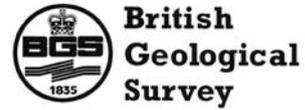


The role of seabed mapping techniques in environmental monitoring and management

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1. Executive summary

This report details work carried out by the Centre for Environment, Fisheries & Aquaculture Science (Cefas), The British Geological Survey (BGS) and Envision Ltd over the course of a 4-year research programme primarily for the Department for Environment, Food and Rural Affairs (Defra). The overall aim of the programme was to evaluate an array of 'state of the art' seabed mapping techniques to establish their suitability for application in areas impacted by man-made activities.

There is now a growing momentum for seabed and resource mapping programmes, driven by several forward-look and horizon-scanning exercises that have recognised the need for seabed maps to underpin spatial planning and the sustainable use of seabed resources (both mineral and biological). A major driver for all this activity is the Marine Bill that is likely to include key commitments for the U.K. Government in terms of implementing marine spatial planning in coastal and offshore waters. The U.K. Government also has an interest in ensuring that the most cost-effective methods of assessment are employed by all those responsible for undertaking environmental monitoring activities. Further core drivers for seabed mapping exist at the international level. OSPAR and ICES are both promoting concerted efforts for trans-national cooperation in seabed and habitat mapping as it is of particular relevance to the ecosystem approach to management and critical to any attempt at integrated assessment of marine ecosystems (e.g. the ICES Regional Ecosystem Study Group for the North Sea (REGNS) initiative). In particular, the OSPAR Commission has identified the need to develop habitat maps covering whole sea areas to contribute to the longer-term needs for assessment and management of the OSPAR area and its sub-regions. In addition, the UK has legally enforceable commitments to the conservation and restoration of seabed habitats in our territorial waters under European treaties (e.g. the 'Habitats Directive').

In summary the core drivers for seabed habitat mapping are:

- The commitments on seabed habitat mapping and the exploration of marine spatial planning in the Defra Marine Stewardship Report 'Safeguarding Our Seas'.
- The commitment to an ecosystem approach to management of the marine environment in the 1992 OSPAR Convention endorsed by the UK at the 5th North Sea Conference.
- OSPAR Annex V - for both the protection of habitats and species and understanding the impacts of human activities.
- The 5th North Sea Conference agreement to invite OSPAR to investigate the possibilities of managing marine activities through spatial planning.

- The EU Agreement on a Recommendation concerning Integrated Coastal Zone Management
- The EU Directives on Habitats and Species and that on the Strategic Environmental Assessment Directive.
- Integrated assessment of marine ecosystems (e.g. the ICES Regional Ecosystem Study Group for the North Sea (REGNS) initiative, the OSPAR Quality Status Reports and the UK state of the seas report 'Charting Progress')
- UN Convention on the Law of the Sea.

The rapid pace of developments in the field of habitat mapping, driven by continuous improvements in acoustic techniques (sidescan sonar, multibeam bathymetry, acoustic ground discrimination systems), has the potential to radically alter approaches to the assessment of anthropogenic impacts at the seabed. In addition to their utility in wide-scale reconnaissance surveys (e.g. in a resource or conservation context), a number of site-specific applications of relevance to Defra and other Government Departments (e.g. dredged material disposal, aggregate extraction, construction activities, oil and gas exploitation, fishing impacts) could also benefit from the use of these techniques. A range of 'state of the art' methodology was therefore evaluated through a programme of rigorous field testing in order to establish the most cost-effective strategies to meet both site-specific and generic (reconnaissance-type) objectives.

Experience of techniques developed in a previous Defra funded programme (AE0908 see Brown *et al.*, 2001), which focussed on gravelly sediments, was extended to sites covering both a broader range of sediments and a wider variety of anthropogenic impacts (dredged material disposal and aggregate extraction). Survey techniques were trialled at a number of sites over the four years of study. Typically, an acoustic survey combining sidescan sonar, multibeam bathymetry and acoustic ground discrimination system (AGDS) was conducted over a study site to identify acoustically distinct areas of the seabed which were then ground-truthed, using grabs, trawls, Sediment Profile Imagery (SPI) and underwater photography, to determine their physical and biological characteristics. This structured approach to surveying the physical and biological conditions of the seabed can be adapted to suit a range of spatial scales and was found to be suitable for both local and broadscale application.

Repeat annual surveys were conducted at two sites, a dredged material disposal site offshore of the Tyne Estuary, in the North Sea (TY070) and an aggregate extraction site off Shoreham (Owers Bank) in the Eastern

English Channel. This work was undertaken to investigate the temporal changes in benthic community structure and the status of physical habitats. At TY070, a soft sediment dredged material disposal site, there was considerable agreement between the sidescan sonar and QTC™ (an AGDS technique) output, the latter even proving sensitive to small features (<100 m across) evident on the sidescan sonar record. Several acoustically distinct areas were recognised, one showing characteristics of disposal activity (i.e. a disposal 'footprint'). Benthic communities and sediments were ground-truthed using a Hamon grab fitted with a video camera. Results indicated a reduction in species richness and total abundance of organisms in the vicinity of the disposal site, but these effects were not widespread. The use of SPI also provided useful additional ground-truth information on the status of the sediments and biogenic activities.

At Owers Bank, a coarse sediment aggregate extraction site off Shoreham, the sidescan sonar record showed that trailer suction dredging activity had encroached northward over time, into an area of active static suction dredging. Both studies demonstrated the benefits of combining conventional methods, acoustic techniques and optical imaging devices when assessing anthropogenic effects. Their collective contribution allowed assessment of ecological status following anthropogenic activities at the seabed. This was found to offer greater utility than individual approaches. The sidescan sonar and multibeam imagery enabled rapid coverage of large areas of seafloor, providing information on the physical characteristics of the seabed and the footprint of disposal and aggregate extraction activity. The use of such an integrated mapping approach appears to be of particular value when assessing anthropogenic effects in areas of known habitat heterogeneity, and for providing baseline information for future monitoring exercises. The approach to habitat mapping, developed during this research project, has now been successfully applied at various disposal sites around the U.K coast as part of routine monitoring programmes undertaken by Cefas on behalf of Defra.

Continuous improvements in acoustic techniques have also led to increased interest in their use for the detection and monitoring of particular features of nature conservation interest. The results of a number of surveys conducted in the Wash and its environs over many years have been reviewed in order to assess the utility of different habitat mapping techniques for assessing the spatial extent, heterogeneity and temporal variability of one biotope of nature conservation significance, namely *Sabellaria spinulosa* biogenic reef.

Acoustic surveys were also undertaken at a study site in the eastern English Channel with the aim of developing a strategy for mapping at different spatial scales. The site comprised a broadscale area (40 x 15 km) between Dungeness and Hastings, within which was nested a smaller study box (4 x 12 km), containing an area licensed for aggregate extraction. During the previous Defra project, a basic (low resolution) interpretation was made of 100% sidescan coverage of the smaller study box. This resulted in the identification of four acoustically distinct areas, which were ground-truthed and classified as four distinct biotopes. The present study made a more detailed (high resolution) interpretation of the same sidescan mosaic, recognising nine different seabed facies (distinct combinations of sediment type and bedform) and mapping the area into ~20 regions. Each of the original acoustically distinct areas contained multiple seabed sediment classes, accounting for the high variability between replicate ground-truth samples noted previously. Consequently, the site was re-visited to ground-truth the seabed facies map. As part of this ground-truthing exercise, a novel spiral sampling strategy was developed and tested. This design proved successful for assessing physical and biological variability within different sediment facies. Spatial analysis also established the facies as having distinct spatial trends in sediment particle size and faunal composition. Furthermore, the faunal assemblages within each of the sampled facies were found to be significantly different. Together, these results demonstrate that seabed facies are ecologically significant units and validate their use in mapping seabed habitats.

The cost of ship time is often the limiting factor in determining the density of sidescan coverage in broadscale areas. We therefore attempted to find an optimum acoustic line spacing that would give a reasonably confident interpretation of seabed facies in a cost-effective way. Within the broadscale study area, sidescan sonar lines spaced at 2 km intervals were gradually augmented with additional 'in-fill' lines to achieve progressively greater density of acoustic coverage. The relationship between density of acoustic coverage and confidence in interpreting broadscale patterns and features was then explored. There was extreme linearity of the interpreted map of seabed sediments and bedforms at 4 km acoustic line spacing and this reduced, as the line spacing got closer. A disturbed area of seabed associated with an extraction site at Hastings was first discernible at 2 km acoustic line spacing but was more accurately represented at 1 km spacing, while a significant area of sand only became apparent at 1 km line spacing. Analysis of further 'in-

fill' lines giving 100% acoustic coverage resulted in only marginal improvement in resolution. It was concluded that, at this site, acoustic line spacing of 1 km gave acceptable results; data from any further 'infill' lines seemed to be redundant at this spatial scale and did not appear to warrant the doubling of survey time and additional costs associated with mapping seabed facies at this resolution over this broad spatial scale.

Developing this strategy further, we examined the comparability of estimates of the abundance of two species derived from samples collected using different sampling equipment. Samples collected by different gears often arrive at different estimates of the relative abundance of the same species, since the sampling gears are employed over varying spatial scales and have differing sampling efficiencies. However, unless data from different gears can be compared directly, biological classifications will differ according to the source of the data, and complicate any resulting habitat classifications. Establishing how surveys conducted at different spatial scales can be linked together is therefore another important consideration in mapping studies. We therefore set out to examine whether associations between key environmental variables and patterns of species distributions strengthen as the spatial extent of the area surveyed increases. Associations between two species (the queen scallop and the hermit crab) and two environmental factors (depth and shear stress) from the broadscale 4 m beam trawl groundfish surveys were compared with species-habitat associations developed from the more localised 2 m beam trawl sampling. For the two species considered here, there is little firm evidence to suggest that species-habitat correlations strengthen as the spatial extent of the area surveyed increases. Correlations remained relatively invariant for scallop and were difficult to detect for the hermit crab regardless of the survey size. The importance of this outcome for mapping studies is that species-habitat relationships quantified at one spatial scale may not necessarily be transferable to another. Notions of habitat drivers for patterns of species distributions may therefore be dependent on the spatial scale of the investigation.

As part of an assessment of the significance of biogeographical variations and their implications for predictive habitat mapping, four sites in the English Channel having similar substratum characteristics were sampled using a Hamon grab. The results confirm that a biogeographic variation exists between sites of similar sediment in the western and eastern English Channel and

indicate that the majority of this variability was accounted for by the rarer benthic species. Removing these rarer species from the data-set resulted in the identification of a core set of species. This sub-set was less prone to biogeographic variability thus providing a better basis for confident prediction of the composition of the more common species in the English Channel.

We also tested alternatives to ground-truthed acoustic maps of the seabed for constructing maps of marine species and community distributions. The first approach combines multivariate classification, Bayesian statistics, and geostatistics to arrive at a series of continuous representations of the distribution of each biological community. Acoustic data (100% sidescan coverage) and biological data (from ground-truth sampling) collected from the Shoreham site were used to assess the validity of the approach and demonstrate its application. A biotope map for the study area was produced showing the maximum likelihood of encountering a particular assemblage at each grab site. Maps developed using a purely objective classification of the biological data were compared with one developed from a supervised classification where the grab samples were assigned to one of eight acoustically distinct regions of the seabed. Whilst the latter approach arrived at a set of biotopes with better spatial definition, biological associations within each biotope were found to be slightly weaker.

Another modelling technique, quantile regression, was used to predict the distribution of adult sole in the eastern English Channel from discrete trawl samples, collected as part of Cefas' annual 4 m groundfish survey, along with the associated physical parameters. Highest catch densities of sole were found to be consistently located in shallow inshore waters where sandier sediments predominate. This agrees with the known habitat requirements of sole and therefore validates this modelling approach for predicting this species' distribution. Both modelling techniques were successful in producing robust maps of marine species from point sample data, thus demonstrating their application for underpinning marine spatial plans.

Finally, experience of various habitat mapping techniques gained over the course of this research programme has been synthesised into a set of electronic guidelines. It is hoped that these guidelines will be of benefit to Government Departments, in facilitating their responsibilities under environmental protection legislation, marine scientists working on behalf of various industries or regulators and those involved in undertaking R&D programmes aimed at holistic (ecosystem-level) assessments.

2. Introduction

Developments in acoustic technology in combination with traditional survey techniques now provide the capability to map the seafloor at high resolution (Pickrill and Todd, 2003). Such habitat maps provide fundamental information for the sustainable management of offshore resources (Pickrill and Todd, 2003). In particular, seabed mapping techniques provide a means to conduct cost-effective, wide-scale reconnaissance surveys, which may serve a number of important purposes. For example, they may be employed in identifying seabed (or sub-seabed) features of conservation, resource or scientific interest (Todd *et al.*, 1999; Kostylev *et al.*, 2003), as an exploratory tool to facilitate the generation of effective site-specific sampling designs (Todd *et al.*, 1999; Kostylev *et al.*, 2001; Brown *et al.*, 2002, 2004) or to provide important information to assist in resolving conflicts arising from multiple uses of the seafloor (Davies *et al.*, 1997; Pickrill and Todd, 2003).

