposal by a number Norwegian organisations, including the Geological Survey of Norway (NGU), to map over 270,000 km^2 of the mid-Norwegian continental shelf and parts of the slope and deep of the Norwegian Sea (Noji and Fosså, 2000).

The aim of **MAREANO** is to investigate the physical, chemical and biological characteristics of the seabed using multi-beam and other seismic methods and integrate with existing and new data on sediment and biota.

Project output will include data, interpretations and maps on:

- Bathymetry and sea bed morphology
- Marine habitats, biological diversity and marine biological resources
- Marine contaminants in sediments
- Sediment classification and geological and sedimentary features

The mapping of marine habitats is intended to inform the process of establishing Marine Protected Areas and assess the degree of biodiversity as well as the biological fisheries resources.

Belgium

The western Coastal Banks has been proposed as an EC-Habitat Directive area and there are also plans to give it the status of a marine protected area (MPA). Interpretation and mapping of the benthic habitat has been conducted (Degaer and others, 2000) and this has been used in the evaluation of the MPA proposal.

The Netherlands

HABIMAP has been developed as a GIS system for marine tidal waters as an aid to defining and interpreting habitats (de Jong, 2000). The method compares the relationship between communities or species and their abiotic environment. The method has evolved as a predictive tool rather than a pure mapping system based purely on real survey data.

Northern Ireland

A project entitled “Broadscale Mapping of the Nearshore Habitats of Northern Ireland” began in 1999 (Service, 2000). It is intended to concentrate on areas between low water springs and the 50m bathymetric contour. The main methods of investigation are sidescan sonar and RoxAnn with ground truthing by video, photography and sampling by grab or diver. The project has similarities with the BGS Inshore Sea Bed Characterisation Project.

6 Conclusions

- The pressure on marine resources and the legislative requirement to manage these resources is stimulating methodologies and classifications to inform the process for environmental managers and politicians. The need for a common and acceptable habitat classification on a European scale is in the throes of development. From the systems that are being developed it is evident that geological and sediment data plays a very important role as a primary building block for habitat classification.

- Within the context of UK initiatives on habitat mapping it is logical that the extensive geological data and maps already produced by BGS should be utilised in conjunction with biological data in any initiative to provide a primary habitat map and classification for UK designated waters.

- BGS expertise, interpretations and maps should also be utilised for larger scale habitat mapping associated with aggregate extraction, wind farm developments, fishery resources and oil and gas exploration and decommissioning.

- Geologists, biologists and ecologists in the UK should develop the dialogue that has begun on the role of geology in habitat classification. Conversely the dialogue should include the relevance of biological data to geological mapping of the sea bed.

- Countries such a Canada, have shown the advantage of co-operative projects and research between geologists, geophysicists and biologists in the mapping of marine habitats. This type of approach has not been adequately funded in the UK. There is a benefit to be gained in funding co-operative research into
  - the methodologies of surveying, sampling and interpreting marine habitats
  - the value and utility of incorporating the extensive geological datasets held by BGS in the mapping of marine habitats in the UK.

7 References

Allee, R.J. 2000. Results of the Aquatic Restoration and Conservation Workshop, p. 68-69. In: Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

Brown, C.J. 2000. Development of sub-tidal biotope mapping techniques in UK waters, with emphasis on gravel substrates, p. 84-88. In: Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

Connor, D.W., Brazier, D.P., Hill, T.O., Northen, K.O. 1997. Marine Nature Conservation Review: Marine biotope classification for Britain and Ireland. Version 97.06. Peterborough, Joint Nature Conservation Committee.

Davies, C.E., Moss, D. 1999. EUNIS Habitat Classification. Draft Final Report to the European Topic Centre on Nature Conservation, European Environment Agency. November 1999. 214pp.

Day, J.C., Roff, J.C. 2000. Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans. Report prepared for World Wildlife Fund Canada, Toronto.

Degraer, S., Lancker, V., Moerkerke, G., Vincx, M., Jacobs, P., Henriet, J.P. 2000. Research project: Intensive evaluation of the evolution of a protected benthic habitat: HABITAT, p. 89-97. In: Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

Evans, C.D.R., Crosby, A., Wingfield, R.T.R., James, J.W.C., Slater, M.P. and Newsham, R. 1998. Inshore seabed characterisation of selected sectors of the English coast. British Geological Survey Technical Report WB/98/45.139pp.

Evans, C D R and Slater, M P. 2000. Inshore seabed characterisation of the sector from Dungeness to the Deben Estuary. British Geological Survey Technical Report WB/00/07. 40pp.

Freeman, S.M. 1999. Comparison: Value of marine benthic faunas – 1st Progress Report. CEFAS Report CO786/01.

Foster-Smith, R.L., Sotheran, I. 1999. Broad scale remote survey and mapping of sublittoral habitats and biota of The Wash and the Lincolnshire and the North Norfolk coasts. English Nature Research Reports, No. 336.

Greenstreet, P.R., Tuck, I.D., Grewar, G.N., Armstrong, E., Reid, D.G., Wright, P.J. 1997. An assessment of the acoustic survey technique, RoxAnn, as a means of sampling seabed habitats. ICES Journal of Marine Science. 54:939-959.

ICES, 2000. Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

de Jong, D.J. 2000. HABIMAP, a GIS-guided method to make habitat maps, p. 104. In: Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

Kaiser, M.J., Armstrong, P.J., Dare, P.J., Flatt, R.P. 1998. Benthic communities associated with a heavily fished scallop ground in the English Channel. Journal of Marine Biological Association of the United Kingdom. 78:1045-1059.

Mackie, A.S.Y., Oliver, P.G. Rees, E.I.S. 1995. Benthic biodiversity in the Southern Irish Sea. Studies in Marine Biodiversity and Systematics from the National Museum of Wales. BIOMOR Reports, 1. 263pp.

