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R L Foster-Smith
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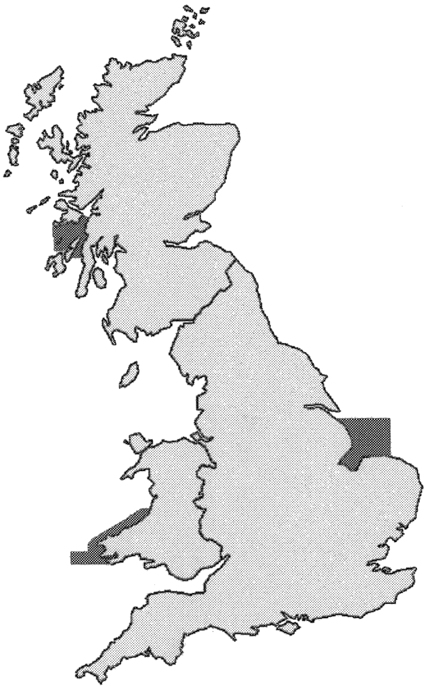

BROAD SCALE REMOTE SURVEY AND MAPPING OF SUBLITTORAL HABITATS AND BIOTA OF THE WASH AND THE LINCOLNSHIRE AND THE NORTH NORFOLK COASTS

R.L.Foster-Smith
Ian Sotheran

1999

This is the final report on sublittoral mapping of the Wash and the Lincolnshire and North Norfolk coasts which formed part of the Broadscale Mapping Project: a project funded by the Crown Estate, Countryside Council for Wales, English Nature, Scottish Natural Heritage and the University of Newcastle (SeaMap). It is supported by the European Commision under the Life programme.

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Preface

Methodologies for broad scale mapping of sublittoral habitats and biota based on acoustic remote sensing have been developed as the Broadscale Mapping Project, a three-year project funded by a consortium consisting of the Crown Estate, the Countryside Council for Wales, English Nature, Scottish Natural Heritage and Newcastle University through the *SeaMap* Research Group. The project has also been supported by the European Commission's *Life* programme.

The survey of the Wash, Lincolnshire and north Norfolk coasts was also supported to a considerable extent by the Eastern Sea Fisheries Joint Committee through the use of their survey vessel and staff.

Acknowledgements

SeaMap would like to thank Dan Laffoley, Helen Vine, Ian Patterson and Paul Gilliland from English Nature and all the staff of the Eastern Sea Fisheries Joint Committee but in particular Mathew Mander, Bill Watson and the crew of the *Surveyor*.

Notes on format of the report

A two digit system has been used to number tables and figures: The first is taken from the major section in which they are located and the second number follows the sequence in which they appear in the text.

All maps use the UK National Grid as their projection with OSGB36 as datum. Maps which are full page have a layout which includes margins marked off in 2.5km sections, a faint grid superimposed showing latitude and longitude and scale. Other smaller figures are embedded in the text and a simplified layout has been.

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BROAD SCALE REMOTE SURVEY AND MAPPING OF SUBLITTORAL HABITATS AND BIOTA OF THE WASH AND THE LINCOLNSHIRE AND NORTH NORFOLK COASTS

1 Executive summary

The survey of the Wash, Lincolnshire and north Norfolk coasts has contributed to the development of a methodology for broad scale survey and mapping of large areas of sea floor using acoustic remote sensing techniques and was one of three trial areas chosen for the Broadscale Mapping Project (BMP). The other areas were the Firth of Lorn and the Pembrokeshire coast. The methodology relies on the relatively inexpensive acoustic ground discrimination system (AGDS) based on a single beam echo sounder. These systems analyse the echo from a sounder and give measures of the acoustic reflectance of the seabed which depend on features such as hardness and roughness of the substratum, as well as depth. These records, in the form of point data, are logged together with time and position as the vessel tracks over the survey area. The point data are used to create continuous digital images for each of the variables through interpolation. This conversion to digital images consisting of rows and columns of pixels enables powerful image processing software, designed primarily for the processing of satellite images, to be applied to the acoustic data.

Image processing requires ground truth samples of the biota and habitats from the sea floor and the techniques used range from the traditional grab, trawl and dredge to remote video. Video is especially useful since it provides a vista of the epibiota and topography of the seabed which is approximately of the same extent as the area of the seafloor that is covered by one pulse from an echo sounder (the 'footprint').

Image processing is a two-stage process: In the first stage the acoustic data in the immediate vicinity of the ground truth positions are selected and tagged according to the type of habitat or biotope of the ground truth sample. The acoustic data is pooled for each habitat or biotope type and the acoustic characteristic calculated from the mean and standard deviation of the depth and the hardness and roughness values. In this way an acoustic signature is created for each habitat or biotope type.

In the second stage each pixel is matched to the signatures and the likelihood of the pixel belonging to each habitat or biotope calculated. An automated process then assigns each pixel to the most likely (most probable) class. This second stage is, therefore, called a **maximum likelihood classification**.

This general approach was used for the survey the Wash and the analysis of the data. However, each of the trial areas used to develop the broad scale methodology has its own special features and characteristics that enabled the methodology to be tested against a wide range of sea floor types and physiographic features. The habitats of the Wash survey area largely comprise sediment ranging from muddy sand to cobbles with smaller areas of soft mud at one extreme and silty boulders at the other. Many of the biotopes could only be described from an analysis of animals and sediment collected using a Day grab. Other biotopes had an epifaunal component either because of the presence of rock or due to the presence of substantial Ross worm reefs (*Sabellaria spinulosa*). These were more effectively sampled using remote video.

Analysis of the grab samples revealed no sharp divisions between biotope types. Instead, the samples could be arranged with overlapping species assemblages into a scheme that had as its basis a core of common species, such as the polychaetes *Scoloplos armiger, Mediomastus* *fragilis* and *Lanice conchilega* and the bivalve mollusc *Abra alba*. *Sabellaria spinulosa* was often abundant and was observed to form extensive reefs. Many other species were found in these Ross worm biotopes apart from the core species and reef biotopes were the most diverse and richest described. Silty sediments supported higher densities of *Abra alba* and the fan worms *Sabella discifera* and *Sabella pavonina*. Less silty sediments were more impoverished and the core species were less abundant. The polychaete *Spiophanes bombyx* was often abundant, but the coarser sediments supported few species, with burrowing carnivorous polychaetes, such as *Nephtys* and amphipods that feed on detritus adhering to loose sand grains. Some of the more silty gravel sediments supported quite a diverse range of carnivorous polychaetes as well as carnivorous ribbon worms (nemerteans).

The epifauna also had a core of hydroid and bryozoan species that were found commonly wherever there were hard substrata present for attachment. These included the hydroid *Nemertesia antenina* and the large bryozoans *Flustra foliacea* and *Eucratea loricata* and the shorter *Bugula* and *Crisia* spp. No sublittoral mussel scars were found in the Wash although *Modolous modiolus* beds were found offshore.

There was little systematic relationship between the infauna and the epifauna that justified combining the two components. Instead, infaunal and epifaunal biotopes were mapped separately, although some key biotopes (e.g., those characterised by *Sabellaria spinulosa*) were mapped in both schemes since they were sampled by grab and video.

Other epifaunal species, such as the brittle stars *Ophiura ophiura* and *Ophiura albida* were found in a wide range of biotopes and sediments and could not be linked to any mappable biotope.

The obvious gradation between biotopes had major implications for the maximum likelihood classification since this process works best with distinct biotope categories. Other classifiers in image processing create maps for each individual class showing the likelihood of the distribution of each. These are termed **probability distribution** maps and were considered to give a more accurate representation of the distribution of the different classes.

Confidences in the maps were expressed in different ways and there is no single best demonstration of accuracy and uncertainty. However, the weight of evidence suggests that much of the Wash was mapped with a fair degree of confidence whilst the north Lincolnshire coast was mapped with much less confidence. The reason for the latter was because of the wide track spacing and limited number of ground truth samples. Methods of mitigating the effects of sparse information through the use of collateral bathymetric data from published Admiralty charts were explored with some success.

The methodology must be promoted to potential users if broad scale survey is to become a standard survey technique for environmental biologists. *SeaMap* have, through working in close collaboration with the Eastern Sea Fisheries Joint Committee, trained their personnel in the use of AGDS and they have had success in the detection of mussel scars and their subsequent seasonal decline.

2 Introduction

The Broadscale Mapping Project (BMP) was designed to test a methodology for surveying and mapping the distribution of habitats and biota of large areas of the seafloor. Broadscale survey and mapping is based on acoustic remote sensing in which acoustic images of the seafloor are interpreted by linking them to sample (ground truth) data. Mapping using remotely sensed images and ground truth data is well established for both land survey and detection of large scale patterns of surface waters in the marine environment. However, similar surveys of seafloor habitats are rarely undertaken and, as a consequence, information on the broadscale distribution of biological resources is not often available to managers of the marine environment.

The Broadscale Mapping Project has been funded by a consortium consisting of the Crown Estate, the Countryside Council for Wales, English Nature, Scottish Natural Heritage and the *SeaMap* research group based at Newcastle University and undertaken by SeaMap. Three trial areas were selected for developing and testing the methodology, although experience from many other surveys conducted by *SeaMap* have also contributed to the development of the methodology. The BMP surveys in each of these areas had two overall objectives; (1) to contribute to the development of a general methodology for broadscale mapping and, (2) to provide a broadscale, spatial description of the area which can be used in conjunction with other data to support management of the Wash and neighbouring inshore waters.

The Wash and inshore waters adjoining the Lincolnshire and north Norfolk coasts (see Figure 2.1) comprise one of the trial areas for the Broadscale Mapping Project (BMP). This area contains sites of nature conservation importance and the Wash and north Norfolk coast has been put forward as a candidate marine Special Area of Conservation (cSAC). There are a number of important fisheries and a wide variety of activities take place within the area including aggregate extraction, military use and recreational activities. Additionally, the Wash receives waters from agricultural land, urban complexes and industrial sites that carry pollutants that impact on the ecosystem.

The area has been the subject of integrated management plans, such as the Wash Estuary Management Plan and a management plan is being formulated for the cSAC. Many agencies have responsibility for managing aspects of the marine environment and the need for sharing information has been identified as crucial to the development of a more integrated approach. This requirement has been underlined during recent meetings of the Wash Forum where it has become clear that much basic information is needed about the status of the marine environment, and in particular commercially important species and those that are thought to be of conservation interest. The BMP was designed to give provide baseline knowledge of the distribution of the major biotopes for the scientific support of management for the Wash and the surrounding area.

One of the objectives of the Broadscale Mapping Project is to promote the use of the techniques developed so that other organisations have the capability to undertake similar mapping surveys. An important aspect of the BMP presence in the Wash area was, therefore, to collaborate with the Eastern Sea Fisheries Joint Committee (ESFJC) on the BMP survey work so that skills could be transferred to their staff to enable them to undertake similar acoustic surveys. This is particularly important since the ESFJC is one of the more active agencies in the area that is charged with monitoring and surveying the marine environment and, therefore, is central to the strategic management of the area.

3 A Description of the Survey Area

A detailed description of the Wash is given in the Wash Estuary Management Plan (Wash Estuary Strategy Group, 1996) and of the wider region in the Coastal Directories Series report for Region 6: Flamborough Head to Great Yarmouth (Barne *et al.*, 1995) and the Marine Nature Conservation Review series: Coasts and seas of the United Kingdom (Hiscock, 1998). A description of the geology of the area, including the more recent, Quaternary sediments on the sea floor, is to be found in the British Geological Survey publication *Geology of the southern North Sea* (Cameron *et al.*, 1992). The following brief introduction to the natural resources of the area and the human activities that impact on them is based on these publications.

3.1 The physical environment: Offshore geology, topography and tidal currents.

The solid geology (pre-Quaternary) is hidden beneath the seabed sediments and do not outcrop within the survey area. The sea floor is flat throughout much of the area, generally less than 20m below chart datum. However, there is an elongate, steep-sided depression that extends from the Wash (the Lynn Deeps) to Silver Pit (and extends outwith the survey area to Skate Hole to the north east).

The sediment distribution is complex, but in general the superficial sediments within the survey area are mostly sandy gravel or gravely sands. They form an unconsolidated veneer (less than 1m thick) over older Pleistocene boulder clay (tills) and gravel. However, sandy deposits overlaying the Pleistocene gravel off the Norfolk coast can reach a maximum thickness of 40m. The superficial sediments in the Wash are of muddy sands in the more sheltered areas, but are predominantly of coarser sands and gravely sands. There is very little mud to be found in the region.

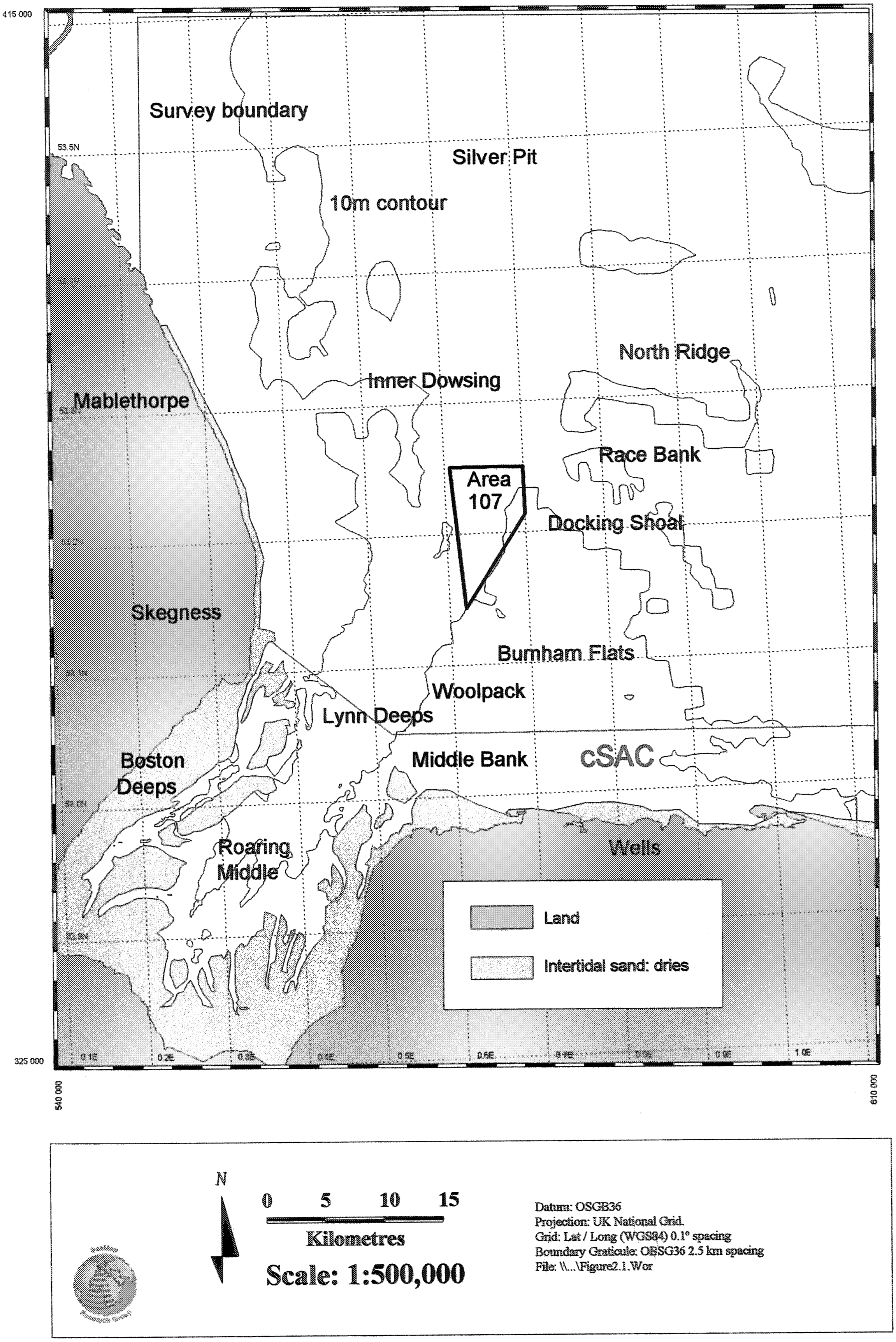
The tidal stream offshore floods southwards and ebbs northwards with a southerly residual flow. The network of channels and sandbanks affects the tidal flow. In the Wash the incoming tidal stream flows into the main channels and is faster than the ebb tidal flow, resulting in sediment deposition and accumulation.

The strong tidal streams, abundance of fine particulate material and shallow seas results in the water being very turbid, especially in the Wash. The sea floor sediments are also mobile and sand ribbons and waves, typical of sediments in hydrodynamically active areas, are found throughout the area. There is a southward drift of sand that is interrupted by the tidal flow into and out of the Wash. A westward drift of sand off the north Norfolk coast contributes to the accumulation of sand at Burnham Flats.

3.2 Sea-bed biota

There is, in general, much more known about the invertebrates of the shore than the sublittoral benthos (Covey, 1998). Offshore gravel is typical of the 'boreal offshore gravel association' described by (Jones, 1950), with the horse mussel *Modiolus modiolus*, brittle stars *Ophiothrix fragilis* and a turf of bryozoans (e.g., *Flustra foliacea*) and hydroids (e.g., *Nemertesia antennina*). The Ross worm *Sabellaria spinulosa* is also widely found (Kenny & Rees 1996) and this species has been the subject of special interest (see below). (Hamond, 1963) gives a useful account of earlier work as well as a general description of the natural history of many of the marine species to be found in the area off the north Norfolk coast. He describes a variety of grounds including (1) barren shelly ground with abundant green urchin

Figure 2.1. Survey area with locations of places and features refered to in the text. The 10m contour line is included.



Psammechinus miliaris, sometimes with a turf of bryozoans and hydroids; (2) shell or small stones with abundant overgrowth of *Sabellaria spinulosa*; (3) clean sand, sometimes with *Ophiura albida*; and, (4) muddy sand with *Ophiura albida* and a tube-building amphipod *Ampelisca tenuicornis*. All of these habitats and associated fauna can be recognised from more recent surveys, including the BMP surveys.

The Wash has been surveyed in much more detail than the offshore areas. (Dipper *et al.*, 1989) describes five main communities based largely on the epifauna and conspicuous infauna from diver observations and dredges. These are (1) a brittlestar *Ophiura albida/Ophiura ophiura* community with a variety of more motile scavengers/carnivores; (2) a fanworm *Sabella pavonina* community on mud; (3) muddy shell gravel with *Flustra foliacea* and other epifaunal turf species; (4) sand with no conspicuous species; and, (5) muddy sand with the lugworm *Arenicola marina*. They also noted the virtual absence of an algal dominated zone in the Wash due to high turbidity.

The other main survey in the Wash was conducted by the National Rivers Authority (National Rivers Authority, 1994). The infaunal samples were dominated by polychaetes and, although the samples were classified into a number of communities, the overlap in the faunal composition was great. Although not within the present survey area, the description of the infaunal communities of the Humber were described by (Rees *et al.*, 1982). Of the more marine communities, they describe an impoverished and a rich polychaete community in sand both characterised by *Spiophanes bombyx* and *Spio filicornis* and a more silty, rich community characterised by *Polydora* sp. and *Pygospio elegans*. As will be seen, these species, together with *Sabellaria spinulosa* and *Lanice conchilega* span a wide range of sediment types and are found throughout the survey area.

3.3 Sublittoral habitats and sea-bed species of conservation interest

The Wash and north Norfolk Coast has been selected as a candidate SAC because it is the largest embayment in Britain with extensive areas of subtidal sandbanks. Although the marine species for which the area has been selected is the common seal *Phoca vitulina*, the site description identifies dense brittle star beds (*Ophiura* sp.), epifaunal turf communities and the Ross worm *Sabellaria spinulosa* and other polychaetes as being noteworthy.

The turf communities and biogenic (*Sabellaria spinulosa*) reefs are thought to be of particular interest because of their high associated species diversity, including commercially exploited brown shrimp (*Crangon crangon*) and pink prawn (*Pandalus montagui*) populations. *Sabellaria* is associated with strong tidal currents carrying a heavy load of suspended sand. Such environmental conditions are harsh and unfavourable to many species. The assumption is, therefore, that *Sabellaria* reefs can increase biomass and biodiversity in environments that might otherwise be impoverished. It is also assumed that well developed reefs are more productive and diverse than poorly developed reefs. However, the extent to which *Sabellaria spinulosa* can create biogenic sand reefs (as compared with those created by the related species *Sabellaria alveolata*) is not known nor whether reefs are essentially ephemeral structures or require many years for their creation.

Although *Sabellaria spinulosa* is very commonly found around the British Isles and the North Sea, there is a general assumption that *Sabellaria spinulosa* has declined in the region in recent years, only being found in larger aggregates in the Wash (Wash Estuary Strategy Group, 1994). This decline has been attributed to destructive effect of trawling and dredging activity. Clearly, physical damage to reefs will result from such activities, although it is by no means certain what such activities play in the dynamics of reef build-up and decline.

The sand mason (*Lanice conchilega*) is thought to act in a similar way to *Sabellaria spinulosa* by stabilising sand which allows other species to colonise the sediment.

Although few benthic species are regarded as nationally rare, the whole ecosystem of the Wash and north Norfolk Coast cSAC is considered to be a key example of the range and variety of such habitats in Britain. In particular, the infaunal invertebrate communities provide a vital food resource for other organisms such as larger crustacea, fish, birds and seals.

3.4 Commercially exploited sea-bed species

The region, and the Wash in particular, supported very productive fisheries that formed an important part of the local economy in the past. The fisheries in the Wash now rely on stocks of cockle, prawn and shrimp. Recently, interest was shown in developing a new fishery exploiting razor shells and potential also exists for exploring the stocks of the bivalves *Spisula* and *Tapes* of the area as new fisheries. However, in response to the potential impact any new fishery could have on the cSAC, an Appropriate Assessment is currently being carried out to ascertain whether a fishery could be sustainable for any of these stocks and, if so, what fishery management measures would be required.

Mussels are harvested from 'lays' where natural mussel stocks are transferred to intertidal areas. There is concern that cockle and mussel stocks have drastically declined in recent years and the shrimp fishery, although potentially valuable, is very dependent upon international prices.

Offshore, commercially exploited shellfish stocks include whelks, queen scallops, edible crab and lobster and there is some crab and lobster fishing in the Boston Deeps within the Wash. Demersal fisheries using fixed nets, longlines or trawls takes place throughout the region. Although dermersal fisheries are restricted as to the size of beam trawls used and the mesh size of nets, there is no such restrictions for shrimp fisheries and concern has been expressed over the effect shrimp fishing might have on juvenile demersal fish and nursery grounds (particularly the important flatfish nursery grounds in the Wash).

3.5 Marine aggregate extraction

Coastal erosion is severe on many parts of the coast. The National Rivers Authority is carrying out a beach nourishment scheme between Mablethorpe and Skegness on the Lincolnshire coast. Sand is pumped onto the 25km stretch of beach with the intention of raising beach height to prolong the life of the concrete sea defences. The sand is dredged offshore (licensed area 107; see Figure 2.1) and is the only active extraction site within the survey area. Nevertheless, the southern North Sea as a whole is important for the extraction of marine sand and gravel for the construction industry. Thus, knowledge of the impacts of dredging upon the seafloor and its communities is important to the management of the coastal waters in the region.

3.6 Offshore structures

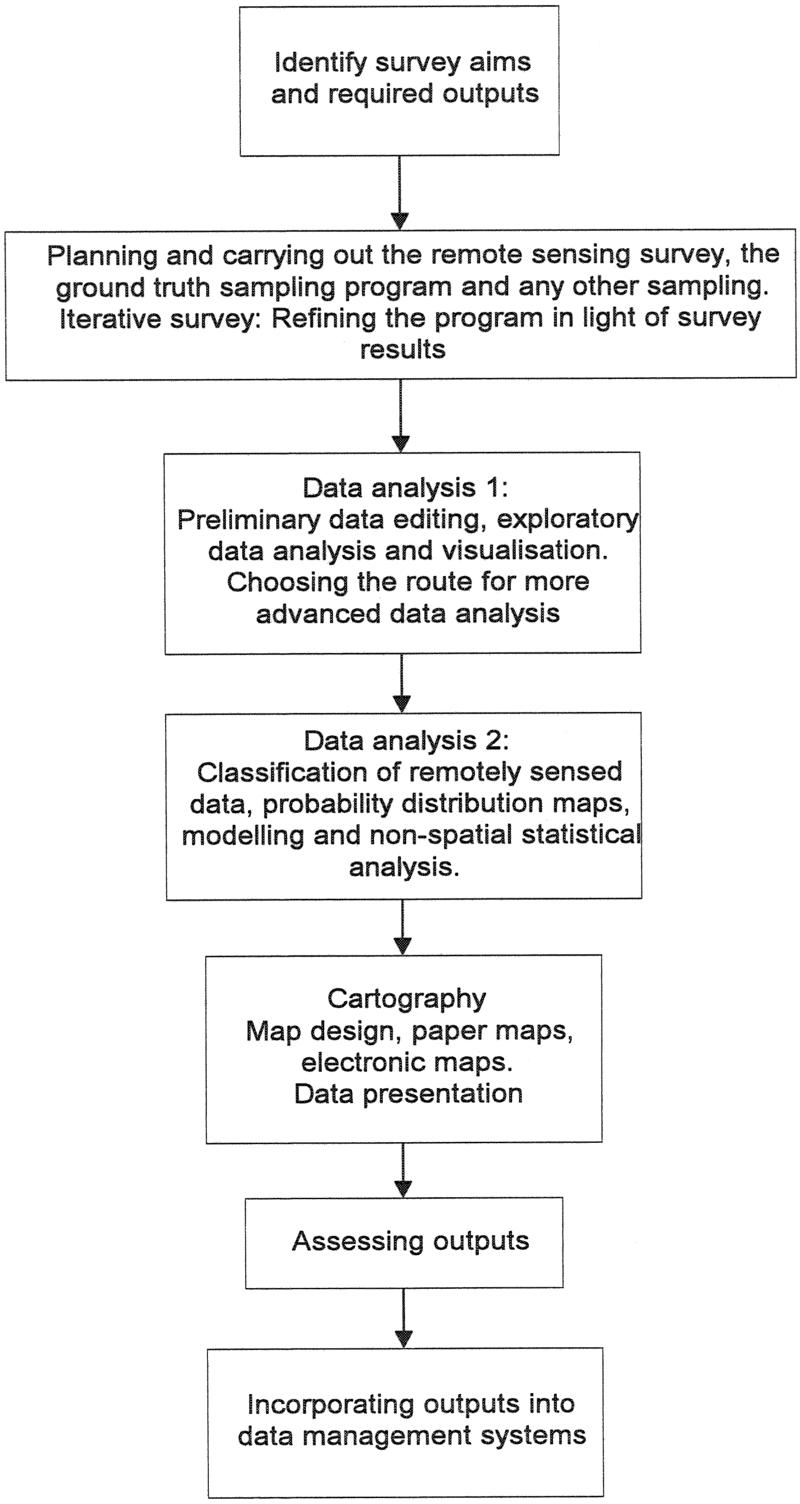
If the United Kingdom is to meet its obligations to replace the burning of fossil fuels for power generation with renewable energy, it is unavoidable that offshore wind generators will be sited off the coast. The shallow seas off Lincolnshire and Norfolk would be particularly suitable locations and the impact of the supporting structures and associated cables will need to be anticipated and monitored.

4 Aims of the survey

Purpose: The main aims and outputs of the survey are identified and the key stages outlined

Broad scale mapping surveys should be planned with clear aims and a realistic expectation of the outputs. The purpose of this section is to bring together the main points that were considered in planning and carrying out the survey, as set out in Figure 4.1.

Figure 4.1. Key stages in planning broad scale survey



The expected outputs from the survey were (a) habitats and biotope maps and (b) supplementary maps and data that supported the interpretation presented in the main habitat and biotope maps.

1. **Habitat and biotope maps:** The main aim of the survey was to map the seafloor sediments and biota. The sediments distribution maps have largely used the classification adopted by the British Geological Survey and show sediment grades based on the Folks triangle (Buchanan, 1984). The biological communities have been classified according to the national biotope classification (Connor *et al.*, 1997).

   Although depth is one of the variables that is recorded, bathymetric maps are not one of the most critical outputs from the survey since, although many of the soundings used in the Admiralty charts are from old surveys, the BMP bathymetry maps cannot rival Admiralty charts for coverage. However, since digital depth information is used in analysis and also for the construction of bathymetric models (together with additional information from Admiralty Hydrographic charts), maps showing bathymetry are also included as standard outputs from broad scale survey.

   Maps of habitats (sediment types) and biotopes are supplemented by drapes of these thematic layers over the bathymetric model to create a three dimensional surface to aid visualisation of the distribution of habitats and biotopes. These 3-D maps are extremely powerful in illustrating features of interest to coastal managers.

2. **Supplementary information:** Habitat and biotope maps are an interpretation of acoustic information and ground truth samples and not a direct measurement of either the habitat types or biotopes. It should be understood when viewing a habitat or biotope map that there will be a margin of error in both the positions of the features and also their identity. This error arises from a variety of sources, but in particular the intensity of acoustic tracking (and consequently the size and extent of gaps in the data) and the ground truth samples used to classify the acoustic data. It is important that the viewers have some knowledge of the key stages in building the habitat and biotope maps. For this reason, supporting maps showing the location and classification of ground truth samples, acoustic tracks and interpolated acoustic variables upon which the maps are based are also provided.

   An assessment of the accuracy of the maps is also presented. Accuracy can be a measure of how well the map matches the ground truth data or and external data set. In addition a map of the uncertainty of the maximum likelihood classification is also presented. Interpretation of the acoustic data uses a process of supervised classification which employs statistical procedures to determine the likelihood that a location on the acoustic map will be a particular habitat or biotope. If there are varying degrees of likelihood of more than one habitat or biotope occurring at a location, then there must be a degree of uncertainty in any map that shows just the most probable class. This uncertainty can be calculated and mapped, which gives an objective assessment of the overall confidence of the habitat or biotope map.

3. **Specific outputs:** The above outputs are standard from BMP broad scale survey. In addition, there are a number of more site specific aims that require dedicated outputs. These have arisen from requests for detailed information about certain sites or biotopes. These are as follows:-

   - The distribution of *Sabellaria spinulosa* biotopes, especially where likely to be in the form of reefs.
   - The distribution of *Ophiura* species, *Lanice* and *Sabella* communities.
   - The distribution of hydroid/bryozoan biotopes.
   - Details of the aggregate extraction area 107.

5 Survey Methods

Purpose: The field survey methods are described, together with an account of the operation of the AGDS.

5.1 Introduction

The Wash survey contributed to the recommendations for a general protocol for broad scale mapping. The following account on the use of AGDS technology for broad scale survey is not intended to be a full description of the way in which acoustic ground discrimination systems work and how they have been used to map biotopes. This is the subject of the BMP Technical Report (Foster-Smith *et al.*, 1999) and the reader is referred to that document for a full account. The account below is given for the benefit of those reading this report as a stand-alone document and to stress those parts of the methodology that are of particular importance to the Wash survey.

Each of the three trial areas in the BMP has its own sea floor characteristics that had to be considered when adapting the general protocol to local conditions. Survey logistics, such as the equipment used, also dictated survey design and the type of analysis that is most appropriate. Attention is drawn to those areas of the survey protocol that were particularly relevant to the Wash survey.

The sea floor in the southern North Sea is largely composed of soft sediments and infaunal biotopes will make an extremely significant contribution to the natural heritage interest of the area. Thus, grab samples have been used extensively for ground truthing. This contrasts with the other two BMP sites (Firth of Lorn and Pembrokeshire) where the primary natural heritage interest lies in the epibiota. This has also resulted in a difference in the approach to the analysis of the ground truth data because of the way in which samples are matched to the U.K. National Marine Biotopes classification (Connor *et al.*, 1997). Epibiota can be readily matched visually to the biotope descriptions in the classification system using conspicuous organisms and obvious differences in habitat features. However, infaunal biotopes require sediment analysis and quantitative or semi-quantitative analysis of the infauna before biotopes can be identified. Even with this data, biotope identification is more problematic for sublittoral sediments because the classification for these habitats is less well developed than for epibiota.

The area surveyed is shown in Figure 2.1. The survey was conducted over a three year period and the dates for the various surveys were as follows:-

Table 5.1. Survey dates

Year and area	Dates
1996; Wash	1st-14th August
1997; Wash, north Norfolk and south Lincolnshire coasts	1st-18th July 15th-20th September
1998; north Lincolnshire coast	3rd-7th August

The survey area and survey logistical support varied from year to year: In the first year (1996) the Wash itself was surveyed in detail using the *RoxAnn* unit from Newcastle University on board the Eastern Joint Sea Fisheries Committee (EJSFC) vessel *Surveyor.* In the second year the *RoxAnn* unit on the *Surveyor* was fully commissioned and utilised. Although the Wash was again partially re-surveyed, the emphasis was on areas off the south Lincolnshire and north Norfolk coasts. Although the EJFSC *RoxAnn* system worked reliably, it was limited to operating in waters shallower than 30m. Partly because of this latter consideration with regard to the deep water of Silver Pit, the 1998 survey, concentrating exclusively on the north Lincolnshire coast, used the *SeaMap* unit on board Newcastle University's research vessel *RV Bernicia*.

5.2 Acoustic ground discrimination systems (AGDS)

5.2.1 Equipment

Both the *SeaMap* and the ESFJC *RoxAnn* systems utilised echo sounders operating at 200kHz. The results from the two systems were (after standardisation) comparable and allowed for a simple amalgamation of the data (see Section 6.2.1). The *SeaMap* system was designed to be portable and the transponder was strapped to the side of the survey vessel on the end of a steel pole. The ESFJC's *RoxAnn* system worked with transponder permanently mounted through the hull of *Surveyor*. The *RoxAnn* and DGPS outputs were logged using *Microplot*™ data software on a PC.

The position of the ship was determined using global positioning. All surveys utilised a differential system (DGPS), although differential capability was not always available due to poor public service DGPS coverage of the U.K. experienced over recent years. Thus, positional accuracy for the survey varied between 15m and 50m.

5.2.2 How AGDS work

Acoustic ground discrimination systems analyse the return signal from a single beam echo sounder and they can be configured for use with any standard echo sounder and transponder used for measuring depth directly underneath a vessel. Transponders shape the pulse of sound into an approximate cone directed towards the sea floor. Sound waves travelling down through the centre of this cone hit the sea floor first and depth is measured from time taken for this returning sound energy to be detected by the transponder. The sound energy that spreads away from the centre of the cone produces a weaker echo. This wave energy takes slightly longer to reach the sea floor because of the extra distance travelled, and this time lag increases as the angle of spread away from the vertical axis of the cone increases. These weaker echoes are not used for depth measurement, but contain useful information of the nature of the sea floor and are used by AGDS.

The *RoxAnn* system uses signal processing hardware to select two elements from the echo and measure a value from each that is an integration of echo signal strength (in millivolts) and time. The first selected segment of the echo is the decaying echo after the initial peak in strength. This measure of time/strength of the decaying echo is termed 'Echo 1' (or 'E1') and is taken to be a measure of roughness of the ground. The second segment is the whole of the first multiple echo and this is taken to be a more sensitive measure of ground hardness than the strength of the first return. It is termed 'Echo 2' (or 'E2'). The two paired variables (E1 and E2) can be displayed quite simply on a Cartesian XY plot, and this is the basis of the *RoxAnn* real-time display as used in the data logging and display systems *Microplot*™.