A number of acoustic techniques (especially sidescan sonar) have been used successfully for many years to monitor physical disturbance of seabed habitats (Friedlander *et al.*, 1999; Limpenny *et al.*, 2002; Humborstad *et al.*, 2004; Brown *et al.*, 2004; Boyd *et al.*, 2004, 2005). Sidescan sonar systems transmit a sound pulse and record the reflection intensity from a swathe across the seabed. These measurements provide a basis for the interpretation of seabed roughness, feature orientation and some geophysical properties of seabed features. In contrast multibeam systems provide both high resolution bathymetric data and sidescan-like backscatter data from a single survey event, so the two types of data are perfectly synchronised and co-located enabling the backscatter image to be draped over the bathymetry and viewed in relief (Todd *et al.*, 1999, Todd *et al.*, 2000). Multibeam acoustic surveys are a more recent development, but the technique is finding increasing application in large-scale seabed mapping programmes e.g. the Irish National Seabed Mapping project (see Parsons *et al.*, 2004) and the Canadian Geoscience for Oceans Management programme. Interest in the UK is exemplified by the initiation of two large-scale habitat mapping programmes in the Eastern English Channel and the Outer Bristol Channel which are expected to deliver the first regional-scale, high-resolution benthic habitat maps in the U.K. (James *et al.*, 2005; Philpott *et al.*, 2005). Such improvements in affordable acoustic techniques have led to increased interest in their use for reconnaissance-style surveys over relatively large sea areas. As a consequence, recent studies have made significant progress in developing broadscale mapping methodologies (Phillips *et al.*, 1990; Prager *et al.*, 1995;

Greenstreet *et al.*, 1997; Anderson *et al.*, 1998; Todd *et al.*, 1999, 2000; Kostylev *et al.*, 2001, 2003; Pickrill and Todd 2003; Ojeda *et al.*, 2004).

Acoustic techniques are also being employed for assessing fish/shellfish habitats and have been used to provide information to help the fishermen identify the most desirable fishing areas, thereby reducing the time spent at sea. For example, data generated from a multibeam seabed mapping survey on Browns Bank on the western Scotian Shelf provided information on the distribution of mature scallops (Manson and Todd, 2000; Kostylev *et al.*, 2001). This allowed the same amount of scallops to be caught whilst cutting the area swept by heavy fishing gear by 75%, resulting in a substantial saving for fishermen (Kostylev *et al.*, 2003). The maps of the seafloor also allowed the fishermen to direct effort to areas without seabed obstacles, thus reducing gear loss and avoiding beds of young scallops. Apart from the obvious economic advantages, the detailed habitat maps have provided a powerful tool enabling the fishery to be managed at a much finer spatial scale than was previously possible whilst affording greater protection to sensitive habitats (Pickrill and Todd, 2003). As the above example illustrates, the advent and continued development of acoustic survey technologies provides real advances in our capability to visualise, map and manage seabed activities.

Research conducted during a previous Defra funded project (AE0908 - see Brown *et al.*, 2001) established that acoustic techniques (primarily high-resolution sidescan sonar and Acoustic Ground Discrimination Systems) used in combination with ground-truthing methods were effective in mapping biological assemblages over coarse seabed habitats most of which were relatively unaffected by anthropogenic activities (Brown *et al.*, 2001; Hewer *et al.*, 2002; Brown *et al.*, 2002). However, the scope for application of such techniques is considerably wider (see above example), and therefore the current project was established to investigate their effectiveness over a variety of other seabed types subjected to a range of anthropogenic disturbances.

Habitat mapping can be considered as the spatial representation of described and classified habitat units (Valentine *et al.*, 2005). The approach adopted by Brown *et al.* (2001) and others overseas (e.g. Kostylev *et al.*, 2001) for generating habitat maps involves the initial production of an acoustic basemap. This basemap is interpreted to define acoustically distinct areas of the seabed which reflect the physical properties of the sediments and topographic features within each area. Even though modern acoustic systems provide detailed

information on the seafloor, it is still necessary to conduct seabed sampling to produce interpreted maps. This process is termed 'ground-truthing' and involves the collection of targeted samples of the seabed sediments and fauna and then relating the resultant data to imagery acquired from acoustic surveys. Following an initial interpretation, the acoustic basemap is used to guide a targeted ground-truthing strategy (using grabs, trawls and/or photographic techniques), to provide an effective biological characterisation over the entire area of the map. The use of video techniques is employed to provide information on the structure of the sediments in terms of their particle size and habitat (Ojeda *et al.*, 2004). They are also survey tools in their own right, providing powerful information for interpreting seabed habitats by capturing in-situ images showing the direct association between the epifauna and surface sediments (Kostylev *et al.*, 2001). A holistic assessment of the seabed or 'habitat map' is then produced through a composite interpretation of several or all of these complementary techniques (see, for example, Kostylev *et al.*, 2001). The benefits of adopting such an integrated approach includes synergies (aspects recognised from combined data sets that were not evident when interpreted separately), corroboration (one technique affirming features detected by another) and negation (the exposure of data artefacts during composite interpretation).

An ongoing challenge of the current project was to establish the extent to which such techniques, used in combination, can be employed to map both the distribution and status of benthic communities in relation to natural and man-made influences in U.K waters. Thus, the current project set out to further evaluate these methods over a wider range of seabed types than had previously been investigated in English waters, including those subject to man-made influences. In parallel, investigations of additional physical and geophysical techniques (e.g. multibeam sonar and sediment profiling using SPI) were undertaken in order to establish the extent to which such techniques could be routinely applied in environmental monitoring programmes and/or sites of nature conservation importance.

Preliminary investigations were undertaken, through the review of existing information and pilot surveys, to identify appropriate site-specific anthropogenic activities for assessment using 'state of the art' techniques. Test sites impacted by selected anthropogenic activities were chosen for in-depth study (e.g. aggregate extraction sites at Shoreham and Hastings, dredged material disposal sites off the Tyne), and the scope and limitations of the mapping techniques identified were then evaluated for use

as monitoring tools. Acoustic data sets (sidescan sonar, AGDS and multibeam) were ground-truthed using a suite of existing and new techniques (e.g. grabs, trawls, dredges, underwater video, sediment profiling cameras). In addition, a review of the outcome of a range of surveys carried out in the southern North Sea was undertaken with a view to establishing the utility of various acoustic techniques and complementary ground-truthing programmes for mapping the distribution of benthic communities at sites having considerable conservation value.

A further challenge for the programme was to determine the effectiveness of established and new seabed mapping tools over a range of spatial scales. This was assessed through the conduct of acoustic and biological surveys at different spatial scales. Surveying of a broadscale area (40 x 15 km) between Hastings and Dungeness, allowed an investigation of the relationship between density of acoustic coverage and confidence in interpreting broadscale patterns and features. The aim here was to develop a framework for assessing the cost-effectiveness of mapping programmes carried out at different spatial scales. Establishing how mapping surveys conducted at different spatial scales can be linked together is another important consideration in mapping studies. Fisheries surveys mapping the spatial extent of commercial shell fish and demersal finfish species and associated habitats tend to be conducted at very large scales. In contrast, surveys investigating 'point-source' anthropogenic impacts at the seabed are usually conducted over much smaller scales and at higher resolution. Concerted effort to explore the interface between these two spatial scales of activity, coupled with a greater harmonisation of methodology, would allow data-sets to be combined in order to encompass large sea areas and would also assist in the evaluation of the entirety of anthropogenic influences at the seabed. The scope for linking data-sets conducted at different spatial scales was attempted in the current project by comparing epifaunal data arising from both 4 m and 2 m beam trawl surveys in the Eastern English Channel.

It was recognised during the previous study that even using 'state of the art' mapping approaches, the inherent complexity of some areas defies neat habitat classification other than into very broad categories (Brown *et al.*, 2001; Hewer *et al.*, 2002). A further element of this evaluation therefore involved the investigation of the variability of fauna within distinct seabed facies and the degree to which epifauna and infauna map to these facies (and/or acoustically distinct areas). For this investigation, we chose a study site which encompassed a marine aggregate extraction site nested within a broadscale area.

One of the fundamental premises behind habitat mapping is that organisms distribute themselves along environmental gradients and their clusters indicate distinct sets of environmental factors. If distinctive benthic assemblages are associated with specific sediment types that have a characteristic acoustic signature, then the acoustic maps showing the distribution of those sediment types can be used as proxy to map benthic habitats (Roff *et al.*, 2003). However, as the composition of benthic assemblages can also be influenced by biogeographical factors, these have the potential to confound the interpretation and/or use of acoustic data for generating habitat maps. The current study therefore set out to determine the significance of variability in biogeographical factors for community composition and hence for the future predictive capability of geophysical mapping tools. This was assessed by the conduct of geophysical and ground-truthing surveys at geographically separate areas having similar sediment characteristic across the English Channel.

Finally, the current programme tested two different methods for delineating the habitat requirements and spatial extent of both commercial demersal finfish species and benthic assemblages using point source data. Both methods were assessed separately in terms of their reliability and precision for predicting the habitat requirements of sole in the Eastern Channel and the composition of benthic assemblages at a site off Shoreham.

The results of this 4 year study are presented and the implications of the findings for improved evaluation and monitoring of marine aggregate extraction and disposal sites are discussed. In addition, the outcome of this programme of testing was the translation of the results of field surveys into guidelines for the cost-effective application of a range of techniques for use in an exploratory or routine monitoring context.

2.1 Objectives

The main aims of the project were to fully evaluate the scope and limitations of a range of suitable techniques for assessing the effects of site-specific anthropogenic activities at the seabed; further develop existing methodologies, and to evaluate additional techniques for use in broadscale mapping exercises. This was achieved through a series of field surveys and trials conducted over a 4 year period. Surveys were designed to test the utility of various acoustic and optical techniques for mapping seabed habitats at sites disturbed by a range of anthropogenic activities.

Specific objectives were:

- To consolidate and expand upon methodologies developed during a previous project (project AE0908-see Brown *et al.*, 2001), and to evaluate additional physical and geophysical techniques for mapping seabed habitats (see Chapters 3 and 5).
- To develop a strategy for the investigation of seabed conditions over different spatial scales (see Chapter 4).
- To evaluate the utility of seabed mapping techniques for determining the significance of several types of anthropogenic disturbances at the seabed (see Chapter 5).
- To evaluate seabed mapping techniques as monitoring tools for assessing temporal changes in community structure, in particular at disturbed sites where recovery is taking place e.g. aggregate extraction areas, or where there are time-dependant variations in the nature and intensity of impacts e.g. dredged material disposal sites (see Chapters 5 and 8).
- To determine the implications of any biogeographical variations in community composition associated with areas of similar substrates for predictive capability (see Chapter 6).
- To examine the scope for linkage between surveys conducted at different spatial scales, for example, those relating to site-specific extraction of marine aggregates versus wider evaluations relating to the fisheries resource, and to promote harmonisation of methodology (see Chapters 4 and 7).
- To produce guidelines on cost-effective applications of mapping techniques to a variety of circumstances of interest to Defra (see Chapter 11).

In addition to the work presented in this report, a number of other publications have been produced as a result of investigations carried out during this project (see Chapter 12). Data arising from surveys undertaken at the North Tyne dredged material disposal site has also been placed on the Cefas web-based GIS (see www.cefas.co.uk/data.htm).

3. Development and evaluation of survey techniques

3.1 Selection of sampling methodologies and survey sites

In the previous project (AE0908 – Brown *et al.*, 2001), a number of habitat mapping tools were employed to test their efficacy for mapping biological assemblages over coarse substrates which were largely unaffected by anthropogenic activities (see Chapter 2). From this study, it was evident that a number of the tools had potential to be used for monitoring and mapping areas of the seabed subjected to anthropogenic activities and in a wider range of sediment types. This Chapter explains our selection of those tools and how the methodologies were developed to meet the objectives framed within this project. Other techniques with less well proven track records in the assessment of anthropogenic disturbance, such as multibeam bathymetry and Sediment Profile Imagery (SPI), were also selected for trial in order to establish their utility. This involved pilot-testing methodologies over the same area of seabed in order to compare data quality and usefulness.

The first year of the project involved the evaluation and selection of suitable acoustic and seabed sampling techniques. Trials with a towed camera sledge provided higher quality photographic images than the drop camera frame system which was used extensively in the previous project (see Brown *et al.*, 2001). As the gear is towed over the seabed rather than 'dangled' above it, the camera maintains a fixed distance from the seabed giving a steadier and more useable image. Therefore the camera sledge was adopted as the main platform for video and still camera surveys. The quality and utility of video and still images collected with conventional analogue systems was compared to that which could be achieved using newer digital methods. Significantly improved image quality and instant image availability (particularly of still images) proved possible with the digital system and consequently a combined digital still and video system was employed in conjunction with the towed sledge. Light Emitting Diode (LED) lighting for the video camera was also tested, but found to be less effective than conventional halogen bulb systems.

The sidescan sonar system that was used for this project is capable of collecting acoustic data at progressively higher resolution as the width of the swathe that is ensonified is reduced. Different swathe widths, ranging between 400 m and 50 m, were tested to assess their utility. Following analysis, it appeared that a swathe width of 400 m provided a reasonable trade-off between feature resolution and cost-effective survey coverage. During the previous project, sidescan sonar data were routinely collected during an initial research cruise and taken back to the laboratory

to be processed and interpreted. Ground-truthing of the acoustic map would then be conducted during a second research cruise. As part of the current project, we tested the introduction of an off-line sidescan sonar post-processing PC to create georeferenced mosaics of the data within an hour of data collection. The output was then used to design and conduct subsequent ground-truthing surveys during the same research cruise. Trials of this process were successful, and therefore where possible, this approach became our preferred method for the acquisition of acoustic data and ground-truth samples. This was a cost-effective innovation, since the ship only had to be mobilised once to achieve fully ground-truthed maps of an area of interest.