Noji, T., Fosså, J.H. 2000. MAREANO – Marine Areal Database for the Norwegian Sea, p. 100-103. In: Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

Pickrill, R.A. 2000. The Application of Geoscience to Marine Habitat Research in Canada, p. 106. In: Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

Service, M. 2000. Habitat Mapping in Northern Ireland, p. 107-109. In: Report of the study group on marine habitat mapping. Annual Meeting, The Hague. April 2000. ICES, CM2000/E:06.

Appendix A

Application of WWF Canada National Classification for Marine Conservation to the Scotian Shelf

Case Study Maps


SCOTIAN SHELF CASE STUDY
MAP 1. Base Map
Locator Map
CANADA
U. S. A.
STUDY AREA
New Brunswick
PEI
Nova Scotia
Maine
Bay of Fundy
SCOTIAN SHELF
Sable Is.
ATLANTIC OCEAN
WWF
45
44
43
42
41
40
39
71
70
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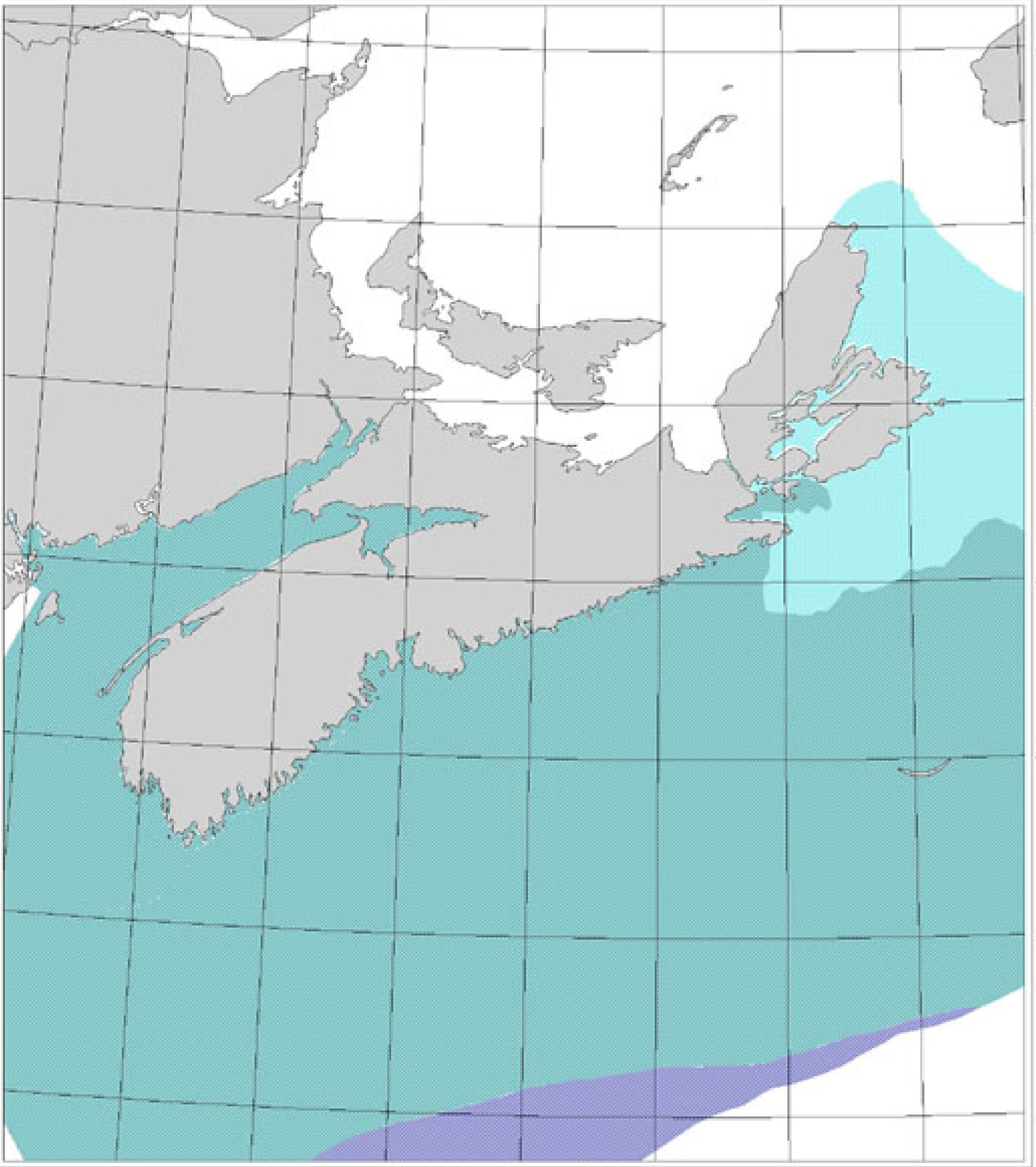
61

SCOTIAN SHELF CASE STUDY

MAP 2. Temperature (Level 3)



Climatic Zones

- Boreal
- Temperate
- Subtropical

Temperature of water masses distinguished by winter and summer isotherms at 0°C, 5°C and 18°C.