5.2.3 The nature of AGDS track data

It follows from the above description of the way an AGDS works in conjunction with a single beam echo sounder that a set of measurements (E1, E2 and depth) is made for each pulse. The E1 and E2 values are taken from an area of sea floor covered by the footprint of the signal, but the area will increase with depth. Not all measurements are logged, however. Average values for E1, E2 and depth are calculated over an interval that can be set by the operator. This is usually 4 seconds, but much of the data from the ESFJC's *RoxAnn* unit were saved at the greater interval of 20 seconds for reasons beyond the control of the operators. These are the values that are logged together with the ships' position at the moment when the values are saved.

The data are in the form of single sets of values recorded from an area of sea floor of variable shape and size whose location corresponds with the ship's last calculated position. The combined ellipse of DGPS error, footprint size and/or gap between saved data gives the maximum resolution of the AGDS. Thus, for a vessel working in about 10m of water at 10 km/h with a beam angle of 15 degrees and a DGPS error of 10m, one might expect a set of E1, E2 and depth values saved every 4 seconds to represent an ellipsoid of approximately 35 x 25m. This is the maximum resolution that might be reliably expected for much of the Wash survey. Any increase in depth, speed or save rate would lower the resolution further. It is considered good practise in remote sensing surveys to work to a coarser resolution than the technical maximum, erring on the side of caution. Thus, a maximum working resolution of 100m was used in this survey.

Acoustic data for a survey area are built up as the survey vessel tracks backwards and forwards across it. These tracks need not necessarily run parallel to each other. In the Wash survey, because of various logistical constraints, the tracks were irregular but quite densely spaced in the Wash itself. Outside of the Wash the tracks were more widely but regularly spaced. The resolution considerations (above) meant that there is little advantage in attempting to navigate tracks closer than 25m. However, the track spacing was far greater than this outside of the Wash. The 1997 survey tracks for south Lincolnshire and north Norfolk were as much as 2km apart and 5km in 1998 for north Lincolnshire (see Figure 7.1 for tracks). The reason for this very wide track spacing was one of time and cost of covering such a large survey area. The implications of wide track spacing for mapping are discussed below together with methods of mitigating its effects.

5.3 Sidescan

Sidescan is an acoustic remote survey tool in its own right and neighbouring images can be added together to create a continuous coverage of an area (Riddy & Masson 1996). However, sidescan sonar was used more as a remote viewing technique in the current survey. The bedforms identified were limited to rippled sand and sand waves (Cameron *et al.*, 1997). This is a limited use of the sidescan, but the time and costs involved with sidescan survey and analysis prohibited its use as a broad scale survey tool. *SeaMap* have an *Eoscan* sidescan.

5.4 Ground truth sampling methods

5.4.1 Equipment

Both epifauna and infauna are important components of the biota of many biotopes from soft sediments or mixed soft and hard sediments. However, the habitat requirements of epifauna are quite different from those of infauna and the distribution of the two faunal assemblages might be quite independent of each other. Thus, it was decided to sample both the infauna and the epifaunal components using the most appropriate sampling methods for each.

5.4.1.1 Day grab

A Day grab was used for infaunal and sediment samples. A small sediment sample was taken from each grab sample and then the remaining sediment was passed through a 1mm sieve. The infaunal samples were preserved in buffered formalin. The infauna was sorted, identified and counted by Dr Peter Garwood of *Identichaete*.

5.4.1.2 Video

Visual inspection of the sea floor was carried out using a towed video system and the tapes viewed to extract information on sediment composition, bedform features and abundances of species (where identifiable) or life forms (Foster-Smith, 1997).

Two video systems were employed for the tasks of obtaining ground truth information, a small drop down system and a large drop down/ towed video system. The smaller system comprised a surface TV unit, a co-axial umbilical, strengthened by polypropylene rope, linked to the sub-surface unit. This was a Sony Hi8 video camera housed in a Greenaway marine divers housing mounted in a stainless steel cage with lights fitted. This system allowed real time video to a viewed on the surface during operations and the camera recorded the video footage. The larger system had a surface unit consisting of a video monitor, Sony Hi8 video recorder and control panel housed in a transit case. The umbilical was a heavy duty 12core armoured tow cable that carried power to the sub-surface unit. The subsurface unit had a CCTV video camera mounted on a tilting tray with lighting provide by 150W flood lamps for forward views and a 100W lamp for vertical views. All of these were mounted either on or within an aluminium frame.

5.4.1.3 Trawls, dredges

Trawls and dredges were also used. A visual inspection was made on board and a record was made of species and their abundances. Specimens were taken when substantial attached epifauna was collected. These were preserved and identified by *Identichaete.*

5.4.2 Analysis of the ground truth data

5.4.2.1 Substrata

Mapping substrata is an important stage in the interpretation of the acoustic data and forms one of the outputs from remote survey. Particle size analysis on samples taken from the grabs was performed using dry sieving through a series of sieves graded according to the Wentworth scale by *SeaMap* personnel (Buchanan, 1984) and a visual assessment was made of the sediment characteristics as shown on the video recordings.

The BGS colour scheme is inadequate for the representation of rocky seabeds and a modified form of the Folks triangle has been devised to include larger rock elements such as cobble, boulders and bedrock (see Appendix 1). The inner triangle is the standard Folks diagram. Categorising samples according to substrata proceeded as follows:-

Categorisation of sediment samples began with a description of the fine sediments. If sediment samples were available or the visual records were sufficiently detailed, then these were given a position in the inner triangle, which is the standard Folks triangle. If larger rock components were present, then (a) the appropriate outer triangle representing cobbles, boulders or bedrock was selected and (b) the sub-unit in this triangle that represents the combination of fine and rock sediment.

The two forms of sampling are, however, quite different and can result in very different impressions of the nature of the sea floor, particularly with regard to the rock elements. This created difficulties when using the samples for ground truthing. The samples selected for the creation of acoustic signatures were carefully chosen from the complete sample set using the following rules. (1) Where two types of samples were taken at the same station, the data was checked to see if they were compatible. If they were, then the modified Folks triangle was used as the common denominator between the samples. If there was obvious conflict in the description of the small particle fraction, then neither sample was used in the development of the signatures. (2) Samples were also rejected if two samples were taken within a distance of about 100m of each other (in other words, where positional error might have resulted in the two samples actually being at the same location) and were not of the same category. The acoustic data was classified using a maximum likelihood classifier using equal probabilities (see Section 6.2.3).

5.4.3 Analysis of biotope data

Note that the term biotope can be used in its broad sense to describe a community and its habitat (Devillers *et al.*, 1991). However, if a biotope category is referred to in this report, then this is taken to be either one that is included in the UK Marine National Biotope Classification or is a provisional biotope category (Connor *et al.*, 1997). Broader descriptive groupings of biotopes are also used. These are the biotope complexes of the national classification scheme.

It was considered prudent to analyse and plot the distribution of the epifaunal and infaunal components separately. However, in practise, the distinction between epifauna and infauna was not clear cut. Animals which were sampled by grab were all analysed as 'infauna' even though this included encrusting and small turf epifauna attached to shell and small stones caught in the grab. These were often too inconspicuous to be seen using remote video. On the other hand, anything viewed on a video was analysed as 'epifauna'. This included 'infaunal' animals that with conspicuous tubes standing proud of the sea floor or which created large openings in the sediment surface. Thus, there was an overlap between infauna and epifauna in that conspicuous infauna was included in both categories.

The following stages were followed for infaunal data analysis:-

1. A generalisation was made of particle size data for the substratum. The summary description followed the nomenclature based on the Folks triangle (Buchanan, 1984).
2. The species of each sample were ranked according to their abundance ratings. A 5 point abundance score was used (not recorded, present, common, abundant and super-abundant).
3. Species were then labelled according to the frequency with which they were found amongst the samples.
4. The frequent and abundant species were then used to derive a number of 'core' communities and then other species or groups of species were then identified that appeared to be associated with these groups or could be used to subdivide them. Multivariate analysis was used to aid this process, but it was found that the results of statistical analysis required a substantial amount of interpretation using taxonomic genera and functional groups (Foster-Smith & Sotheran, 1998).
5. A matrix of species/abundance versus biotope for the MNCR biotope categories was drawn up for easy reference and the outcome of the analysis from stage '5' compared to the biotope classification. The closest match between survey samples and the biotope classification was found, but these were modified to produce local variants to match the sample descriptions better.

Sampling biota is expensive and time consuming. Thus, it would make sound economic sense to use existing data sets to (a) compile a description of the biotopes in a locality and (b) ground truth acoustic data or test the predictive accuracy of a biotope map. However, differences in sampling technique, identification skills and analysis together with uncertainty in geographic position of samples and temporal change makes the first option (a) difficult and the second (b) particularly problematic. The use of existing data sets for ground truthing was explored in an earlier BMP report (Foster-Smith & Sotheran, 1998) and dismissed. However, it was useful to analyse different data sets to add confidence to biotope descriptions for a locality. The results of the comparative analysis of the NRA data set from 1991 (National Rivers Authority, 1994) and the BMP 1997 Wash survey are used to describe the biotopes used in the distribution maps.

5.4.4 Colours used to represent biotopes

The use of colour for mapping is extremely important and colour coding biotopes by their life forms means that maps show patterns in the distribution of biological communities. The clarity with which these broad trends will be shown on a map will, in turn, depend on the colours and symbols selected to represent biotope categories. **It is fundamental that maps convey visually (by the careful use of colour, shading, hatching, line styles and symbols) an overview of biotope distribution.**

The colours adopted by the BMP for biotope maps are those based on an arrangement of the biotopes into groups that reflect their general appearance referred to as life forms (Foster-Smith, 1997). The general life form mapping colour scheme is set out in Appendix 2. Shades and hatch patterns for a biotope might change from one set of maps to another depending upon cartographic requirements, but the main colour representing the life forms will remain constant.

6 Analysis of acoustic data

Purpose: Section 6 gives a detailed account of the analyses used to interpret the acoustic data, including background information needed for a full appreciation of the methodology.

6.1 Cartographic model for data analysis

Although *RoxAnn* can be used for real-time survey, post processing offers far greater scope for analysis. There are many stages of analysis between collecting the data and the final production of biotope or habitat maps and this will require a suite of software packages to be assembled in which data can be passed from one to the other as a scheme for analysis and interpretation of the data are executed. This assembly of software and is termed a 'ring' of modules (Eastman, 1997). The scheme or flow chart constructed to guide analysis is termed the cartographic model and is valuable in the laying down of guidelines for a step-by-step approach to complex data processing.

The standard approach to the classification of remotely sensed images is to select small areas of the image where the attributes of the ground are known and to use these areas as training sites to extract image characteristics (the 'signature'). Each habitat or biotope class will have at least one training site so that there will be a signature for each class. Then the whole image is classified into habitat or biotope classes using these signatures. This procedure can be adapted for use with AGDS data after first generating continuous, digital images (similar in format to those obtained by satellite or airborne sensors).

This has been used successfully by *SeaMap* for surveys in which only one AGDS data set is involved or where different data sets can be amalgamated and is the method adopted for the analysis of the data from the Wash survey. However, as will be discussed, this was modified to take account of collateral bathymetric data from Admiralty charts in interpolation where track spacing was wide. The process was also modified to take account of broad trends in the distribution of biotopes as determined from the ground truth samples. The outline of the complete process for analysing the data are shown in Figure 6.1 and the various steps are described more fully in subsequent sections.

6.2 Software used for data processing and map preparation

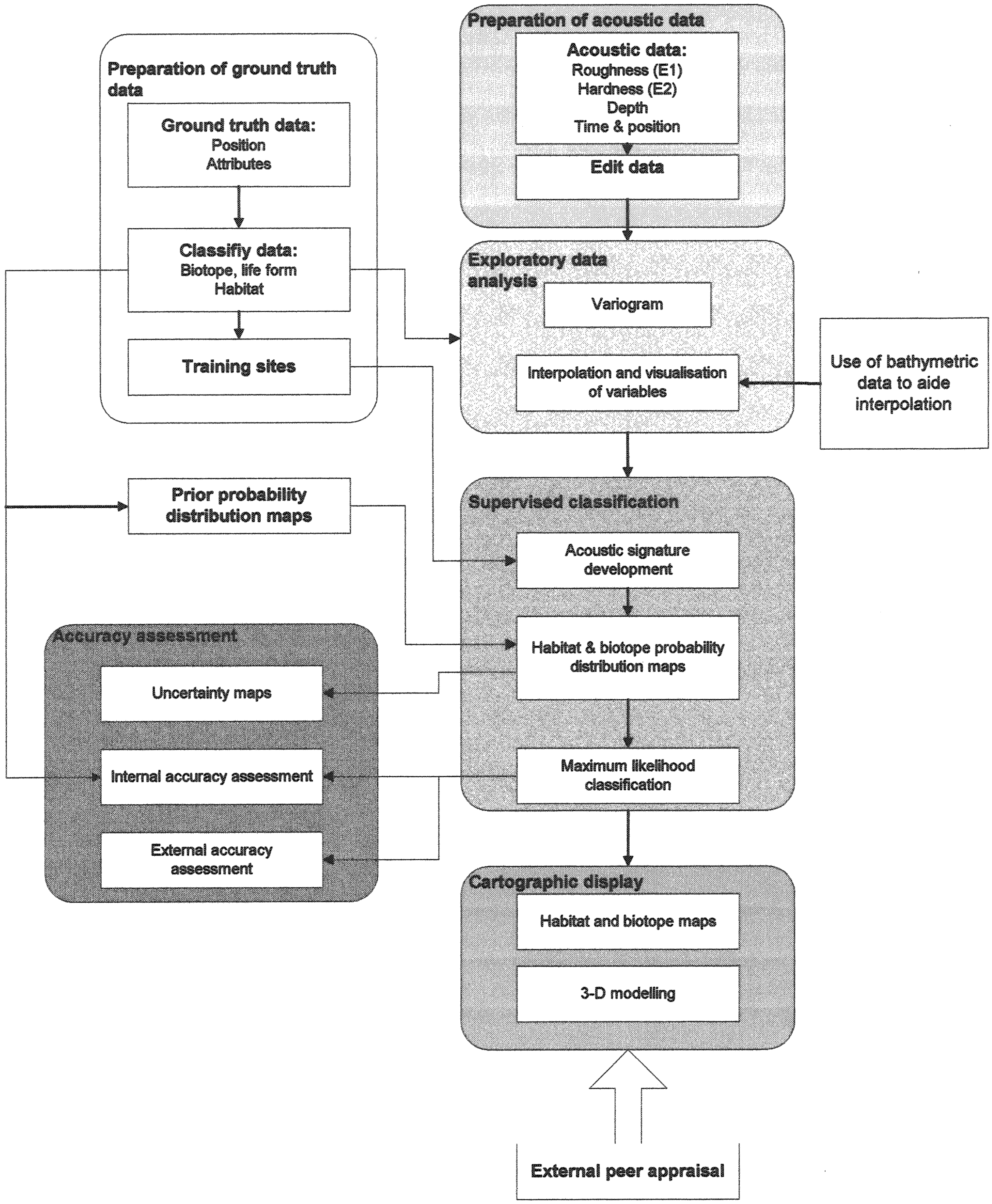
The data are exported from the logging software as ASCII text files and imported into a spreadsheet (*Excel*™) where various routines are employed to edit out spurious data, derive other variables and generally prepare the data for subsequent analysis and image processing. *Excel* is also used for much of the exploratory data analysis and some statistical treatment and graphical display of data resulting from analyses performed in other software.

The data are imported into software specifically designed for interpolation. *Surfer for Windows*™ is used primarily although *Vertical Mapper*™ is also used in some instances and, specifically, for the creation of three-dimensional models based on bathymetry.

Classification of the acoustic data is performed using *Idrisi for Windows*™. Other operations are also performed in *Idrisi*, such as image enhancement, cross-tabulation and the calculation of error matrices. The conversion of the *Idrisi* raster images to vector polygons suitable for import into the GIS involved the use of modules in *ArcInfo*™..

MapInfo Professional is the geographic information system (GIS) in which most of the spatial display (including map design), the creation of vector layers (such as coastlines), the digitising of points and lines from paper charts, spatial editing, spatial query and the creation of vector buffers are performed.

Figure 6.1. Key stages in the interpretation of the data and production of maps



6.2.1 Data editing

Depths were adjusted to chart datum by applying corrections calculated from the tidal prediction program using the simplified harmonic method produced by the UK Hydrographic Office (Anon 1991). The data were corrected using the nearest reference port. The corrections were applied at the minimum time interval of 10 minutes to reduce the size of the steps in the corrected depth records between intervals.

Acoustic data need inspection to eliminate dubious points related either to large skips in position caused by GPS error or to spurious depth, E1 and E2 values. This was done by a visual inspection of the track data displayed in *MapInfo*.

An automatic procedure was applied to the depth data to highlight those sections of track where changes in depth were erratic. Each depth record was compared to the average value of the two previous track points together with the two following points. Track points where a large difference (>5m) was calculated were highlighted and inspected. If a point appeared to be out of step with its neighbours, then it was deleted. Note that the whole record, including E1 and E2, is deleted.

Standardisation is recommended when data from surveys of the same area obtained on separate dates and/or using different vessels are to be combined for processing or compared, as was the case with the Wash survey. Data were standardised by dividing all the records by the 95th percentile value (allowing for a wide scatter of values in the upper 5% band). This value was found by sorting the records for E1 (the process being repeated for E2) in descending order of magnitude to find the record that separated the first 5% of the records from the subsequent 95%. The value for E1 for this record was then used for standardisation. This has been found to produce a good match between surveys.

6.2.2 Generating a continuous coverage from track data

6.2.2.1 Interpolation

The AGDS track data do not constitute a comprehensive coverage in the sense that the echo sounder footprints will rarely be contiguous between tracks. There will be gaps over the survey area for which there is no remotely sensed data. Whilst it is possible to interpret track point data and display the results on a map, it is more acceptable to the eye to view maps which form a complete coverage. (Burroughs & McDonnell, 1998) review the process of generating a continuous coverage from point locations. The analysis of the Wash data was based on the reasonable assumption that E1 and E2 are, like depth, continuous data (i.e., any value for between the minimum and maximum could be found) and a coverage was generated for each of these three variables. This was done through a mathematical process termed 'interpolation'. Interpolation predicts unknown values at locations for which there are no direct measurements using known values at multiple locations around the unknown value. In essence, interpolation places a grid of 'n' rows and 'm' columns over the track point data and calculates a value for each grid node.

Many geostatistical and mapping software packages offer a range of different interpolation methods to choose from and most interpolation procedures will calculate values that are faithful to real data if these are spatially close to the estimated values. Thus, unless there are large gaps in the track data, interpolation is a robust procedure and unlikely to be unduly sensitive to the interpolation method used. Unfortunately, large gaps inevitably do occur in survey data. In such cases, the emphasis of interpolation changes from a process of filling in missing data between tracks with 'obvious' values to one of mathematical modelling.

As track spacing increases, interpolation introduces an increasing degree of uncertainty that may be unacceptably high for a useful biotope map. However, it is unrealistic to conduct an intensive survey over areas as large as the Wash, north Norfolk and Lincolnshire coasts. A compromise must be reached between costs and benefits. The homogeneity/heterogeneity of the ground must be considered and a direct link between the degree of uncertainty and track spacing cannot be universally applied to all surveys. Homogeneous areas require less intensive tracking than heterogeneous areas. As will be seen, it is reasonable to assume that much of the offshore area was homogeneous at a broad scale and a broader track spacing here was probably justified.

6.2.2.2 Spatial variability and the variogram

Interpolation is required to generate a continuous digital image from point data. However, the success or otherwise of this process depends upon the spatial correlation between points and the way this varies with distance between points. A good way of modelling this spatial variability is through the creation of the variogram. The reasoning underlying the use and production of the variogram is as follows: It is a basic assumption of interpolation that the values of points that lie close together are more likely to be similar than points which lie further apart. The correlation decreases with increasing separation until a distance is reached where the values of two points have no systematic relationship to each other. The way in which the relationship varies with separation and, in particular, the maximum range over which there is some correlation between data, is important to interpolation. For example, there is no justification for interpolating values at locations which lie at a distance greater than the range from real track data. If tracks lie further apart than twice this range, then it is clear that there will be ground between the tracks where values cannot be estimated from the spatial pattern of the track data. The average value for the locality (i.e., without taking any spatial pattern into account) is the best estimate in such cases. Indeed, since interpolation can be forced to calculate values way beyond the range of spatial correlation by selecting a large search radius, it is important to realise that estimated values might simply be the local average of the data found within the search radius.

A graph showing the variance between points at increasing separation illustrates the nature of the spatial correlation within the data. These graphs are termed 'variograms'. The variance (average of the sum of squares of the differences) between values at different 'lags' (the term used to denote the distance that separates two points) are plotted against the lag distances (Burroughs & McDonnell, 1998). The differences in, for example, E1 values are calculated between records as follows:- Z_i-Z_{i+2}; Z_i-Z_{i+3}; Z_i-Z_{i+4} .... Z_i-Z_{i+n}. These calculations are performed on the whole data set and the average variance found for each lag distance. The lag distances can be estimated from the average distance between consecutive points (Pythagorean distance).

6.2.2.3 Modelling with collateral data

The very broadly spaced tracks of the north Lincolnshire coast resulted in disjointed maps and methods were explored for using bathymetry data from Admiralty hydrographic charts as collateral for interpolating E1 and E2 values. In some environments, such as the Wash, the area is very hydrodynamically active and there are a number of very well defined topographic features with associated sediment types (Cameron *et al.* 1992). Under these circumstances it is reasonable to assume that the sediment characteristics (and hence E1 and E2 values) are related to depth at a very local level. If additional depth data are available from charts, then it is possible to interpolate E1 and E2 data for a particular depth range into areas that are bounded by those same depth ranges. In other words, interpolation of E1 and E2 follows the depth contours taken from the charts.

The process of interpolation was carried out as follows:-

1998 data:

1. Depth data were supplemented by readings digitised directly from the Admiralty hydrographic chart and entered into a spreadsheet together with their co-ordinates.
2. Depth contours were digitised (in the form of closed polygons) for the ranges 0-5m, 5-10m, 10-20m, 20-30m, 30-40m, 40-50m, 50m+.
3. The acoustic data were divided into subsets for depth ranges of 0-7m, 3-15m, 7-25m, 15-35m, 25-45m and 35-55m and 45m+.
4. The data in the subsets were then interpolated but only the values inside their respective contour ranges of 0-5m, 5-10m, 10-20m, 20-30m, 30-40m, 40-50m and 50m+ were removed. Note that depth ranges for the acoustic data subsets are wider than their corresponding contour ranges. This overlap was necessary to smooth interpolated values at contour boundaries. A wide grid spacing (250m) was selected so that a relatively small number of values were created. This was done so that subsequent interpolation (see step 5) was weighted towards real values.
5. These interpolated values were added to the original track data. This was done so that subsequent interpolation (see step 7) was weighted towards real values.

All data:

6. The 1998 data, including the widely spaced gridded values, were combined with the 1996 and 1997 data.
7. A second interpolation was carried out on this data set, but using the much smaller grid spacing of 100m and a smaller search radius of 1.5km.

6.2.3 Interpreting AGDS data

The grid of interpolated values for the variables measured by *RoxAnn* (E1, E2 and depth) the coverages can be treated as digital images. This opens the possibility of using powerful image processing software designed primarily for use with satellite or airborne remote images and modelling within geographic information systems (GIS). Interpretation of a digital image is a two-stage process of deriving an acoustic profile or 'signature' for each biotope type and using these signatures to classify the image. *SeaMap* routinely use Idrisi (Eastman, 1997) for image processing and classification.

6.2.3.1 Signature development

The acoustic data for the construction of these signatures are taken from that which is in the immediate neighbourhood of the ground truth points. A buffer (circle) of a radius set by the analyst is constructed centred on each ground truth point and the acoustic data which are overlain by the buffers are extracted from the whole acoustic data set and attributed to the biotope type of the ground truth point. The acoustic data for each biotope type are amalgamated and the signature is constructed from the mean, maximum and minimum values and standard deviations for each of the variables (E1, E2 and depth).

The signature will not properly represent a biotope if acoustic data from too great a distance are included in the calculation. This is almost inevitable because of positional inaccuracies of both the vessel and the sampling device, especially if the ground is inherently heterogeneous. In order to minimise this source of error, ground truth points which could not be located on the acoustic map were not included in any signature development.

Another source of error that is easily overlooked is the quality of the classified ground truth data. Interpretation requires the samples to be consistently identified with clearly defined, distinctive and easily recognisable biotope categories. Matching sample data to a classification system is always problematic, especially with infauna, and special analysis of the infaunal data was required (see Section 7.2). One option to overcome poor discrimination due to uncertainty of biotope identification is to group biotopes into more appropriate categories for acoustic mapping. In this survey groups of biotopes were considered together because no clear distinction could be maintained between samples.

6.2.3.2 Image classification

The signatures are used to classify the image of the whole survey area by a process that is termed 'maximum likelihood supervised classification' and results in an interpreted image that can be evaluated as to its accuracy and predictive capability. The process involves matching each pixel to the various signatures and calculating the likelihood of a pixel belonging to each biotope category. The program assigns each pixel to the biotope class to which it most likely belongs. Since only one category can be assigned to a pixel, maximum likelihood is termed a 'hard' classifier.

It is important to realise that there is uncertainty in the classification process and that the automated choice might have been made between two or more biotopes with very similar likelihoods. This will especially be true when biotope classes themselves grade into each other with no clear distinction and/or when the biotopes geographically grade into each other. Maximum likelihood actually calculates a probability image for each of the biotopes and selects from these. Although this part of the process is hidden when maximum likelihood is run, these images can be viewed and reveal useful information about the distribution of individual biotopes. *Idrisi* allows these images to be created and viewed by running a module that is termed a 'soft' classifier (*Bayclass*). However, it is difficult to represent such shades of biotope membership on a map and a more simple representation of the most likely biotopes suits many purposes.

Classified images can also look very confused in regions where large proportions of neighbouring pixels are differently classified. Simplification of an image may be required and the image can be filtered to remove isolated pixels. This is, in a sense, extending the principle of automated choice of the most likely category for the classification of one pixel to a group of pixels.

Whilst maximum likelihood and filtering might make maps more easy on the eye, there is the risk that the viewer is unaware of the likelihood that other biotopes may be found within an area represented on a map. For these reasons, it is important to convey a measure of accuracy and uncertainty about a map and this will be discussed in Section 6.2.5.

6.2.4 Using prior probability images to incorporate knowledge into classification

When ground truth data were plotted on a map of the survey area it became clear that there were broad scale trends in the distribution of biotope and habitat type. For example, *Modiolus* communities were found some distance off the Norfolk and Lincolnshire coasts, but never in the Wash. Again, *Abra* biotopes were found much more commonly in the sheltered parts of the Wash than elsewhere.

Maximum likelihood classification can, however, take broad distribution trends into account through the application of prior probabilities although this facility is underused in classification (Eastman, 1997). It is often assumed in image classification that each class is equally likely to be represented in an area since there is often little information to know *a priori* what the proportional composition actually is. However, the classification process can make use of prior knowledge to estimate the probability of an hypothesis being true (the membership of a pixel belonging to a biotope class is an hypothesis in this context). These prior probabilities can be estimated from the distribution of the ground truth data and other data or knowledge and expressed as a **prior probability image**. These images can be incorporated into the maximum likelihood classification and modify the posterior (output) likelihood.

Prior probability images were generated as follows: The plot of the ground truth data were divided into polygons each containing between 5 and 10 samples. These polygons were drawn to coincide with important physiographic boundaries to enclose areas with a fairly similar representation of habitats or biotopes. The ground truth samples were counted and the proportion of each biotope or habitat class calculated for that polygon. This was repeated for all polygons which results in a probability density distribution for each habitat or biotope class separately.

Using polygons results in sharp transitions in probability densities, which is unrealistic. Substituting a number of points for the polygons and interpolating the probability density values can create a more gradual transition. These substitute points can be created in a number of ways: in this analysis it was convenient to use the positions of the original ground truth locations for the positions of the new points. These points were given the probability density values of the polygon in which they were situated.

A continuous probability surface was then created using these points through interpolation. The same geographic boundaries and grid spacing were set for this interpolation that were used for the creation of the acoustic images so that the prior probability image could be overlain onto the acoustic images exactly. With so few points, it was important not to use an interpolation algorithm that emphasised individual point values (producing what is called a 'bulls-eye effect'). Minimum curvature was used because it gave a very smooth interpolation (Keckler, 1994). At the conclusion of this process there was a prior probability image for each of the habitat or biotope classes. These prior probability images were selected when maximum likelihood was run.

6.2.5 Accuracy assessment

How much confidence can be placed in a biotope or habitat map? There are various ways in which confidence, accuracy and uncertainty can be expressed that apply to different stages in the interpretation process.

6.2.5.1 Visual assessment of coverage

Confidence can be gained visually by displaying the track data and ground truth data so that areas where the data are sparse can be seen. Interpolation can be qualified by the calculation of the range and representing the likely areas where interpolated values are likely to be poorly supported by the data (see Figures 7.1 & 8.3).

6.2.5.2 Error matrices

Two digital images that are co-registered and have the same pixel size can be overlain and the pixels from one image compared with those of the other. This is an extremely useful facility for the comparison of two images. For example, accuracy assessment requires a comparison between the ground truth data and the interpreted map. One image shows ground truth information: Pixels in the buffer zone around ground truth samples are given the habitat or biotope code of the sample. The second image shows the acoustic data classified by the same codes. When the two images are overlain, each pixel with a code in the ground truth image can be compared with the code of the corresponding pixel of the map. Each pixel-to-pixel comparison has two possible interpretations. Firstly, if the map incorrectly predicts the class, then the error is termed one of **commission** in that the map has included classes that were not, in fact, present. These classes have been over-represented on the map. The second interpretation is that the correct class has been omitted, so the comparisons can be framed as errors of **omission**. These classes have been under-represented on the map.

These comparisons are made through the construction of a matrix (see Tables 9.1 & 9.2 for examples) of ground truth data (columns) and mapped data (rows). The row totals gives the number of pixels in the map image that have been classified as particular habitat or biotope classes (but only counting those pixels for which there are corresponding ground truth pixels). The figures in the various columns of that row give the break down of this total in terms of the classes as indicated by the ground truth data.

The column totals give the number of pixels that have been assigned to a particular class from the ground truth data whilst the figures in the rows give the break down of this total in terms of how these pixels were interpreted.

The diagonal gives the tally of correct predictions and the percent correct calculated as an overall figure for the comparison (total correct matches/total pixels used in the comparison). Percentage correct can also be calculated for each individual biotope.

6.2.5.3 Certainty maps

Probability distribution maps can also be used to determine certainty in image classification. Certainty is a measure of the probability of a pixel belonging to the most likely habitat or biotope class. If the probability is high for the most likely class, then the classification of that pixel has a high level of certainty. If, on the other hand, the probability is not great, then the classification is uncertain. The value can be plotted for each pixel giving a certainty map for the survey area.

7 Survey results

Purpose: This Section presents the acoustic track data and sample data that were used in the analyses to be described in the following sections.

7.1 Coverage of the AGDS tracks

The coverage of the track data over the survey area is shown in Figure 7.1 and reference to this may be made when viewing all subsequent maps based on the interpolated track data. This enables a visual assessment to be made of the confidence that should be placed on the detail contained within the continuous coverage maps. The track data are shown as point symbols colour coded according to a reclassification of E1 and E2 on a Cartesian plot as shown in the inset. The coloured boxes are designed to show small increments in E1 (roughness) and E2 (hardness) and the track data represents the acoustic survey data closest to its 'raw' form. This is similar to the real-time *Microplot* display except that the data have been standardised.

The distribution of E1/E2 categories indicates the following areas of ground types might be reflected in the final interpretation of the acoustic data:-

1. The majority of the Wash area consisted of soft/smooth – very soft/smooth ground with scars of moderately hard/rough ground.
2. The deep channel running from the Lynn Deeps was of hard/rough to hard/very rough ground.
3. The shallow Docking Shoal was an extensive area of moderately soft/moderately smooth ground.
4. The inshore area off Wells-next-the-Sea was variable with some soft ground.
5. There was a large area of hard/rough ground to the north of Wells-next-the-Sea extending to the latitude of Mablethorpe.
6. The north eastern section of the survey area was of variable but mostly moderately hard/rough ground.
7. Silver Pit was of hard but moderately smooth ground with some localised very soft ground.
8. The inshore area off the Lincolnshire coast was moderately hard and very rough, except for a small area next to Mablethorpe.

7.2 Analysis of samples

7.2.1 Analysis of substrata

The predominant sediment characteristics of all samples are given in the overall ground truth summary spreadsheet in Appendix 5. These sediment characteristics are shown in Figure 7.2 below. The various sediment types were patchily distributed with very different types lying close to each other. This is especially the case for the Wash. Finer sediments predominate in the inner parts of the Wash with many occurrences of silty shell. The sediments offshore tended to be of coarse with the only soft sediment (mud) being restricted to the western side of Silver Pit. Silty sand sediments were also found close inshore off the north Norfolk coast. Sediment with rocks larger than cobble were rarely found, the only instance being in the deeper water in the entrance to the Wash.

7.2.2 Analysis of infaunal biotopes

7.2.2.1 Description of the main biological characteristics

Although only the BMP samples were used for interpretation of the acoustic data, the NRA 1991 data (National Rivers Authority, 1994) were also analysed to aid the derivation of biotopes descriptions. Analysis was directed towards finding similarities and differences between samples from the BMP and the NRA surveys. Species were sorted into the following classes:-

1. Frequent; often super-abundant: found in >25% of the samples and super-abundant in >5% of the samples.
2. Frequent; occasionally super-abundant: found in >25% of the samples but super-abundant in <5% of the samples.
3. Frequent; abundant in some samples: found in >25% of the samples and abundant in at least one of the samples.
4. Frequent; low abundance: found in <25% of the samples but never abundant.
5. Not frequent; found in <25% of the samples and sometimes abundant or super-abundant.
6. Not frequent; never abundant: found in <25% of the samples and never abundant.
7. Rare; not abundant: found in <5% of the samples and always of low abundance.

N.B. rare species that were nevertheless abundant were not encountered although this remains a possible class for analysis of other data sets. The species/sample list was arranged by Class membership and was used to match the similarity between the BMP and the NRA 1991 data sets. Table 7.2 gives a complete list of those species which have been placed in Classes 1-5 (Class 6 is too numerous) on the basis of either the BMP or the NRA data. Table 7.1 compares the two data sets in terms of their percent similarity (using the Sorenson index for presence/absence and the Sorenson quantitative index to take class differences into account).

Table 7.1. Comparison of species classes from samples taken in the BMP and NRA surveys to show the level of similarity.

Highest joint class	Total number of species for BMP & NRA	Percent similarity (presence/absence)	Percent similarity (quantitative)
Class 1	9	89	82
Class 2	19	79	57
Class 3	28	82	44
Class 4	71	58	23
Class 5	14	64	62
Class 6	79	45	47
Class 7	162	13	25
Overall	382	40	35

The greatest similarity between the samples from the two surveys lies with the commonest and most frequently encountered species (Classes 1, 2 & 3). This suggests that only the most common and abundant fauna can be used to find a common denominator between surveys and that, even so, similarity might not be very high.

The infaunal communities as described by both surveys contain much the same species and are differentiated mostly by (a) the presence/relative abundance of some species, elevated to the status of 'key' species; (b) overall species diversity and (c) sediment composition. Some trends are common to both the BMP and the NRA surveys and these have implications for deriving robust classes used for biotope maps: -

Figure 7.1. Track data coloured according to the strengths of E1 and E2.