A number of automated sidescan sonar data classification systems became available during the course of the project, and we tested one such system. Whilst the system was to some extent capable of automatically defining distinct sediment types, it was not as accurate as (or appreciably quicker than) expert human interpretation and further time had to be spent correcting the interpretation by hand. It was therefore decided that the project would rely wholly on expert human interpretation of sidescan sonar data.

The superior facilities of the new research vessel, *Cefas Endeavour*, which were available from 2003 onwards, enabled further development and testing of techniques for surveying the seabed. In particular, the hull-mounted dual-head multibeam bathymetry system produced fine-scale bathymetric maps of survey areas, adding a new acoustic technique to those already under evaluation. Using the vessel's Ultra Short Base Line (USBL) location system (HiPap™) to locate towed gears also improved the georeferencing of sidescan sonar, beam trawl and video sledge surveys, leading to greater accuracy (and hence confidence) in ground-truth sampling. The research vessel was also fitted with a dynamic positioning system which allowed equipment to be placed on, and towed across the seabed with a high degree of precision. For example, the towed camera sledge, when used in conjunction with *Cefas Endeavour's* USBL and dynamic positioning systems, had potential to provide very precise ground-truth information across habitat boundaries and also enabled targeting of particular features of interest.

We collected single beam echo-sounder data at a number of frequencies (38 kHz, 50 kHz and 200 kHz) to judge the ability of each frequency to provide effective acoustic ground discrimination. Given the range of ground types that were encountered, we adopted 200kHz as our preferred frequency, since this provides greater insight into the nature of surficial sediments than lower frequencies which penetrate deeper in softer sediments.

Pilot surveys were conducted at a variety of sites in years 1 and 2 of the project which facilitated the decision-making process regarding site selection, and the identification on a site-specific basis of the most cost-effective acoustic survey and ground-truth sampling strategies. Five dredged material disposal sites were surveyed during pilot investigations. The site at Inner Gabbard, in the southern North Sea had received maintenance dredgings prior to sampling, and surveys revealed reasonably homogeneous sandy sediments with a distinct area of finer sediment to the south of and within the disposal site. Nab Tower disposal site is a complex, heterogeneous site off the Isle of Wight which receives both capital and maintenance dredged material. Here the survey revealed high variability of sediments over a small spatial scale (patchiness), making it difficult both to discern the effects of disposal and to decide the most appropriate spatial scale at which to map sediment features. 'Site Z', in Liverpool Bay, regularly receives large quantities of maintenance dredgings which are frequently similar in nature to the natural sediments which surround the site. The Souter Point disposal site off the north east coast has received both colliery waste and maintenance dredgings over many years and there is some bathymetric evidence to suggest that dredged material has accumulated within the site. The North Tyne disposal site (TY070) off the Tyne has, for many years, received relatively large quantities of a range of dredged material types (e.g. maintenance dredgings and colliery waste). Regular routine monitoring surveys of this site carried out by Cefas showed that the seabed foot-print of disposal could be detected using conventional sampling techniques.

In addition, three aggregate extraction areas were surveyed as part of these pilot investigations. The first study site encompassed the Hastings Shingle Bank, a distinctive topographic feature aligned in a ENE/WSW direction in the eastern English Channel. This area has been the subject of previous investigations by Brown *et al.* (2001, 2004), Foster-Smith *et al.* (2004) and Boyd *et al.* (2004). A site off Shoreham in the eastern English Channel that was previously targeted by Brown *et al.* (2001, 2002) as part of the former project was also revisited to assess a discrete area of static suction hopper dredging. Finally, a limited amount of survey work was carried out at a relinquished aggregate extraction site known as Area 222 in the Outer Thames (see Boyd *et al.*, 2002, 2004).

Having successfully conducted pilot surveys at a variety of sites in years 1 and 2 of the project, a site selection process was undertaken to focus attention on those sites which best suited the aims of the project. Sites

were sought which were geographically separated and suitable for evaluating the scope and limitations of a range of seabed mapping tools in a variety of environmental circumstances. As part of a strategy to investigate the most effective survey and sampling strategies for broader spatial evaluation of seabed status, a number of acoustic and biological surveys were conducted at different spatial scales. A tiered survey design was adopted. This consisted of a broadscale survey area between Dungeness and Hastings within which was nested the Hastings site containing an area of the Hastings Shingle Bank licensed for marine aggregate extraction (see Chapter 4).

Repeat (annual) surveys were also conducted at the aggregate extraction site off Shoreham, in the eastern English Channel and the dredged material disposal site off the Tyne (TY070) in the North Sea in order to investigate temporal changes in benthic community structure and the status of physical habitats (see Chapter 5 for further details).

At an early stage in this project, a meta analysis of infaunal data arising from surveys reported in Brown *et al.* (2001) was undertaken and this indicated a possible geographic cline in community structure within the eastern Channel. In an attempt to further explore this east-west biogeographical variation, a site off Looe was surveyed to provide comparative data from the western Channel (see Chapter 6). Chapter 7 represents the results of a number of desk-based modelling exercises and the methods associated with this work are reported separately within the chapter. Finally, the outcome of various acoustic and ground-truthing surveys conducted within the Wash by Envision Ltd were reviewed with a view to assessing the utility of mapping techniques for monitoring particular sites of conservation importance (see Chapter 8).

The five areas shown in Figure 3.1 represent the sites over which the techniques described in Chapters 4, 5, 6 and 8 were applied.

3.2 Methods - Acoustic surveys

3.2.1 Digital sidescan sonar

Sidescan sonar technology has been used successfully for many years to produce high resolution acoustic maps of the seabed (Brown *et al.*, 2001, 2004; Boyd *et al.*, 2004, 2005). Typically, sidescan sonar data are produced using a pair of transducers mounted either side of a towfish which is connected to a survey vessel by means of a cable (Figure 3.2). The sound emitted from the transducers ensonifies a continuous swathe of seabed either side of the transducers (Blondel and Murton, 1997). Reflected

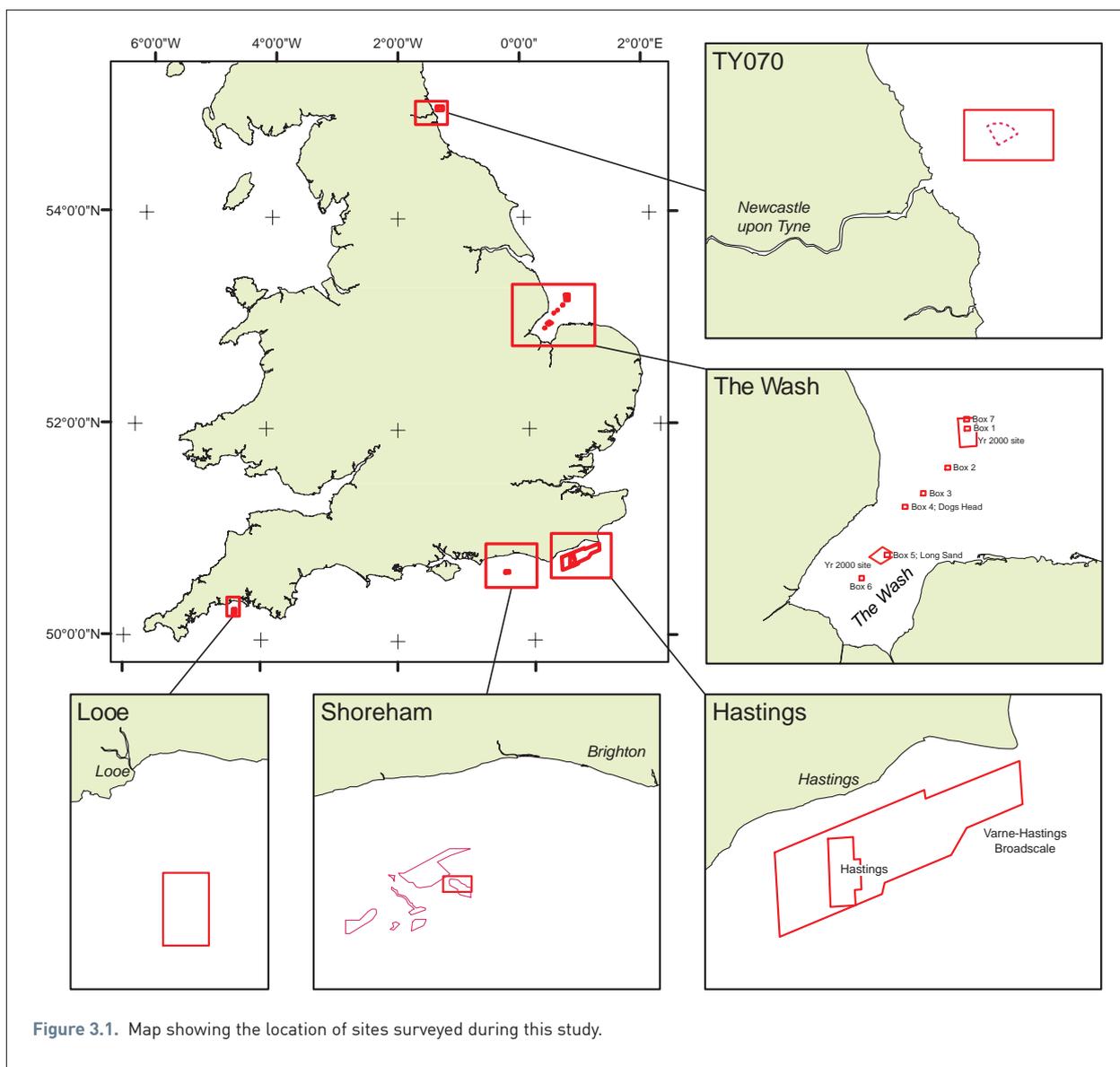


Figure 3.1. Map showing the location of sites surveyed during this study.

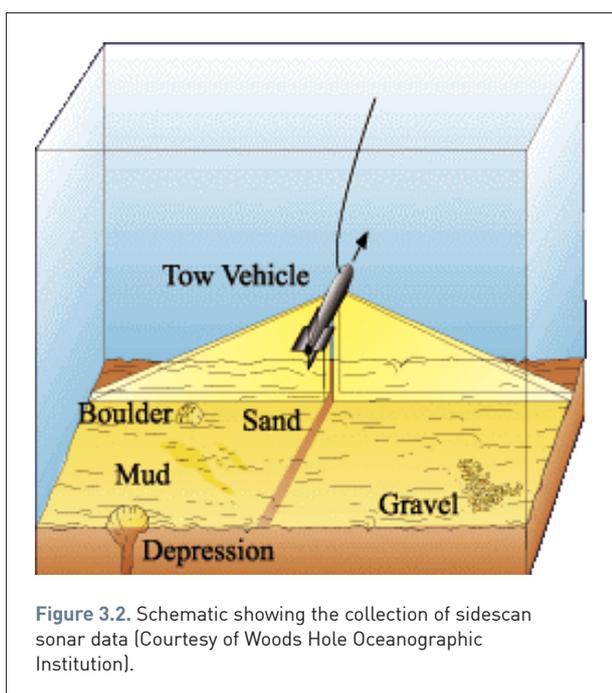
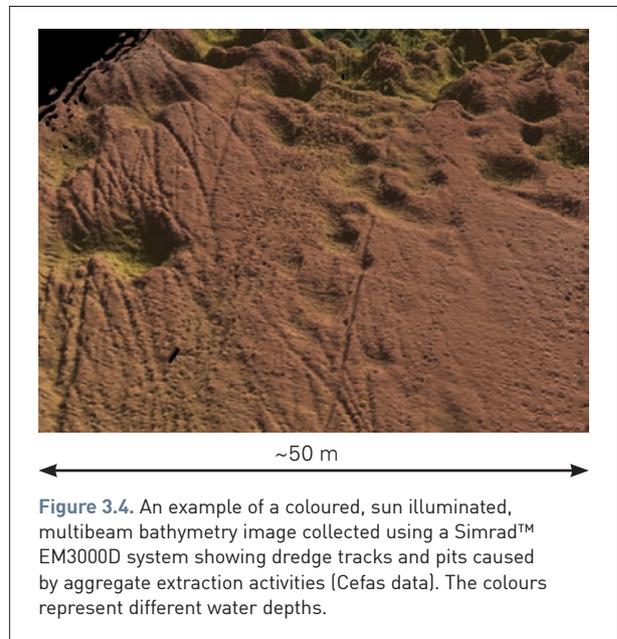
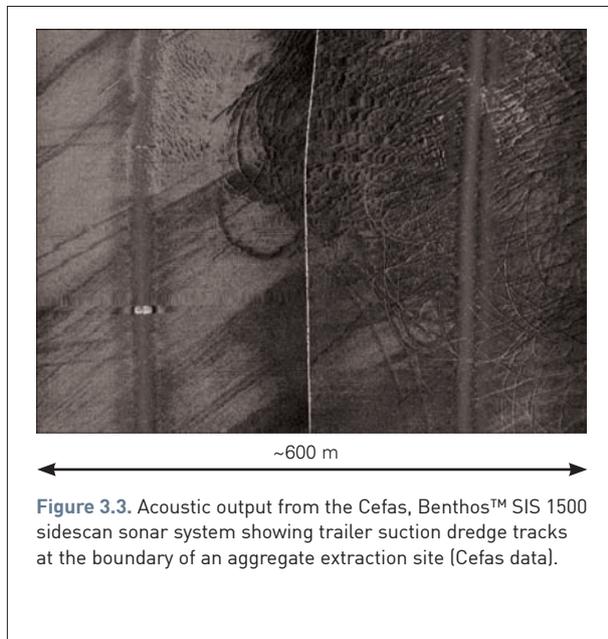


Figure 3.2. Schematic showing the collection of sidescan sonar data (Courtesy of Woods Hole Oceanographic Institution).

sound received by the transducers from the surface of the seabed provides information on the nature (e.g. hardness, roughness, texture) of the sediments and the presence and disposition of seabed features (e.g. sand waves, rock outcrops and anthropogenic features) across the swathe (Fish and Carr, 1990) (Figure 3.3).