0 100 200 km

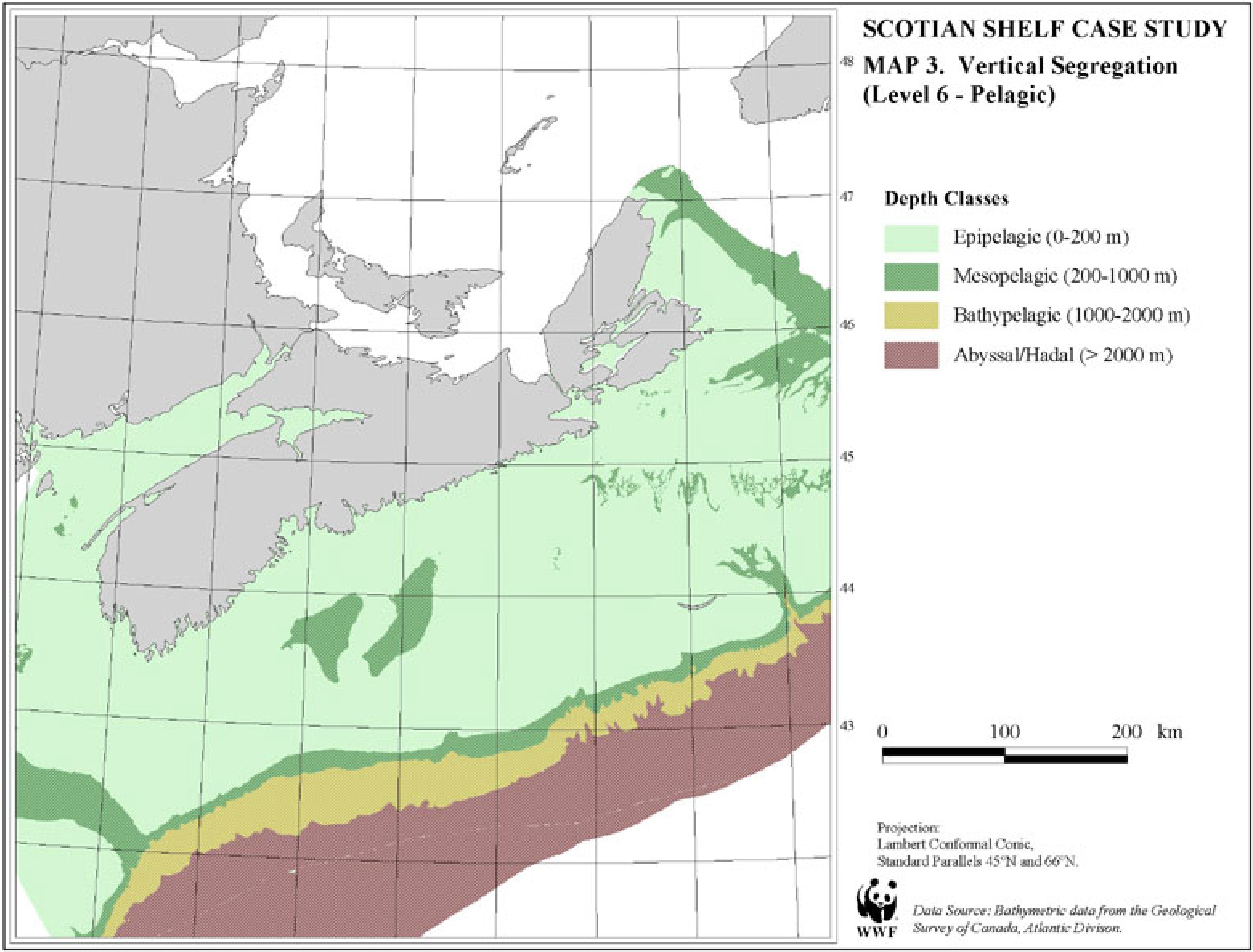
Projection:
Lambert Conformal Conic,
Standard Parallels 45°N and 66°N.