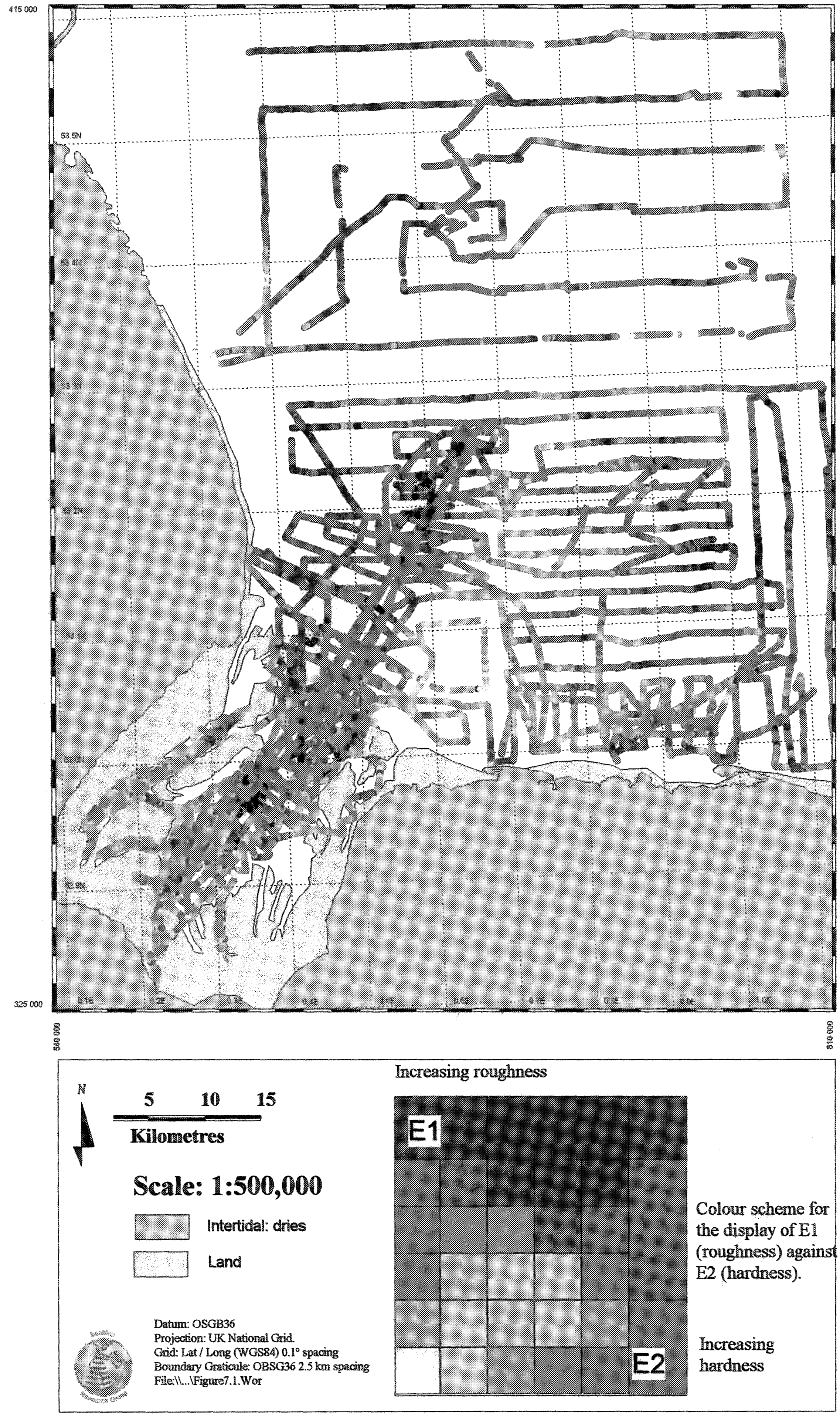
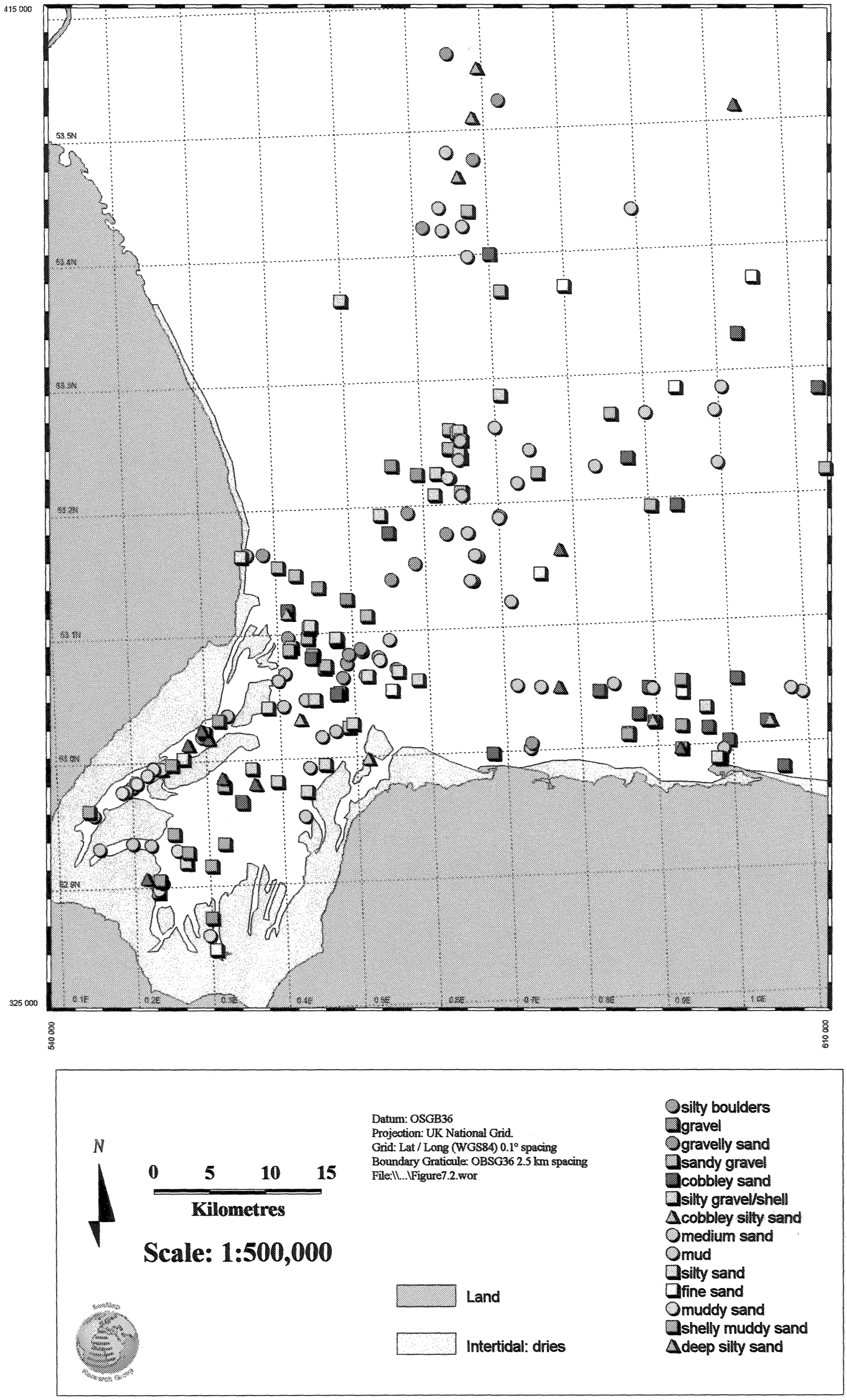


Figure 7.2. Distribution of sediment ground truth samples.



1. Very low diversity samples have few Class 1 and 2 animals and were typified by *Nephtys* sp, and other burrowing carnivores and amphipod detritivores specialising in sand grain processing.
2. The spionid small-tube dwelling surface deposit feeding polychaete *Spiophanes bombyx* dominated low diversity samples. *Scoloplos armiger*, a burrowing subsurface deposit feeding polychaete, became co-dominant with increasing species diversity. Both species were also found in very diverse communities, although *Spiophanes bombyx* was not typical of high diversity samples.
3. Although the small deposit feeding bivalve *Abra alba* was found in low diversity communities, it was more typically found associated with moderate species diversity.
4. The tube dwelling polychaete *Sabellaria spinulosa* was associated with diverse communities even when this species was found in low abundances. However, the highest species diversity of all samples was found associated with *Sabellaria* reefs. These communities had most of those species from Class 1, although *Spiophanes bombyx* was often absent from reefs. *Sabellaria spinulosa* formed colonies that ranged from a low-lying, loose arrangement of tubes to large colonies. These colonies were associated with a large number of mobile carnivorous polychaetes and other surface feeders. Mysid shrimps, swimming crabs, edible crabs and even lobsters were seen in association with these reefs.
5. Rich infaunal samples were augmented by a greater range of bivalves (e.g., *Mya truncata, Mysella bidendtata*), spionids (e.g., *Polydora* spp., *Spio* spp.), and capitellids (e.g., *Heteromastus filiformis* and *Capitella capitata*) and other subsurface deposit feeders (e.g., *Myriochele oculata*) and surface deposit feeding cirratulids (e.g., *Caulleriella alata*).
6. Multivariate analysis performed on the data (Foster-Smith and Sotheran 1998) indicated that *Sabella pavonina* (in very silty habitats with shell) and *Sabella discifera* (in silty sediments) might be distinct groups
7. There was a reasonably good relationship between sediment and the Class 1 species. *Sabellaria* was associated with gravely sediments; *Abra/Scoloplos/Spiophanes* communities with silty sand; *Spiophanes* with medium fine-coarse sands; and more barren communities with coarse sands.

7.2.2.2 Matching infaunal samples to the national biotope classification system

A full description of the infaunal biotopes is given in Appendix 3. Whilst every attempt has been made to use the national MNCR classification scheme for coding biotopes, difficulty was experienced for the following reasons: -

1. A large number of biotopes could be classified as the *Sabellaria spinulosa* biotope (MNCR code SspiMx) since this appears to be a key species for biotope identification. However, it would be pointless to attempt image processing of the acoustic data if the majority of samples were of a single biotope category and much valuable information on the distribution of biota would be lost. Consequently, the *Sabellaria spinulosa* biotope has been subdivided into a number of more detailed biotopes suitable for the local data set.

2. Either an infaunal or an epifaunal biotope could describe the same location. Instead of making an arbitrary assignment, combinations of infaunal and epifaunal biotopes have been used to describe such areas where appropriate.

3. Some samples do not match biotope categories sufficiently well for a confident identification. The nearest biotope has been used, but other indentifications could also be valid and these are indicated in Table 7.3.

Table 7.2 Comparison of frequency/abundance classes between the BMP samples and those collected for the National Rivers Authority 1991 survey (National Rivers Authority (1994).

Species	BMP class	NRA class
Class 1		
Abra alba	1	1
Harmothoe indet.	1	1
Mytilus edulis	1	
Pholoe sp	1	1
Sabellaria spinulosa	1	1
Scoloplos armiger	1	1
Spiophanes bombyx	1	1
Mediomastus fragilis	3	1
Pariambus typicus	4	1
Class 2		
Achelia echinata	2	3
Actinaria indet.	2	3
Eumida juv. indet.	2	
Eusyllis blomstrandi	2	3
Lanice conchilega	2	2
Mya truncata	2	6
Nephtys indet.	2	2
Nereis longissima	2	5
Ampelisca diadema	4	2
Autolytus langerhansi	4	2
Microprotopus maculatus	4	2
Ampharete lindstroemi	6	2
Capitella capitata	6	2
Mysella bidentata	6	2
Perioculodes longimanus	7	2
Phoronis muelleri	7	2
Eumida bahusiensis		2
Harmothoe impar		2
Modiolus sp		2
T marioni		2
Class 3		
Anoplodactylus petiolatus	3	3
Bodotria scorpioides	3	5
Nemertea indet.	3	3
Nephtys cirrosa	3	3
Ophelina acuminata	3	6
Photis pollex	3	5

Species	BMP class	NRA class
Class 3 cont.		
Ampelisca brevicornis	4	3
Cumopsis goodsiri	4	3
Nephtys hombergii	4	3
Nucula nucleus	4	3
Ophiura albida	4	3
Pelecypoda juv. indet.	4	3
Pisidia longicornis	4	3
Pisidia longicornis	4	3
Polydora indet,	4	3
Pseudocuma longicornis	4	3
Pseudocuma longicornis	4	3
Pseudopolydora pulchra	4	3
Scalibregma inflatum	4	3
Aricidea minuta	6	3
Fabulina fabula	7	3
Pycnogonum littorale	7	3
Actiniidae		3
Anobothrus gracilis		3
Retusa obtusa		3
Tanaid ind		3
Tubificoides pseudogaster		3
Class 4		
Abludomelita obtusata	4	5
Ampelisca spinipes	4	6
Amphipholis squamata	4	6
Amphipoda indet.	4	4
Aonides paucibranchiata	4	6
Aora gracilis acutifrons	4	4
Aphelochaeta sp.	4	
Atylus guttatus	4	5
Atylus sp	4	6
Autolytus brachycephalus	4	
Autolytus prolifera	4	7
Bathyporeia elegans	4	6
Bathyporeia sarsi	4	5
Carcinus maenas	4	
Caulleriella zetlandica	4	
Cephalothricidae indet.	4	

Species	BMP class	NRA class
Class 4 cont.		
Cirratulidae indet.	4	7
Crepidula fornicata	4	6
Dyopedos monacanthus	4	6
Enchytraeidae indet.	4	
Ensis directus	4	4
Eteone picta	4	
Eulalia ornata	4	
Eumida ockelmanni	4	
Exogone naidina	4	7
Golfingia elongata	4	
Golfingia juv. indet.	4	
Halacaridae indet.	4	
Harmothoe glabra	4	
Harpinia pectinata	4	6
Hesionidae indet.	4	7
Lagis koreni	4	4
Lepidonotus squamatus	4	6
Lumbrineris gracilis	4	6
Melita hergensis	4	
Molgula manhattensis	4	
Myriochele oculata	4	
Nephtys caeca	4	5
Noemiamea dolioliformis	4	7
Nudibranchia indet.	4	6
Nymphon brevirostre	4	6
Owenia fusiformis	4	6
Phyllodoce rosea	4	7
Polycirrus medusa	4	
Pomatoceros triqueter	4	4
Proceraea cornuta	4	7
Protodorvillea kefersteini	4	6
Pseudocuma longicornis	4	6
Pseudocuma longicornis	4	6
Pygospio elegans	4	6
Sabella discifera	4	
Sabella pavonina	4	6

Species	BMP class	NRA class
Class 4 cont.		
Sabelliphyllus elongatus	4	
Semibalanus balanoides	4	
Sphaerosyllis taylori	4	
Spio armata	4	
Sthenelais boa	4	6
Tanaissus lilljeborgi	4	
Tubificidae indet.	4	7
Tubulanus superbus	4	7
Urothoe brevicornis	4	6
Hesionura elongata	7	4
Phyllodoce ind	7	4
Tubificoides benedii	7	4
Abra sp		4
Cardium edule		4
M similis		4
Partulida pellucida		4
Sphaerosyllis bulbosa		4
Spisula elliptica		4
Tunica ind		4
Class 5		
Eteone longa	5	5
Angulus tenuis	6	5
Exogone hebes	6	5
Notomastus latericeus	6	5
Ophiura ophiura	6	5
Diastylis bradyi	7	5
Magelona mirabilis	7	5
Pontocrates altamarinus	7	5
Streptosyllis websteri	7	5
Atylus swammerdamei		5
Glycera sp		5
Hydrobia ulvae		5
Parapleustes bicuspis		5
Psammechinus miliaris		5

The biotopes were not clearly defined, but graded into each other with overlapping species compositions and ranges of sediment characteristics. Table 7.3 summarises those infaunal biotopes used in the classification of the acoustic data. Figure 7.4 sets out in a schematic form the way in which the infaunal Wash biotopes grade into each other.

Table 7.3. The biotopes used for the classification of infaunal samples from the BMP survey with provisional local codes where appropriate.

Community categories	National biotope code equivalents (alternative interpretations in brackets)	Possible local code justified
Sabellaria	CMX.SspiMx	CMX.SspiMx.reef(Wash)
Sabellaria/Lanice	CMX.SspiMx	
Sabella discifera/Sabellaria	CMS.AbrNucCor (CMX.SspiMx)	CMS.AbrNucCor.Sdisc(Wash)
Sabella pavonina	CMS.AbrNucCor	CMS.AbrNucCor.Spav(Wash)
Abra	CMS.AbrNucCor	
Ophiura albida	CMS.AbrNucCor	CMS.AbrNucCor.Ophalb(Wash)
Scoloplos/Spiophanes	IMS.FaMS.SpiSpi	CMS.ScoSpi(Wash)
Nephtys/Scoloplos	IMS.FaMS.SpiSpi	CMS.ScoNep(Wash)
Nephtys/Bathyporeia	IGS.Fas.NcirBat	
Sparse polychaetes/nemertean	IMS.FaMS.SpiSpi	CMS.Nem(Wash)
Lanice	IGS.Fas.Lcon (IGS.Fas.Mob)	
Ensis	IMS.FaMS.EcorEns	
Modiolus	CMX. ModMx	

7.2.2.3 Distribution of infaunal biotopes from samples

The distribution of the ground truth samples that have been characterised by their predominant biotopes are shown in Figure 7.3. The data are summarised in Appendix 5.

The ground truth samples from the inner parts of the Wash were predominantly of the biotopes *Abra, Scoloplos/Spiophanes* and *Nephtys/Scoloplos*, which were typical in silty sand. In the more open parts of the Wash and much of the offshore region, *Sabellaria spinulosa/Lanice* biotopes were very common, with *Nephtys/Bathyporeia* on the raised coarse sand banks and polychaetes/nemerteans in the coarser sediments off the north Lincolnshire coast. Communities characterised by super-abundant *Sabellaria* were found along the deep channel running from the Wash towards Docking Shoal and were seen on video records to have formed substantial and extensive reefs in the clearer waters offshore. Turbid water in the Wash prevented the use of video on many of the sampling locations where super-abundant *Sabellaria* was found and the formation of reefs must remain in doubt until they can be confirmed visually. For this reason the label '*Sabellaria*' has been used to denote biotopes where the worm was super-abundant and reefs might be expected rather than the more definitive term 'Reef'.

Sabella pavonina was only found in the Boston Deeps whilst biotopes characterised by *Sabella discifera* were found inshore on silty sand scattered throughout the area. *Sabella discifera* was, however, a commonly occurring species in *Sabellaria* biotopes.

The *Sabellaria spinulosa* reefs were found along the channel extending from the Lynn Deeps. However, they were only positively identified as being in the form of substantial reefs close to area 107. This was largely because reefs can only be positively identified from video and the visibility was too poor for the deployment of video in much of the Wash. Nevertheless, the samples in the Wash where *Sabellaria spinulosa* was super-abundant and supported a diverse infauna may also have been in the form of reefs.

7.2.3 Epifaunal biotopes

7.2.3.1 Description and distribution of epifaunal biotopes

The distribution of the epifaunal samples is shown in Figure 7.4. The epifaunal samples matched the UK National Marine Biotopes classification well, as summarised in Appendix 5. The epifaunal communities are described in Appendix 3. The amount of epifauna, not surprisingly, varied with the presence of shell and cobbles in the sediment. Again, there was a core of tall and short faunal turf and encrusting species that were found ubiquitously. Tall faunal turf species included the hydroids *Nemertesia antenina, Abietenaria abietina, Halecium halecium, Hydralmania falcata* and *Obelia longissima*, and the bryozoans *Flustra foliacea* and *Eucratea loricata*. Short faunal turf species were the bryozoans *Bugula plumosa, Crisia* spp., and *Alcyonidium* spp. Encrusting fauna included the bryozoans *Conopeum reticulatum, Electra pilosa,* barnacles and the keelworm *Pomatoceros triqueter.*

Encrusting coralline algae were common, as were the anemone *Urticina* whilst *Sagartia* spp. were found on the more gravely, shelly substrata. Many of the tall faunal turf species were found in sand-swept habitats without any accompanying short faunal turf or encrusting species.

The epifaunal communities also encompass *Sabellaria* reefs and infaunal biotopes that can be characterised by conspicuous surface features, such as *Lanice* and *Ensis*. Other infaunal biotopes have been grouped into a category labelled 'no conspicuous fauna' and included in the classification.

Figure 7.3. Distribution of the infaunal ground truth biotopes.

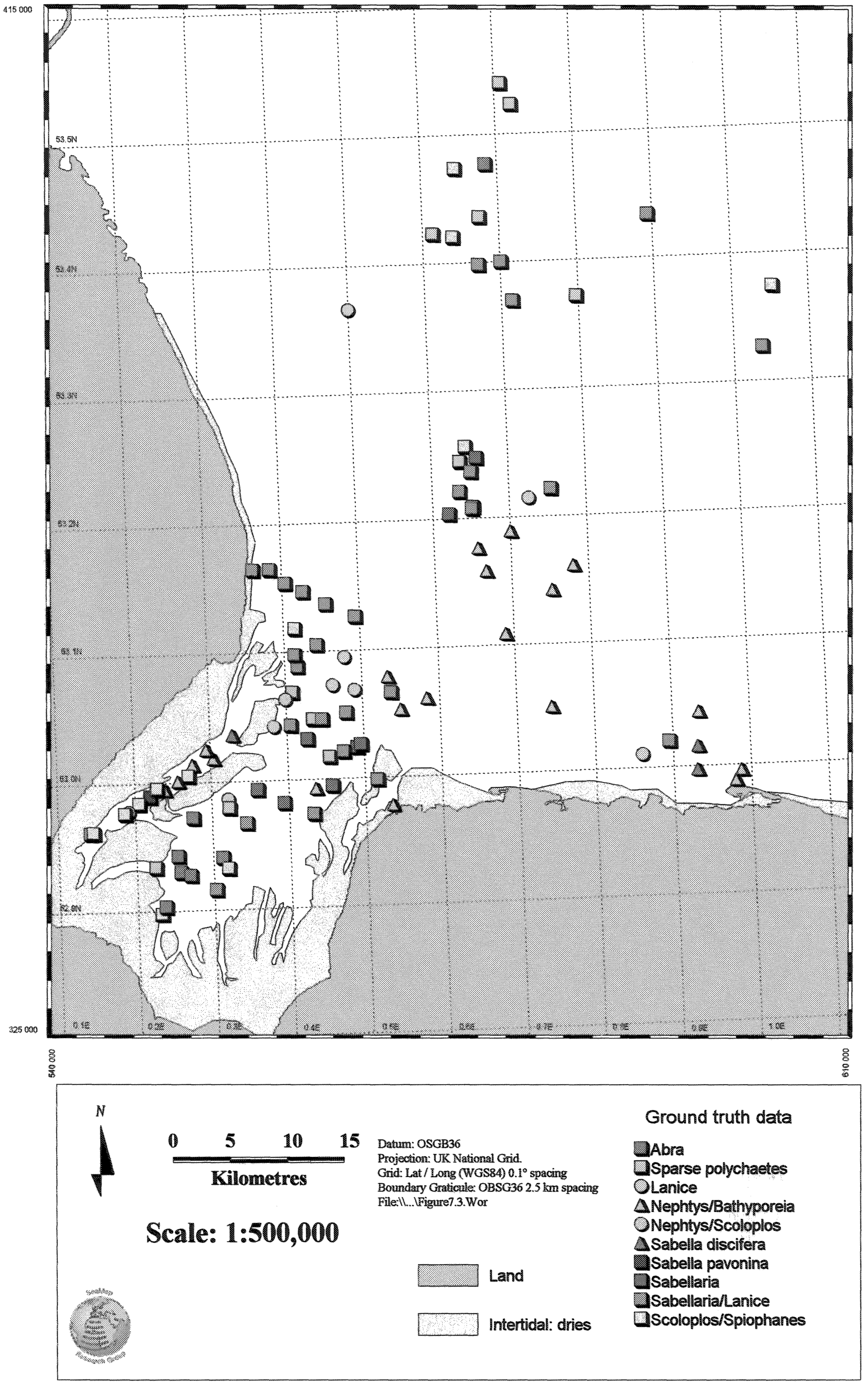
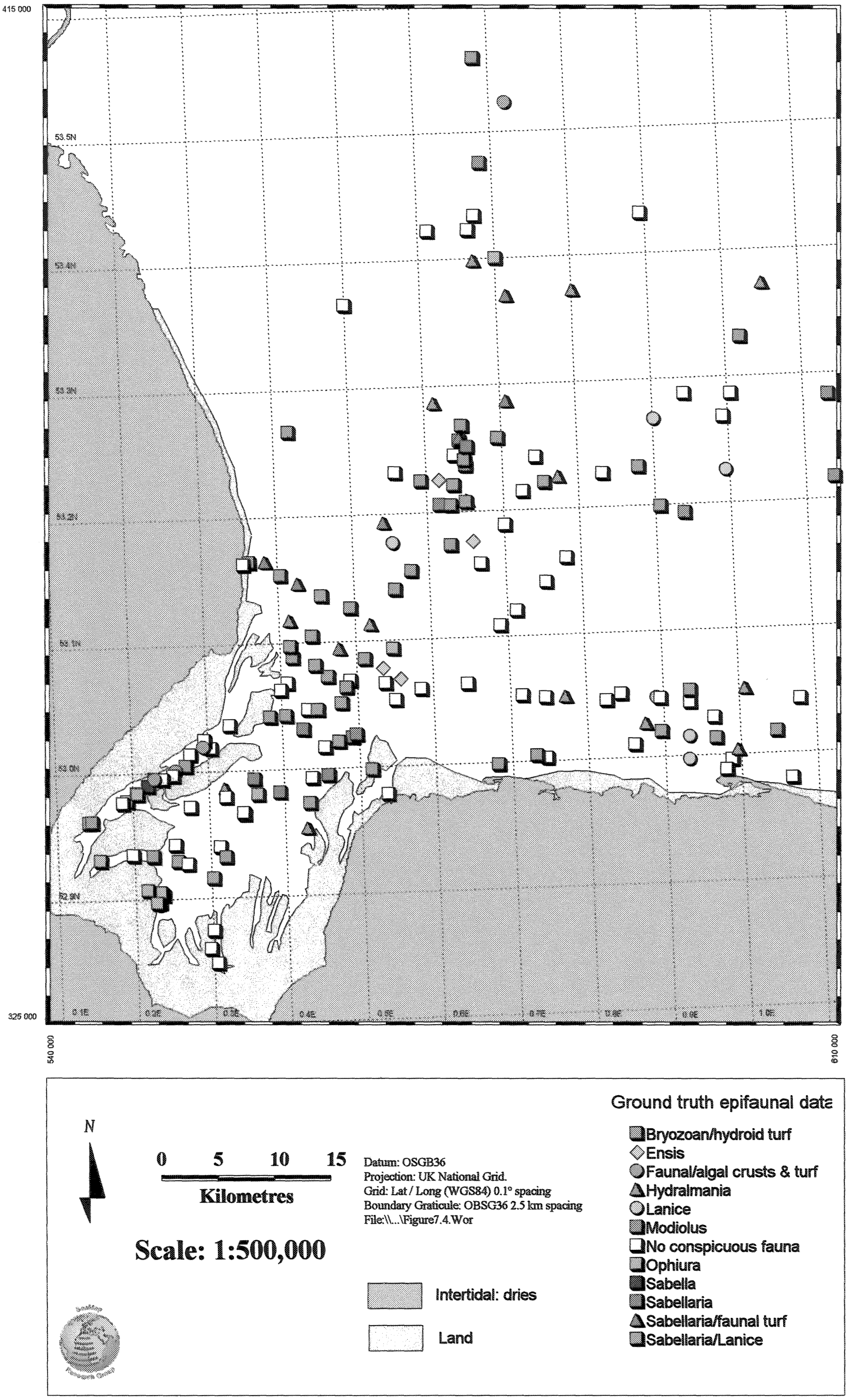


Figure 7.4. Distribution of the epifaunal biotope ground truth samples.



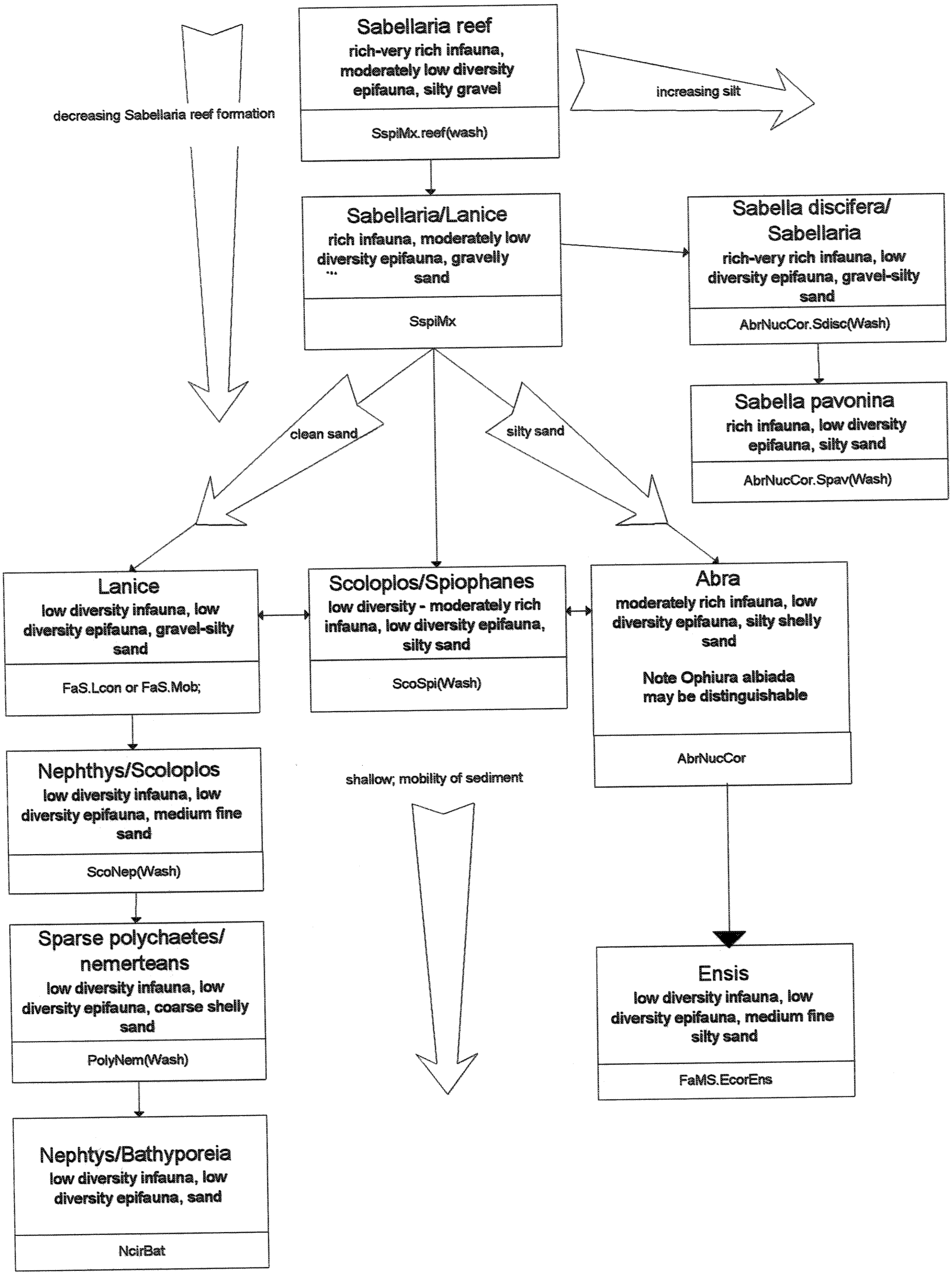


Diagram 7.1. Schematic representation of the relationship between the main infaunal biotopes.