In the current project, sidescan sonar data were collected using the Benthos™ SIS 1500 digital CHIRP (190-210 kHz) sidescan sonar system in conjunction with the Triton Isis™ data acquisition software. Data was processed, georeferenced and mosaiced using the Triton Isis™ software package to produce continuous acoustic maps of the area surveyed. The vessel position was provided by a Thales 3011™/ Fugro SeaStar™ DGPS system and the position of the sidescan towfish was calculated by using vessel heading, vessel offsets, towcable layback and towfish depth. Survey line spacing was designed to produce 100% coverage of the areas of interest, with limited overlap of data. Further guidelines on the conduct of such surveys can be found in Boyd (2002) and Davies *et al.* (2001). Ground-truthing of the acoustic maps was

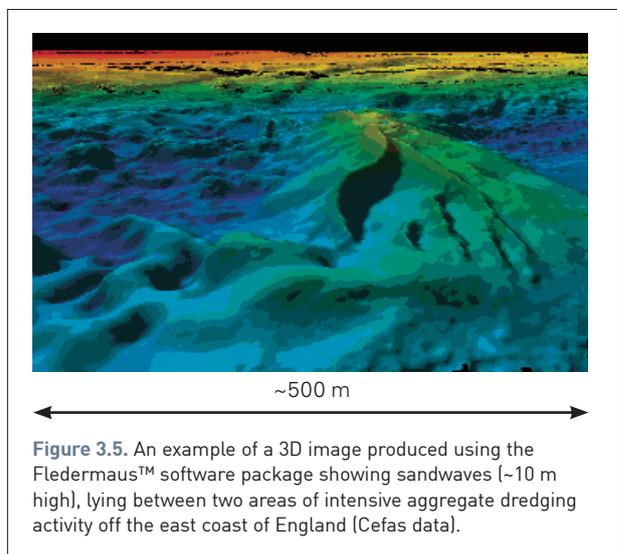


conducted using grab and trawl sampling, alternative acoustic methods and optical techniques (e.g. SPI and video camera techniques).

3.2.2 Multibeam bathymetry

Multibeam bathymetry is a method of rapidly mapping the topography and nature of the seabed (Kostylev *et al.*, 2001; Pickrill and Todd, 2003; Parsons *et al.*, 2004). The outputs from multibeam bathymetric surveys were used to produce continuous, high resolution topographic maps of the seabed and, under good conditions, features of less than 10 cm in height were resolved. Multibeam bathymetric data was also used to create coloured, shaded relief images that depict seafloor morphology. Such data was imported into 3D visualization software packages to create video style “fly-throughs” around the topographic surface. These images were used to interpret features on the seafloor such as sand banks, channels, sand waves, areas of bedrock outcrop, wrecks and other anthropogenic features such as those caused by aggregate extraction (Figures 3.4 and 3.5). Acoustic backscatter intensity measurements (similar to sidescan sonar data but lower in quality) were collected simultaneously with the depth information, and were also used to determine the general distribution of sediments and their associated features.

There are two main types of multibeam system: true multibeam (or focussed multibeam) and interferometric (or bathymetric sidescan sonar) systems. The primary differences between the systems are that true multibeam



systems are generally more expensive than interferometric systems but provide more accurate soundings in areas of high topographic variability (Parsons *et al.*, 2004). Interferometric systems are also able to collect wider swathes of data in shallow (~<10 m) water. Both systems are dependent on a very high quality motion reference unit (MRU) to determine the position and attitude of the transducers. This apparatus significantly increases the cost of the system but is essential for accurate and precise depth measurement.

The primary system adopted in the current study was the 300kHz, Kongsberg Simrad™ EM3000D dual-head “true” multibeam system, which used transducers mounted in ‘V’ formation on the drop keel of the *Cefas Endeavour*. Positioning of the data was achieved using a Thales 3011™/Fugro SeaStar™ satellite differential system. Vessel, pitch, roll and heave were measured with a Kongsberg/Seatech™ MRU5 motion reference unit. These parameters were corrected in real time within the EM3000D processing unit which then output the data to either a Triton Isis™ or Kongsberg SIS™ logging package. Sound velocity at the sonar head was measured with a Reson™ sound velocity probe. The data were then imported into CARIS™ HIPS where further corrections were made using predicted tidal data and sound velocity profiles. Erroneous soundings were filtered and a corrected XYZ dataset was produced for each survey. These XYZ grids were then imported into the 3D visualisation software package Fledermaus™, where coloured, sun-illuminated topographic images depicting the surface of the seabed were produced.

The GeoSwath™ 250 kHz interferometric system was used for the bathymetric work carried out in the Wash (see Chapter 8). A fuller description of the methods and equipment specification is presented in Chapter 8. Further information on this system can also be found in Hogarth (2003).

3.2.3 Acoustic Ground Discrimination Systems

Acoustic ground discrimination systems (AGDS) are a relatively cheap and rapid method which when appropriately ground-truthed can be used to generate maps of the distribution of habitats. Such systems constitute one category of an increasing number of acoustic tools currently being utilised in the field of habitat mapping (Greenstreet *et al.*, 1997; Foster-Smith *et al.*, 2001; Anderson *et al.*, 2002; Brown *et al.*, 2005). AGDS are designed to detect the acoustic reflectance properties of the seabed which is linked to the physical, or occasionally biological nature (e.g. mussel beds) of the seafloor. For the most frequently applied systems, a vessel mounted wide-beam, single beam echosounder is used. The sounder generates an acoustic pulse which travels through the water column, is reflected off the seabed, and is received back on board the vessel by the transducer. Each acoustic pulse is received and processed by the AGDS in order to characterize and subsequently classify variations in the signal.

During this project, three AGDS were used, RoxAnn™, Echoplus™ and QTCT™. A full account of the operation of these systems is given in Section 5.3.

AGDS were used to determine their utility for discriminating different seabed habitats, particularly in areas impacted by human activities. The effectiveness of this acoustic technique was also compared with other acoustic systems as a stand-alone method and as an additional tool to complement other methods.

3.2.4 Data interpretation

Seabed features (sand ripples, bedrock outcrops etc) and an indication of the sediment characteristics (soft or hard sediments) were determined from an analysis of sidescan sonar mosaics, augmented by specialist geological knowledge, in order to generate seabed facies maps. These map sediments in greater detail than previous attempts using ‘acoustically distinct areas’ (see Brown *et al.*, 2001). The presence and identity of seabed facies was confirmed through underwater video data collected at ground-truthing sites. Using this approach, the Tyne, Shoreham, Hastings and Looe sites were divided into areas which represented different seabed facies. These seabed facies maps formed the basis for the subsequent biological and ground-truthing surveys (see individual Chapters for details on the rationale behind sampling designs adopted in each location). The output from multibeam bathymetry surveys, was, where available, also employed in the generation of seabed facies maps. This technique provided data on the topography of the seabed and in some instances, allowed the discrimination and scale of certain anthropogenic features such as the presence of disposed dredged material or dredge tracks from aggregate extraction activities. In addition, the output provided an acoustic basemap upon which other data-sets derived from ground-truthing surveys could be superimposed. This offered the possibility of viewing multiple data-sets together and allowed the investigation of potential independencies between data-sets. The ability to run three acoustic systems (sidescan sonar, multibeam bathymetry and AGDS) simultaneously delivered significant operational efficiencies and their synchronous use led to synergies during interpretation.

3.3 Methods - biological surveys and ground-truthing

At each location, the design of the biological and ground-truthing surveys were structured around the seabed facies maps identified from the output from sidescan sonar surveys. The ability to map ecologically relevant patterns rests not only on the resolution (spatial and level of discrimination) of the remote sensing equipment, but

also on the inherent heterogeneity of the seafloor and the nature of device used for ground-truthing. Surveys were therefore designed on a site-specific basis taking account of information gained from acoustic surveys on the heterogeneity of the area and the likely nature of seabed sediments. All surveys were conducted at the same time of year between May-July from 2001-2004. The description below represents the generic methods adopted for the collection, processing and analysis of samples collected during field surveys. Further details on the methodology employed can be found within individual Chapters.

3.3.1 Grab sampling

Due to the coarse nature of the sediments frequently encountered during this project, quantitative faunal sampling was conducted using the 0.1 m² Hamon grab (Oele, 1978) (Figure 3.6). A full account of the methodology for the operation of this grab, and the collection and processing of the physical and biological samples gained from it, is given in Boyd (2002). This grab generates a disturbed sample when recovered on deck. The Hamon grab was therefore fitted with a video camera and a light source in order that an image of the sediment surface immediately adjacent to where the sample was collected could be obtained. This information was important, as it provided a visual impression of the seabed in an undisturbed state, which proved useful for informing subsequent acoustic and biological interpretations. Following the estimation of total volume of each grab sample, a 500 ml sub-sample was removed for laboratory particle size analysis. The remaining sample was washed over a 5 mm and 1 mm square mesh sieves to remove fine sediment fractions. The retained macrofauna were fixed in 4-6% buffered formaldehyde solution (diluted with seawater) for subsequent laboratory identification and enumeration.

3.3.2 Beam trawling

The Jennings 2 m beam trawl (Figure 3.7) was used for the semi-quantitative collection of epifauna samples (Jennings *et al.*, 1999). This trawl was designed for use over coarse sediments such as those frequently found at dredged material disposal sites and aggregate extraction sites. The device is fitted with a chain mat and robust chafers to assist effective sampling and to limit net damage. The beam trawl was deployed from the stern of *Cefas Endeavour* using a warp length of at least 3 times the water depth. For each deployment, the trawl was towed over a fixed distance at a fixed speed to achieve operational standardisation between sampling sites. On retrieval of the beam trawl, the sample volume was measured and

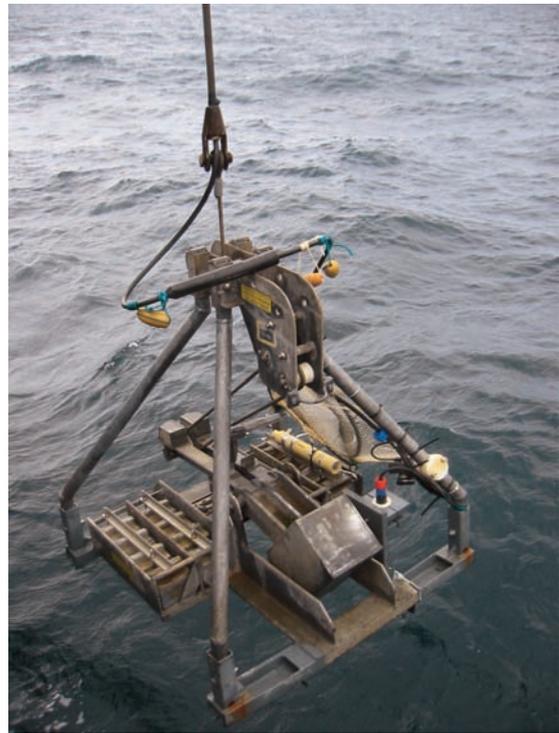


Figure 3.6. Image of 0.1 m² Hamon grab with video camera fitted.

each sample was washed over a 5 mm square mesh to retain smaller and rarer free-living species. On occasions where retained beam trawl samples were viewed to be too large to process efficiently and/or where the catch contained many hundreds of organisms of the same taxon, a sub-sampling procedure was adopted. This involved taking a representative sub-sample of a known volume of the catch (usually between 4-10 litres depending on the volume of the total sample). This sub-sample was then removed and examined for all specimens, grouping each taxa separately. If the numbers of individuals of one taxon reached 100 or more, this taxon was no longer counted in any subsequent sub-samples and a note was made of the volume in which the initial count was determined. Values of each taxon subsampled were then raised in order to estimate the total abundance in the whole sample. For any taxa with <100 individuals in the sub-sample, the process was repeated with further sub-samples. This process of sorting cumulative sub-samples was continued until the entire catch was sorted. This sub-sampling procedure was adopted to ensure that the entire catch was sorted properly accounting for less numerous taxa and making



Figure 3.7. Recovering a 2 m Jennings beam trawl on the aft-deck of the *Cefas Endeavour*. Note the chain mat ahead of the entrance to the net and the yellow chafer protecting the cod-end.



Figure 3.8. Digital still image of a 2 m beam trawl sample in a 60 l temporary storage container.

reliable estimates of highly numerous taxa. All specimens were identified to species level using a range of standard taxonomic keys and enumerated with the exception of colonial and encrusting taxa, which were recorded on a presence/absence basis. Representative specimens of each taxon encountered at sea were preserved in 4-6% buffered formaldehyde solution and identification confirmed in the laboratory.

3.3.3 On-deck photography

Photographs were taken of each grab and trawl sample (Figure 3.8) that was recovered on deck. These images provided an overall impression of the nature of each sample, and were used as additional ground-truthing information.