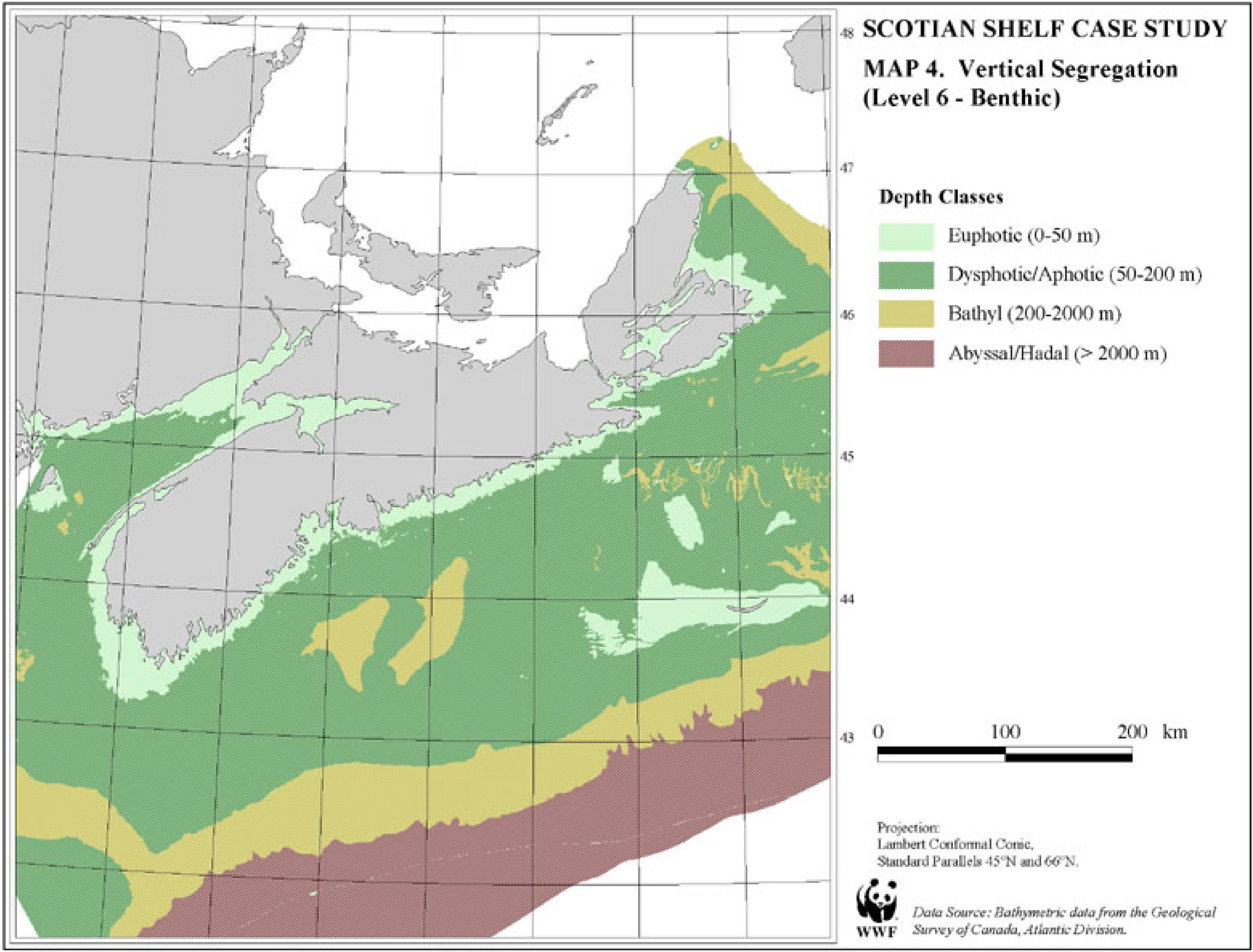
WWF

Data Source: Temperature data compiled by Geomatics International for WWF Canada.