Figure 7.5. Four infaunal biotopes spanning the range from high to low diversity communities

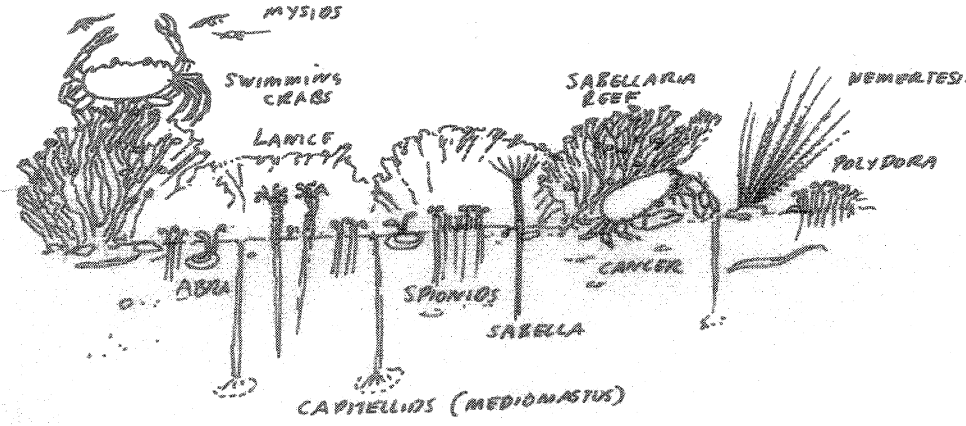


Figure 7.5a. *Sabellaria* reef with rich infauna

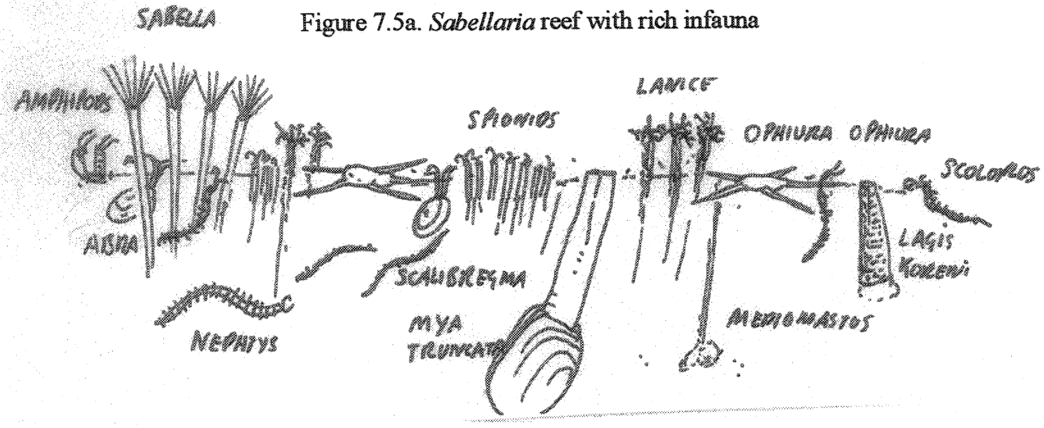


Figure 7.5b. *Sabella discifera* with rich infauna

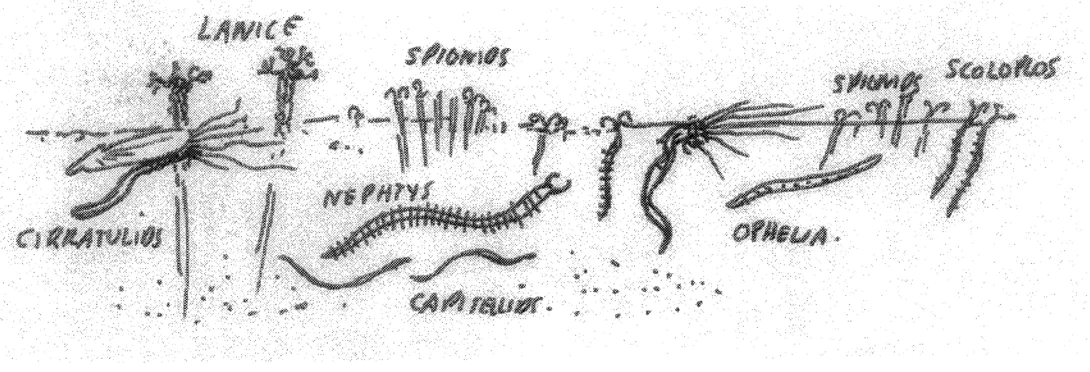


Figure 7.5c. *Scoloplos/Spiophanes* with moderately rich infauna

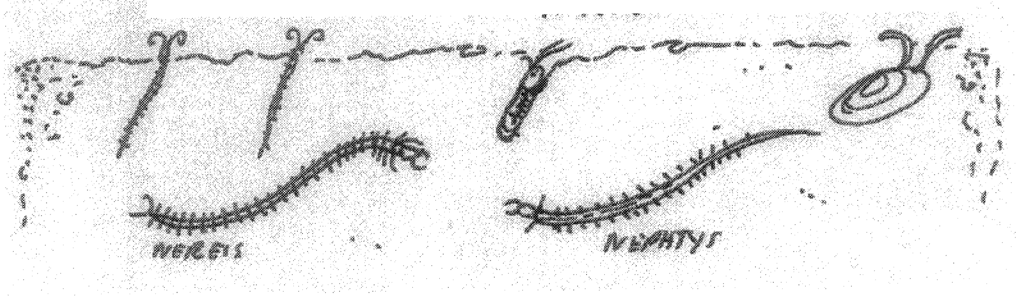


Figure 7.5d. *Nephtys/Scoloplos*

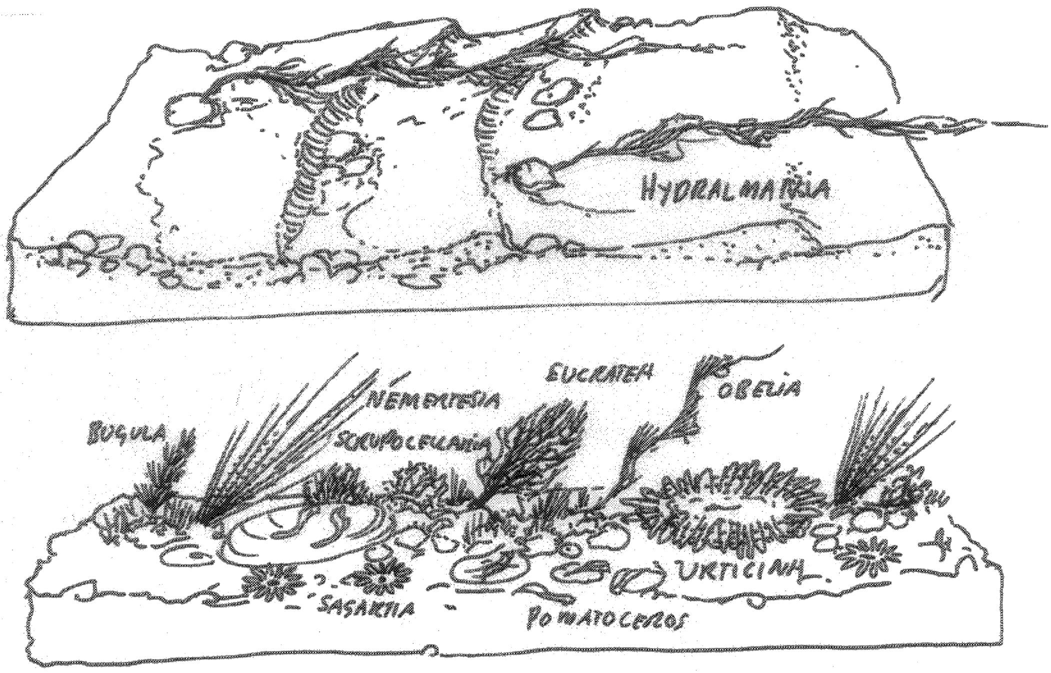


Figure 7.6. Two epifaunal biotopes illustrating t5he range of biota found in the Wash. The top figure shows hydroids trailing over current-swept cobble and mobile sand. The bottom figure illustrates a rich faunal turf community with tall and short hydroids and bryozoans on a shelly cobble and sand substratum.

8 Exploratory analysis of the acoustic data

Purpose: Section 8 investigates the spatial nature of the AGDS data, including a visualisation of the bathymetric data as a three-dimensional model.

8.1 The variogram and ranges for interpolation

The following two graphs (Figures 8.1 & 8.2) are based on data from (a) the Wash (where the ground can be variable over short distances) and (b) off the Lincolnshire coast (where the ground is more homogeneous). The first graph presents the standard layout of the variogram (Burroughs and McDonnell 1998) with the lag shown on a linear scale of distance. In the second graph the lag is on a log scale which expands the pattern of spatial variability over the smaller distance ranges. These graphs indicate that the spatial correlation is quite high over small distances and increases exponentially over moderate distances. The variance then levels off towards a maximum for the data sets (the 'sill') and this point on the graph indicates the maximum range over which interpolation can be justified. It is probably reasonable to assume that this along-track variogram would also hold true for points between tracks and can be used to justify distances over which interpolation can be taken to give more information than simply the local mean. However, the spatial correlation is low at the maximum range and a much smaller distance would be desirable for interpolation.

Figure 8.2 indicate that a good degree of spatial correlation might be assumed for distances of about 500m for both the Wash and the Lincolnshire coast (giving a variance of about 0.05 in both cases) and an upper range of 2.5km, a point at which the variance is about one half the maximum in both data sets. This assumes that there would be some advantage in interpolation over the local average if the acceptable variance was about one half that of the maximum. The corresponding inter-track distances would be twice this figure.

Figure 8.1. Variogram for the Wash and Lincolnshire E1 track data using a linear scale for the lag.

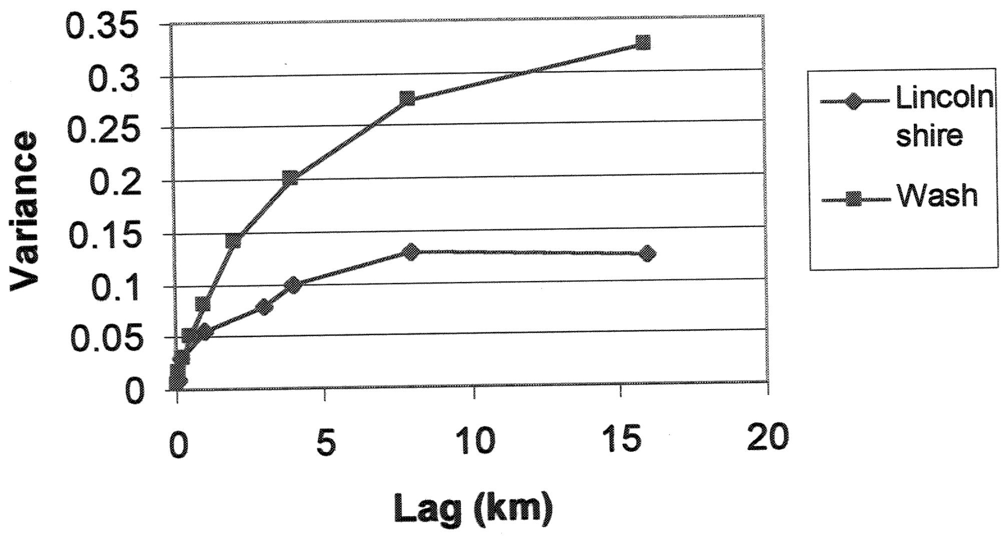
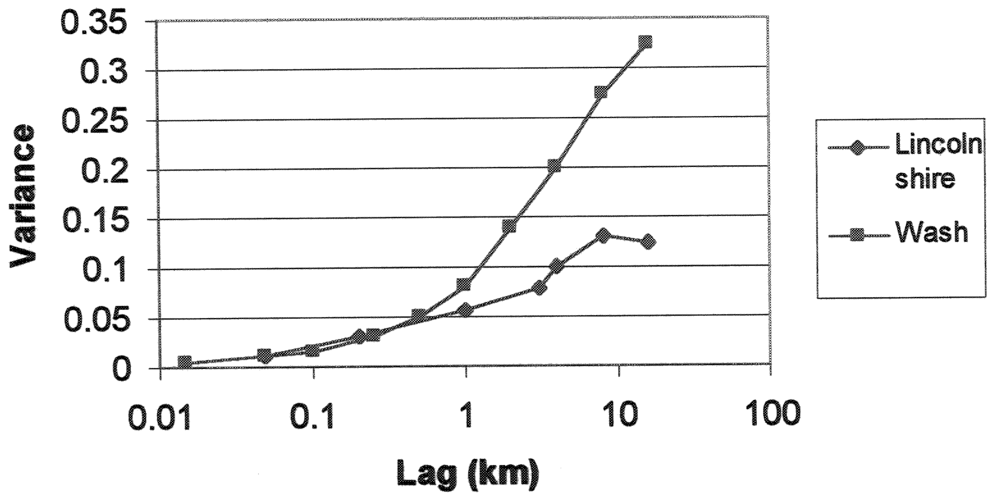


Figure 8.2. Variogram for the Wash and Lincolnshire E1 track data using a logarithmic scale for the lag.



These ranges are guidelines for the survey area and differences in the variogram might be expected throughout the survey area. Nevertheless, these ranges are useful as a means of expressing areas where the uncertainty in the interpolated values might be expected to be high. A zone of 750m and 2.5km either side of the track has been created and is shown as dark and light shaded areas in Figure 8.3. This indicates that the Wash and southern section of the offshore survey area (1996-7 data) have been covered adequately, but that the inter-track distance has exceeded the guideline distance for the north Lincolnshire coast. It was because of this that interpolation in this latter section was supplemented by depth information from the Admiralty hydrographic charts.

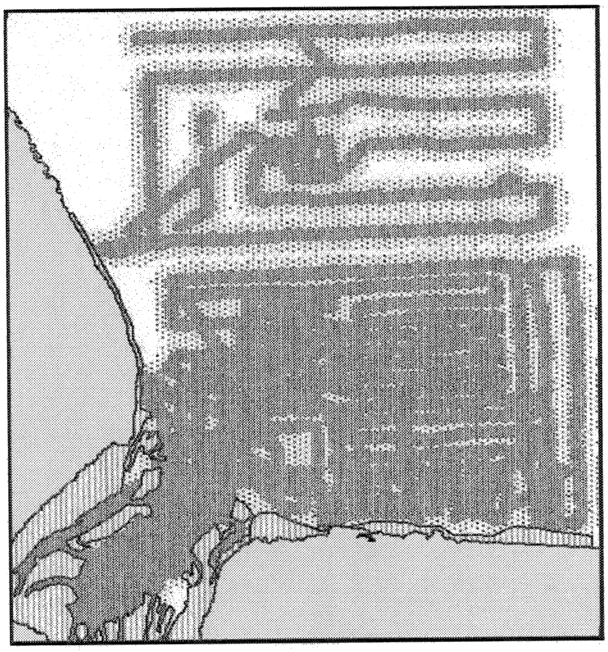


Figure 8.3. Zones around track data indicating areas where interpolation could be expected to return reliable estimated values for E1 and E2 (dark shade) and less reliable estimates (pale shade). Estimates for areas outside of these zones would be the local non-spatial average (see text).

8.2 Using bathymetric data to assist interpolation

There may be situations where the track data are too widely separated to map large topographic features that are shown on hydrographic charts. For example, a ridge might lie north west/south east across a small number of AGDS data tracks that run east/west. The tracks will show these features as short lengths of track of elevated bathymetry that are offset from track to track. Interpolation does not cope well with this type of data and the result will look like a series of offset raised blocks.

Bathymetric information from charts may be used to improve the depth models based on the AGDS and this information is easy to incorporate. However, can bathymetric data also help to improve the interpolation of E1 and E2 values? The results of the simple modelling outlined in the methods section (Section 6.2.2.3) carried out for the Lincolnshire data are shown as raster images in Figure 8.5 as compared to interpolation without this additional modelling in Figure 8.4. Interpolation of the E1 and E2 data using depth contours as constraints appears to improve the images in that the 'jumps' in values between tracks is much less obvious. Since these jumps are clearly an artefact of the tracks, it is assumed that the improved appearance of the images also reflects an improvement in the interpolated values, although this has not been tested against an independent data source.

Figure 8.4. E1 values interpolated for an area of approximately 15km by 25km off the north Lincolnshire coast in the locality of Silver Pit. In this figure the track data have been interpolated without reference to data from the hydrographic charts.

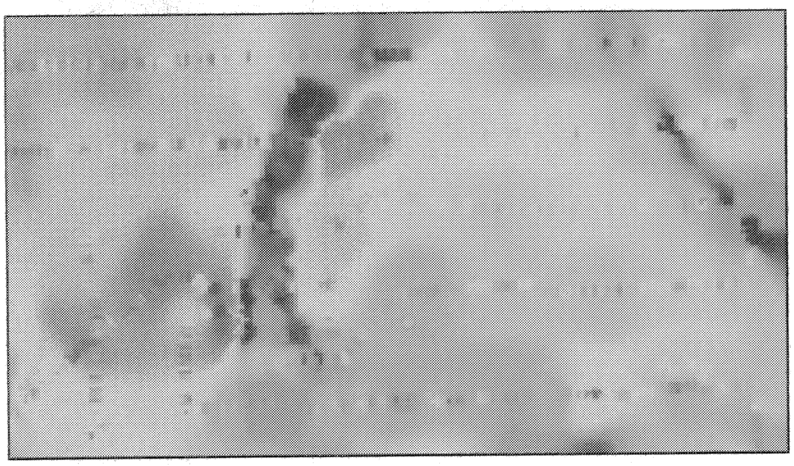


Figure 8.5 the interpolation has been constrained within depth ranges as explained in the text.

8.3 Visualisation of interpolated acoustic data

Most of the tracks were sufficiently closely spaced to justify the use of interpolation being carried out using the track point data. However, the very wide track spacing over much of the northern part of the survey area required a mixture of interpolation and modelling techniques to create a continuous coverage.

The results can be seen in the raster images of the interpolated data for depth, E1 and E2 (Figures 8.6). Although the validity of the interpolation cannot be assessed without testing against an independent data set, the hybrid procedure designed for the uneven distribution of original track data produced images with no obvious boundaries between the different years' data sets.

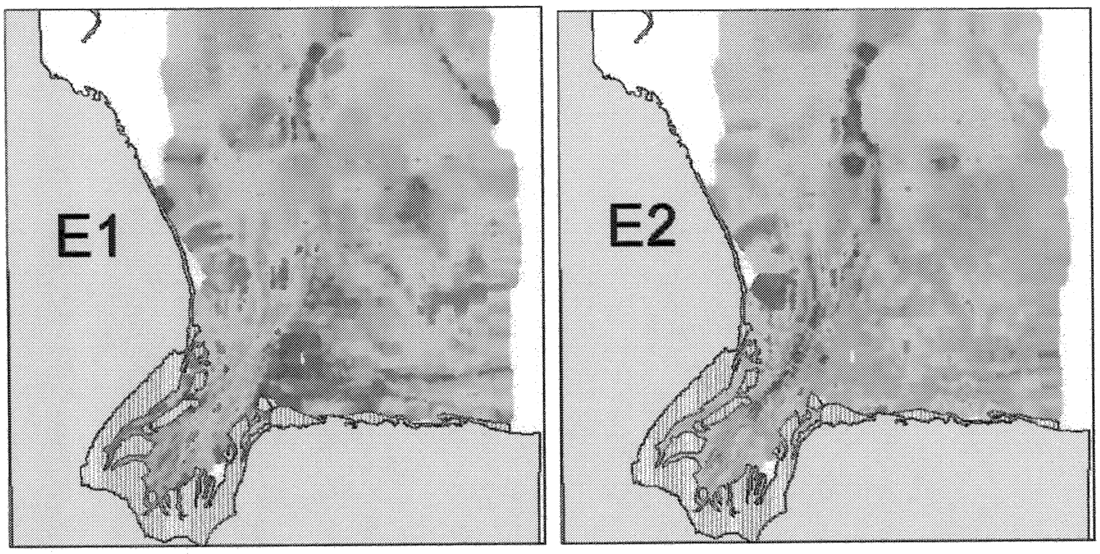


Figure 8.6. Raster images of interpolated E1 (roughness) and E2 (hardness) values. Red represents high values and blue low values.

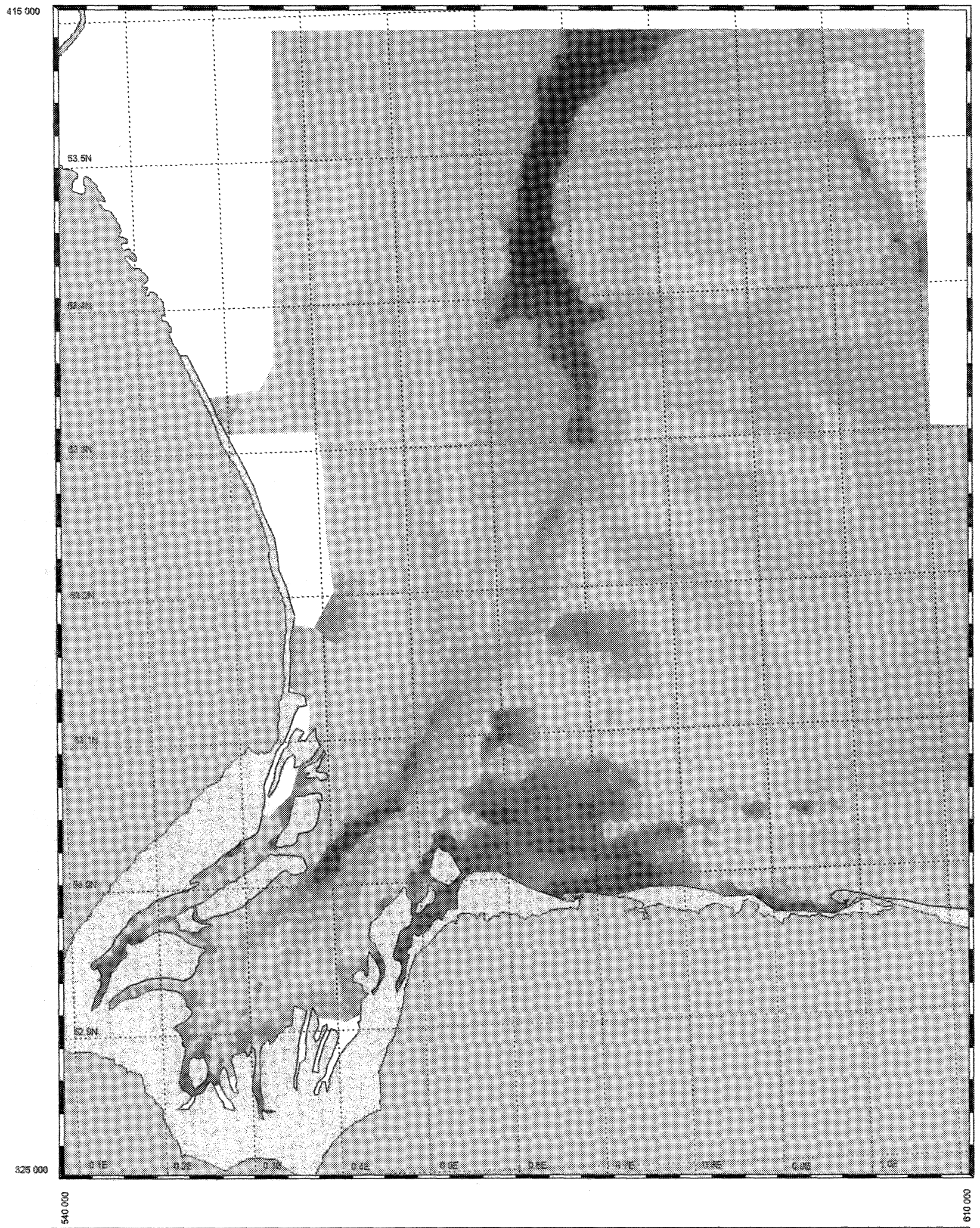
8.4 Bathymetry and digital elevation models

Depths recorded during the survey are shown on Figure 8.7. It should be pointed out that the depths, even after correcting to chart datum and using 10 minute intervals, will not be absolutely accurate since the distance from the nearest reference port varied and, in any case, atmospheric conditions would have affected actual tide heights. Thus, the recorded depths cannot rival the Admiralty charts for accuracy or coverage. However, the interpolated data are in digital form and can thus be used to create a digital elevation model (DEM).

The depth records were found to correspond well with the depths shown on charts and extra depths records were digitised from the charts to complete the DEM without introducing obvious discontinuities between the recorded data and the digitised values. These values taken from the Admiralty charts were used extensively in the 1998 survey area (and to some extent in the adjacent 1997 survey area).

The three dimensional model is shown in Figure 8.8. This illustrates the main topographical features of the region. The deep channel running from the Lynn Deeps to Silver Pit is very obvious, as are various ridges and banks. This model was primarily constructed for draping other maps and is not intended to be a detailed and accurate representation of either the bathymetry or the finer topographical features. The fine north/south striations, for example, are an artefact of the interpolation of the AGDS data and do not represent real features on the seabed

Figure 8.7. Bathymetry (depths corrected to chart datum).



N

0 5 10 15

Kilometres

Scale: 1:500,000

Datum: OSGB36
Projection: UK National Grid.
Grid: Lat / Long (WGS84) 0.1° spacing
Boundary Graticule: OBSG36 2.5 km spacing
File:\\...\Figure8.7.Wor

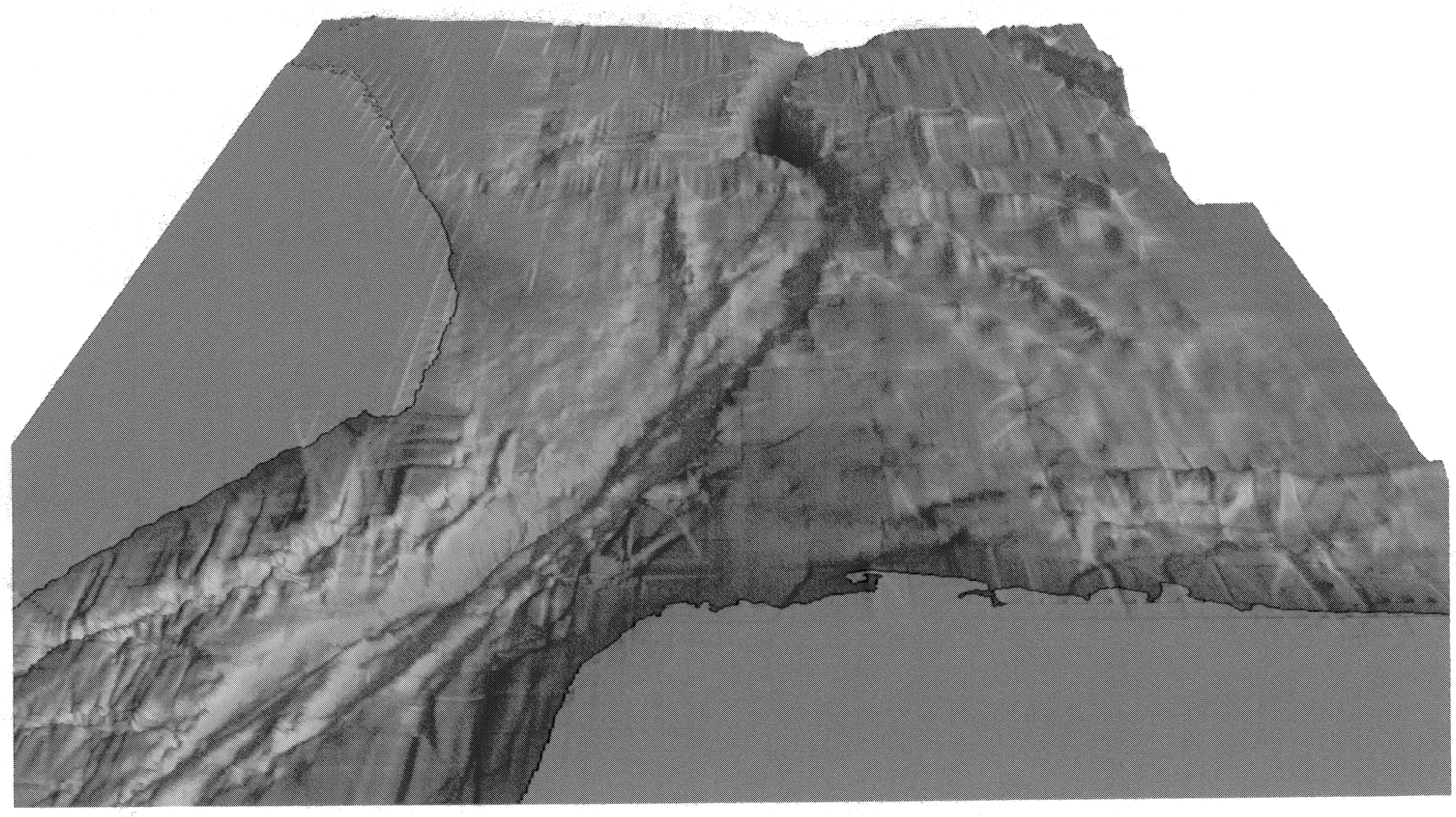
Intertidal: dries

Land

Depths

- 0-5m
- 5-10m
- 10-15m
- 15-20m
- 20-30m
- 30-40m
- 40-50m
- 50-60m
- 60-90m

Figure 8.8. Bathymetric model for the Wash, north Norfolk and Lincolnshire coasts. Colours show depth (see Figure 8.6)



9 Image processing

Purpose: Interpretation of the habitat and biotope maps are illustrated with the results of analyses. This highlights the key stages that have been used to create the maps: (a) calculation of prior probability images for the habitat or biotope categories; (b) track probability plots; (c) interpolated habitat or biotope class probability images, and; (d) maximum likelihood classification. These stages are illustrated with examples. The distribution maps are then presented and described.

9.1 Key stages in image processing

9.1.1 Prior probability images

The conclusion from the analysis of the ground truth data was that the habitat and life form categories should be used for image processing rather than the biotopes (see Section 7.2).

The broad scale trends in the data as shown in the prior probability images express the likelihood of finding a particular habitat or biotope in a sector of the survey area based on what is known about their distribution from the ground truth data. The polygons used for the estimation of likelihood were somewhat arbitrary, but the interpolation 'smoothed' these estimates heavily so that likelihood values did not change sharply at polygon boundaries.

The following maps (Figures 9.1a & b) show an example of prior probabilities applied to the distribution of super-abundant *Sabellaria* (reef) biotopes. Figure 9.1a is the prior probability distribution of the reefs (suggesting where reefs are most likely to be found on the evidence of ground truth data). Figure 9.1b shows the posterior probability after the pixels have been matched to the acoustic signature of the reef biotope. It is important to appreciate that this process will not 'find' a particular biotope where the pixels do not match the biotope's signature. But where a pixel might be classified as either of two biotopes (a) because signatures overlap considerably or (b) because the characteristics of a pixel lie equidistant between two signatures, then the choice is influenced by the prior probability by increasing the posterior probability of one biotope and reducing the probability of the other. Prior probabilities reflect what the analyst believes about the likely distribution of a habitat or biotope before looking at the acoustic evidence. This belief should be justifiable and arrived at in a systematic way.

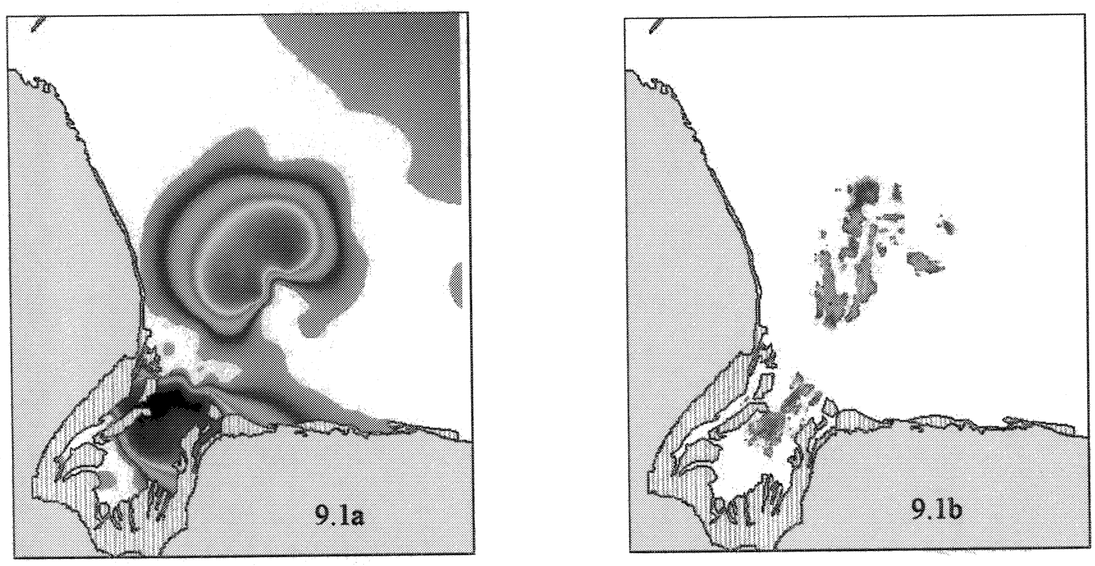


Figure 9.1. A prior probability image (9.1a) has been used to in the calculation of the probability distribution of super-abundant *Sabellaria* (reefs) (9.1b).

9.1.2 Maximum likelihood classification

The maximum likelihood classification can be performed on these images once they have been imported into *Idrisi* using the module *Maxbay*. The interpreted maps were inspected and where there were obvious mismatches between ground truth data and the interpreted images, attempts were made to trace the causes. Often this was due to poor signature development where a 'rogue' sample (perhaps one where the position was wrongly transcribed) introduced erroneous E1, E2 or depth records into the signatures. All doubtful signatures were inspected, using the *Idrisi* histogram tool, to see if some values were obvious outliers. If this seemed likely, then the signature was edited to remove the data and the classification process re-run.

Nevertheless, many mismatches remain, but it is important not to introduce a level of subjectivity into the editing process to bias the interpretation along a particular direction. It is better to accept the errors and interpret what implications they have for the map in general terms.

9.2 Sediment distribution maps

The map of the sediment types is shown in Figure 9.2 and this has been draped over a 3D model of bathymetry in Figure 9.3. Inspection of the BGS sea bed sediment maps (sheets for Spurn and East Anglia) show that there is broad overall agreement between the BMP surveys and the BGS maps. The main difference between the two maps, apart from detail, lies in the extra information the BMP survey adds with regards to the presence of larger sediment (cobble and boulders). This information is of great significance to biotope mapping because of the importance of epifauna, which is dependent upon solid surfaces for its development.

Most of the sediments were predominantly sandy grading into gravel or silty sand. All these sediments were found with a variable shell and cobble component. Mud was found only on the steep western sides of the Silver Pit. This general picture accords well with the account of sediments given by Cameron *et al.* (1992). Although interpretation of the acoustic map tends to smooth sharp boundaries between sediment types and accentuate continua, it would appear that there are distinct boundaries between sand and cobble around the deep channel running from the deep Lynn Deeps towards Silver Pit. It also seems that there is a stratum of cobbles lying around the edges of the Docking Shoal and Burnham Flats (and probably underlying the sandbanks (Cameron *et al.*, 1992).

Bedforms

Examples of the sonargrams from the sidescan tows are shown in Appendix 4 and the position of the tows on Figure 9.4. The distribution of sand waves accords well with the account of this bedform in Cameron *et al.* (1992) in that they appear on the northern flank of Burnham Flats and run at right angles to the main tidal flow.

9.3 Biotope distribution maps

The interpretation of the acoustic data has been achieved by using the known broad spatial trends in the distribution of the biotopes (from the ground truth data) as the prior probability images in the maximum likelihood classifier (see Section 6.2 for explanation). Note that the maps show the most likely biotope and that there may be a high degree of uncertainty where two or more biotopes have almost equal levels of likelihood. The implications of this will be discussed in the following Section.

The whole area of the Wash and the Lincolnshire and north Norfolk coasts is very large and the Wash was surveyed to a much greater intensity than for the trial survey areas as a whole. This was the result of logistics (the ESFJC's vessels are based in Sutton Bridge) and the demand for specific detailed information from the Wash and north Norfolk coast cSAC. For this reason, two levels of interpretation were carried out: (a) The whole trial area and; (b) the cSAC. These interpretations were carried out separately, but using identical techniques and a subset of the ground truth and acoustic data that lay within the cSAC for the latter interpretation.

Six distribution maps have been prepared as set out in the Table below:-

Table 9.1. Biotope distribution maps.

Area	Subject	Figure number
The whole trial area	Infauna; plan	Figure 9.5
	Epifauna; plan	Figure 9.6
	Infauna; 3-D	Figure 9.7
	Epifauna; 3-D	Figure 9.8
The cSAC	Infauna	Figure 9.9
	Epifauna	Figure 9.10

The whole-area maps and the cSAC maps are complementary in that the former gives a more general picture than the latter. There are some areas where there is apparent conflict between the two interpretations, but these are largely between similar biotopes. Many of the smaller biotope polygons shown on the maps for the cSAC are subsumed into larger polygons in the whole-area maps.

9.3.1 Infauna

Sabellaria biotopes were well distributed with the richest reefs bordering the channel running from the Lynn Deeps to Docking Shoal/Scott Patch. The *Sabellaria/Lanice* gravel was widely distributed throughout the survey area. The silty *Sabella discifera/Sabellaria* biotope was found scattered throughout the area including a large area to the east and south of Docking Shoal which was predicted to support this biotope. The *Abra* biotope was largely found in the Wash, although it was also found in Silver Pit.

The cleaner, coarser sand biotopes were typical of large areas both within the Wash and further offshore. The area to the west of Silver Pit, off the north Lincolnshire coast, was coarse-grained and supported a community of motile carnivorous polychaetes and nemerteans whilst the extensive sand banks of Burnham Flats and Woolpack supported *Nephtys/Bathyporeia* and *Lanice* communities. *Ensis* was found in a restricted locality on Middle Bank, although it was also predicted to be present at other locations on Burnham Flats.

The more detailed biotope maps of the Wash have subdivided the *Abra* biotopes and show a more complicated pattern of biotopes associated with coarser sediments (in particular *Nephtys/Bathyporeia*) intermixed with *Abra* biotopes.

Super-abundant *Sabellaria spinulosa* (termed 'reef', see Section 7.2.2.3) were associated with the Lynn Deeps.

9.3.2 Epifauna

Much of the *Sabellaria/Lanice* gravel supported a moderately rich to rich bryozoan/hydroid turf, although the richest faunal turf lay in the Lynn Deeps. The large areas to the north east of Docking Shoal and the north Lincolnshire coast were insufficiently sampled, but the prediction

Figure 9.2. Distribution of sediments predicted from the acoustic and ground truth data.