3.3.4 Underwater video and stills photography

Remote underwater video and stills photography are effective means of visually characterising relatively large areas of the seabed (Davies *et al.*, 2001). The camera

sledge (Shand and Priestly, 1999) was fitted with a forwardly inclined, combined digital video and stills camera (Kongsberg™ 14-208-0105) with a downward pointing flash system (Figure 3.9). Various flood- and spot-lights were fitted to the sledge frame to give optimal illumination of the seabed. The video image covered approximately 1 m² of seabed and the stills image (Figure 3.10) provided similar coverage. The video data was relayed via an armoured umbilical tow-cable to the vessel, where it was recorded to SVHS tape and DVD. Digital still images were taken periodically by the operator along each tow, with the intention of providing a series of images which suitably characterised the substrates encountered. Still images were downloaded on the vessel after each tow.

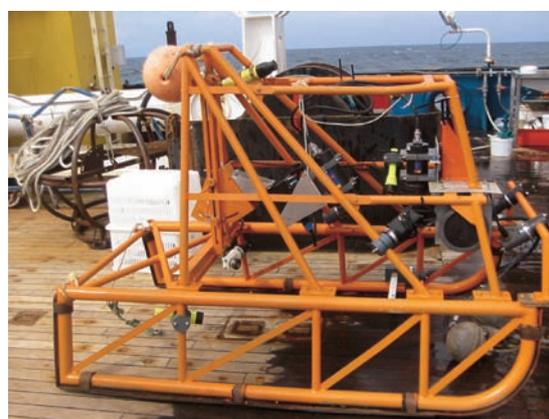


Figure 3.9. Cefas towed video sledge fitted with Kongsberg™ combined digital video and stills camera, flash unit and lights.

Photographic images collected in this way were used in a qualitative manner insofar as they provided corroborative ground-truth information in support of other techniques such as sidescan sonar and grab and trawl sampling. In particular, this information helped to validate and describe habitat boundaries apparent from acoustic surveys. Video data were also used to observe the presence of low density conspicuous megafauna which may not have been sampled using grab and trawl methods.

Cefas Endeavour is fitted with Dynamic Positioning (DP) capability which allows the vessel to tow equipment along pre-specified survey lines with a high degree of control over speed and position. This facility was used to great effect to tow the camera sledge over pre-defined sediment boundaries and seabed features and facies.

3.3.5 Sediment Profile Imagery

A further optical technique, Sediment Profile Imagery (SPI) was tested in soft sediments at TY070 providing photographs of the sediment profile to approximately 25 cm depth. SPI is a rapid method for characterising the benthic habitat at and below the surface of the seabed (Solan *et al.*, 2003). The system consists of a camera mounted above a wedge shaped prism with a plexiglass faceplate and an internal flash strobe (Figure 3.11). The back of the prism has a mirror mounted at a 45 degree angle which reflects the profile of the sediment water interface to the camera mounted above it. This equipment is mounted within a supporting frame which is lowered to the seabed. As the frame approaches the seabed, a trigger device which hangs below the frame, is activated, causing a photograph to be taken of the plan view of the seabed surface from above. The frame continues its descent until it comes to rest on the seabed, and the prism is then gently lowered through the sediment-water interface. When the prism comes to rest at its full penetration, a photograph is taken through the plexiglass window of the water-sediment profile (Figure 3.12). Under ideal sampling conditions, a photographic image is taken showing a profile through the surface 25 cm of the seabed with approximately 5cm of overlying water.

The camera used during this project was a Nikon F-801s SLR, and the images were analysed using Image Analyst for Macintosh™ version 9.0.3. Site characteristics (biological, chemical and sedimentological) were assessed by image analysis, deriving a suite of indices most applicable to monitoring. For example, from each image, sediment type, sediment boundary roughness (SBR), apparent redox potential discontinuity (ARPD) depth, the organism-sediment index-OSI (Rhoads and Germano, 1986) and the



Figure 3.10. An example image of an encrusting sponge habitat of the south coast of England taken with the Kongsberg™ combined digital video and still camera system.



Figure 3.11. Image of the Cefas SPI unit prior to deployment.

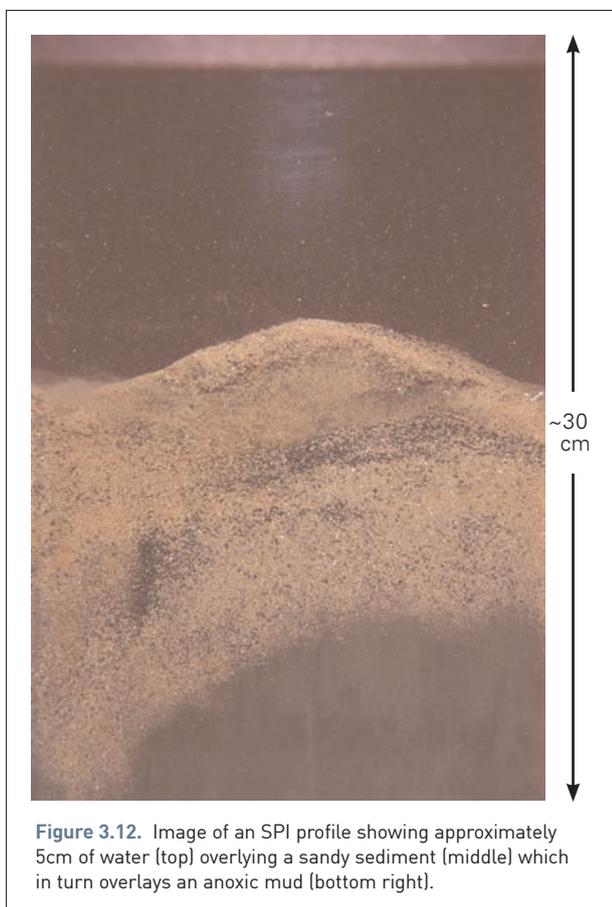


Figure 3.12. Image of an SPI profile showing approximately 5cm of water (top) overlying a sandy sediment (middle) which in turn overlays an anoxic mud (bottom right).

benthic habitat quality index-BHQ (Nilsson and Rosenberg, 1997) were calculated based on the techniques developed by Rhoads and Cande (1971), Rhoads and Germano (1982) and O'Connor *et al.* (1989). This rapid technology gave information on a spatial scale (centimetres) not well addressed by other methods.

3.4 Logging and archiving of field data

The previous project relied primarily on a conventional paper logbook recording system to document the information associated with the collection of samples and the conduct of surveys at sea. During this project, a bespoke Access database known as “Digilog” was developed by Cefas to hold all metadata associated with field surveys. Relevant metadata such as sample position, gear type, the nature and quality of a sample and its storage details were recorded and archived using this software.

This system proved to be more effective than the logbook system in that it prompted an input for a number

of required fields, thus ensuring that a more consistent and complete set of metadata were recorded for each gear deployment. The use of an electronic system also enabled the project team to query the database and extract data efficiently and accurately.

3.5 Laboratory sample processing

3.5.1 Macrofaunal samples

Macrofaunal samples were processed according to the guidelines given in Boyd (2002). In the laboratory, Hamon grab samples were first washed with freshwater over a 1mm square mesh in a fume cupboard to remove the excess formaldehyde solution. Samples were then sorted and the specimens placed in Petri-dishes or jars containing a preservative mixture of 70% methanol, 10% glycerol and 20% tapwater. Specimens were identified to species level, as far as possible, using standard taxonomic keys. The number of individuals of each species was recorded and colonial species were recorded as present or absent.

3.5.2 Particle size analysis

In most cases, a full particle size analysis (PSA) was conducted on the sediments collected during this project. This involved wet sieving each sub-sample over a 500 μm sieve and dry sieving the >500 μm fraction at 0.5 phi intervals using a stack of test sieves. The <500 μm fraction was laser sized using a Malvern™ Mastersizer. This process measures the quantity of material within each 0.5 phi subclass allowing the data to be combined with the coarse fraction, thus providing a full particle size distribution (PSD) for each sample.

In some cases, a summary PSD was deemed adequate to ground-truth acoustic datasets and in these cases the sediment samples were wet sieved at 63 μm and the >63 μm fraction was dry sieved at 0.5 phi intervals. The <63 μm fraction was dried and weighed but not laser sized, and the contribution of this size class towards the overall sample was expressed as a proportion of the total.

3.6 Data analysis

Univariate analysis, based on total number of individuals (excluding colonial species) and the total number of species, were calculated from the Hamon grab and beam trawl samples to provide a quantitative assessment of benthic assemblages within each seabed facies (and/or acoustically distinct region). Associations between benthic assemblages and acoustically distinct regions were also examined using multivariate statistical methods.

Sample and species associations within survey sites were assessed by non-metric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure based on transformed abundance data (excluding colonial taxa) using the software package PRIMER (Clarke and Warwick, 1994). Analysis of similarities (ANOSIM, Clarke, 1993) was performed to test the significance of differences in macrofauna assemblage composition between samples. The nature of the groupings identified in the MDS ordinations were explored further by applying the similarity percentages program (SIMPER) to determine the contribution of individual species to the average dissimilarity between samples. Relationships between environmental variables and multivariate community structure were also assessed using the BIO-ENV procedure within the PRIMER programme. In this procedure rank correlations (ρ_{RV}) between a similarity matrix derived from the biotic data and matrices derived from various subsets of environmental data are calculated, thereby defining suites of environmental variables which best explain the biotic structure. Further details on particular data analyses performed during this study can be found within individual Chapters.

4. Investigating seabed conditions over different spatial scales

4.1 Introduction

The ability of acoustic techniques to detect seabed features and discriminate different types of sediment presents the prospect of making accurate and reliable seabed maps that are of great value in the conservation, management and monitoring of the marine environment (Brown *et al.*, 2001, 2002, 2004). However, their limited spatial coverage and inability to detect benthic fauna means their application in mapping seabed habitats requires a structured approach to survey design that can be adapted to suit the requirements for mapping at different spatial scales. There are two main steps in this structured approach, the first being to map acoustically distinct areas of seabed, and the second to ground-truth that map to determine the nature of the sediments and fauna in each area. If it can be demonstrated that different benthic communities are associated with different sediment types, then the distribution of those sediments can be used as a proxy to map benthic habitats and biotopes (Roff *et al.*, 2003).

The swathe width of sidescan and multibeam sonar systems is typically limited to a few hundred metres, so to achieve an acoustic image of a wider area requires several parallel swathe tracks to be pasted together in an acoustic 'mosaic'. Areas up to ~ 50 sq km can be surveyed in a single day of vessel time and this is usually sufficient to cover discrete sites of specific interest, such as those licensed for aggregate extraction or dredged material disposal. Considerably greater time and effort would be required to cover broadscale areas (~ 500 sq km) or regional seas where there is currently great demand for maps to underpin marine spatial planning initiatives, but the cost of doing so may become prohibitive.

An acoustic image can contain a great deal of detail due to the high resolving power of modern acoustic systems, being in the order of one metre for sidescan sonar and a few centimetres for multibeam sonar (Kenny *et al.*, 2003). When delineating acoustically distinct areas from the sonar mosaic, consideration must be given to the intended purpose of the resulting map and the appropriate resolution, which will be related to spatial scale. High resolution maps of broad spatial areas are usually overcrowded with information and difficult to interpret, while low resolution maps of small spatial areas rarely supply sufficient detail.

As different sediment types have different acoustic signatures, an experienced observer can provide a preliminary interpretation of the major sediment types associated with acoustically distinct areas (e.g. sands or gravels). Ground-truth sampling is required to verify such general interpretations and to obtain a more precise

description of the sediments (e.g. slightly gravelly, muddy sand) through particle size analysis of grab or core samples. Variability within each area can be assessed by comparing a number of replicate samples.

Mapping seabed habitats and biotopes requires further ground-truth sampling to determine the composition and distribution of benthic macrofaunal communities. Several sampling techniques can be employed, using grabs or cores to collect infauna and trawls or dredges for epifauna. Observational techniques (video or photographs) are also useful on hard substrates that are not amenable to physical sampling. Different species are adapted to live in different sediments, but gross sediment type is not the only determinant of habitat suitability. Other physical factors such as depth of water and current velocity are also influential in structuring the seabed (e.g. different bedforms such as sand waves or megaripples) and their associated communities (Warwick and Uncles, 1980; Holme and Wilson, 1985; Barros *et al.*, 2004). Consequently, seabed facies (distinct combinations of sediment type and bedform) may prove better proxies for mapping benthic habitats and biotopes than gross sediment type.

The aim of this part of the project was to develop a strategy for investigating seabed conditions over different spatial scales. To this end we adopted a nested survey design, expanding and developing surveys of the Hastings Shingle Bank undertaken by Brown *et al.* (2001, 2004), and of the broader area between Hastings and Dungeness (Foster-Smith *et al.*, 2004). These earlier studies employed a relatively coarse interpretation of acoustic data to classify seabed sediments, but the present study focused on a more detailed interpretation, supported by existing geological data sets and complemented by ground-truthing techniques, to investigate the feasibility and utility of mapping seabed facies. With a further view to developing a cost-effective strategy for surveying larger spatial areas, we investigated the density of sidescan coverage required to produce broadscale facies maps that were fit for purpose.