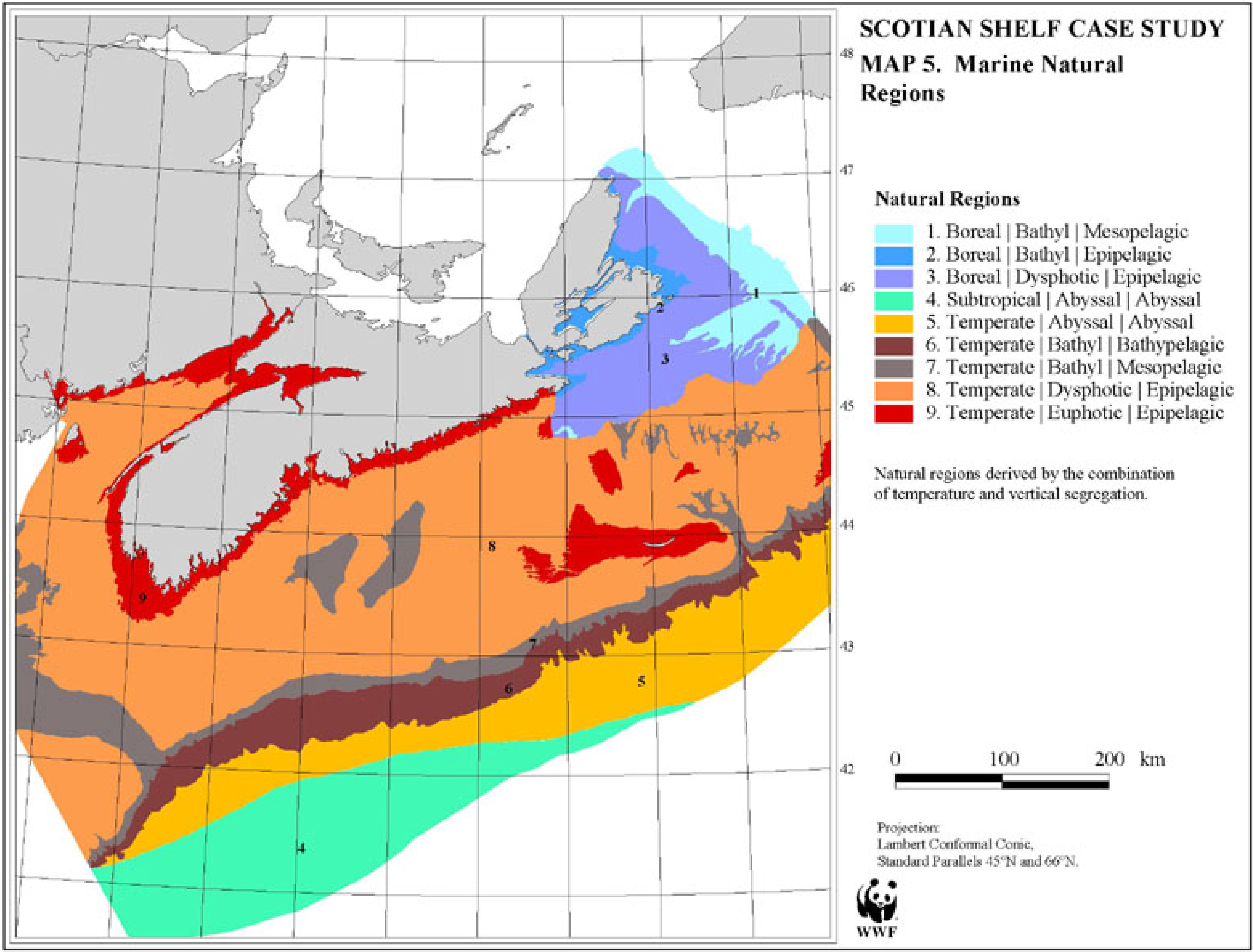
SCOTIAN SHELF CASE STUDY

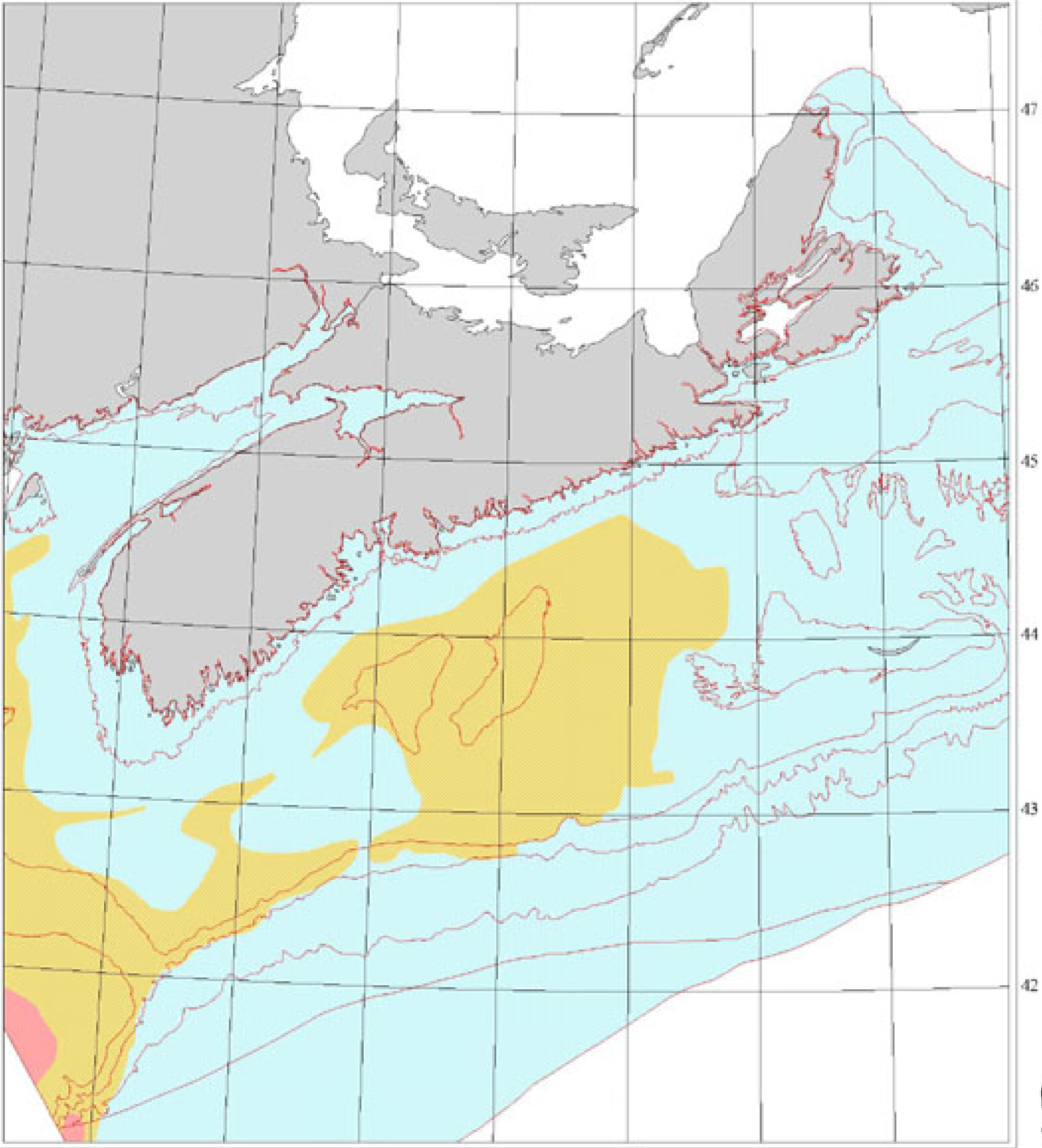
MAP 3. Vertical Segregation (Level 6 - Pelagic)





SCOTIAN SHELF CASE STUDY
MAP 4. Vertical Segregation
(Level 6 - Benthic)
48
47
46
45
44
43
Depth Classes
Euphotic (0-50 m)
Dysphotic/Aphotic (50-200 m)
Bathyl (200-2000 m)
Abyssal/Hadal (> 2000 m)
0
100
200
km
Projection:
Lambert Conformal Conic,
Standard Parallels 45°N and 66°N.
WWF
Data Source: Bathymetric data from the Geological Survey of Canada, Atlantic Division.


SCOTIAN SHELF CASE STUDY
MAP 5. Marine Natural Regions
Natural Regions
1. Boreal | Bathyl | Mesopelagic
2. Boreal | Bathyl | Epipelagic
3. Boreal | Dysphotic | Epipelagic
4. Subtropical | Abyssal | Abyssal
5. Temperate | Abyssal | Abyssal
6. Temperate | Bathyl | Bathypelagic
7. Temperate | Bathyl | Mesopelagic
8. Temperate | Dysphotic | Epipelagic
9. Temperate | Euphotic | Epipelagic
Natural regions derived by the combination of temperature and vertical segregation.
0 100 200 km
Projection: Lambert Conformal Conic, Standard Parallels 45°N and 66°N.
WWF
48
47
46
45
44
43
42
1
2
3
4
5
6
7
8
9



SCOTIAN SHELF CASE STUDY

MAP 6. Benthic Temperature (Level 6b)

Temperature Zones

Cold Subarctic (< 6°C)

Moderate Temperate (6-9°C)

Warm Gulf Stream (> 9°C)

Marine Natural Regions

Temperature distinctions based on bottom temperature isotherms of 6°C and 9°C.