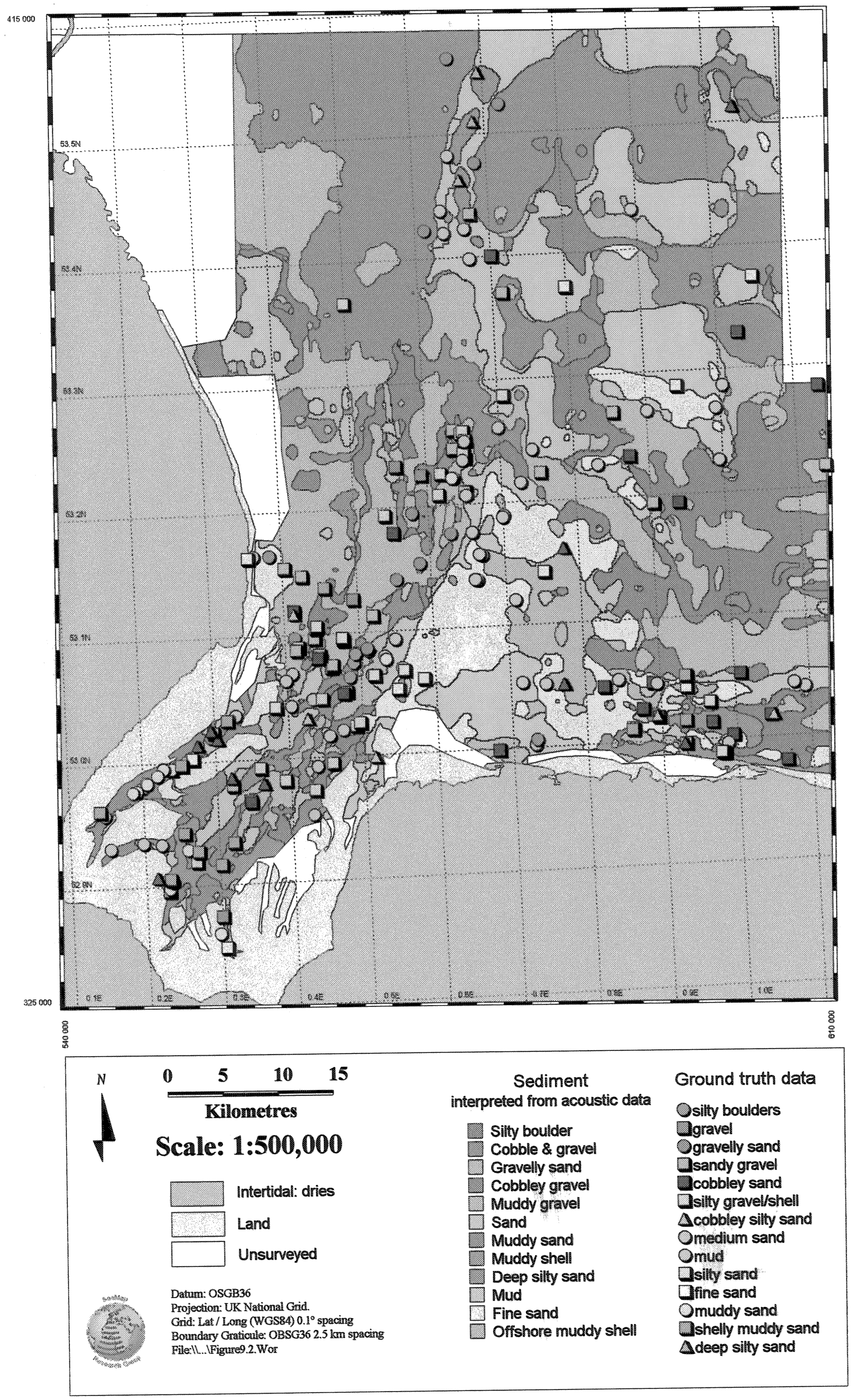


Figure 9.3. A drape of the infaunal biotope map over the bathymetric model of the survey area.

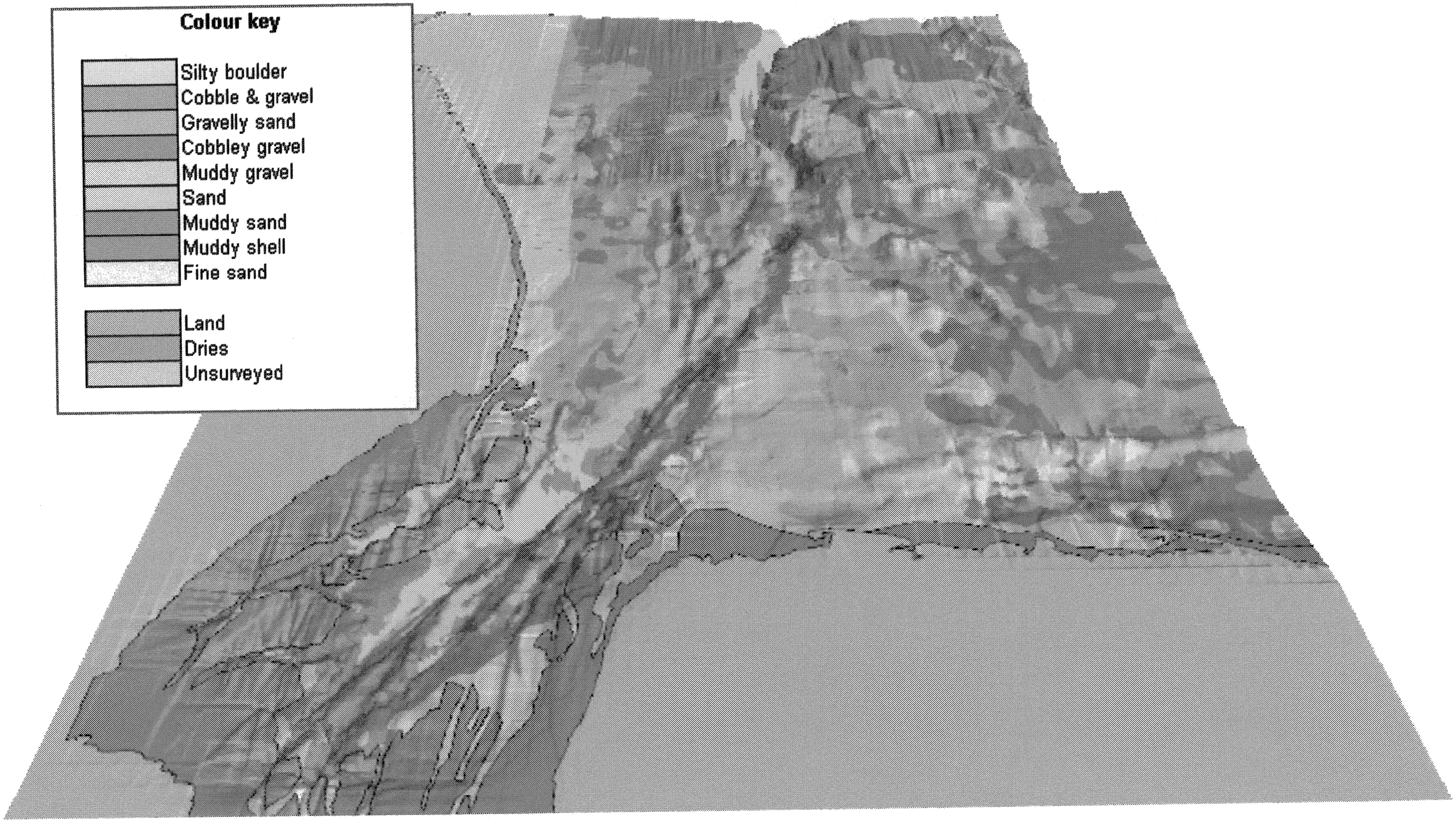


Figure 9.4. Position of sidescan tows.
See Appendix 4 for examples of side-scan sonar images.

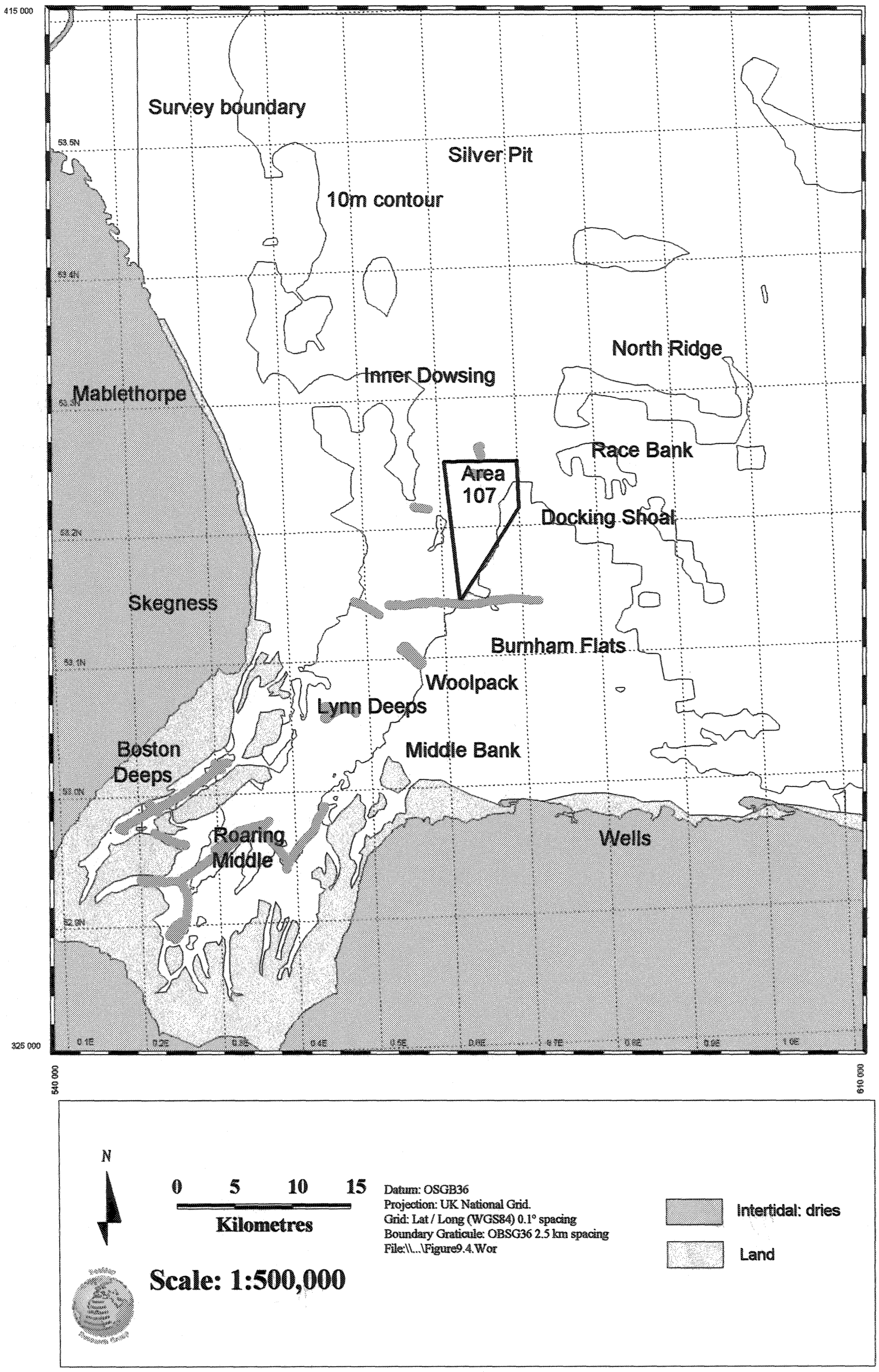


Figure 9.5. Distribution of the infaunal biota predicted from the acoustic and ground truth data.

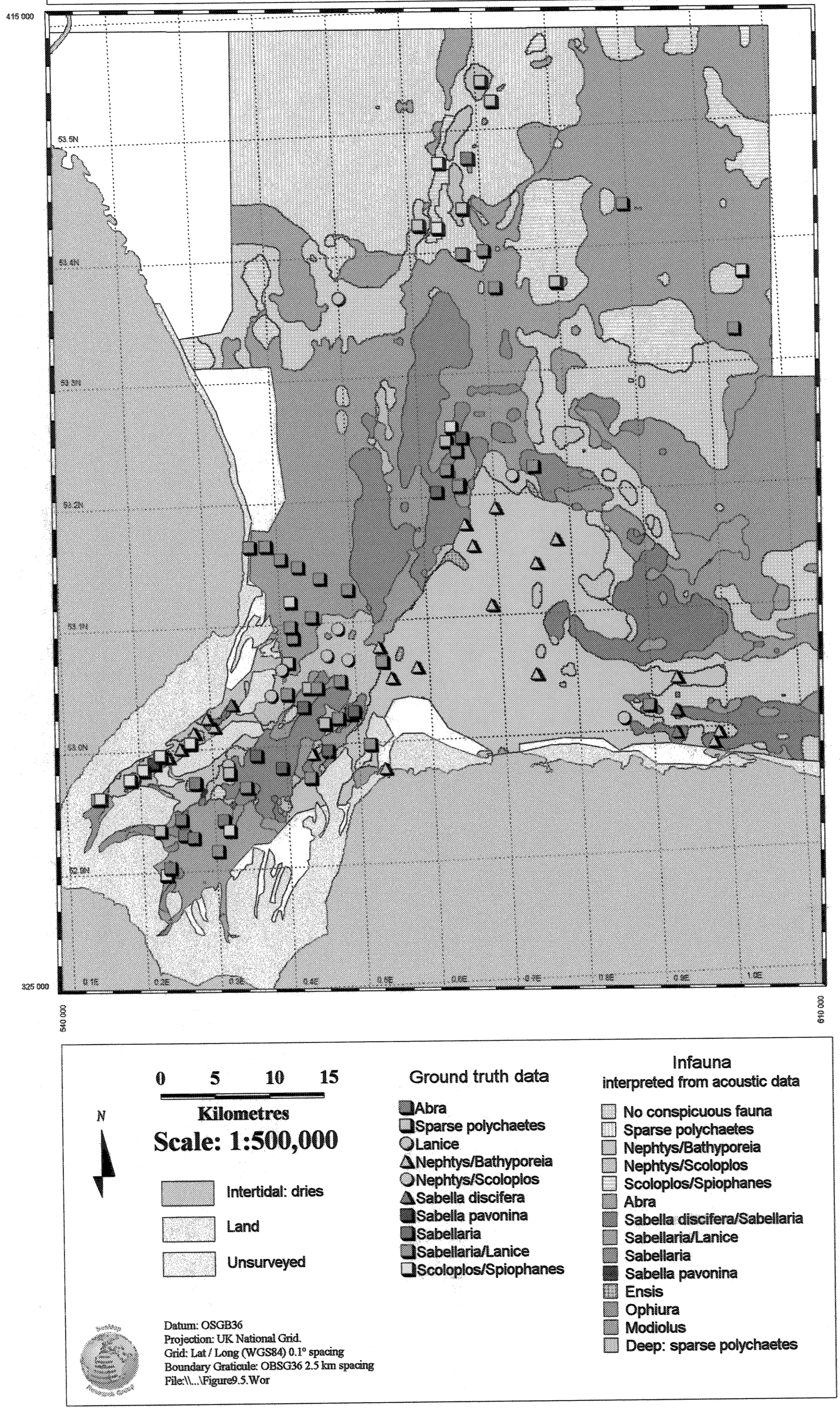


Figure 9.6. Distribution of the epifaunal biota predicted from the acoustic and ground truth data.

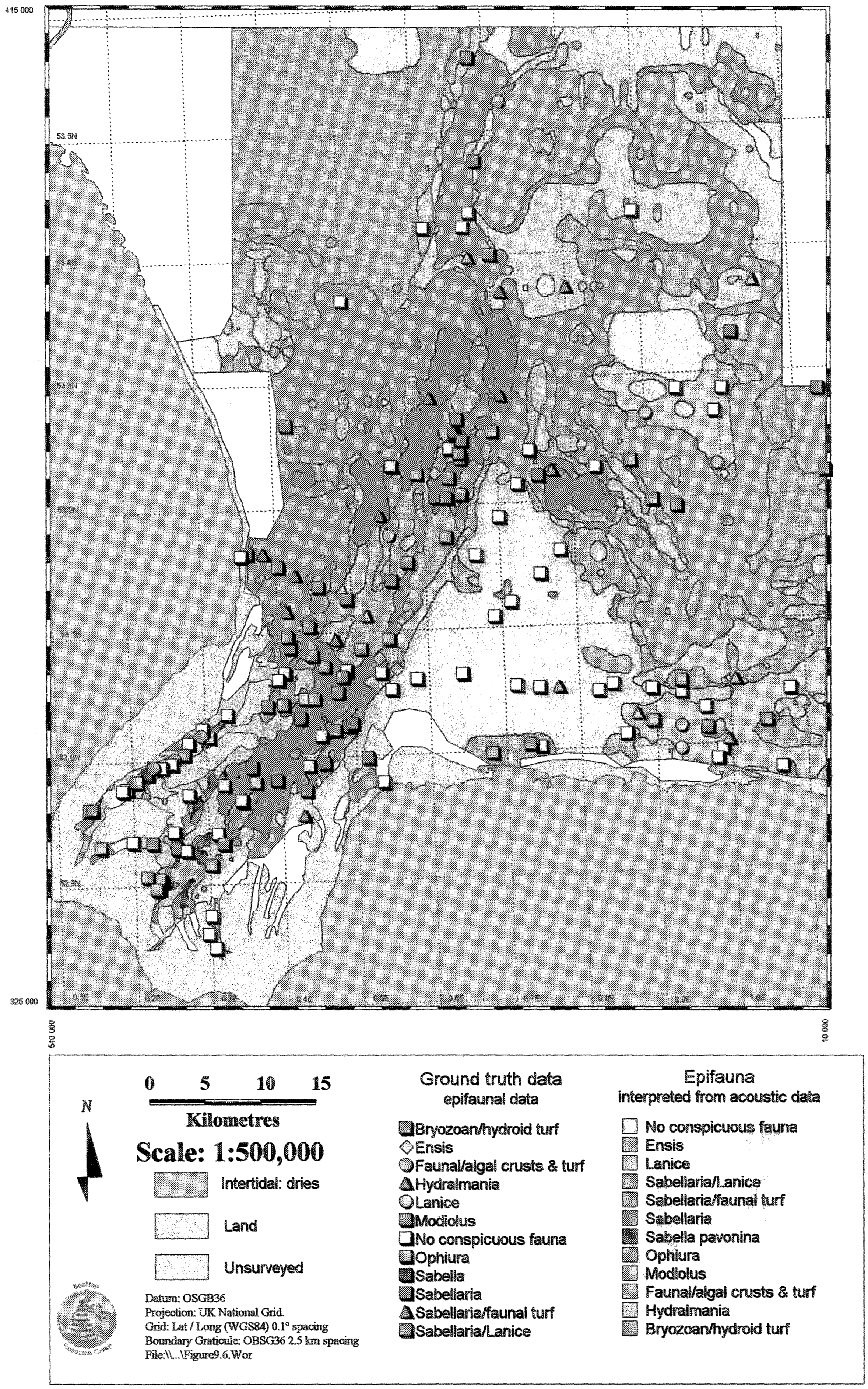


Figure 9.7. A drape of the infaunal biotope map over the bathymetric model of the survey area.

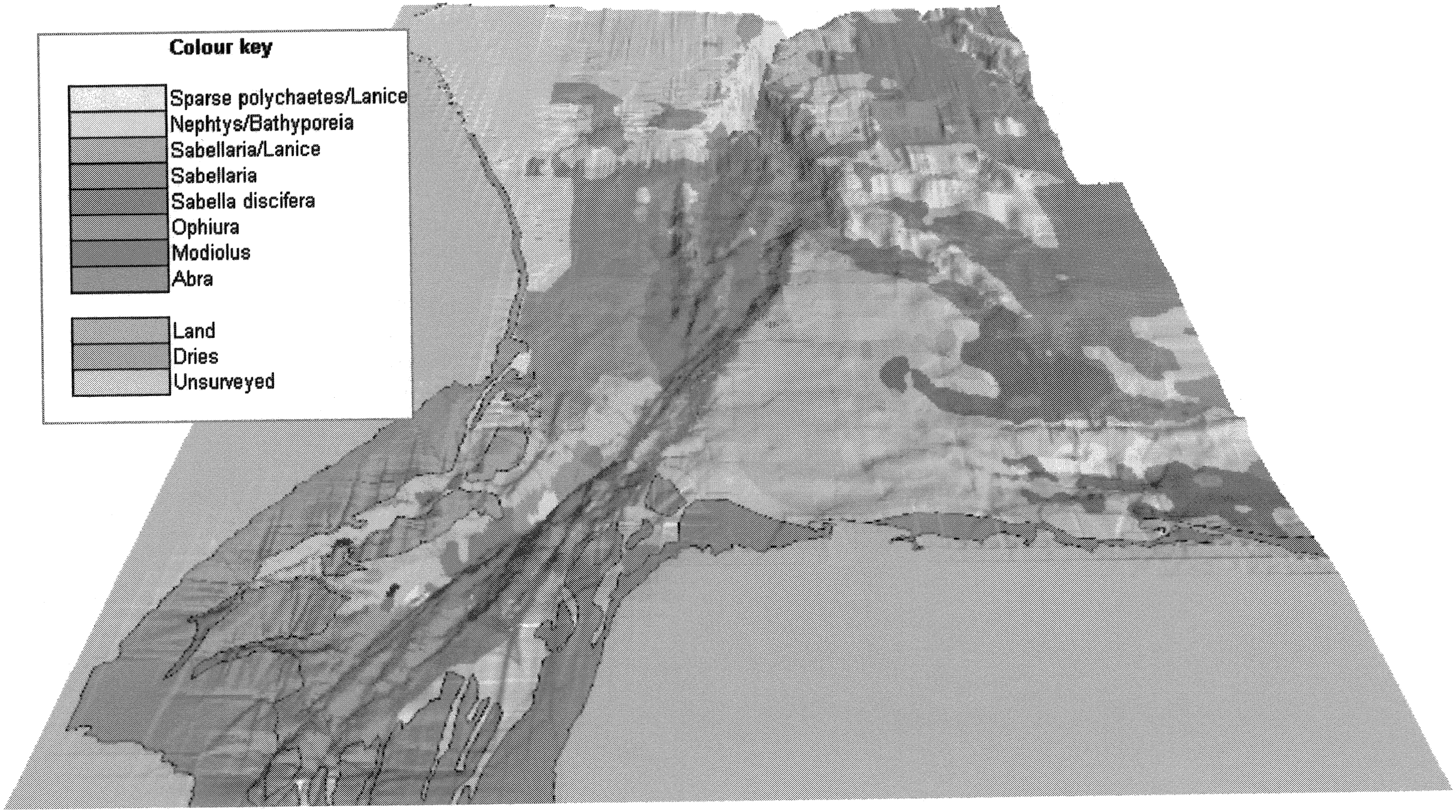


Figure 9.8. A drape of the epifaunal biotope map over the bathymetric model of the survey area.

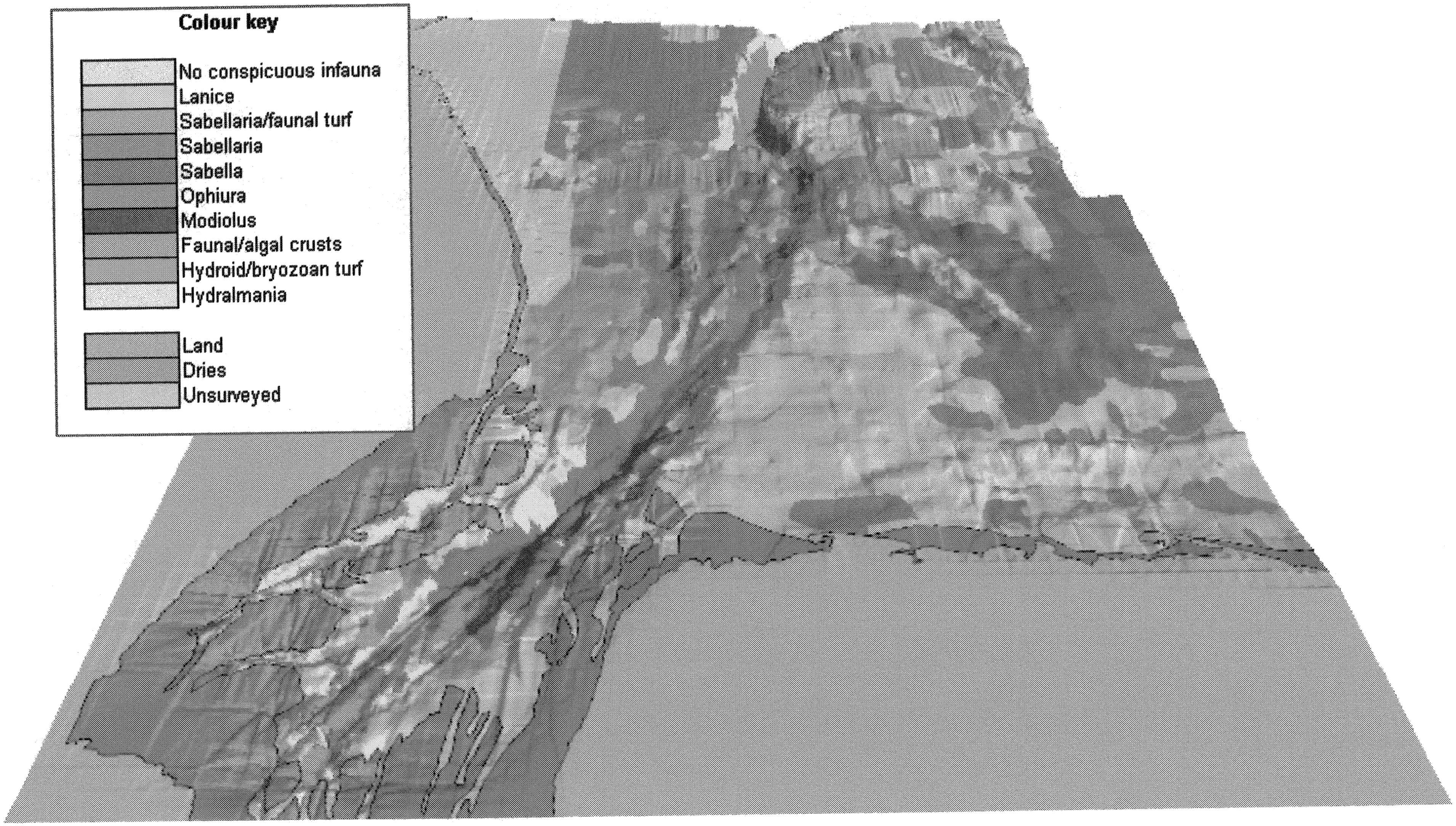


Figure 9.9. Distribution of the infaunal biota predicted from the acoustic and ground truth data for the Wash.

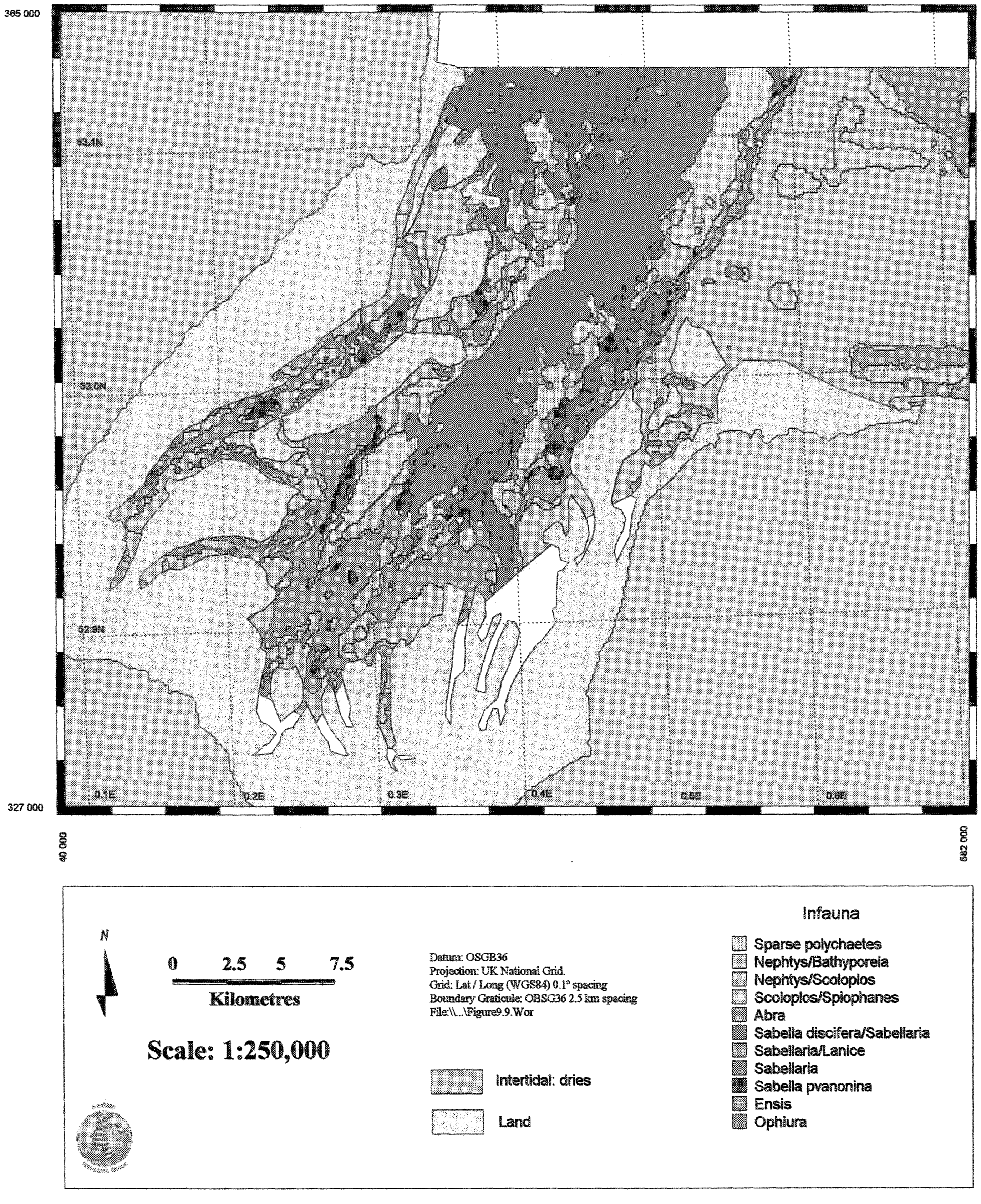
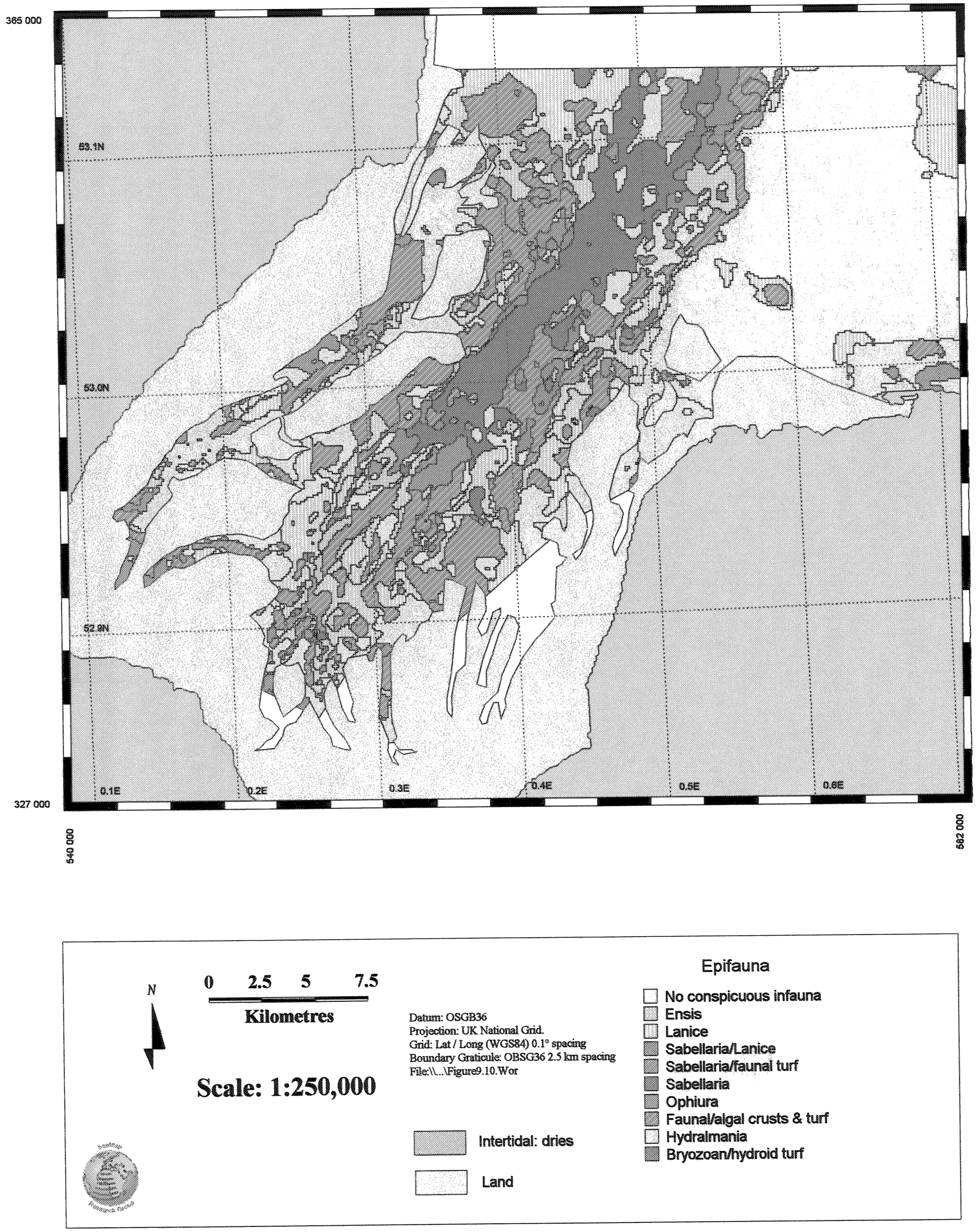


Figure 9.10. Distribution of the epifaunal biota predicted from the acoustic and ground truth data for the Wash.



is that much of this area will be a combination of bryozoan/hydroid turf, *Sabellaria* gravel and *Modiolus*.

The offshore areas of the north Lincolnshire coast were also predicted to have a significant epifaunal component. Inshore of Silver Pit the ground was hard and rough with a bryozoan/hydroid turf whilst east of Silver Pit the coarse sand probably supported a shorter bryozoan turf with encrusting fauna and *Hydralmania*.

9.4 Accuracy assessment

9.4.1 Internal accuracy

The internal accuracy assessments for infaunal and epifaunal biotope maps are given in Tables 9.2 and 9.3. Note that the diagonal gives the number of pixels in each image (the ground truth and the classified map) that were in agreement. Reading figures along the rows indicates those pixels which were classified on the map as one biotope whereas in fact the ground truth data showed the pixels to have been another biotope. These are errors of commission. Reading the figures down the columns indicates those pixels from the ground truth image that showed the ground to be of one biotope whereas they were classified as another biotope on the map. These are errors of omission.

Table 9.2. Error matrix for the infaunal biotope map of the whole survey area.