4.2 Background

The study site comprised a broadscale area (40 x 15 km) within which was nested the Hastings site (4 x 12 km) containing an area of the Hastings Shingle Bank that is licensed for aggregate extraction (Figure 4.1). Brown *et al.* (2001, 2004) had acquired 100% sidescan coverage of the Hastings site, and recognised four acoustically distinct regions (Figure 4.2) that were ground-truthed by random stratified sampling. The nature of the sediments and their

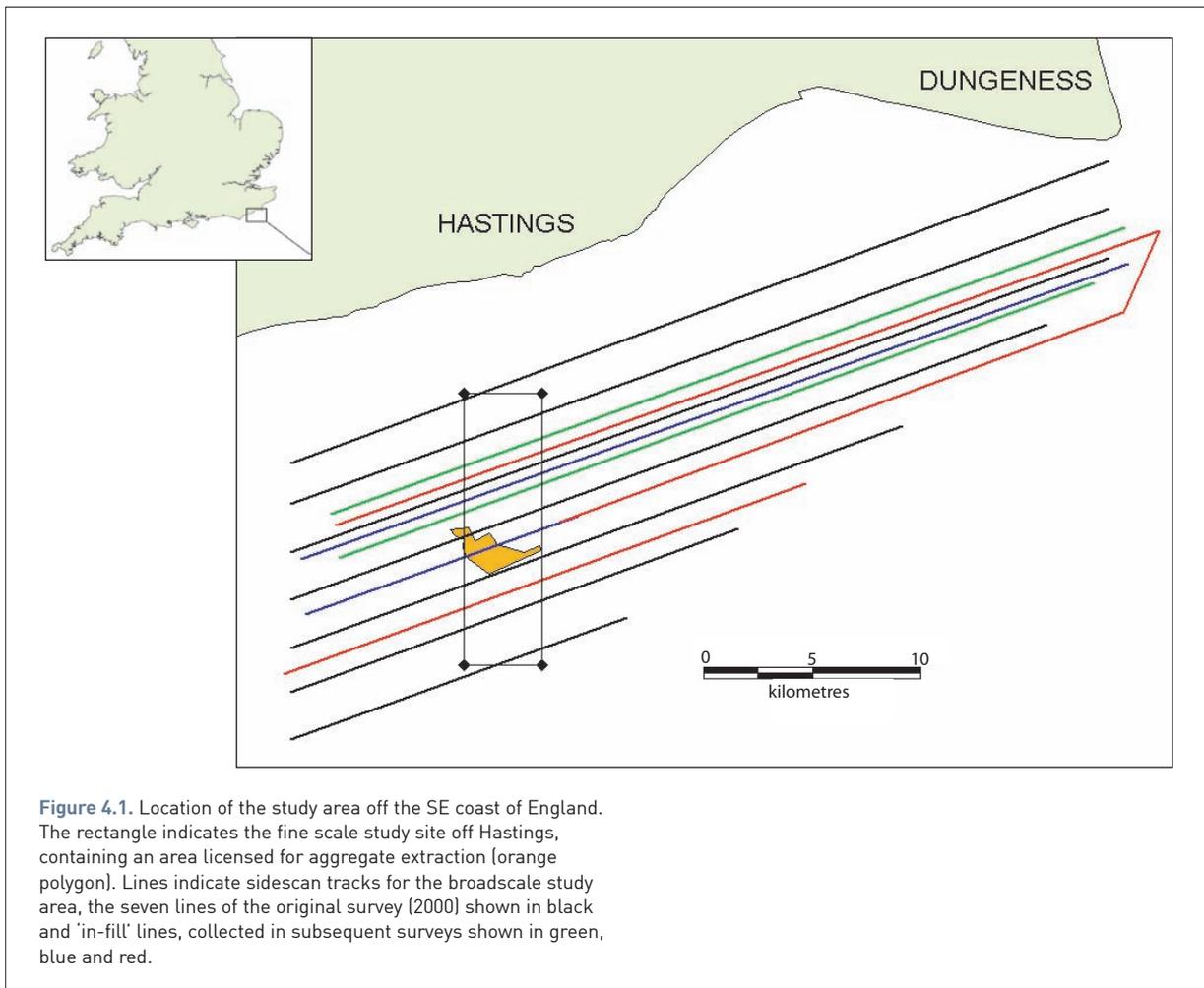


Figure 4.1. Location of the study area off the SE coast of England. The rectangle indicates the fine scale study site off Hastings, containing an area licensed for aggregate extraction (orange polygon). Lines indicate sidescan tracks for the broadscale study area, the seven lines of the original survey (2000) shown in black and 'in-fill' lines, collected in subsequent surveys shown in green, blue and red.

associated macrofaunal assemblages were determined from sediment samples collected by 0.1 m² Hamon grab, while more mobile epifaunal species were sampled by a 2-metre wide 'Jennings' beam trawl (Jennings *et al.*, 1999). Statistical analyses of the ground-truth data showed the four acoustic regions differed in both their physical and biological characteristics, allowing each to be described as a different biotope (Figure 4.2, A = shallow water polychaete dominated fine sand, B = coarse gravel with attached epifauna, C = disturbed (dredged) sandy gravel, D = deeper water coarse sand). Although the biotopes were clearly distinct from one another, Brown *et al.* (2001, 2004) noted that replicate samples from within each acoustic region could be quite dissimilar.

4.3 Methods

4.3.1 Hastings study area

The present study made a more detailed interpretation of the original sidescan sonar mosaic of the Hastings site, taking into consideration the bedforms and transport indicators and further geophysical data available in the archives of the British Geological Survey. This produced a seabed facies map (Figure 4.3), recognising nine different facies and mapping the area into >20 regions, as opposed to the original four. Overlaying the original ground-truth positions on the new facies map showed that a number of

different facies had been sampled within each acoustically distinct area (Figure 4.4), which may account for the variability within replicates noted by Brown *et al.* (2001, 2004). The site was re-visited to ground-truth the facies map using a suite of sampling techniques.

The accuracy of the facies descriptions and the distinctness of their boundaries was assessed from video recordings of seven camera sledge tows (Shand and Priestly, 1999) made at strategic points throughout the site (Figure 4.5, CS1 - 7). The entire video record for each tow was analysed, noting sediment types and topographic features, and comparing these observations with what was expected from the facies map.

Epifaunal samples were collected from ten of the facies using the standard 2-metre 'Jennings' beam trawl towed over a nominal distance of 200 metres (Figure 4.5, JB1 - 10). Samples were washed over a 5 mm square mesh sieve prior to identification and enumeration, with colonial species being recorded as 'present'. Associations between epifaunal assemblages and seabed facies were examined by univariate and multivariate analyses following the general methodology of Clarke and Warwick (1994), using the PRIMER software package (v5, Clarke and Gorley, 2001). Sample similarities were calculated using the Bray-Curtis similarity index based on square root transformed abundance data and represented by dendrograms and non metric multi-dimensional scaling (MDS) ordination

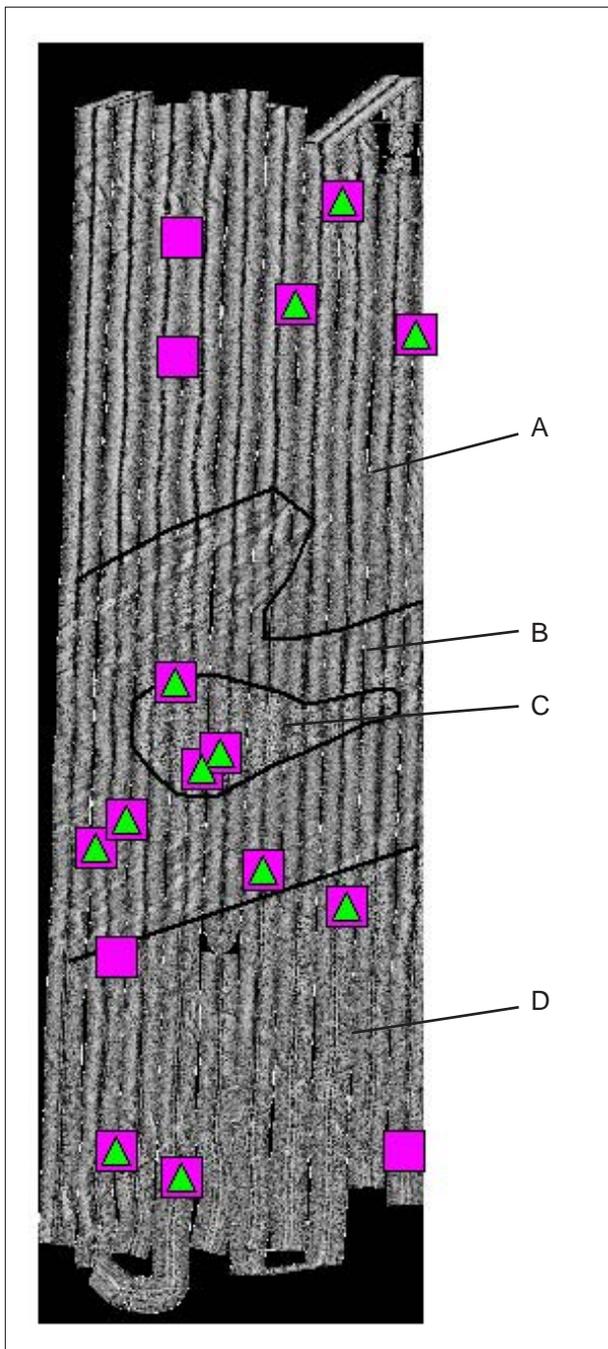


Figure 4.2. Sidescan mosaic of the Hastings site, showing the four acoustically distinct areas determined by Brown *et al.* (2001, 2004) and the position of their ground-truth sampling with Hamon grabs (purple squares) and 2-metre beam trawls (green triangles).

each facies (Figure 4.6). The sampling pattern described an angular spiral with sides of relative length 1, 2, 3, 5 and 8, based on the Fibonacci series of numbers (add the previous two to get the next). With just six sampling points, 15 different pair-wise comparisons can be made ($5 + 4 + 3 + 2 + 1$), each having a different 'lag' distance (separation between points). Using this pattern, spatial variability within a facies can be assessed graphically, plotting some measure of similarity (or dissimilarity) between sample pairs against lag distance in a simple Cartesian (x,y) chart. The sampling pattern provided a more structured approach to assessing variability than would a random stratified sampling design. In practice the distances between sampling points were 100, 200, 300 etc. metres. Each sample was treated in the same manner, with a sub-sample used for particle size analysis, and the remaining material washed over a 1 mm sieve to collect macrofauna for identification and enumeration.

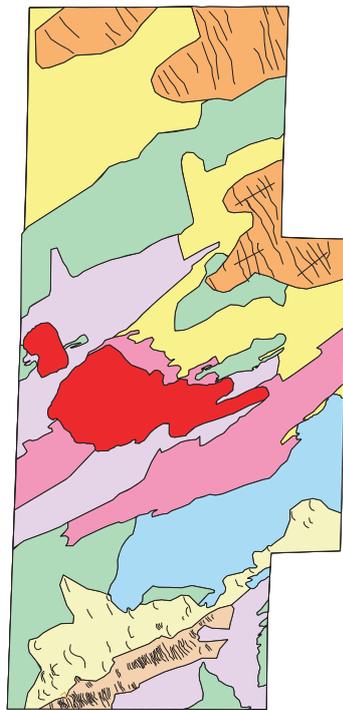
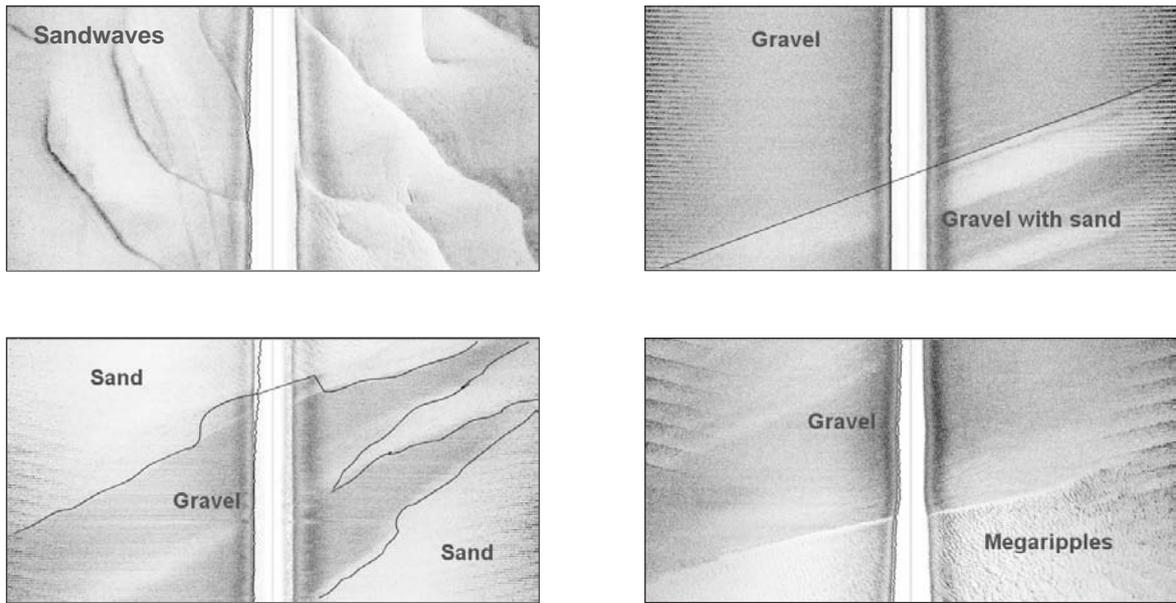
Sediment grain size was expressed in whole phi (ϕ) units and samples compared by graphical analysis of the size-frequency distributions. Spatial variability among samples was examined as described above, plotting Euclidean dissimilarity for sediment samples (based on square root transformation of % frequency in each grain size class) and Bray-Curtis dissimilarity for biotic samples ($100 - \text{Bray-Curtis similarity}$, based on 4th root transformed abundance data, colonial organisms excluded). Further community analyses were undertaken using the PRIMER package to investigate the linkage between different faunal assemblages and different sediment types, and to determine the species that typify or discriminate between the four facies that had been sampled.