0 100 200 km

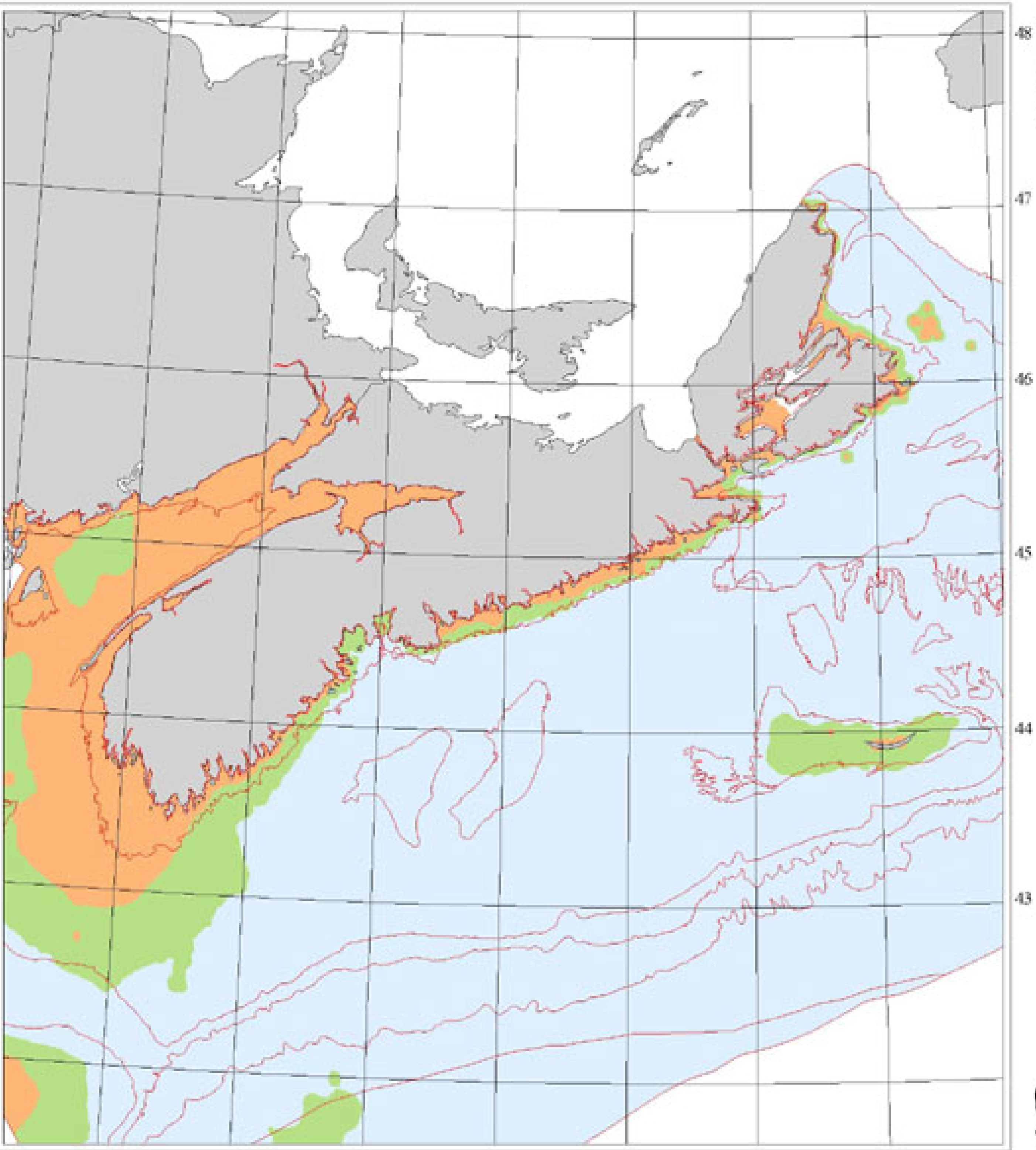
Projection:
Lambert Conformal Conic,
Standard Parallels 45°N and 66°N.

WWF

Data Source: Temperature data compiled by Geomatics International for WWF Canada.

SCOTIAN SHELF CASE STUDY

MAP 7. Mixing and Wave Action (Level 7 - Pelagic)



Stratification Classes

- Nonstratified Epipelagic
- Frontal Epipelagic
- Stratified Epipelagic
- Marine Natural Regions

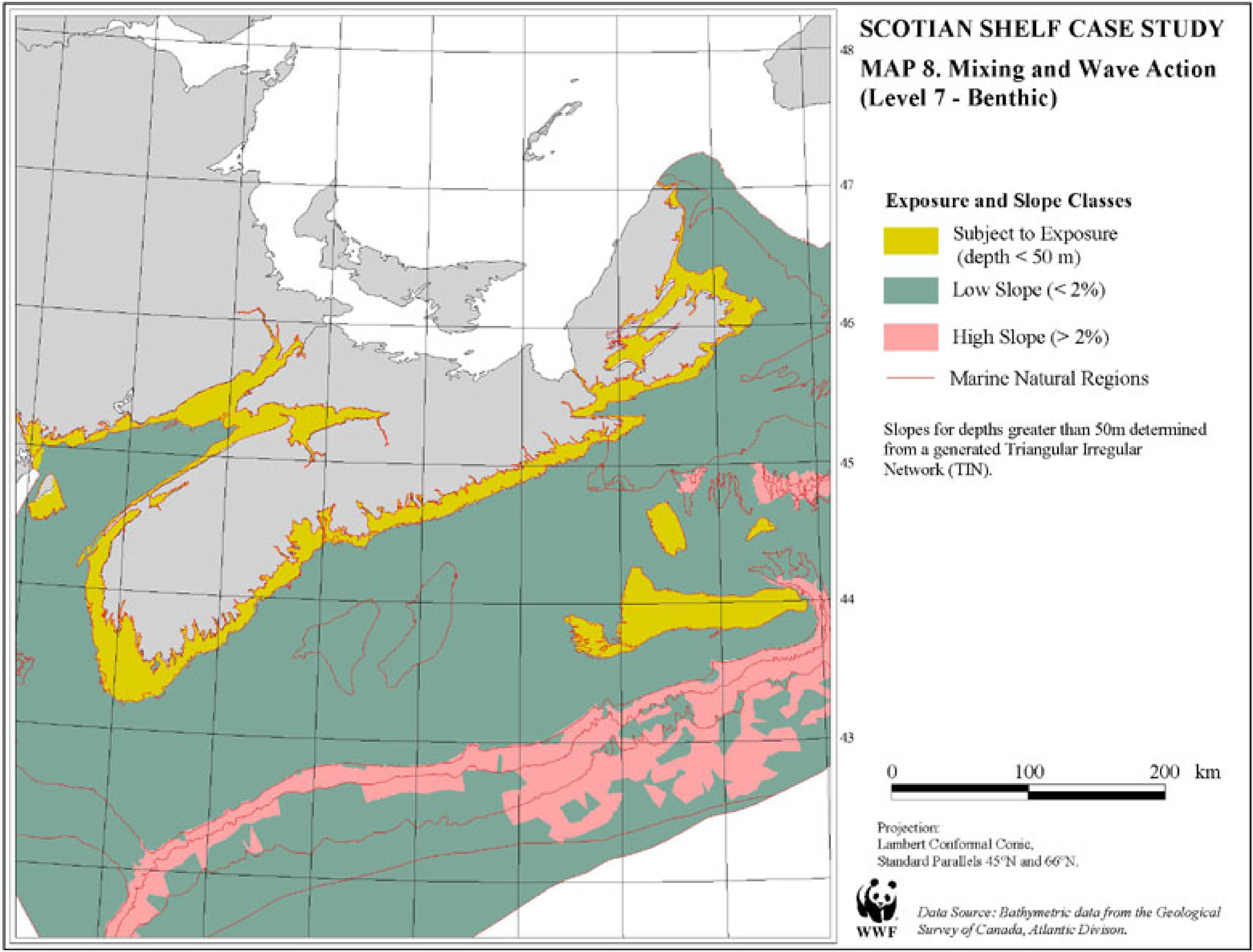
Stratification classes derived from calculated density anomalies. Density anomaly values used as a surrogate for the stratification parameter.