Rows: As classified on map	Columns: As classified in ground truth image												
	Lanice	PolyNem	NepBat	NepSco	ScoSpi	Abra	Sabdisc	SabLan	Reef	Sabpav	Ensis	Ophiura	Modiolus
Lanice	20	4	7	0	0	0	1	0	0	0	0	0	0
PolyNem	0	28	0	0	14	11	0	11	0	0	0	0	0
NepBat	7	0	92	16	23	1	0	12	0	7	0	0	0
NepSco	0	11	2	41	0	5	4	14	0	0	0	0	0
ScoSpi	0	7	0	0	0	0	0	0	0	0	0	0	0
Abra	0	0	0	0	7	25	0	7	0	0	0	10	0
Sabdisc	0	0	12	0	0	0	17	7	0	0	0	0	0
SabLan	0	14	11	7	18	0	0	125	16	0	8	7	0
Reef	7	4	5	1	1	0	0	38	53	0	0	6	0
Sabpav	0	0	1	0	0	0	0	0	0	8	0	0	0
Ensis	0	0	0	0	0	0	0	0	0	0	8	0	0
Ophiura	0	6	0	0	12	11	0	13	0	0	0	22	0
Modiolus	0	0	0	0	0	0	0	0	0	0	0	0	21

The overall agreements between both the infaunal biotope map and the epifaunal biotope map and their respective ground truth images are only moderately good (Table 9.4). The proportion 'correct' is the easiest statistic to interpret and is a simple pixel match between ground truth image and map. However, allowance may be made for chance correct predictions and the Kappa index gives a measure of agreement that takes this into account (Wilke and Finn 1996). If agreement was purely by chance, then the Kappa value would be zero. Very poor matches within some categories compromise the values. For example, the biotope

Scololepis/Spiophanes would appear to be very poor in terms of discrimination and, perhaps, should be amalgamated into another biotope class.

The matrix gives some idea as to which biotopes were likely to be confused with each other. For example, reefs were likely to be confused with *Sabellaria/Lanice* both through commission

Table 9.3. Error matrix for the epifaunal biotope map.

Rows: As classified on map	Columns: As classified in ground truth image: Ensis	Lanice	Sab/Lanice	Sab/turf	Reef	Sabella	Ophiura	Modiolus	Crust	Hydralmania	Bry/hyd
Ensis	35	0	9	0	0	0	0	0	0	0	11
Lanice	0	64	14	12	0	0	0	0	0	24	23
Sab/Lanice	0	0	70	0	10	0	0	0	0	0	10
Sab/turf	11	0	42	44	9	0	0	0	0	12	32
Reef	1	0	90	25	84	0	13	0	0	32	37
Sabella	0	0	12	0	0	25	0	0	0	0	0
Ophiura	0	0	0	0	0	0	41	2	1	1	0
Modiolus	0	0	0	0	0	0	0	43	0	0	12
Crust	0	0	13	0	0	0	30	2	29	0	12
Hydralmania	0	0	0	9	0	0	0	0	0	32	23
Bry/hyd	0	1	0	0	0	0	12	0	0	13	99

and omission. These biotopes are, indeed, very similar to each other. Confusion was also likely to be experienced between *Ophiura albida* and *Abra* biotopes that are also similar.

Table 9.4. Overall agreement values between ground truth image and map.

	Proportion correct	Kappa agreement
Infauna	0.542	0.30
Epifauna	0.564	0.36

Bryozoan and hydroid turf was much more widespread than is indicated by the epifaunal biotope map, as indicated by the confusion in the image processing between the bryozoan/hydroid turf biotope complex and others where a bryozoan/hydroid turf component formed part of the description. It is likely that this turf overlies a wide range of primarily infaunal biotopes and is variably represented in them, rather than forming a distinct biotope in its own right.

It should be remembered that these accuracy figures give a guideline only as to the reliability of the maps. It should also be remembered that the biotopes are not distinct entities, but grade into each other or overlay each other. Samples that lie between biotope categories must be expected. When they occur, they cause confusion by through inconsistent categorisation of the samples into biotope types. Since they are also physically quite similar and overlap with one another, there will be overlap in the acoustic signatures. This blurring of distinctions between biotopes is reflected in the pattern of errors of commission and omission as seen in the error matrices.

It must also be remembered that the automated classification of the acoustic data has picked the most likely biotope. Although others may also be expected to occur, these are 'hidden' by the most probable biotope. With this in mind, alternative ways of mapping biotopes are a useful complement to the maximum likelihood classification. These are presented in the next Section.

9.4.2 External accuracy

External accuracy assessment involves the use of an external sample data set not used in image processing. External sample data sets are only available for the Wash (Dipper *et al.*, 1989; National Rivers Authority, 1994). Strict comparison between surveys is difficult because (1) the emphasis on different sampling methods varies from survey to survey, (2) they are separated by a number of years and, (3) the positions of the samples were estimated in different ways.

An attempt has been made to assess the match between the CSD survey (Dipper *et al.*, 1988) and the BMP biotope map (Figure 9.11). The sample data in the CSD report was reduced to a small range of broad categories. These were:-

Table 9.5. Communities identified from the CSD report (Dipper *et al.*, 1989) compared with biotopes from the BMP survey.

Lanice	Sand with variable amounts of *Lanice*, probably equivalent to *Nephtys/Bathyporeia* and *Nephtys/Scoloplos*
Epifauna	Any sample in which bryozoan/hydroid turf and/or *Flustra* was recorded as common to abundant.
Ophiura	Any sample in which *Ophiura albida* and/or *Ophiura ophiura* was recorded as common to abundant. Probably equivalent to *Abra* infaunal biotopes
Sabellaria	Any sample in which *Sabellaria* was recorded as common to abundant. Equivalent to *Sabellaria/Lanice, Sabella discifera* and *Sabellaria* reef biotopes.
Sabella	Any sample in which *Sabella pavonina* was recorded

Figure 9.11 shows there to be a reasonably good match, bearing in mind positional inaccuracies, between the *Ophiura* CSD communities and the *Abra* biotopes and the *Sabellaria spinulosa* CSD communities and biotopes. The *Lanice* CSD communities are probably more scattered over the area than predicted from the BMP survey although they seem to be associated reasonably well with the coarser sediment biotopes.

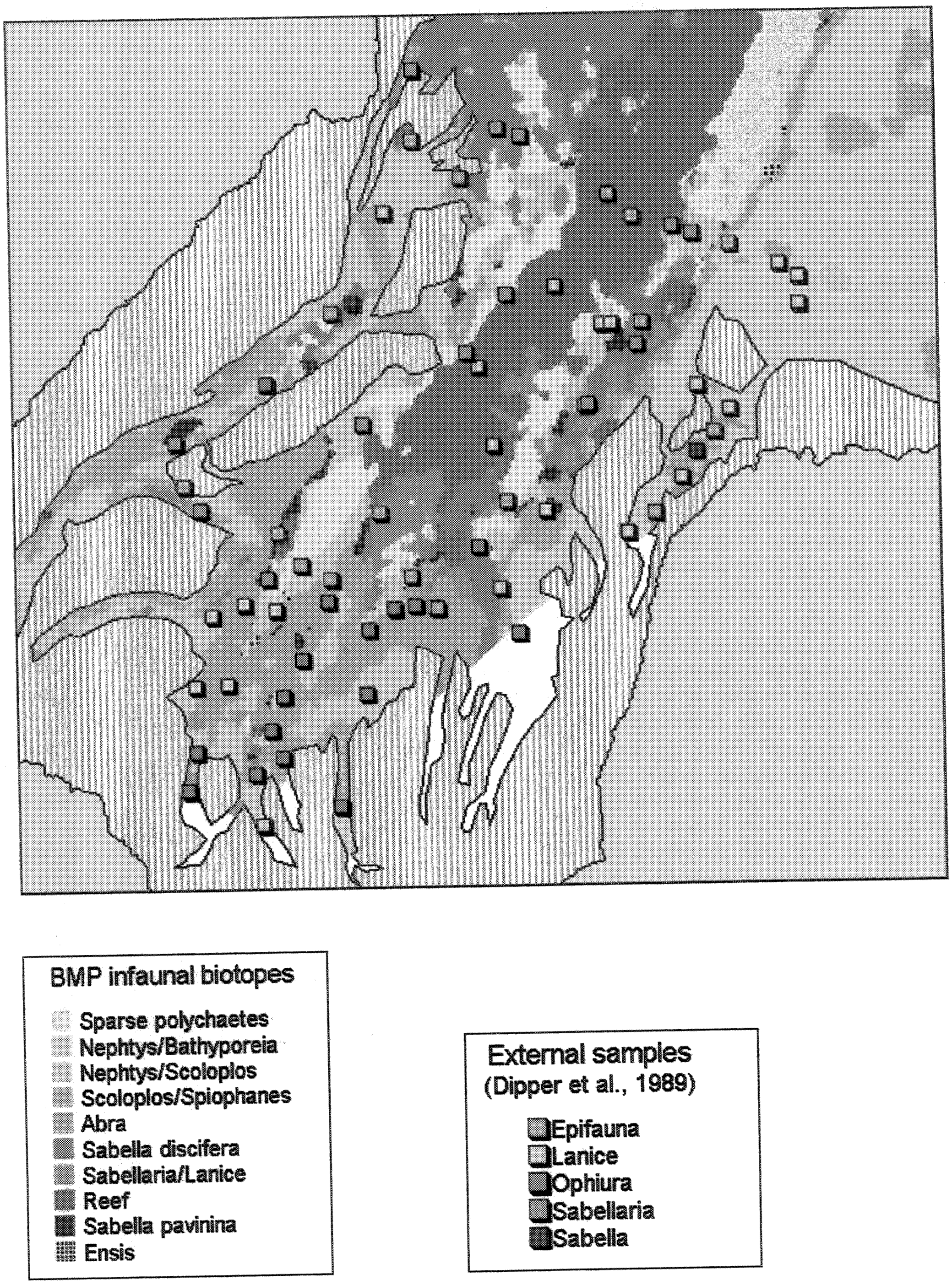


Figure 9.11. The broad community categories taken from the CSD report (Dipper *et al.*, 1989) superimposed on the infaunal biotope distribution map from the BMP survey of the Wash.

9.4.3 Certainty of classification

Certainty (see Section 6.2.5.3) is a measure of the probability of a pixel belonging to the most likely habitat or biotope class. It must be stressed that this is a mathematical process and is not a direct measure of the accuracy of the map. Figure 9.12 shows the maximum probability for each pixel in the image using the infaunal biotope classes. The map shows that the certainty is low for much of the northern sector of the survey area, which is to be expected bearing in mind the track spacing and relatively low level of ground truthing. There are some parts of the Wash, however, where certainty is also low despite a much greater intensity of survey. This is probably a reflection of the extent to which various classes overlap. The *Modiolus* biotope can be given as an example of why caution must be used when interpreting these maps. The *Modiolus* biotope is predicted to occur over quite large parts of the seabed off the Norfolk coast. The acoustic signature for this biotope is quite distinctive and, if a pixel is attributed to the *Modiolus* class, then the probability is high. However, the ground truth samples for *Modiolus* are few in numbers. Thus, although the ground is acoustically distinctive, its links to *Modiolus* may not be as strong as the certainty map suggests.

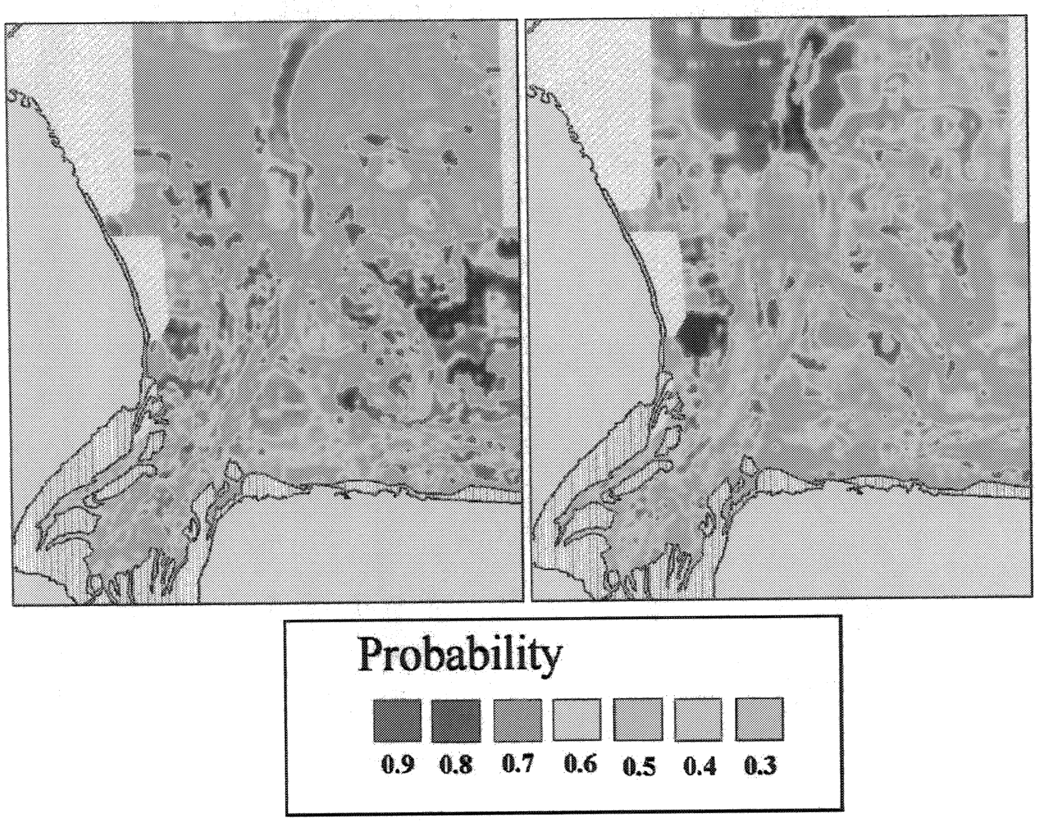


Figure 9.12. The certainty map for the infaunal biotopes (a) and epifaunal biotopes (b)

The certainty map for the epifaunal biotopes reflects, in general, the predominance of the epifaunal component of biotopes. In other words, the probabilities are highest where the epifaunal biotopes were found. The class 'no conspicuous fauna' is too broad a catchall category to have a distinctive acoustic signature and the probabilities are low where it was predicted.

9.5 Biotope probability distributions

The values for E1, E2 and depth for each pixel are matched to the acoustic signature during the classification process. Pixels whose values which lie close to the acoustic signatures (i.e., the mean values of E1, E2 and depth for the biotope signature) will be given a high likelihood of belonging to that biotope class and the likelihood decreases with distance away from the mean. If there are large overlaps between different signatures, which is often the case, then the mean values for E1, E2 and depth of a pixel might lie within the signature 'envelope' of more than one biotope. It is then given a likelihood of membership to each biotope (zero if outside the envelope or a value up to 1).

Maximum likelihood assigns a pixel to the biotope with the highest likelihood score. However, as has been discussed previously, the margin by which this selection has been made might be small. Very different classifications might result with small changes in E1, E2 or depth values.

However, the likelihood values for each biotope can be displayed. These can also be modified by the prior probability of finding the biotope in an area, as determined by broad trends in biotope distribution established from the ground truth or other data. Examples are given below (Figure 9.13) of biotope probability maps that have taken these broad trends into consideration (see Section 6.2.4).

The likelihood maps also show the areas that have been classified as being those biotopes using maximum likelihood. The boundaries for probabilities greater than 0.1 for super-abundant *Sabellaria* and *Nephtys/Bathyporeia* biotopes agree well with the distribution of these biotopes as determined by maximum likelihood. There is also reasonably good agreement between likelihoods >0.1 and the maximum likelihood for *Abra* in the Wash but *Abra* may be more widely distributed than the maximum likelihood classification suggests in the north of the survey area. However, other biotopes (particularly sparse polychaetes/nemerteans) have been predicted at a greater likelihood for much of this area.

Sabellaria/Lanice, on the other hand, has been selected as the most likely biotope for large areas offshore although the likelihood is low (<0.1). This would indicate that there is a high level of uncertainty over much of this area, despite the fact that *Sabellaria/Lanice* was the only biotope found (see the ground truth samples as displayed on Figure 7.4 & 7.5) within the appropriate biotope boundaries. Thus, although likelihood is low, *Sabellaria/Lanice* is still the best prediction and this is confirmed by the ground truth data.

The probability maps can be overlain on 3-D bathymetric models, together with other information, to produce images that are useful for demonstrating the spatial relationship between a particular biotope and topography. Figure 9.14 is an example where the probability of finding *Sabellaria* reefs has been draped over a model of the sandbanks around the licensed aggregate extraction area 107. This indicates that the reefs are more likely to be found on the sides of the channels than elsewhere.

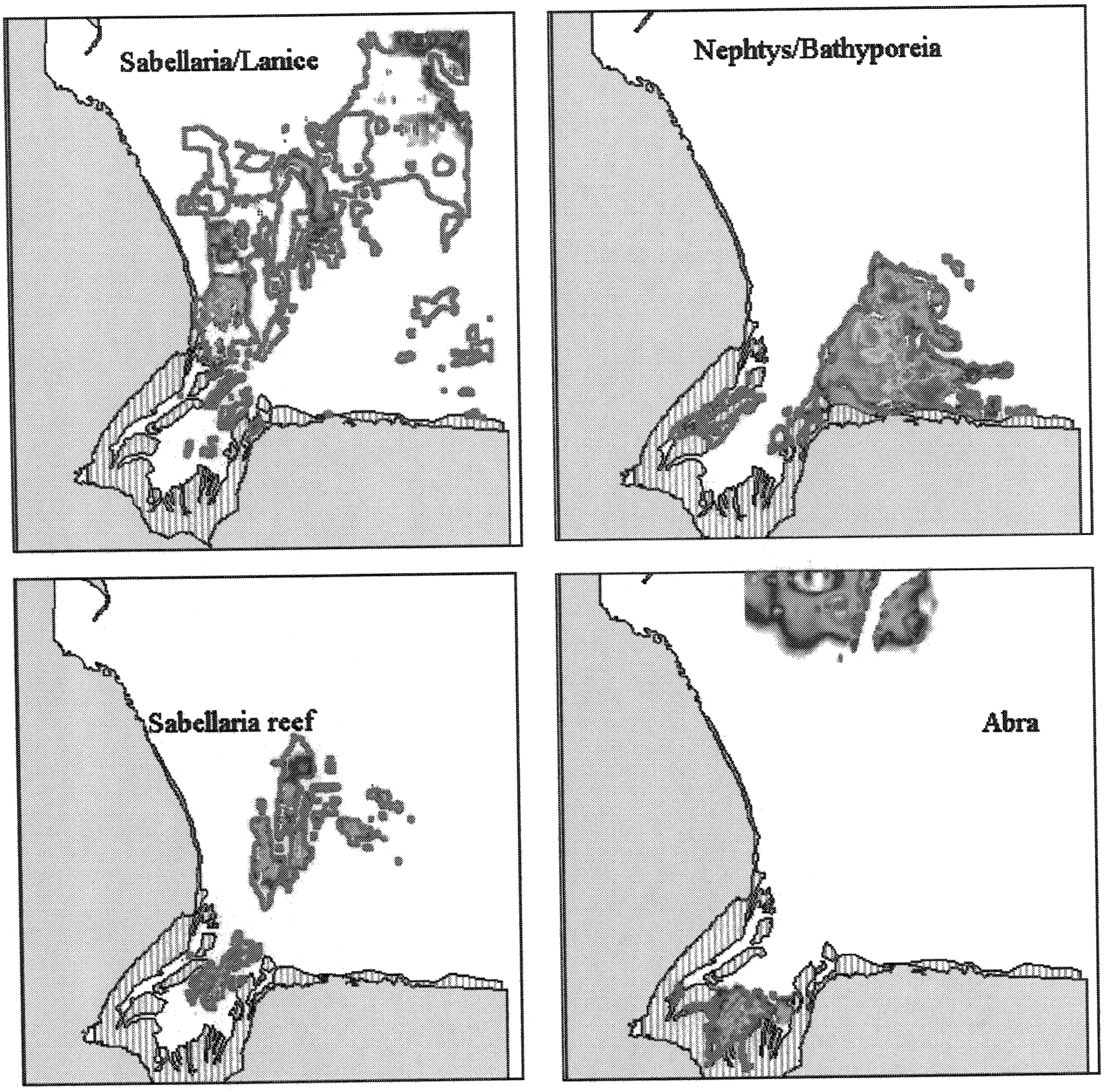


Figure 9.13. Examples of likelihood maps for four different biotopes. Blue = likelihood of 0.1; red = likelihood of 0.9. Likelihoods <0.1 have been excluded to simplify the maps. The red lines enclose areas that have been classified by the maximum likelihood classification procedure (i.e., the areas enclosed by the red lines have been classified as being the corresponding biotope whilst all areas outside of the red line have been classified as some other biotope).

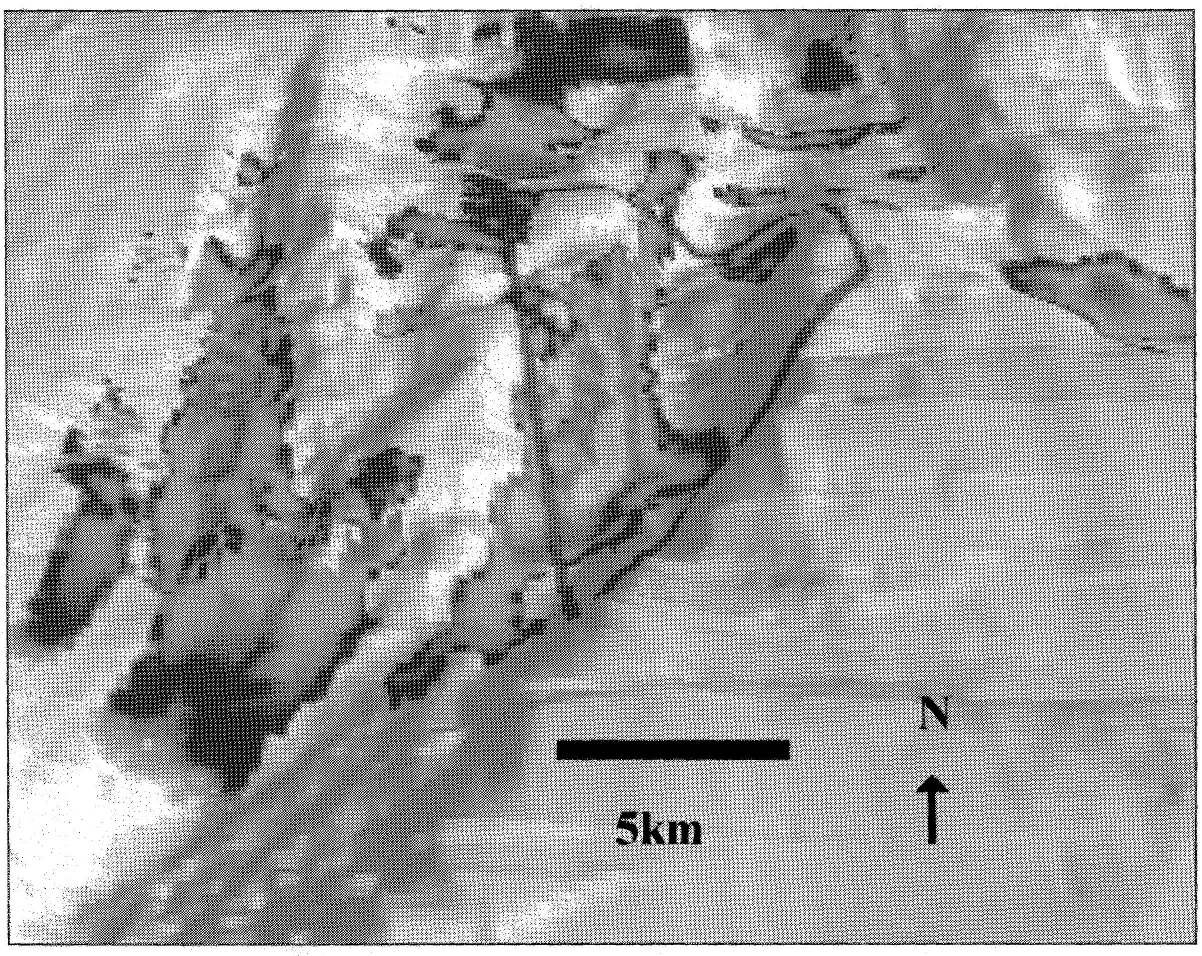


Figure 9.14. The probability of the occurrence of *Sabellaria spinulosa* reefs in the vicinity of the aggregate extraction area 107 (marked with a red outline). The probability map for *Sabellaria* has been draped over a DEM for the area.

9.6 Life form and MNCR colour palettes

Grab samples were the primary tool for ground truthing and the infauna were analysed in some detail supplemented by video and dredge samples. Hence, the level of information and detail of the infauna was commensurate with the level of detail of the data used in the construction of the MNCR biotope classification. Thus, it was possible to describe the ground truth samples to the biotope level. Indeed, it was often felt that biotopes could be further subdivided into local variations on the basis of the detail collected and their distinctiveness from the nearest MNCR biotope.

Two maps are presented (Figures 9.15 and 9.16) which shows how the biotopes can be displayed according to different levels of the MNCR classification scheme and using their colour palette (Connor *et al.*, 1997). The two maps can be compared with Figure 9.9 which displays the biotopes labelled according to their most characteristic or conspicuous species and uses the life form colour palette. These biotopes can be directly translated into MNCR biotopes but giving the codes a suffix to represent to local variants (Figure 9.15). In Figure 9.16 the biotopes displayed have been restricted to those in the MNCR classification (Connor *et al.*, 1997).

Figure 9.15. Infaunal biotope distribution in the Wash showing the local variants of MNCR biotopes that have been described from ground truth samples. The MNCR colour pallette has been used (Connor et al., 1997)

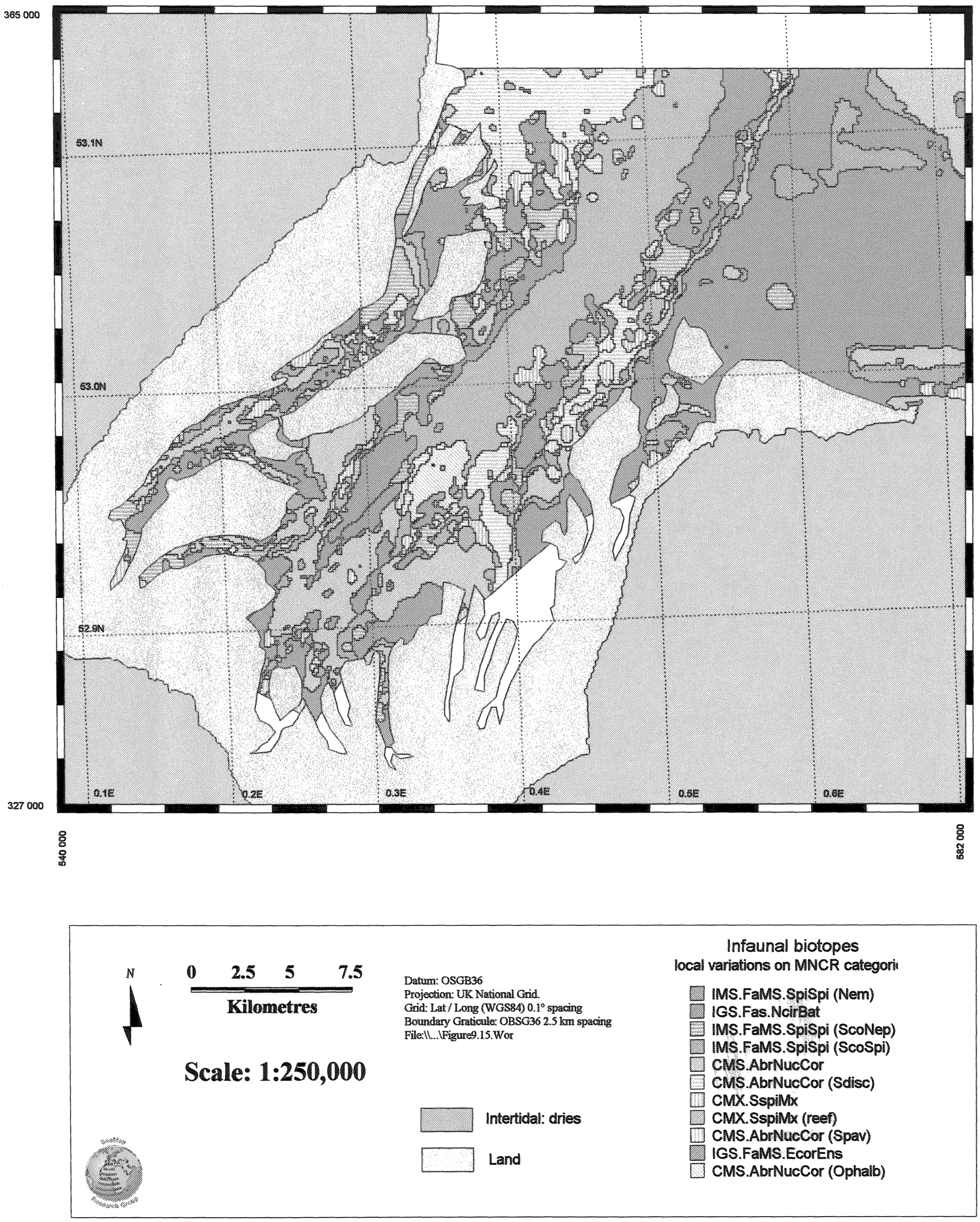
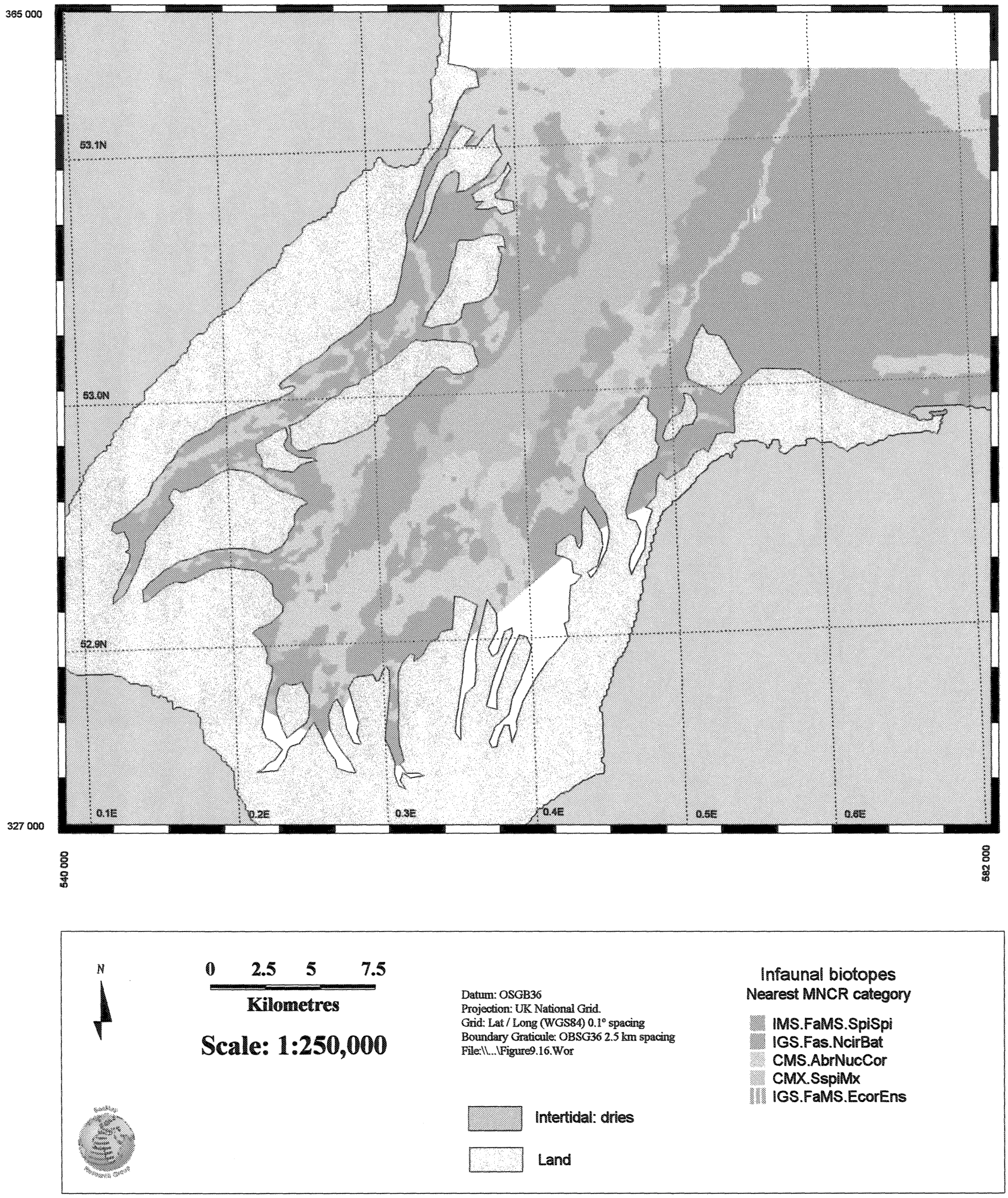


Figure 9.16. Infaunal biotope distribution in the Wash showing the nearest MNCR biotope that matched the ground truth samples. Biotope boundaries have not been outlined in black so that local variants



The life form and MNCR colour palettes for the sediment biotopes are, in any case, fairly similar. The life form colour scheme in the Wash (Figure 9.9) emphasises the following five components: (a) biotopes associated with mobile, medium fine – coarse sand (yellow); (b) muddy sand (olive); (c) biogenic sand reefs and accretions (orange); (d) muddy biotopes (brown), and; (e) shelly biotopes (grey). Similar trends are harder to distinguish from the colours in Figures 9.15 and 9.16. although they do show major trends in the distribution of the substrata ranging from coarse sand in many shallow areas, through muddy sands in shallow and intermediate depths to mixed sediments in deeper water. The MNCR colour palette also shows shallow infralittoral and deeper circalittoral biotopes. However, many apparent trends in the distribution of infralittoral and circalittoral biotopes are spurious since the samples have been categorised primarily according to the composition of the biota and there may be conflicts with depth ranges as indicated by the position in the MNCR classification system.

10 Discussion

10.1 Contribution of the survey to the Broadscale Mapping Project

The main purpose of the Broadscale Mapping Project was to devise a methodology for the survey, analysis and cartographic display of the predominant biotopes of large areas of sea floor. It was the intention that this methodology, developed in three test areas, could be used for the survey of much larger areas so that a baseline knowledge of biotope distribution would become available, much as there are maps of sea floor sediments for most of the British Isles. Each of the areas have their own characteristics which tested the methodology against a wide range of different types of sea floor topography, sediment and biotopes. Apart from the development of general methodology, the Wash and surrounding seas were used to for the following: -

1. The development of methods for using additional bathymetric data for assisting interpolation;
2. The application of a methodology that has been developed mainly for epibiota to areas where infauna is of equal or greater heritage interest;
3. The use of biotope probabilities to qualify biotope distribution maps;
4. The use of prior probabilities for refining biotope distributions (developed in this survey and applied successfully to other areas).

The Wash was perhaps the largest area of the three trial areas and the experience here indicates that such large areas can be tracked comprehensively to a minimum intensity and that areas of more intensive tracking can be interpreted at a smaller scale.

10.2 Confidence

The best measure of success of the methodology is whether or not the maps prove to be useful. Do users have confidence in the maps and, if they are used in a predictive capacity, do users find that the maps stand up to scrutiny? There is no single, easy answer to these questions at this stage and they will emerge through use. However, some assessment of confidence can be made so that potential users of the maps can decide how best to frame their queries and if the maps are likely to provide the information they require. Thus, there are a number of ways of assessing the success of a map and the methodology that underlies it: -

1. **An understanding of the methodology and sources of error:** No map should be taken on trust without at least having a knowledge of the data upon which it is based, how the data were collected and analysed and what are the potential sources of error. These have been discussed in more detail in the accompanying BMP Technical Report. In summary, these are:-
   (a) The ranges of variables measured by *RoxAnn* are few and this limits the scope for discrimination.
   (b) The echo sounder measures reflectivity properties of the sea floor and not the habitat or biota directly. These must be interpreted from the acoustic and ground truth data.