4.3.2 BROADSCALE STUDY AREA

In the broadscale study area between Hastings and Dungeness, the earlier studies had conducted a sidescan sonar survey comprising seven parallel lines at 2 km track spacing (Figure 4.1) using a digital chirps sidescan sonar system with a 400 m total swathe width (Brown *et al.*, 2004, Foster-Smith *et al.*, 2004). To obtain some indication of the density of sidescan coverage required to produce a reliable broadscale facies map, the current project surveyed a series of 'in-fill' lines to provide progressively greater density coverage, reaching 100% along a central SW-NE corridor. Each of the sidescan lines was individually interpreted to mark the facies boundaries, following which four interpolated facies maps were made representing progressively greater density coverage, three based on subsets of the data (namely 4 km, 2 km and 1 km line spacing) and the fourth using all available lines.

to determine distinct sample groups. The significance of differences between sample groups was tested by an analysis of similarities (ANOSIM, Clarke and Green, 1988) and the taxa primarily accounting for their similarities/differences determined using the similarity percentages routine (SIMPER, Clarke, 1993). Analyses were based on numeric (abundance) data, so colonial taxa were excluded. A comparison between the two studies of the Hastings site (Brown *et al.*, 2004 and the present study) was made using similar analyses on a pooled data set. To lessen the influence of rare taxa, those with an occurrence of $n < 10$ in the pooled data set were excluded from the analysis.

Sediment and macrofaunal samples were collected from four of the facies using a 0.1 m² Hamon grab, with a novel sampling design being tested to investigate variability within



- Dredged area
- Featureless sand
- Featureless gravel
- Gravel with sand patches
- Sand waves, $w = 100 - 200$ m
- Sand waves, $w = 20 - 50$ m
- Lunate sand waves
- Megaripple, $w = 10 - 30$ m
- Megaripple, $w < 10$ m

Figure 4.3. Four examples of facies interpretations from sidescan sonar images (400 m swathe width) and the seabed facies map of the Hastings study site derived by interpretation of the sidescan sonar mosaic shown in Figure 4.2. Coloured polygons delineate individual facies, and lines within them mark the crests of individual sand waves (w = wavelength).

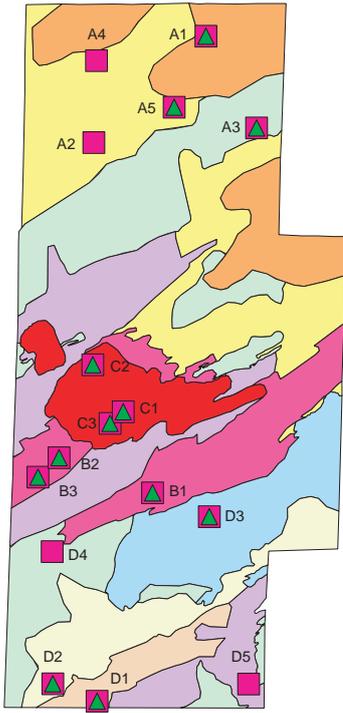


Figure 4.4. Location of ground-truth sampling stations taken by the prior study (Brown *et al.*, 2001, 2004) overlain on the seabed facies map for Hastings. Symbols as in Figure 4.2.

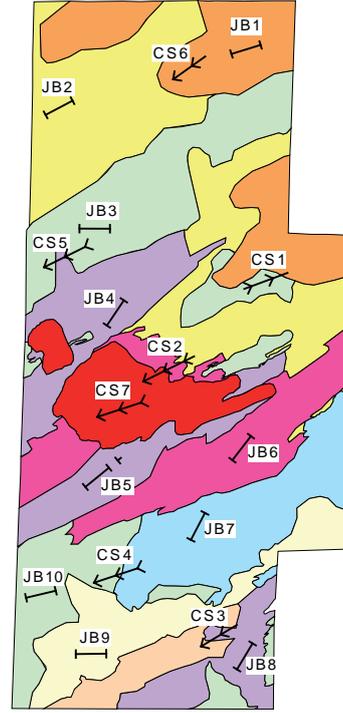


Figure 4.5. Location of ground-truth sampling stations for the present study. Bars indicate beam trawls (JB1 - 10), arrows indicate camera sledge tows (CS1 - 7).

Figure 4.6. Location of Hamon grab samples used for ground-truthing the Hastings facies map, and the 'Fibonacci' sampling pattern designed to test variability within each facies. The angular spiral has six sampling points (numbered boxes) separated by increasing distances (italic numerals), providing 15 lag distances in all.

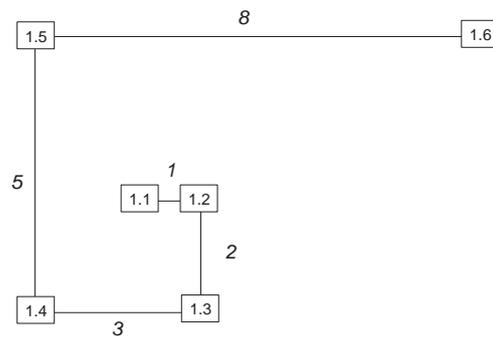
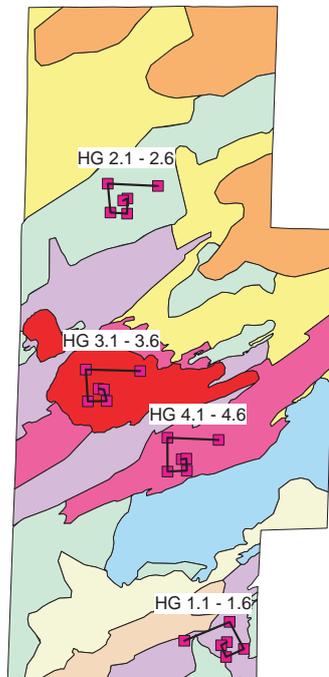
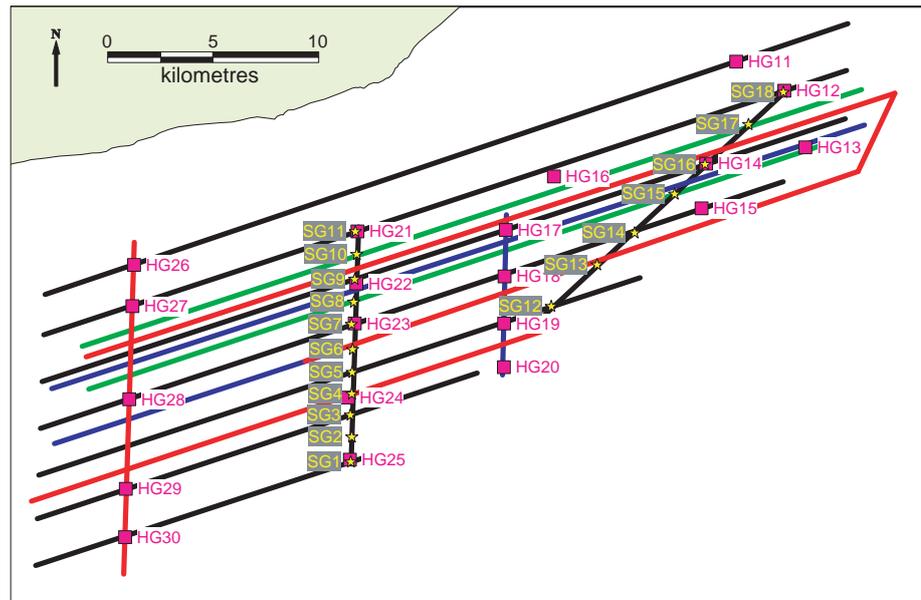


Figure 4.7. Positions and numbering of ground-truth sampling sites in relation to sidescan survey lines. SG = Shipek Grabs (yellow stars), HG = Hamon Grabs (purple squares). Beam trawl samples were also taken at each of the HG locations.



Ground-truth sampling was undertaken concurrently with the sidescan surveys (Figure 4.7). In the initial survey, a series of 18 Shipek grabs (denoted SG1-18) were taken for particle size analysis (PSA) only. In the current project, a further 20 stations were sampled by Hamon grab (denoted HG11-30) for PSA and faunal analysis following standard procedures. The same locations were sampled for epifauna using a 2-metre Jennings beam trawl (denoted JB11-30) towed for a nominal distance of 200 m; again samples were processed following standard procedure. The array of sampling sites was selected to give a broad coverage of the survey area, with each site lying on (or close to) one of the sidescan lines. The interpretation of the ground-truth data was used to make inferences about the suitability of the broadscale facies map and to examine and compare multivariate patterns in the physical and biological data.

4.4 Results

4.4.1 Hastings study area

Facies map

The facies interpretation provided a higher resolution map than the coarser interpretation of the previous study (Brown *et al.*, 2001, 2004). The two interpretations were consistent, showing shallow sand substrates to the north, dredged and undisturbed gravel areas in the centre and deeper sand substrates to the south, but each of the non-dredged areas identified by Brown *et al.* (2001, 2004) was seen to comprise several different facies (Figure 4.3). The shallow sand area contained long wavelength sand waves, featureless sand and short wavelength megaripples. The central area contained both featureless gravel and gravel with sand patches, and two areas of dredged gravel. The deeper sands were separated into two megaripple facies (short and long wavelength), two sand wave facies (lunate and short wavelength) and an area of gravel (with sand

patches) at the extreme south east of the site, which had not previously been noted. Considerable detail was evident in the delineation of boundaries between facies, which appear well defined.

Video assessment

There was a high degree of agreement between the sediment types observed on the video record and those expected from the seabed facies map (Table 4.1). Boundaries between facies appeared well defined on the video, generally changing from one type to another in a brief transitional zone (Tx in Table 4.1) over an estimated distance of 10 to 20 metres. Occasionally, boundaries were extremely abrupt, changing in <5 m distance. The presence/absence of motile and attached epifauna was noted and proved useful in characterising the different facies.

Certain consistent features of sand wave and megaripple fields were noted and form an important part of the video interpretation. Large scale topographical features such as sand waves or megaripples could not be observed directly as the camera was angled at approximately 30 degrees from vertical and viewed an area of ~1 square metre of seabed to the front of the sledge. However their presence was inferred from other cues, particularly characteristic patterns in the wavelength of small-scale sand ripples that were clearly visible on the video record (Figures 4.8 and 4.9). As the sledge travelled up the rise, over the peak and down the slope of a large sand wave, the wavelength of the associated sand ripples progressively increased; ripples were commonly absent in the wave troughs leaving a flat expanse (up to ~1 metre wide) where larger material (shell fragments or gravel) frequently accumulated (Figures 4.8 and 4.10). An abrupt change to short wavelength ripples indicated that the sledge had started to climb the rise of the next sand wave (Figure 4.10). On megaripple fields, the wavelength of the associated sand ripples was

Table 4.1. Summary of video observations from seven camera sledge tows (CS1 – 7 in Figure 4.5) at the Hastings site, indicating main (M) or transitional (Tx) sediment zones, the types of sediment and bedform observed and notes on the type and abundance of epifauna.

| Tow | Zone | Sediment type | Bedform | Epifauna |
|-----|------|---|----------------|---|
| CS6 | M | rippled sand | sand waves | sparse, motile forms only |
| CS5 | M | rippled sand with shell fragments | sand waves | sparse, motile forms only |
| | Tx | gravelly sand | flat | frequent motile forms |
| | M | mixed gravel/sand with sand veneers over gravel | flat | dense attached epifauna, frequent motile forms |
| | Tx | less gravel | | |
| | M | rippled sand | sand waves | sparse, motile forms only |
| CS1 | M | rippled sand | megaripples | sparse, motile forms only |
| | Tx | silty sand | no megaripples | worm casts and tubes |
| | M | rippled sand | | |
| CS2 | M | rippled sand, scattered gravel & shell fragments | flat | some burrows, sparse motile and attached forms |
| | Tx | increasing gravel content | flat | more frequent and diverse motile and attached forms |
| | M | sandy, coarser gravel | flat | more abundant hydroids and queen scallops |
| | Tx | dusting of fine silt over gravel | flat | less abundant |
| | M | far sandier gravel | flat | sparse |
| CS7 | M | silt covered gravel | flat | none |
| | M | highly disturbed, alternating gravel ridges and sand-filled furrows | dredged gravel | frequent starfish |
| | M | patches of sand and sandy gravel | flat | occasional starfish and queen scallops |
| CS4 | M | rippled sand with shell fragments | low sand waves | sparse, motile forms only |
| | M | unrippled gravelly, shelly sand base with frequent transverse sand ridges | megaripple | |
| CS3 | M | sand with gravel, pebbles & cobbles, & mud patches | flat | sparse, motile forms only some burrows |
| | M | rippled sand | low sand waves | |

Figure 4.8. Schematic diagram illustrating the pattern of wavelengths of small sand ripples (plan view, lower line) associated with topographic features of large sand waves and long wavelength megaripple fields (cross section, upper line).