0 100 200 km

Projection:
Lambert Conformal Conic,
Standard Parallels 45°N and 66°N.

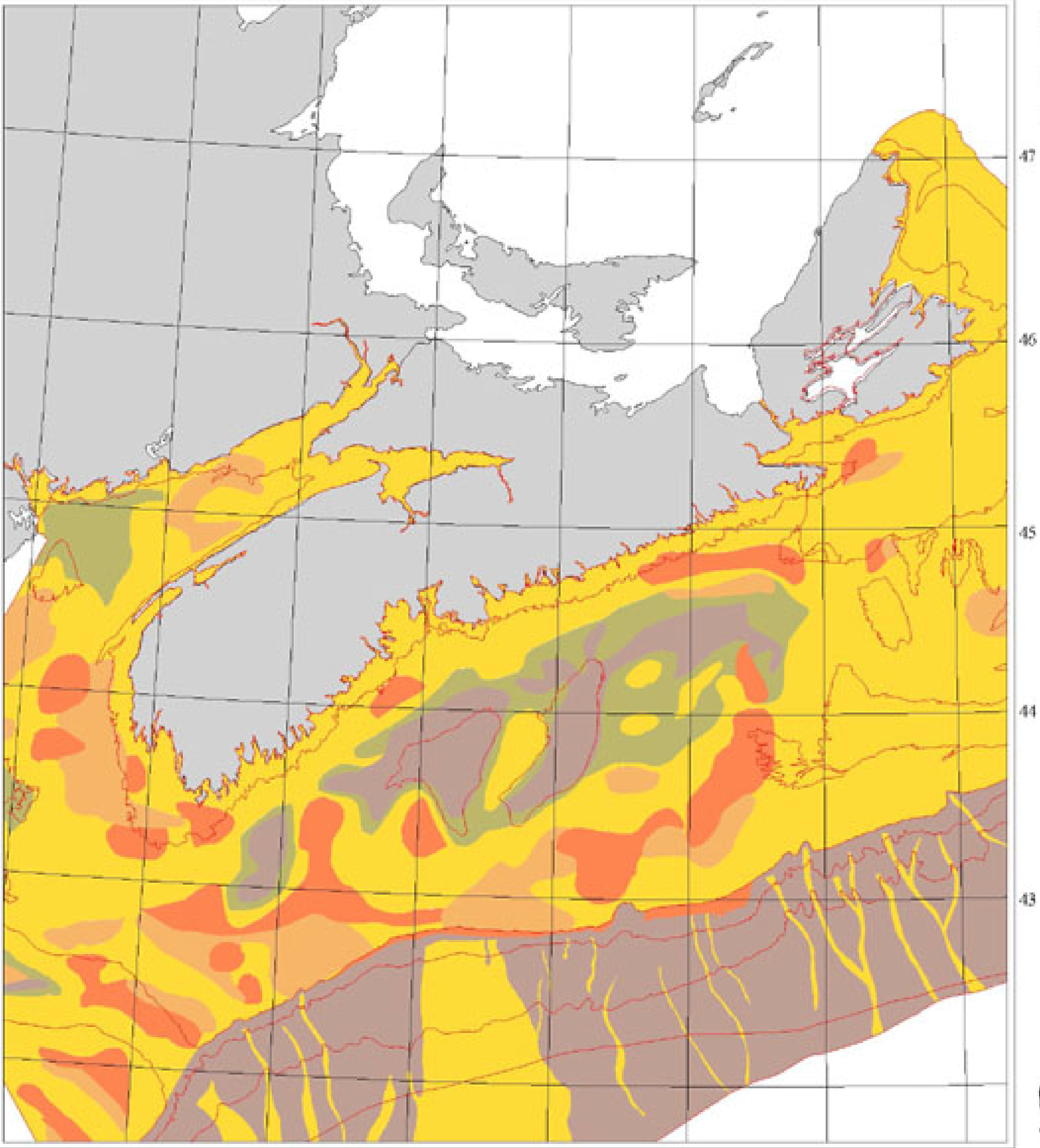
WWF

Data Source: John Loder, Bedford Institute of Oceanography, DFO.