(c) There is a maximum spatial resolution of the system set by position error and the footprint of the sounder. Spatial uncertainty may result in poor acoustic signature development, especially where the sea floor is very heterogeneous.

(d) Interpolated values are used to create continuous-coverage digital images suitable for processing. These are calculated values that may be poorly supported by real data with increasing distance from tracks.

(e) Maximum likelihood classifiers assigns each pixel to habitat or biotope class to which it most likely belongs. This requires the classifier to select between biotopes that may have very similar probabilities. Thus, there is the possibility that other classes with slightly lower levels of probability may be under-represented on the map. Although there are ways of conveying this uncertainty, it is possible that many users will assume that the classes are mutually exclusive.

(f) It is assumed for the purposes of map production, that the list of biotopes and accompanying descriptions used for the categorisation of samples is complete and the biotope classes are discrete entities. Neither of these assumptions need necessarily hold true. Intermediates between two or more biotopes will occur or samples whose composition is not very similar to any existing biotope. The map user should be aware that, even though one biotope is indicated on a map, it might be expected that related biotopes might also be found. These relationships should be explained in accompanying documentation.

2. **An appreciation of the scale and level of detail that the map purports to show:** The resolution of a map is unlikely to be the maximum that is technically possible, especially with broad scale surveys, because of the time and cost involved. Resolution and spatial detail is primarily determined by track spacing and is also a function of the heterogeneity of the sea floor. If a map shows the results of a broad scale survey, then it is unreasonable to expect it to show fine spatial structure. A biotope map should be reproduced at the appropriate scale and the resolution indicated by the dimensions represented by a pixel.

3. **A measure of uncertainty and internal accuracy of the data:** Various ways of indicating uncertainty have been explored in this survey which include showing tracks, variograms and internal accuracy assessment through error matrices. Although the latter provides statistics that are useful as a guideline to accuracy, the actual values are very dependent upon survey area and the range of biotopes to be classified (larger more diverse areas will tend to produce lower internal accuracy measures). The level of detail of the biotopes also has an effect on accuracy (fewer broad categories tend to result in higher accuracy measures than more numerous biotope classes).

4. **An assessment of how well the map reflects expert local opinion:** However well the analyst regards the match between the map and the survey data, a map is unlikely to carry conviction if it conflicts with the view of local biological expert opinion. It is important, therefore, that maps are circulated for comment and any concerns expressed explored by reanalysis of the data.

5. **A measure of the predictive ability of the map as tested by users:** Ultimately, there is only one way to test the usefulness of a map and that is by testing its predictive capability. Ideally, a user should plan further sampling based on the map to prove its accuracy.

6. **Ease of use:** Maps should be easy to read and use. This may entail a compromise between the level of detail available and simplicity. This is especially important for digital image processing where it is tempting to represent the interpretation of every pixel no matter how isolated it may be. Thus, filtering is usually required to simplify the image for ease of viewing. The user should know what level of filtering has been applied.

What is the overall assessment of the Wash maps, bearing in mind the above points? The resolution of the map is lower that the technical maximum due to wide track spacing. Thus, the pixel size is 100m and the intended scale for display is 1:250 000.

The majority of the interpolated values used for the construction of the digital images lie within or close to a range distance set (conservatively) at half the maximum variance. However, it must be expected that calculated values for points approaching this distance will be poorly supported by real data. Much of the survey area off the north Lincolnshire coasts is covered by widely spaced tracks and this introduces uncertainty into the interpolated values in this section. However, bathymetric data from the hydrographic charts have been incorporated into the interpolation process to mitigate the effect of wide track spacing.

However, the uncertainty in this area remains high, as can be judged from the very low likelihood levels for the predominant biotopes over much of this section. Agreement between the most likely biotope (i.e., the biotope selected using maximum likelihood) and probability values is much closer in other parts of the survey area and this justifies a higher level of confidence that can be placed in the maximum likelihood classification.

Internal measures of overall accuracy are modest although these vary considerably between biotopes. The error matrices also show that some confusion lies between closely related biotopes (in terms of their species composition and their associated sediments). Thus, much of the apparent problems with the classification of the acoustic data might stem from the confusion between similar biotopes.

10.3 Biotope descriptions and their distribution

The descriptions of biotopes used in this survey are similar to those from other local surveys (Hamond, 1963; Rees *et al.*, 1982; Dipper *et al.*, 1989; National Rivers Authority, 1994), although they differed somewhat from those in the U.K. national marine classification (Connor *et al.*, 1997). Data on the distribution of biotopes are sparse, especially for the offshore areas. But the widespread distribution of *Sabellaria spinulosa* and bryozoan/hydroid turf described previously would appear to be supported by the biotope maps. The distributions of biotopes in the Wash accord well with previous records, particularly at the broad level of biotopes associated with silty sand, coarse sand and boulder. The biotope distribution maps have also been inspected by a number of individuals with local knowledge and they report no obvious points of conflict with their expert opinion.

Perhaps the single most significant advance in knowledge of the biology of the region is the graphic description of substantial *Sabellaria spinulosa* reefs with their associated high diversity and large numbers of crustacean species. This has a great significance for the management of the conservation interest of the area and this knowledge has already contributed to management support. For example, reference has been made to the biotope maps to ascertain the proximity of these reefs to areas where active dredging occurs in area 107 and to the proposed sites for offshore structures.

The biotope distribution maps have also been used to support proposals for future monitoring within the cSAC. In particular, the maps have been used to identify representative areas and those of high diversity.

Ultimately, the value of the biotope maps will be established through their use in a management support capacity. It is to be expected that there will be areas where improvements can be made and it is recommended that the maps be revised in the light of experience and increased knowledge in future years.

10.4 The future of broadscale mapping in the Wash and surrounding area

Mapping wider sea areas: There is no doubt that broad scale habitat and biotope maps are a useful resource in their own right for supporting management of large sea areas, as can be judged by their use to date in areas of high conservation interest. If these broad scale surveys are extended over very large sections of the U.K. coastline, this new knowledge of the distribution of biotopes will help in the management of the wider seas. The wider spatial context of the Wash and north Norfolk coast is particularly important because of the dynamic nature of the environment and the key species. Anything that affects sediment transport and the biota within the wider area of the southern North Sea will have an impact on sites that have been designated of particular heritage interest.

The BMP has demonstrated that it is possible to amalgamate data sets from many surveys that have used different AGDS. This is crucial to the further development of the main aims of the project, namely to survey large areas of the continental shelf of U.K. waters. If this were to be done, then it is inevitable that many different surveyors would be involved.

Maps in data management systems: Biotope resource maps form a useful baseline of information in an electronic integrated data management system. These can be used simply as a backdrop for other types of information or can be used as a front-end for geographic query. Although single layer showing the most likely biotope distribution is easiest to view for these types of application, probability images for each biotope are more versatile and can readily be incorporated into risk assessment models. It is anticipated that these probability maps will be used in combination with other data to compute and show the likely effect of impacts on the environment.

Maps in the study of dynamic processes: Biotope maps are essentially a snap-shot in time. How will distribution change over time? How can our knowledge of the dynamics of habitats and biotopes be incorporated into dynamic distribution models? Again, probability maps could form the basis of dynamic models by providing predictions on changing patterns of biotope distribution at different scales that can be tested through a highly targeted, stratified sampling program.

Monitoring; maps as part of a wider integrated survey strategy: The biotope maps have already been used in a number of ways for the management of the Wash and the surrounding seas. Detailed maps of the are centred on the aggregate extraction site 107 have been used to formulate an appropriate response to the application to continue extraction. Within the cSAC the maps have been used to formulate a monitoring scheme to assess the diversity of a wide range of biotopes. Any monitoring based on repeat sampling at set locations over time will be sensitive to heterogeneity and small changes in position of the sampling device. Mapping, even if restricted to the area in the vicinity of the sampling, could be useful for interpreting the significance of these detailed point samples.

The lessons learnt from the use of mapping in conjunction with more traditional grab sample surveys could have enormous implications for the future design of monitoring surveys. Knowledge of the distribution of biota could structure future surveys leading to a cost-effective strategy that is based on refining our knowledge of the processes that determine biological community structure.

Biotope maps will undoubtedly fulfil a central role in the support of scientifically based decision making in the marine environment. The next step is to provide this spatial information for larger sea areas and in a format that can be used in the new generation of data management and risk assessment systems that are being developed for integrated marine management.

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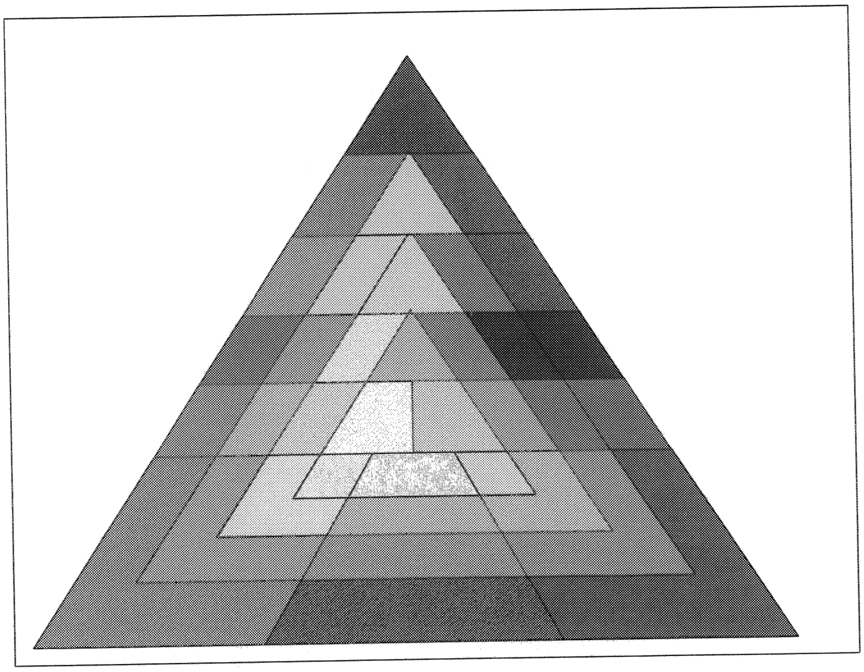
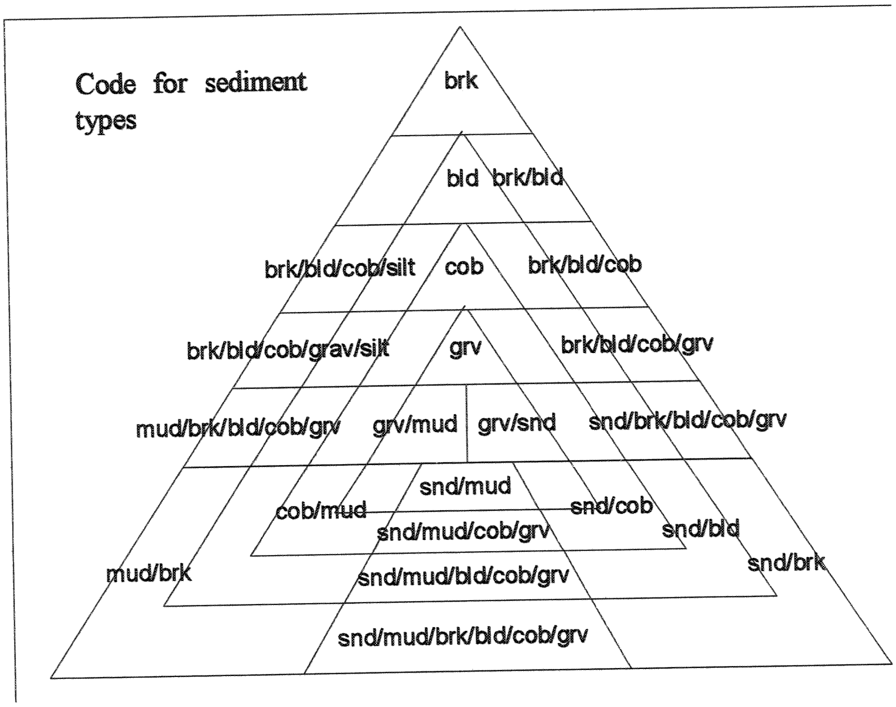
Appendix 1: Modified Folks triangle used in sediment analysis





Abbreviation	Description	Abbreviation	Description
brk	bedrock	grv	gravel
bld	boulder	snd	sand
cob	cobble	mud	mud (or silt on bedrock)

Appendix 2: Life form colours used in the maps

Life form & colour code		Biotopes/life forms
FAUNAL & ALGAL CRUSTS		
Light red		PomByC
FAUNAL TURF		
Mid blue		ByH, ByH.Flu
BIOGENIC SAND REEFS		
Orange		SspiMx.reef; SspiMx
MUSSEL BEDS		
Dark grey/blue		ModMX
SHINGLE, SHELL & MIXED SEDIMENTS		
Grey/brown		AbrNucCor.Ophalb(Wash)
SAND		
Yellow		ScoSpi(Wash); Ncir.Bat Lcon, EcorEns,Nem(Wash)
SILTY SAND		
Green-brown		AbrNucCor, AbrNucCor.Sdisc(Wash)
MUD		
Dark brown		AbrNucCor.Spav

Note that shades of these colours are used to separate the biotopes within the life forms.

Appendix 3: Description of categories of biota used in distribution maps

Note that not all biotopes are illustrated with frame grabs from video. This is due to many biotopes being described from analysis of infauna and not from the external appearance of the biotope from the video. The underwater visibility also precluded the use of video in many situations.

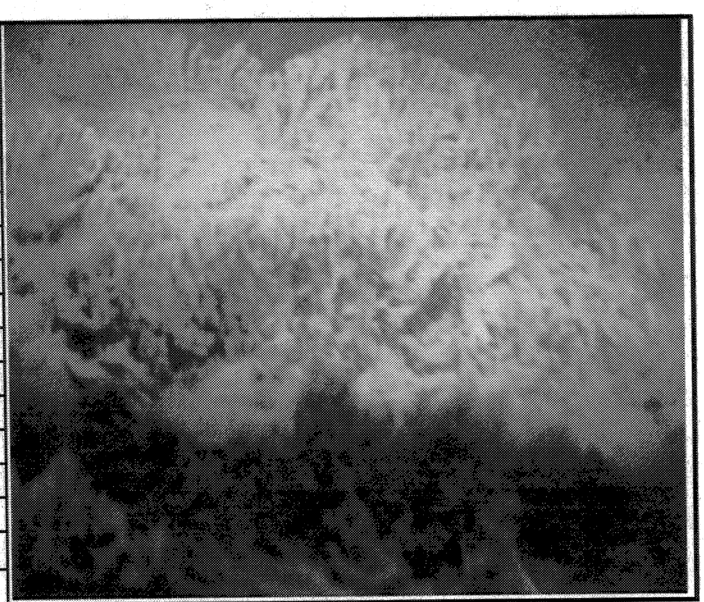
1. **Sabellaria (super-abundant, including reefs)**

Provisional biotope CMX.SspiMx.reef(Wash) as a subdivision of CMX.SspiMx

Justification for this biotope is based on superabundance of *Sabellaria spinulosa* and video evidence of reef structures. This community is otherwise similar in composition to the *Sabellaria/Lanice* community.

Silty sandy gravel.

Species	Abundance
Sabellaria spinulosa	SA
Pholoe inornata	A
Pisidia longicornis	A
Scoloplos armiger	A
Harmothoe indet.	C-A
Mytilus edulis	C-A
Autolytus prolifera	C
Eulalia ornata	C
Eumida ockelmanni	C
Exogone hebes	C
Mediomastus fragilis	C
Nereis longissima	C
Abra alba	O-C
Ampharete lindstroemi	O-C
Caulleriella zetlandica	O-C
Protodorvillea kefersteini	O-C



2. **Sabellaria/Lanice**

Biotope CMX.SspiMx

Sabellaria spinulosa is abundant, but video evidence suggests that this is in the form of low encrustations over cobble or small clumps together with loose gravel. *Lanice* is usually present and is obvious from the video. The fauna is diverse, often with a high component of epifauna (higher than for the *Sabellaria* biotope).

Gravely sand to coarse sand, often with cobbles.,

Species	Abundances
Sabellaria spinulosa	C-A
Scoloplos armiger	O-A
Lanice conchilega	O-C
Mya truncata	O-C
Mytilus edulis	O-C
Abra alba	O
Bodotria scorpioides	O
Mediomastus fragilis	O
Nephtys juv. indet.	O
Pholoe inornata	O
Sabella discifera	O*

Some samples, especially the gravely shelly sands off the Lincolnshire coast, have more amphipods, such as *Urothoe elegans* and *Ampelisca* spp.

3. **Sabella discifera**

Provisional biotope CMS.AbrNucCor.Sdisc(Wash) as a subdivision of CMS.AbrNucCor (or possibly CMX.SspiMx

There are a small number of samples that are similar to the above biotope, but *Sabella discifera* is abundant-superabundant and *Sabellaria spinulosa* is absent. Found on gravely silty sand.

Species	Abundances	Species	Abundances
Sabella discifera	A-SA	Abra alba	O
Scoloplos armiger	O-A	Bodotria	O
Lanice conchilega	O-C	Mediomastus	O
Mya truncata	O-C	Nephtys juv. indet.	O
Mytilus edulis	O-C	Pholoe inornata	O
		Sabellaria	O*

4. **Scoloplos/Spiophanes and diverse fauna**

Provisional biotope CMS.ScoSpi(Wash) possibly related to IMS.FaMS.SpiSpi

Scoloplos armiger and *Spiophanes bombyx* are commonly found in most biotopes. The associated fauna is quite diverse, although *Sabellaria spinulosa* is either absent or in very low abundances. The internal accuracy assessment indicates that this biotope is poorly discriminated and is likely to be confused with biotopes ranging from *Nephtys/Bathyporeia* to *Sabellaria/Lanice*. It is likely that the infaunal components are common to a wide range of other biotopes and that the sediment characteristics are also too wide for more confident discrimination. Nevertheless, the biotope is used for image classification.

Mostly silty fine sand, but sometimes on gravely sand.

Species	Abundances	Species	Abundances
Spiophanes bombyx	C-SA	Ophiura ophiura	P-O
Scoloplos armiger	C-A	Spio armata	P-O
Nephtys juv. indet.	C	Pariambus typicus	P
Abra spp.	P-C	Pholoe inornata	P
Ophiura albida	P-C	Pholoe inornata	O

5. Sabella pavonina

Provisional biotope CMS.AbrNucCor.Spav(Wash)as a subdivision of CMS.AbrNucCor.Spav

Sabella pavonina has been found in the Boston Deeps and would appear to have similar species as other diverse sites. However, there is a complete absence of *Sabellaria spinulosa*. This species has also been found in other parts of Wash off Hunstanton (Dipper *et al.*, 1989) and in the Lynn Deeps (NRA, 1994).

Silty fine sand with shell.

Species	Abundances	Species	Abundances
Sabella pavonina	C-A	Harmothoe	C-A
Autolytus spp.	C-A	Nereis longissima	O-C
Mytilus edulis	C-A	Proceraea cornuta	C
Sabelliphyllus	O-A	Lanice conchilega	C-A

6. Scoloplos/Nephtys

Provisional biotope CMS.ScoNep(Wash) possibly related to IMS.FaMS.SpiSpi

Sparse fauna typified by *Scoloplos armiger* and *Nepthys* species. This biotope lies between the even less diverse *Nepthys/Bathyporeia* biotope and the more diverse *Scoloplos/Spiophanes* biotope.

Medium fine sand

Species	Abundances	Species	Abundances
Scoloplos armiger	C	Abra alba	P-C
Nephtys hombergii	C	Mytilus edulis	O
Spiophanes bombyx	O-C	Nemertea indet.	O

7. Abra

Biotope CMS.AbrNucCor

Moderately diverse fauna characterised by high abundances of Abra alba. The sediment tends towards the silty. The *Abra* biotope is wide-ranging in its characteristics. In particular, the representation of the brittlestars *Ophiura albida* and *Ophiura ophiura* is very variable and this biotope merges into the *Ophiura* biotopes and may be considered the same biotope.

Silty sand

Species	Abundances
Abra alba	C-SA
Scalibregma inflatum	C-A
Lanice conchilega	O-C
Nephtys juv. indet.	O-C
Pariambus typicus	O-C
Scoloplos armiger	O-C
Ophiura albida	O
Ophiura ophiura	O
Mediomastus fragilis	P
Pholoe inornata	P
Spiophanes bombyx	P

8. Nephtys/Bathyporeia

Biotope IGS.Fas.NcirBat

A biotope associated with mobile sand in shallow water. The diversity and abundance of species is low with a preponderance of motile species, especially carnivorous polychaetes and amphipods that work sand grains for diatoms and detritus

Medium fine sand.

Species	Abundances	Species	Abundances
Bathyporeia elegans	P-C	Pontocrates	*-P
Nephtys cirrosa	P-C	Pseudocuma	*-P
Ensis juv. indet.	P-O	Spiophanes	*-P

9. Sparse polychaetes (nemerteans)

Provisional biotope CMS.Nem(Wash) possibly related to IMS.FaMS.SpiSpi

Sparse fauna with motile carnivorous polychaetes and nemerteans found in open gravely sand and shell. This presumably favours motile carnivores and detritivores.

Gravely, shelly sand.

Species	Abundances	Species	Abundances
Cephalothricidae	C	Nephtys cirrosa	P-O
Hesionura elongata	P-C	Sphaerosyllis spp.	P-O
Glycera lapidum	O	Spiophanes	P
Ophelia borealis	O	Urothoe brevicornis	P

10. Lanice

Biotope IGS.Fas.Lcon or possibly IGS.Fas.Mob

A biotope of sand in shallow water found widely throughout the survey area. The biotope characteristics range from mobile sediment with sparse *Lanice* to more stable sand with dense populations of *Lanice*. The latter are associated with *Sabellaria spinulosa* and the *Lanice* biotope merges with the *Sabellaria/Lanice* biotope.

Medium fine sand

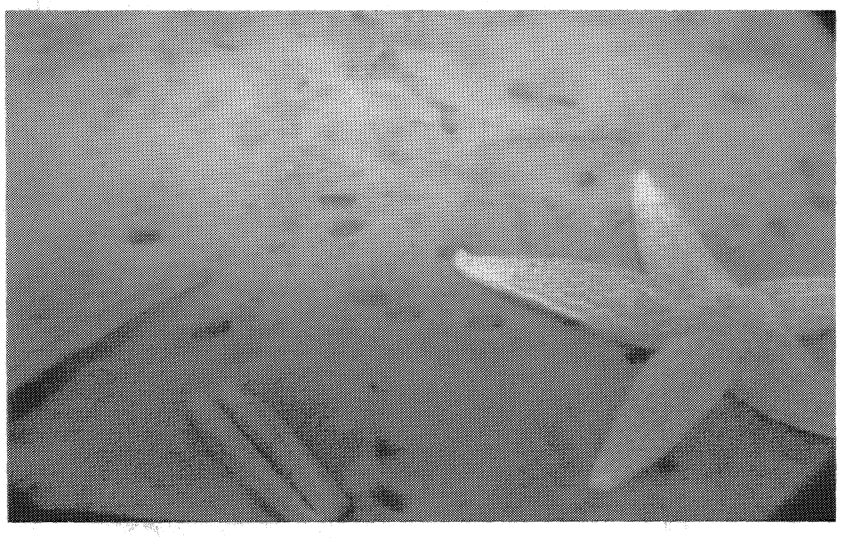
Species	Abundances	Species	Abundances
Lanice conchilega	C-A	Sabellaria	O-C
Spiophanes bombyx	O-C	Nephtys juv. indet.	O
Scoloplos armiger	O-C	Abra alba	O

11. Ensis

Biotope IGS.FaMS.EcorEns

This biotope was identified from video only. It was found in only a small locality, but could be more widespread. Unfortunately, the grab samples were lost for this station and infaunal composition is unknown.

Medium fine sand.



12. Ophiura albida

Biotope CMS. AbrNucCor.Ophalb(Wash) (uncertain)

Dense *Ophiura albida* and some *Ophiura ophiura* may distinguish this from the *Abra* biotope. and the species composition is similar. This has been included in the classification of the biotope map although its usefulness is uncertain. It has been separated from the *Abra* biotope because of the importance of the brittlestars in the context of the conservation interest of the Wash.

13. Modiolus

Biotope MNCR code CMX. ModMx.

This biotope was under sampled in the survey and was identified on the basis of live specimens being taken in grabs together with stones. The epifauna attached to shells and stones and was similar to faunal crusts and turf and the biotope might be regarded as faunal turf.

14. Bryozoan/hydroid turf

Biotope MCR.ByH.Flu

Tall faunal turf species includes the hydroids *Nemertesia antenina, Abietenaria abietina, Halecium halecium, Hydralmania falcata* and *Obelia longissima*, and the bryozoans *Flustra foliacea* and *Eucratea loricata*. Short faunal turf species were the bryozoans *Bugula plumosa, Crisia* spp., and *Alcyonidium* spp. Sponges (unidentified) and *Alcyonium digitatum* are also present. No infaunal data exists for these samples.

Found on silty boulders and cobbles in deeper water.

15. Hydralmania

Biotope IGS.FaS.ScupHyd

Usually very sparse epifaunal turf and no encrusting epifauna. Sand ripples overlay cobble and, presumably, results in sand scour. The hydroids *Hydralmania falcata* and *Obelia longissima* are attached to small stones and shell and trail over the sand in the tidal streams. infauna usually consists of spionid/deposit feeders.

Sand with stones and shell.

16. Sabellaria/faunal turf

Biotope complex MCR.ByH

Sparse to moderately rich bryozoan/hydroid turf epifauna on a silty gravely sand substratum with a *Sabellaria* gravel/shell component. Infaunal communities are usually spionid/deposit feeders. The infaunal biotope is used in preference where sufficient sample data exists and the infaunal equivalent in *Sabellaria/Lanice*.

17. Faunal crusts and turf

Biotope ECR.Efa.PomByC

Loose gravel, shell and cobble with sparse serpulid worm tubes (*Pomatoceros triqueter*), barnacles (*Balanus crenatus*) encrusting bryozoans (*Conopeum reticulatum*), tufted bryozoans (*Crisia* sp. & *Bugula* sp.) and the sea squirt *Dendrodoa grossularia*. There may also be quite high densities of the anemone *Sagartia troglodytes*. Coralline algae were widespread.

18. Ophiura ophiura

Biotope CGS.Ven.Bra (uncertain)

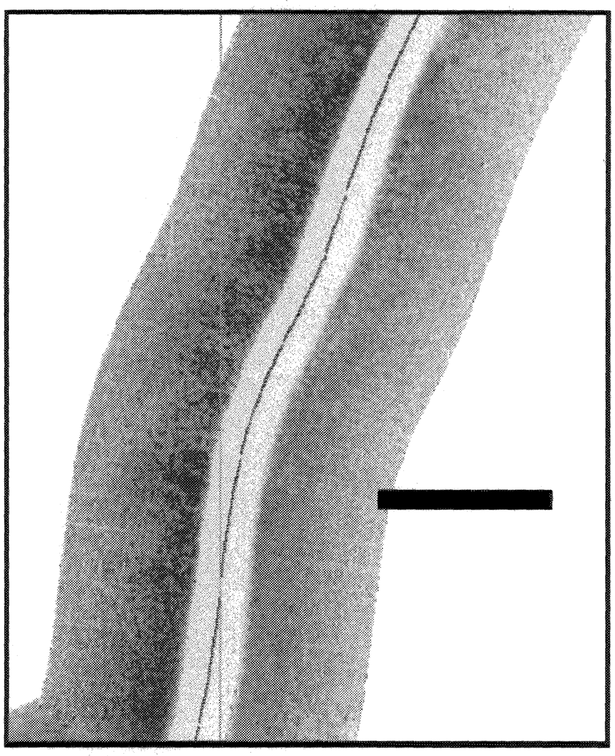
Silty sandy shell ground was found in many areas in the Wash. The fauna consisted of abundant brittle stars (*Ophiura ophiura* and *Ophiura albida*), the green urchin *Psammechinus miliaris* and starfish (*Asterias rubens*). The sea mouse (a polychaete) *Aphrodite aculeata* was also found in some dredge samples.

Appendix 4: Examples of bedforms using sidescan sonar images.

The examples included show some of the bedforms that were detected using sidescan sonar. The grey strip of varying thickness in the centre of all the images is the time delay resulting from the depth of water under the 'fish' and can be edited out. However, this does indicate changes in depth and hence topography which is useful in the interpretation of these images. For this reason, this strip has been left in. The images are 'negative' in that the darker areas are caused by strong echoes resulting either from harder ground or surfaces that are angled so that they face the fish. Hence light areas are either soft ground or shadows behind raised features.

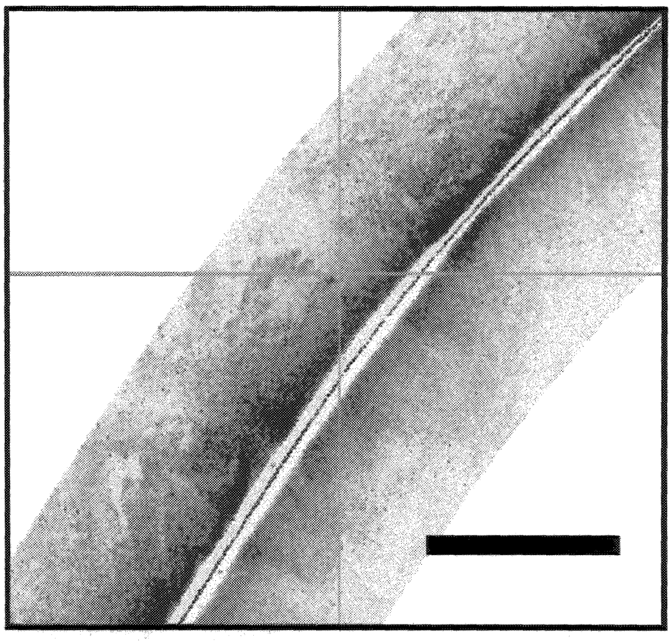
Note also that the solid bar represents a distance of about 200m.

Example 1. *Sabellaria* reef.

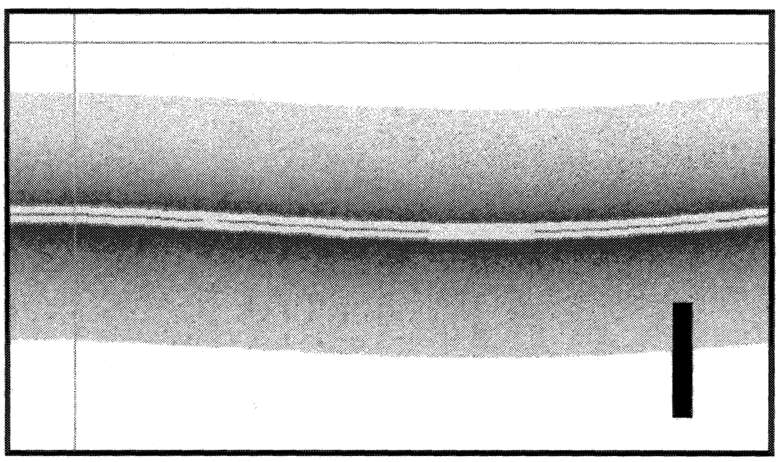


Example 1. Relatively hard sediment with a faint granular image texture in places. This example was from the *Sabellaria* reefs in are 107 and it appeared unlikely that the reefs could be successfully detected and mapped using *SeaMap* sidescan system. It is possible that towing the system closer to the sea floor could accentuate the shadows associated with the granular features seen on the above image. Video tow over the same area indicated extensive reefs in this area.

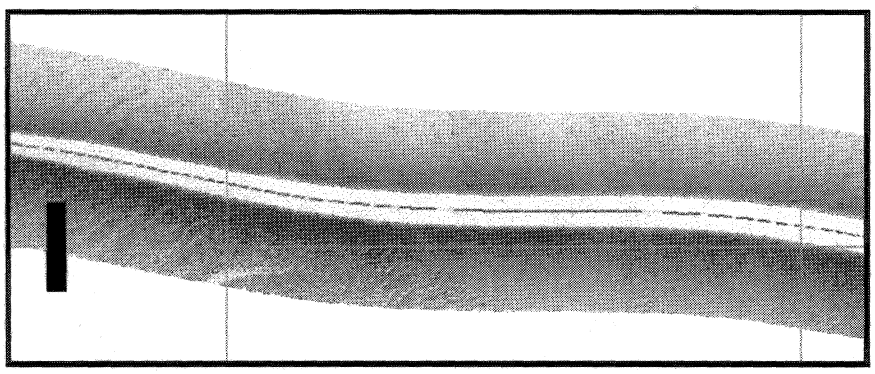
Example 2. An example of shelly ground from the Roaring Middle, a raised shell bank in the Wash.



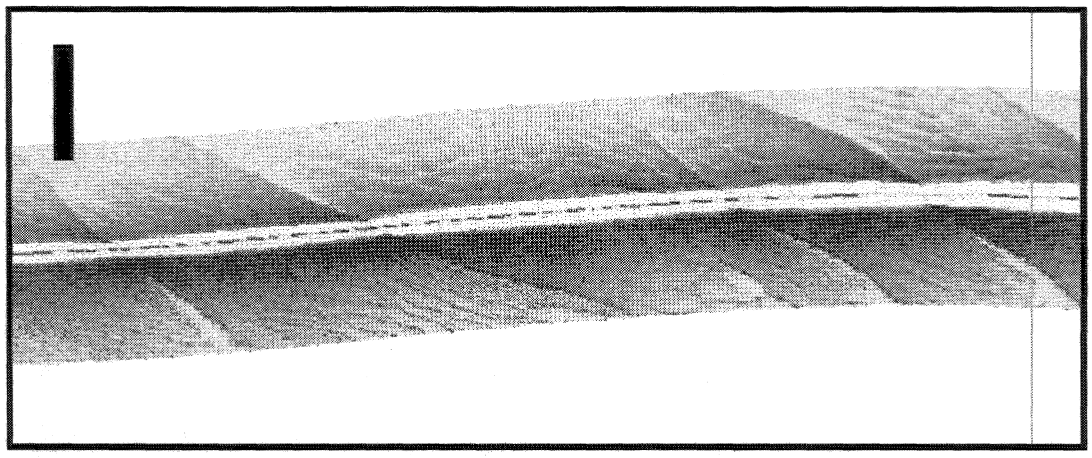
Example 3. Shallow coarse sand from a long tow (Examples 3-7) running west from Burnham Flats into the deeper water north east of the Lynn Deeps. Example 3 shows coarse, featureless sand with a uniformly hard reflection.



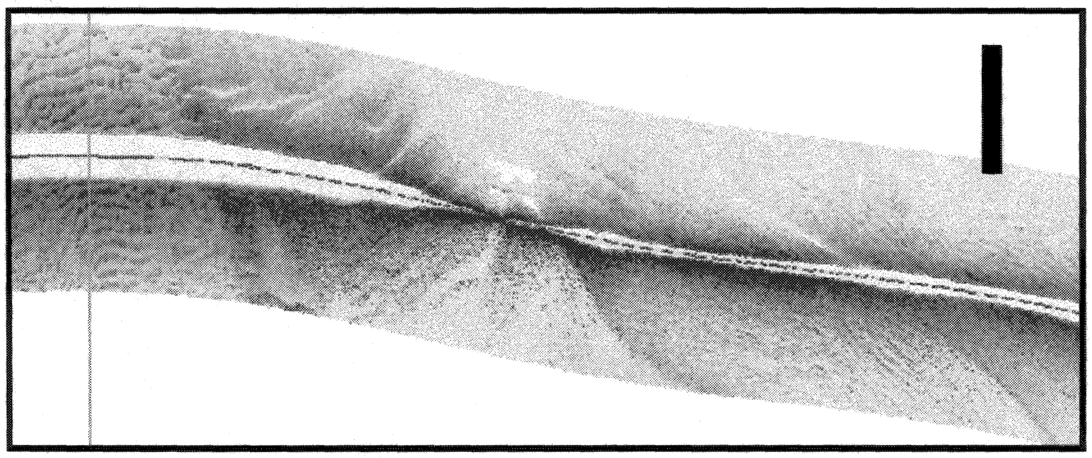
Example 4. The western edge of Burnham Flats drops gradually into deeper water and ripple marks begin to appear.