SCOTIAN SHELF CASE STUDY
MAP 8. Mixing and Wave Action (Level 7 - Benthic)
Exposure and Slope Classes
Subject to Exposure (depth < 50 m)
Low Slope (< 2%)
High Slope (> 2%)
Marine Natural Regions
Slopes for depths greater than 50m determined from a generated Triangular Irregular Network (TIN).
48
47
46
45
44
43
0
100
200
km
Projection:
Lambert Conformal Conic,
Standard Parallels 45°N and 66°N.
WWF
Data Source: Bathymetric data from the Geological Survey of Canada, Atlantic Division.

SCOTIAN SHELF CASE STUDY

MAP 9. Benthic Substrate (Level 8)



Sediment Classes

- Mud
- Mostly Sand (20-80% sand)
- Partially Sand (0-20% sand)
- Partially Gravel (5-50% gravel)
- Mostly Gravel (> 50% gravel)
- Marine Natural Regions

Note: The Benthic substrate classification is different from the prescribed classification. Modifications reflect availability of data.

0 100 200 km

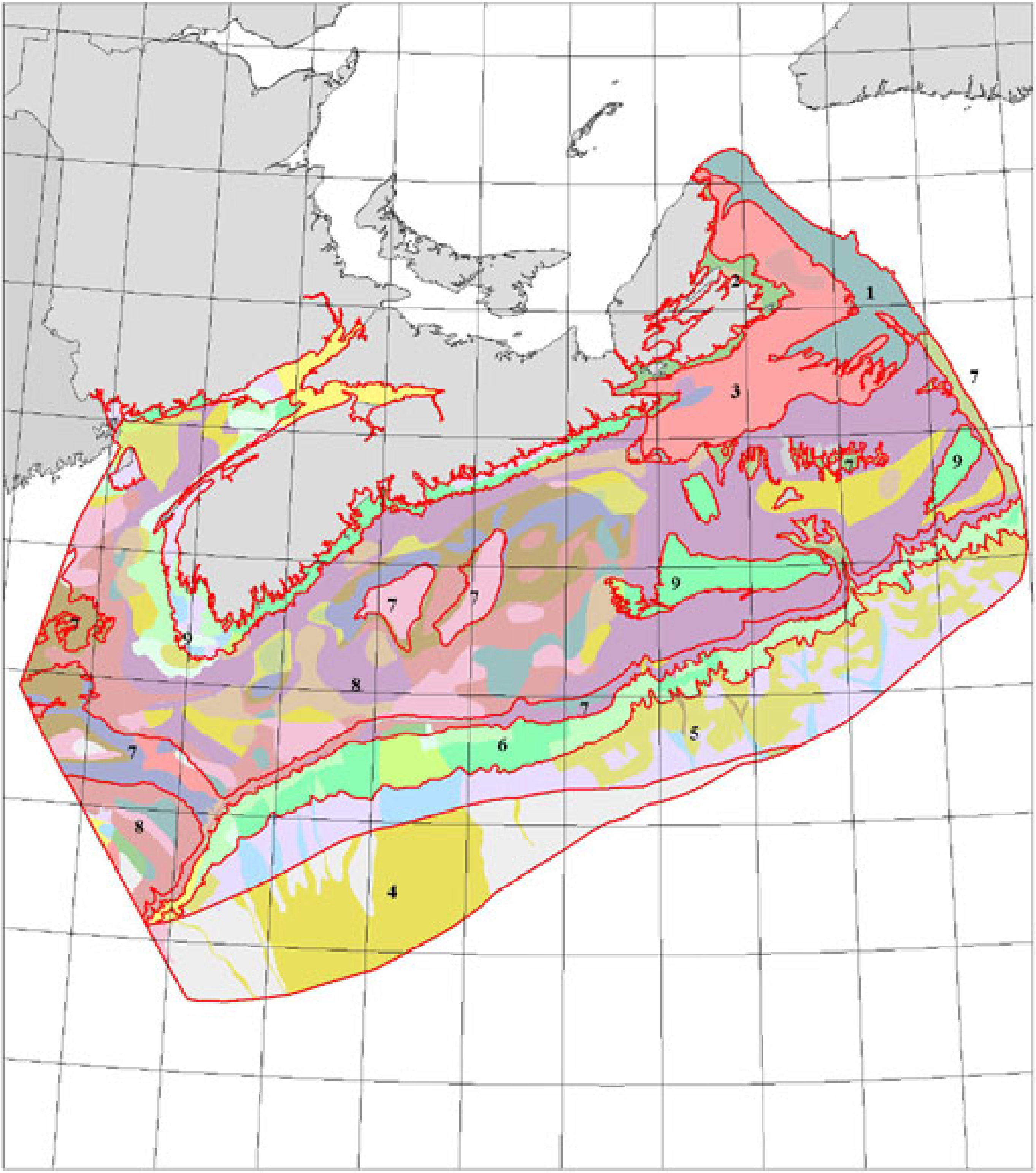
Projection:
Lambert Conformal Conic,
Standard Parallels 45°N and 66°N.

WWF

Data Source: Based on data provided by Carl Amos, Geological Survey of Canada.

SCOTIAN SHELF CASE STUDY

MAP 10. Seascapes and Marine Natural Regions



Seascapes and Marine Regions

Marine natural regions as numbered

Seascapes as shaded

Seascapes derived from combining data for temperature, vertical segregation, benthic temperature, stratification (pelagic), exposure (benthic) and sediments (benthic).

0 100 200 km

Projection:
Lambert Conformal Conic,
Standard Parallels 45°N and 66°N.

WWF