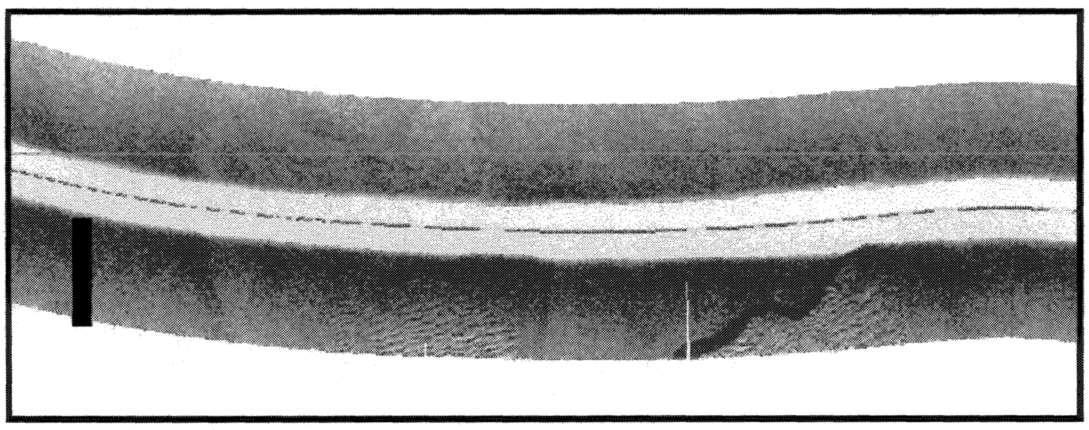
Example 5. The ripples seen in Example 4 gave way to larger waves with sharp crests running north west/south east. The 'face' of the sand waves were directed towards the north west whilst the 'back' of the waves dipped south west. Smaller ripples were superimposed.



Example 6. Very coarse sand forming irregular wavelets and a large ridge with ripples superimposed.



Example 7.Softer sediment in deeper water with sand forming a dune with face directed towards the north west.



Appendix 5: Summary of ground truth sample data.

Note that all positions use OSGB36 as the reference system.

Sediment characteristics

east	north	long	lat	sediment
583395.5	348842.7	0.733617	53.0051	cob/grv
566569.1	354688.1	0.4861	53.0631	bld/silty
573120.7	372880.4	0.593608	53.2244	grv
575985.3	375158.5	0.637733	53.2439	grv
570832.8	373621.9	0.559767	53.2318	grv
564912.5	355532.7	0.461833	53.0712	grv
566918.1	361675.6	0.494933	53.1258	grv
554896.6	333211.1	0.301767	52.8737	grv
568223.3	357052.4	0.512	53.0838	cob/grv
570852.1	363449.3	0.554617	53.1405	cob/grv
572968.1	364903.5	0.587006	53.1528	cob/grv
575784.1	367556.8	0.630533	53.1758	cob/grv
572309.1	369445.6	0.579608	53.1938	cob/grv
568129.3	357279.2	0.510717	53.0859	cob/grv
578194	401031.6	0.685375	53.4755	cob/grv
580382.7	406332.2	0.721367	53.5224	cob/grv
578526.1	409212.8	0.695033	53.5489	deep sand
559428.2	365678.8	0.385083	53.164	cob/grv
561658.9	358262.8	0.414683	53.0968	cob/grv
553941.8	349338.7	0.29525	53.0189	cob/grv
573657.1	394933.1	0.613717	53.4223	cob/grv
554230.9	349711.5	0.299735	53.0221	grv/snd(shell)
555951.5	344943	0.323067	52.9788	grv/snd(shell)
557510.2	343613.4	0.345617	52.9664	grv/snd(shell)
577140.8	371322.4	0.6529	53.2091	grv/snd(shell)
577095.7	371276.2	0.6522	53.2087	grv/snd(shell)
576022.7	376889.6	0.63925	53.2595	grv/snd(shell)
576038.2	375205	0.63855	53.2443	grv/snd(shell)
583894.3	373027.3	0.7549	53.2221	grv/snd(shell)
565045	355743.2	0.463917	53.0731	grv/snd(shell)
563923.6	356738.4	0.4477	53.0824	grv/snd(shell)
561988.8	357392.5	0.419167	53.0888	grv/snd(shell)
566325.4	353364	0.481783	53.0513	grv/snd(shell)
596765.2	350456.2	0.933608	53.0149	grv/snd(shell)
596826.9	354510.1	0.937	53.0513	grv/snd(shell)
594008.7	370151.6	0.904467	53.1927	grv/snd(shell)
590456.8	378384	0.856283	53.2679	grv/snd(shell)
609533	373486.7	1.1387	53.2168	grv/snd(shell)
561801.1	357128.4	0.416233	53.0865	grv/snd(shell)
580573.1	389267.1	0.714441	53.3691	grv/snd(shell)
577702.5	396397.2	0.675358	53.4341	grv/snd(shell)
560793.3	364514.8	0.4049	53.1532	grv/snd(shell)
562342.5	363793.3	0.427683	53.1462	grv/snd(shell)
568703	360216.5	0.520817	53.1121	grv/snd(shell)
563446.4	358150.9	0.4413	53.0952	grv/snd(shell)
600991.9	349213.7	0.995758	53.0022	cob/sand
601661.7	354732.2	1.00917	53.0514	cob/sand
604331.7	350986.3	1.04658	53.0168	cob/sand
605855.5	346864.9	1.06664	52.9792	cob/sand
570599.9	367638	0.553083	53.1782	cob/sand
591937.5	374443.1	0.876083	53.232	cob/sand
596287.5	370233.6	0.938583	53.1926	cob/sand
593812	353898.3	0.891708	53.0469	cob/sand
592902.9	351535.9	0.87675	53.026	cob/sand
589444.2	353568.1	0.826433	53.0455	cob/sand
579961.2	347919.5	0.681975	52.998	cob/sand
594297.4	350815.2	0.897083	53.019	cob/sand
599143.7	350345.3	0.96895	53.013	cob/sand
608881	380755.1	1.13372	53.2823	cob/sand
561613.6	360668	0.415217	53.1184	cob/sand

563782.5	356453.3	0.44545	53.0799	cob/sand
566007.8	353204.5	0.476967	53.05	cob/sand
601703.3	385551	1.02925	53.3281	cob/sand
557595.9	343460.3	0.346817	52.965	cob/sand
552588.7	338108	0.2698	52.9184	grv/silty(shell)
577081.1	374369.5	0.6537	53.2365	grv/silty(shell)
563520.3	359096.1	0.442883	53.1037	grv/silty(shell)
566039	357989.4	0.4799	53.093	grv/silty(shell)
564996.6	346925.7	0.458683	52.9939	grv/silty(shell)
564065	352699.9	0.44775	53.0461	grv/silty(shell)
567126.3	350268.8	0.492117	53.0233	grv/silty(shell)
567459.6	350530.9	0.497217	53.0255	grv/silty(shell)
563390.9	344490.3	0.43355	52.9725	grv/silty(shell)
560742.8	345403.1	0.3946	52.9815	grv/silty(shell)
558438.9	346538.3	0.360867	52.9924	grv/silty(shell)
574876.8	372948.2	0.619925	53.2245	grv/silty(shell)
576930.9	374758.3	0.651667	53.24	grv/silty(shell)
576678.2	376543.6	0.648875	53.2562	grv/silty(shell)
596782.7	348388.1	0.932608	52.9963	grv/silty(shell)
574703.6	371032.2	0.616283	53.2073	grv/silty(shell)
576906.3	376740.4	0.6524	53.2578	grv/silty(shell)
577111.8	375942.6	0.655033	53.2506	grv/silty(shell)
569850.9	369231.4	0.542733	53.1927	grv/silty(shell)
580561.6	379988.2	0.708983	53.2858	grv/silty(shell)
566383.6	388336.5	0.500883	53.3654	grv/silty(shell)
604681.9	351019.8	1.05182	53.017	cob/grv/silty
594222	350910.5	0.896017	53.0199	cob/grv/silty
561627.4	360423.5	0.4153	53.1162	cob/grv/silty
568872.8	347466.5	0.516667	52.9975	cob/grv/silty
562797.8	350957	0.427983	53.0308	cob/grv/silty
556248.1	351249.7	0.330532	53.0354	snd(shell)
607484.7	353574	1.09518	53.0388	snd(shell)
600548	348432.2	0.988667	52.9953	snd(shell)
577715.4	367644.9	0.65945	53.1759	snd(shell)
578548.4	365584.3	0.67075	53.1571	snd(shell)
580506.5	369178.6	0.702033	53.1887	snd(shell)
582053.7	372162.4	0.726867	53.215	snd(shell)
578155.5	363342.6	0.663633	53.1371	snd(shell)
584179.7	353878.3	0.748167	53.0501	snd(shell)
561417.4	355018.6	0.40945	53.0677	snd(shell)
549441.7	339679.2	0.22375	52.9334	snd(shell)
563601.3	346672.1	0.437783	52.992	snd(shell)
564719	349410	0.455817	53.0163	snd(shell)
561286.2	352136.3	0.40605	53.0418	snd(shell)
560839.6	354385.1	0.400517	53.0622	snd(shell)
563235.4	352695.8	0.435383	53.0463	snd(shell)
580091	377107.5	0.7003	53.2601	snd(shell)
606469.8	353883.9	1.08027	53.042	snd(shell)
578321.9	365658.4	0.667408	53.1579	snd(shell)
577664.3	367641.1	0.658683	53.1759	snd(shell)
577157.2	371000.1	0.652967	53.2062	snd(shell)
589063.9	373659.2	0.832617	53.226	snd(shell)
599966.9	374033.2	0.995966	53.2254	snd(shell)
594128.6	353802.5	0.896367	53.0459	snd(shell)
590704.3	354174.8	0.845567	53.0505	snd(shell)
582056.4	354000.6	0.716592	53.0519	snd(shell)
583276.6	348405.7	0.7316	53.0012	snd(shell)
577040.3	375888	0.653933	53.2501	snd(shell)
576884.3	374182.1	0.65065	53.2349	snd(shell)
576077.6	372571	0.637685	53.2207	snd(shell)
580419.7	369026.8	0.70065	53.1874	snd(shell)
599673.9	378737.3	0.994533	53.2677	snd(shell)
593506	378495.8	0.902017	53.2678	snd(shell)
583138.7	375114.2	0.744793	53.2411	snd(shell)
577924.4	363374.7	0.6602	53.1375	snd(shell)
581538.4	361517.1	0.713117	53.1196	snd(shell)
600331.2	380760.7	1.00565	53.2856	snd(shell)
569709.3	356548	0.5339	53.0789	snd(shell)
571314.3	355506.4	0.557283	53.069	snd(shell)

568554.1	354853.9	0.515783	53.064	snd(shell)
577185.6	395030.3	0.666817	53.422	snd(shell)
592287.4	396710.9	0.894833	53.4318	snd(shell)
577659.3	392330.9	0.672417	53.3976	snd(shell)
557984.3	365642	0.363483	53.1641	snd(shell)
570673.2	358098.4	0.5491	53.0925	snd(shell)
565941.4	349912.2	0.474283	53.0204	snd(shell)
547773.7	339791	0.199	52.9348	snd(shell)
544811.4	339296.8	0.154733	52.9312	mud
575397.9	394685.4	0.63975	53.4195	mud
600220.2	347481	0.9832	52.9869	snd/silty
571473.9	355261.6	0.559533	53.0667	snd/silty
573259.5	354475.8	0.585733	53.0591	snd/silty
568761.3	354813	0.51885	53.0636	snd/silty
559866.5	351984.9	0.384817	53.0409	snd/silty
598919.4	352153.4	0.966725	53.0293	snd/silty
600002	347568.5	0.980008	52.9877	snd/silty
592011.8	349776.7	0.862433	53.0105	snd/silty
563664	359269.8	0.445117	53.1052	snd/silty
565931	358202.8	0.4784	53.0949	snd/silty
579599.1	392604.4	0.701717	53.3994	cob/sand
552292.3	347382.4	0.269755	53.0018	fine snd
596793.3	353472.9	0.935867	53.042	fine snd
584136.9	364036.7	0.75335	53.1413	fine snd
570932.6	353575.9	0.550567	53.0518	fine snd
596179	380715.8	0.943417	53.2868	fine snd
603065.2	390582.8	1.0529	53.3728	fine snd
586252.5	389737.1	0.799983	53.3714	fine snd
557493.6	365440.4	0.35605	53.1625	fine snd
555289.3	330347.8	0.306233	52.8479	fine snd
554611.9	349211	0.305172	53.0175	med/f snd
553987.3	349964.6	0.296227	53.0245	med/f snd
552771.7	348658	0.277497	53.0131	med/f snd
555868.7	345701	0.3222	52.9856	med/f snd
596697.2	348438.4	0.931367	52.9968	med/f snd
585938.4	366212.9	0.781517	53.1602	med/f snd
550373.4	346457.6	0.24075	52.994	med/f snd
585888.9	353914.6	0.773658	53.0498	med/f snd
550414.2	346500.9	0.241377	52.9944	mud/snd
549630	346502.1	0.229702	52.9946	mud/snd
549074.4	345873.1	0.22114	52.9891	mud/snd
547748.2	344816.6	0.200913	52.98	mud/snd
544313.6	342287.5	0.148662	52.9582	mud/snd
575869.9	372552.2	0.634567	53.2206	mud/snd
569850.5	356283.9	0.535867	53.0764	mud/snd
549647.8	346535.2	0.229983	52.9949	mud/snd
548085.6	345247.6	0.206133	52.9838	mud/snd
547218.2	344504.8	0.192883	52.9773	mud/snd
546852.1	344356.4	0.187367	52.9761	mud/snd
550137.8	335680.5	0.23225	52.8973	mud/snd
550462.4	336315.8	0.237367	52.9029	mud/snd
551802.9	339203.7	0.258633	52.9284	mud/snd
554659.9	331626.4	0.2975	52.8595	mud/snd
548145.2	345166	0.206983	52.983	mud/snd
555504.2	350794	0.319227	53.0315	mud/shell/snd
543903.8	342628.6	0.142717	52.9614	mud/shell/snd
551500.1	340704.4	0.254833	52.942	mud/shell/snd
596749.1	350480.6	0.933383	53.0151	mud/shell/snd
596714.2	354529.7	0.935333	53.0515	mud/shell/snd
591973.9	349661.9	0.8618	53.0095	mud/shell/snd
555991.7	339858.8	0.321217	52.9331	mud/shell/snd
552771.2	339039.5	0.27295	52.9267	mud/shell/snd
564367.2	362728.6	0.457383	53.136	mud/shell/snd
550113.8	335475.7	0.2318	52.8954	mud/shell/snd
550235.1	336516.5	0.234083	52.9047	mud/shell/snd
554845.7	337840.4	0.303217	52.9153	mud/shell/snd
551300.4	346820.6	0.254722	52.997	mud/shell/snd
549109.2	336689.4	0.217433	52.9066	shell
558798.2	345182.7	0.36555	52.9801	shell

Infaunal biotopes: Infaunal community names refer to the biotopes used for classification and are used in the maps. See Table 7.3 and Appendix 3.

east	north	Long	Lat	Infaunal community
556248.1	351249.7	0.330532	53.0354	Sabella discifera
554611.9	349211	0.305172	53.0175	Nephtys/Bathyporeia
553987.3	349964.6	0.296227	53.0245	Nephtys/Bathyporeia
552771.7	348658	0.277497	53.0131	Nephtys/Bathyporeia
552403.8	347673.9	0.271553	53.0044	Scoloplos/Spiophanes
551500.5	347239.6	0.257897	53.0007	Nephtys/Bathyporeia
549630	346502.1	0.229702	52.9946	Sabella pavonina
549074.4	345873.1	0.22114	52.9891	Sabella pavonina
552817.1	344073.8	0.276007	52.9719	Abra
543903.8	342628.6	0.142717	52.9614	Sabellaria/Lanice
544158.4	342652	0.146515	52.9615	Scoloplos/Spiophanes
555868.7	345701	0.3222	52.9856	Nephtys/Scoloplos
555951.5	344943	0.323067	52.9788	Carnivorous
557510.2	343613.4	0.345617	52.9664	Sabellaria/Lanice
555432.2	340607	0.313258	52.94	Abra
551500.1	340704.4	0.254833	52.942	Abra
570268.2	345290.1	0.536294	52.9776	Nephtys/Bathyporeia
600548	348432.2	0.988667	52.9953	Nephtys/Bathyporeia
600074.7	347539.4	0.981072	52.9875	Nephtys/Bathyporeia
596754.1	348404.8	0.932194	52.9965	Sabella discifera
596759.8	350464.3	0.933533	53.0149	Sabella discifera
596793.3	353472.9	0.935867	53.042	Nephtys/Bathyporeia
577176.7	371240.3	0.653392	53.2084	Sabellaria/Lanice
577098.7	371059.2	0.652125	53.2068	Sabellaria/Lanice
577681.3	367642.4	0.658939	53.1759	Nephtys/Bathyporeia
578397.4	365633.7	0.668522	53.1576	Nephtys/Bathyporeia
584136.9	364036.7	0.75335	53.1413	Nephtys/Bathyporeia
585938.4	366212.9	0.781517	53.1602	Nephtys/Bathyporeia
576443.6	376490.7	0.645333	53.2558	Scoloplos/Spiophanes
576011.8	375181.7	0.638142	53.2441	Carnivorous
576982.7	374275.8	0.652175	53.2357	Sabellaria/Lanice
575973.7	372561.6	0.636126	53.2206	Sabellaria/Lanice
580463.1	369102.8	0.701342	53.1881	Nephtys/Bathyporeia
582020.9	372031.2	0.7263	53.2138	Nephtys/Scoloplos
583931	372870.1	0.755358	53.2207	Sabellaria/Lanice
580084	360197.7	0.690667	53.1082	Nephtys/Bathyporeia
584092.8	353854.6	0.746858	53.0499	Nephtys/Bathyporeia
591965.5	349704.4	0.8617	53.0099	Nephtys/Scoloplos
594259.7	350862.9	0.89655	53.0194	Sabellaria/Lanice
561620.4	360545.7	0.415258	53.1173	Scoloplos/Spiophanes
563592.2	359182.9	0.444	53.1044	Sabellaria/Lanice
565985	358096.1	0.47915	53.0939	Nephtys/Scoloplos
569779.9	356416	0.534883	53.0776	Nephtys/Bathyporeia
570014.1	355057.6	0.537658	53.0654	Sabellaria/Lanice
573192.1	354563.4	0.584775	53.0599	Nephtys/Bathyporeia
566902.9	355277.7	0.491383	53.0683	Nephtys/Scoloplos
570932.6	353575.9	0.550567	53.0518	Nephtys/Bathyporeia
564978.8	355637.9	0.462875	53.0722	Nephtys/Scoloplos
561894.9	357260.4	0.4177	53.0877	Sabellaria/Lanice
561425.6	355038.4	0.409583	53.0679	Carnivorous
559838.8	352026.7	0.384425	53.0413	Nephtys/Scoloplos
566166.6	353284.3	0.479375	53.0506	Sabellaria/Lanice
550373.4	346457.6	0.24075	52.994	Nephtys/Bathyporeia
549647.8	346535.2	0.229983	52.9949	Scoloplos/Spiophanes

548085.6	345247.6	0.206133	52.9838	Scoloplos/Spiophanes
547218.2	344504.8	0.192883	52.9773	Nephtys/Scoloplos
546852.1	344356.4	0.187367	52.9761	Scoloplos/Spiophanes
550137.8	335680.5	0.23225	52.8973	Scoloplos/Spiophanes
550462.4	336315.8	0.237367	52.9029	Abra
551766.4	339294.2	0.258133	52.9293	Abra
549570.3	339678.2	0.225661	52.9333	Carnivorous
555934.8	339711.6	0.3203	52.9318	Scoloplos/Spiophanes
552618.6	339061.6	0.270692	52.9269	Abra
563601.3	346672.1	0.437783	52.992	Nephtys/Bathyporeia
564996.6	346925.7	0.458683	52.9939	Sabellaria
568872.8	347466.5	0.516667	52.9975	Sabellaria/Lanice
564719	349410	0.455817	53.0163	Carnivorous
562797.8	350957	0.427983	53.0308	Sabellaria
561286.2	352136.3	0.40605	53.0418	Sabellaria/Lanice
560839.6	354385.1	0.400517	53.0622	Nephtys/Scoloplos
563235.4	352695.8	0.435383	53.0463	Carnivorous
564065	352699.9	0.44775	53.0461	Sabellaria/Lanice
567126.3	350268.8	0.492117	53.0233	Sabellaria
567459.6	350530.9	0.497217	53.0255	Sabellaria
563390.9	344490.3	0.43355	52.9725	Sabellaria/Lanice
560742.8	345403.1	0.3946	52.9815	Sabellaria
558438.9	346538.3	0.360867	52.9924	Sabellaria
602281.9	385352.8	1.0378	53.3261	Sabellaria/Lanice
603099.1	390645.6	1.05345	53.3733	Scoloplos/Spiophanes
586115.4	389692.8	0.7979	53.371	Carnivorous
580603.2	389245.9	0.714883	53.3689	Sabellaria/Lanice
573657.1	394933.1	0.613717	53.4223	Carnivorous
575397.9	394685.4	0.63975	53.4195	Scoloplos/Spiophanes
577700.8	396486.2	0.675383	53.4349	Carnivorous
566383.6	388336.5	0.500883	53.3654	Lanice
575539.1	400648.3	0.6452	53.473	Scoloplos/Spiophanes
578209.2	401082.3	0.685633	53.476	Abra
592305.9	396800.7	0.895167	53.4326	Sabellaria/Lanice
579599.1	392604.4	0.701717	53.3994	Sabellaria/Lanice
577659.3	392330.9	0.672417	53.3976	Sabellaria/Lanice
580382.7	406332.2	0.721367	53.5224	Carnivorous
579446.4	408178.6	0.708317	53.5393	Carnivorous
557984.3	365642	0.363483	53.1641	Sabellaria/Lanice
559428.2	365678.8	0.385083	53.164	Sabellaria/Lanice
560793.3	364514.8	0.4049	53.1532	Sabellaria/Lanice
562342.5	363793.3	0.427683	53.1462	Sabellaria/Lanice
564367.2	362728.6	0.457383	53.136	Sabellaria/Lanice
566918.1	361675.6	0.494933	53.1258	Sabellaria/Lanice
561658.9	358262.8	0.414683	53.0968	Sabellaria/Lanice
565941.4	349912.2	0.474283	53.0204	Sabellaria/Lanice
554845.7	337840.4	0.303217	52.9153	Sabellaria/Lanice

Epifaunal biotopes: epifaunal community names refer to the biotopes used for classification and are used in the maps. See Appendix 3.

east	north	Long	Lat	Epifaunal community
556248.1	351249.7	0.330532	53.0354	No conspicuous fauna
554611.9	349211	0.305172	53.0175	No conspicuous fauna
553987.3	349964.6	0.296227	53.0245	No conspicuous fauna
552771.7	348658	0.277497	53.0131	No conspicuous fauna
552403.8	347673.9	0.271553	53.0044	Bryozoan/hydroid turf

551500.5	347239.6	0.257897	53.0007	Faunal crusts
549630	346502.1	0.229702	52.9946	Sabella
549074.4	345873.1	0.22114	52.9891	Sabella
552817.1	344073.8	0.276007	52.9719	No conspicuous fauna
543903.8	342628.6	0.142717	52.9614	Sabellaria/Lanice
544158.4	342652	0.146515	52.9615	Bryozoan/hydroid turf
555868.7	345701	0.3222	52.9856	Hydralmania
555951.5	344943	0.323067	52.9788	No conspicuous fauna
557510.2	343613.4	0.345617	52.9664	No conspicuous fauna
555432.2	340607	0.313258	52.94	No conspicuous fauna
551500.1	340704.4	0.254833	52.942	No conspicuous fauna
570268.2	345290.1	0.536294	52.9776	No conspicuous fauna
604448.5	350997.5	1.04833	53.0169	Bryozoan/hydroid turf
600548	348432.2	0.988667	52.9953	No conspicuous fauna
600074.7	347539.4	0.981072	52.9875	No conspicuous fauna
596754.1	348404.8	0.932194	52.9965	Lanice
596759.8	350464.3	0.933533	53.0149	Lanice
596793.3	353472.9	0.935867	53.042	No conspicuous fauna
596789.3	354516.6	0.936444	53.0513	Bryozoan/hydroid turf
577176.7	371240.3	0.653392	53.2084	Sabellaria/faunal turf
577098.7	371059.2	0.652125	53.2068	Sabellaria/Lanice
577681.3	367642.4	0.658939	53.1759	Ensis
578397.4	365633.7	0.668522	53.1576	No conspicuous fauna
584136.9	364036.7	0.75335	53.1413	No conspicuous fauna
585938.4	366212.9	0.781517	53.1602	No conspicuous fauna
576443.6	376490.7	0.645333	53.2558	Sabellaria
576011.8	375181.7	0.638142	53.2441	No conspicuous fauna
576982.7	374275.8	0.652175	53.2357	Sabellaria/Lanice
575973.7	372561.6	0.636126	53.2206	Sabellaria/Lanice
580463.1	369102.8	0.701342	53.1881	No conspicuous fauna
582020.9	372031.2	0.7263	53.2138	No conspicuous fauna
583931	372870.1	0.755358	53.2207	Sabellaria/Lanice
580084	360197.7	0.690667	53.1082	No conspicuous fauna
584092.8	353854.6	0.746858	53.0499	No conspicuous fauna
591965.5	349704.4	0.8617	53.0099	No conspicuous fauna
594259.7	350862.9	0.89655	53.0194	Sabellaria/Lanice
561620.4	360545.7	0.415258	53.1173	Hydralmania
563592.2	359182.9	0.444	53.1044	Sabellaria/Lanice
565985	358096.1	0.47915	53.0939	Sabellaria/faunal turf
568176.3	357165.8	0.511358	53.0849	Bryozoan/hydroid turf
569779.9	356416	0.534883	53.0776	Ensis
570014.1	355057.6	0.537658	53.0654	No conspicuous fauna
573192.1	354563.4	0.584775	53.0599	No conspicuous fauna
566902.9	355277.7	0.491383	53.0683	No conspicuous fauna
570932.6	353575.9	0.550567	53.0518	No conspicuous fauna
564978.8	355637.9	0.462875	53.0722	Sabellaria/Lanice
563853.1	356595.8	0.446575	53.0811	Sabellaria/Lanice
561894.9	357260.4	0.4177	53.0877	Sabellaria/Lanice
561425.6	355038.4	0.409583	53.0679	No conspicuous fauna
559838.8	352026.7	0.384425	53.0413	Bryozoan/hydroid turf
566166.6	353284.3	0.479375	53.0506	Sabellaria/Lanice
550373.4	346457.6	0.24075	52.994	No conspicuous fauna
549647.8	346535.2	0.229983	52.9949	Faunal crusts
548085.6	345247.6	0.206133	52.9838	No conspicuous fauna
547218.2	344504.8	0.192883	52.9773	No conspicuous fauna
546852.1	344356.4	0.187367	52.9761	No conspicuous fauna
550137.8	335680.5	0.23225	52.8973	No conspicuous fauna
550462.4	336315.8	0.237367	52.9029	Sabellaria/Lanice

551766.4	339294.2	0.258133	52.9293	Sabellaria/Lanice
549570.3	339678.2	0.225661	52.9333	Bryozoan/hydroid turf
544888.6	339276.8	0.155872	52.931	Ophiura
555934.8	339711.6	0.3203	52.9318	Bryozoan/hydroid turf
552618.6	339061.6	0.270692	52.9269	No conspicuous fauna
563601.3	346672.1	0.437783	52.992	No conspicuous fauna
564996.6	346925.7	0.458683	52.9939	Sabellaria
568872.8	347466.5	0.516667	52.9975	Sabellaria/Lanice
564719	349410	0.455817	53.0163	No conspicuous fauna
562797.8	350957	0.427983	53.0308	Sabellaria
561286.2	352136.3	0.40605	53.0418	Sabellaria/Lanice
560839.6	354385.1	0.400517	53.0622	No conspicuous fauna
563235.4	352695.8	0.435383	53.0463	No conspicuous fauna
564065	352699.9	0.44775	53.0461	Sabellaria/Lanice
567126.3	350268.8	0.492117	53.0233	Sabellaria
567459.6	350530.9	0.497217	53.0255	Sabellaria
563390.9	344490.3	0.43355	52.9725	Sabellaria/Lanice
560742.8	345403.1	0.3946	52.9815	Sabellaria
558438.9	346538.3	0.360867	52.9924	Sabellaria
576474.6	376697.8	0.645911	53.2576	Sabellaria/faunal turf
606469.8	353883.9	1.08027	53.042	No conspicuous fauna
601095.4	349313.9	0.997361	53.003	Hydralmania
585230.1	373348.9	0.775072	53.2246	Hydralmania
574682.6	373015.9	0.617056	53.2251	Ensis
579800.9	376767.6	0.695762	53.2571	Bryozoan/hydroid turf
570869.5	363328.8	0.554813	53.1394	Bryozoan/hydroid turf
572318.3	364995.3	0.577348	53.1539	Bryozoan/hydroid turf
575752.2	367271.6	0.6299	53.1732	Bryozoan/hydroid turf
570628.1	367434.4	0.553396	53.1763	Lanice
577252.1	355021.8	0.645551	53.0627	No conspicuous fauna
574791.5	370820.6	0.617483	53.2054	Sabellaria
592218.4	374230.8	0.880158	53.23	Bryozoan/hydroid turf
594130.1	370758.9	0.90665	53.1981	Bryozoan/hydroid turf
579961.2	347919.5	0.681975	52.998	Bryozoan/hydroid turf
584291	348523.7	0.746767	53.002	No conspicuous fauna
576649.2	377805.6	0.649142	53.2675	Bryozoan/hydroid turf
583331.4	348717.7	0.732592	53.004	Bryozoan/hydroid turf
573120.7	372880.4	0.593608	53.2244	Bryozoan/hydroid turf
576930.9	374758.3	0.651667	53.24	Bryozoan/hydroid turf
598919.4	352153.4	0.966725	53.0293	No conspicuous fauna
601661.7	354732.2	1.00917	53.0514	Hydralmania
605855.5	346864.9	1.06664	52.9792	No conspicuous fauna
589063.9	373659.2	0.832617	53.226	No conspicuous fauna
599966.9	374033.2	0.995966	53.2254	Lanice
596287.5	370233.6	0.938583	53.1926	Modiolus
593812	353898.3	0.891708	53.0469	Lanice
594128.6	353802.5	0.896367	53.0459	No conspicuous fauna
592902.9	351535.9	0.87675	53.026	Hydralmania
590704.3	354174.8	0.845567	53.0505	No conspicuous fauna
589444.2	353568.1	0.826433	53.0455	No conspicuous fauna
585888.9	353914.6	0.773658	53.0498	Hydralmania
582056.4	354000.6	0.716592	53.0519	No conspicuous fauna
577111.8	375942.6	0.655033	53.2506	Sabellaria
575783.8	370776.8	0.6323	53.2047	Bryozoan/hydroid turf
599673.9	378737.3	0.994533	53.2677	No conspicuous fauna
593506	378495.8	0.902017	53.2678	Lanice
583138.7	375114.2	0.744793	53.2411	No conspicuous fauna
561476	377161.3	0.4215	53.2666	Bryozoan/hydroid turf

570832.8	373621.9	0.559767	53.2318	No conspicuous fauna
569850.9	369231.4	0.542733	53.1927	Sabellaria/faunal turf
581538.4	361517.1	0.713117	53.1196	No conspicuous fauna
599143.7	350345.3	0.96895	53.013	Bryozoan/hydroid turf
609533	373486.7	1.1387	53.2168	Modiolus
608881	380755.1	1.13372	53.2823	Modiolus
600331.2	380760.7	1.00565	53.2856	No conspicuous fauna
596179	380715.8	0.943417	53.2868	No conspicuous fauna
580561.6	379988.2	0.708983	53.2858	Sabellaria/faunal turf
574238.1	379735.9	0.614083	53.2856	Hydralmania
571314.3	355506.4	0.557283	53.069	Ensis
566569.1	354688.1	0.4861	53.0631	Bryozoan/hydroid turf
557984.3	365642	0.363483	53.1641	Sabellaria/Lanice
559428.2	365678.8	0.385083	53.164	Sabellaria/faunal turf
560793.3	364514.8	0.4049	53.1532	Sabellaria/Lanice
562342.5	363793.3	0.427683	53.1462	Sabellaria/faunal turf
564367.2	362728.6	0.457383	53.136	Sabellaria/Lanice
566918.1	361675.6	0.494933	53.1258	Bryozoan/hydroid turf
561658.9	358262.8	0.414683	53.0968	Sabellaria/Lanice
565941.4	349912.2	0.474283	53.0204	Sabellaria/Lanice
554845.7	337840.4	0.303217	52.9153	Sabellaria/Lanice
557493.6	365440.4	0.35605	53.1625	No conspicuous fauna
568703	360216.5	0.520817	53.1121	Hydralmania
570673.2	358098.4	0.5491	53.0925	Ophiura
563217.1	342281.8	0.42985	52.9527	Hydralmania
550113.8	335475.7	0.2318	52.8954	Faunal crusts
550235.1	336516.5	0.234083	52.9047	Ophiura
549109.2	336689.4	0.217433	52.9066	Ophiura
549933.2	335585.1	0.229167	52.8965	Ophiura
547773.7	339791	0.199	52.9348	No conspicuous fauna
557595.9	343460.3	0.346817	52.965	Ophiura
558798.2	345182.7	0.36555	52.9801	Ophiura
554896.6	333211.1	0.301767	52.8737	No conspicuous fauna
554659.9	331626.4	0.2975	52.8595	No conspicuous fauna
555289.3	330347.8	0.306233	52.8479	No conspicuous fauna
551300.4	346820.6	0.254722	52.997	No conspicuous fauna
548145.2	345166	0.206983	52.983	Ophiura
553941.8	349338.7	0.29525	53.0189	Faunal crusts
601124.7	385749.2	1.0207	53.3301	Bryozoan/hydroid turf
603031.2	390520.1	1.05235	53.3722	Hydralmania
586389.5	389781.5	0.802067	53.3717	Hydralmania
580542.8	389288.2	0.714	53.3693	Sabellaria/faunal turf
573657.1	394933.1	0.613717	53.4223	No conspicuous fauna
577185.6	395030.3	0.666817	53.422	No conspicuous fauna
577704.1	396308.1	0.675333	53.4333	No conspicuous fauna
566383.6	388336.5	0.500883	53.3654	No conspicuous fauna
578178.7	400980.9	0.685117	53.4751	Modiolus
592268.8	396621	0.8945	53.431	No conspicuous fauna
579599.1	392604.4	0.701717	53.3994	Ophiura
577659.3	392330.9	0.672417	53.3976	Hydralmania
580382.7	406332.2	0.721367	53.5224	Faunal crusts
577606.1	410247.1	0.68175	53.5585	Bryozoan/hydroid turf