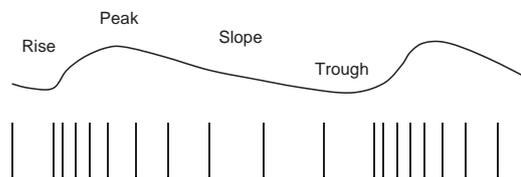


Figure 4.9. As for Figure 4.8, but for a short wavelength megaripple field, showing characteristic narrow, steep sided trenches and the near constant wavelength of the associated sand ripples.

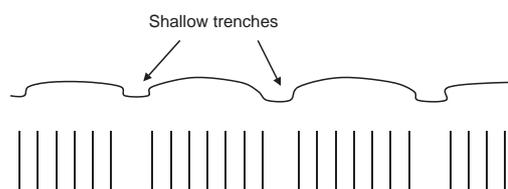




Figure 4.10. Photographs illustrating small-scale sediment features typically associated with large sand waves or megaripples. Top: sand wave trough and rise, with flattened area of the trough in the foreground and short wavelength ripples on the rise. Bottom: the gentler slope behind the peak of the sand wave characterised by longer wavelength ripples. The area in each photograph is ~ 1m².

far more constant (Figure 4.9), and the sledge runners frequently crossed shallow but steep sided trenches that separated each megaripple from its neighbour.

Epifaunal analysis

A total of 70 epifaunal taxa were identified in the 10 trawls, with samples from gravel substrates having notably more specious and abundant epifauna, leading to higher indices of richness (Table 4.2). Cluster analysis and multi-dimensional scaling (MDS) ordination identified three major clusters among the samples (Figure 4.11) which were significantly different (ANOSIM, $p = 0.1\%$). These three clusters map to three general sediment types, namely the shallow sands to the north of the dredge site (trawls 1, 2 and 3), deeper sands to the south (trawls 7, 9 and 10) and gravel substrates (both around the dredge site and in deeper water; trawls 4, 5, 6 and 8). Samples from deep sands proved most similar (61.5%; Table 4.3), while the greatest dissimilarity was between the shallow sands and the gravel clusters (72.2%; Table 4.3). The main characterising taxa from each cluster were determined by SIMPER analysis (Table 4.4). Juvenile swimming crabs (*Liocarcinus* juv.) and shrimps (*Crangon* sp. and *Pontophilus* sp.) characterised both shallow and deep sand substrates, but not gravel. Hermit crabs characterised all three clusters, though *Pagurus bernhardus* was a main species on shallow sands and *Anapagurus laevis* on deep sands. Both species were also important on gravel substrates, along with another hermit crab, *Pagurus prideauxi* and its commensal anemone, *Adamsia carciniopados*. As their common name suggests, two stone crab genera, *Macropodia* sp. and *Hyas* sp. (family

Table 4.2. Summary statistics for the ten beam trawl epifauna samples [JB1-10] collected in the present study, giving the depth zone of the station, the seabed facies, number of taxa (S), number of individuals (N) and Margalef's index of richness (d).

| Sample | Depth zone (m) | Seabed facies | S | N | d |
|--------|----------------|--------------------------|----|-----|------|
| JB1 | 10-15 | sand waves | 18 | 125 | 3.52 |
| JB2 | 10-15 | featureless sand | 9 | 58 | 1.97 |
| JB3 | 10-15 | short megaripples | 12 | 24 | 3.46 |
| JB4 | 15-20 | gravel with sand patches | 34 | 746 | 4.99 |
| JB5 | 15-20 | gravel with sand patches | 32 | 238 | 5.66 |
| JB6 | 15-20 | featureless gravel | 29 | 292 | 4.93 |
| JB7 | 25-30 | long megaripples | 21 | 153 | 3.98 |
| JB8 | 40-45 | gravel with sand patches | 29 | 446 | 4.59 |
| JB9 | 35-40 | lunate sand waves | 14 | 161 | 2.56 |
| JB10 | 30-35 | short megaripples | 24 | 221 | 4.26 |

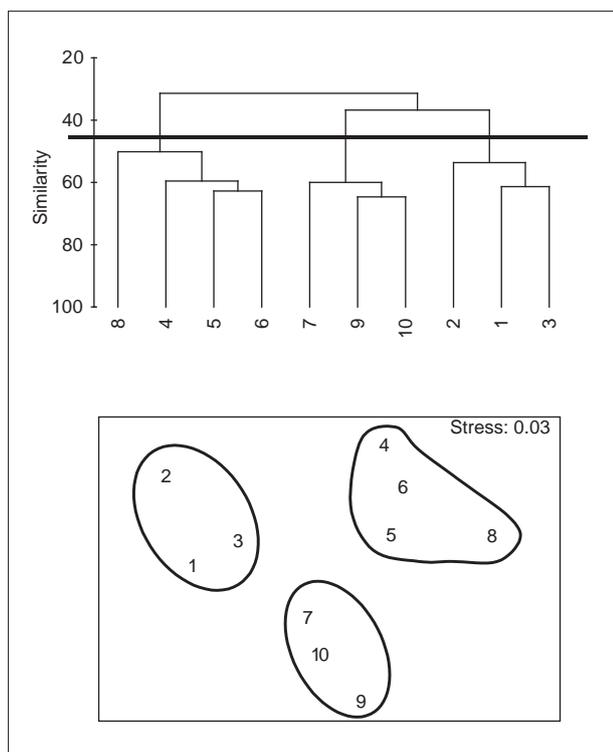


Figure 4.11. Dendrogram and MDS ordination of similarities between epifaunal samples collected in 10 beam trawl tows (JB1-10) from the Hastings site. Contours on the MDS plot represent the 45% similarity line indicated on the dendrogram. Analysis based on Bray-Curtis similarity index of square root transformed abundance data (colonial taxa excluded).

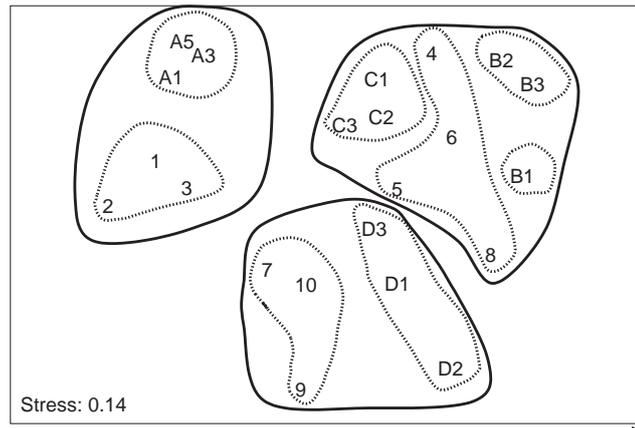
Table 4.3. Results from SIMPER analyses for the beam trawl samples from the Hastings site, showing the average % similarity within cluster groups (shaded cells) and the average % dissimilarity between them.

| | Shallow Sands | Gravels | Deep Sand |
|---------------|---------------|---------|-----------|
| Shallow Sands | 56.2 | - | - |
| Gravels | 72.2 | 55.4 | - |
| Deep Sands | 63.3 | 65.0 | 61.5 |

Table 4.4. Results of SIMPER analysis for epifaunal samples from the Hastings site (excluding colonial species) giving the average abundance and contribution to similarity (as % and cumulative %) for the main characterising taxa in clusters representing three general sediment types at the Hastings site.

| Sediment type | Taxon | Average abundance | % Contribution | Cumulative % |
|------------------------|--------------------------------|-------------------|----------------|--------------|
| Shallow water sands | <i>Pagurus bernhardus</i> | 19.3 | 21.8 | 21.8 |
| | <i>Asterias rubens</i> | 8.3 | 18.0 | 39.8 |
| | <i>Hinia</i> sp. | 7.7 | 16.2 | 55.9 |
| | <i>Liocarcinus</i> juv. | 3.3 | 11.2 | 67.1 |
| | <i>Pontophilus</i> sp. | 4.3 | 10.6 | 77.7 |
| Gravels | <i>Ophiura albida</i> | 85.3 | 11.2 | 11.2 |
| | <i>Pagurus bernhardus</i> | 24.8 | 8.9 | 20.1 |
| | <i>Macropodia</i> sp. | 23.8 | 8.2 | 28.3 |
| | <i>Pagurus prideauxi</i> | 16.0 | 7.5 | 35.8 |
| | <i>Psammechinus miliaris</i> | 40.5 | 7.2 | 42.9 |
| | <i>Adamsia carciniopados</i> | 11.8 | 6.6 | 49.5 |
| | <i>Anapagurus laevis</i> | 20.5 | 5.3 | 54.8 |
| | <i>Asterias rubens</i> | 17.5 | 4.8 | 59.6 |
| | Gobiidae | 12.5 | 4.7 | 64.3 |
| | <i>Buccinum undatum</i> | 9.8 | 4.2 | 68.5 |
| | <i>Aequipecten opercularis</i> | 8.0 | 3.9 | 72.4 |
| <i>Hyas</i> sp. | 4.3 | 3.3 | 75.6 | |
| Deeper water sands | <i>Liocarcinus</i> juv. | 42.0 | 19.4 | 19.4 |
| | <i>Crangon</i> sp. | 41.3 | 18.3 | 37.8 |
| | <i>Ophiura albida</i> | 14.7 | 10.7 | 48.5 |
| | <i>Echiichthys vipera</i> | 13.0 | 10.3 | 58.8 |
| | <i>Anapagurus laevis</i> | 12.3 | 9.3 | 68.1 |
| <i>Pontophilus</i> sp. | 9.3 | 8.8 | 76.9 | |

Figure 4.12. MDS plot for the pooled epifauna data from the present study and that of Brown *et al.* (2004), based on Bray-Curtis similarity index for square root transformed abundance data. Contours represent similarities of 45% (solid line) and 55% (dashed line). Major clusters form for samples from shallow sands (upper left), gravels (upper right) and deeper sands (lower centre), while minor clusters tend to separate samples from the two studies. Site labels are given in Figures 4.4 and 4.5.



Majidae) also characterised the gravel substrates, as did the urchin *Psammechinus miliaris*. Two other echinoderms also featured, but were less discriminant; the brittle star, *Ophiura albida*, was the foremost characterising species of gravels, but was also a major species on deeper sand substrates, while the starfish, *Asterias rubens*, was the second most characteristic species for shallow sands, and the 8th for gravels. Trawl sample and video records also indicated that attached epifauna (particularly hydroids) were characteristic of gravel substrates. Analysis of the available data gave a similar overall interpretation of the Hastings site as the initial study (Brown *et al.*, 2004), namely that there were three main epifaunal assemblages associated with shallow sands, gravel and deeper sand. A more formal comparison was made between the two studies by analysing a pooled data set, with colonial and rare taxa (total $n < 10$) excluded. The distinction between the shallow sands, gravel and deep sand substrates persisted, showing a consistent pattern over time, though there was some separation of the samples from the different studies (Figure 4.12). While depth appears to be an important factor in discriminating epifaunal communities of sandy substrates, the importance of sediment type in structuring the communities is highlighted by the association of the deeper gravel site (trawl 8) with the cluster of other gravel sites rather than other deep sites (Figures 4.11 and 4.12) and is further reflected by comparison of the univariate indices among the various sites (Table 4.2)

Sediment and infaunal analysis

The composition and variability of sediments and their associated fauna was examined in four of the seabed facies, sampled by 0.1 m² Hamon grab following the spiral sampling pattern described above (Figure 4.6). The frequency distribution plots of grain size presented in Figure 4.13 provide an overview of sediment variability within each of the facies. Samples from the deep area of gravel with sand patches (HG1) showed least variability, each containing some gravel (-1 to -5 phi) but being dominated by a single mode of medium sand grains (2 phi). Variability was greatest in the dredged gravel area (HG3), some samples having a high gravel content while

others (HG3.6) were mostly fine sand (3 phi). In the shallow water megaripple field (HG2) one sample had a far higher gravel content than all others (HG2.6), and in the undredged gravel area (HG4) there was an appreciable difference in gravel particle size between samples (-3, -4, -5 phi). Principal component analysis showed three grain size categories, namely 3, 2 and -5 phi contributing 94% of total variability between sediment samples.

The spiral sampling pattern revealed notable spatial trends in two of the four seabed facies (Figure 4.13). In the shallow water megaripple field, the composition of sediments and faunal communities became more dissimilar as distance between samples (lag distance) increased, while in the dredged gravel area, sediment dissimilarity increased with lag distance, but faunal dissimilarity remained consistently high, indicating a 'patchiness' in the faunal distribution. These two facies were therefore considered to be quite heterogeneous. There were no marked spatial trends in the two remaining facies, but a consistently low dissimilarity between sediment samples from the gravel with sand facies (HG1) indicated this area was notably homogeneous.

A total of 198 taxa were identified from the Hamon grab samples (excluding colonial species). Univariate indices highlighted the gross differences in populations between facies (Figure 4.14) indicating an impoverished fauna (low abundance, few species) in both the shallow megaripple field (HG2) and dredged gravel area (HG3), but a rich and diverse community in the undredged gravel (HG4). Multivariate analyses gave a more detailed insight into these differences and how they relate to sediment structure. Figure 4.15 compares the outputs from non-metric multi-dimensional scaling (MDS) ordination for the sediment grain structure (PSA data) and faunal community structure (abundance data), showing three clusters among the sediments, but four clusters among the fauna. Both the shallow megaripple field (HG2) and the deeper gravel/patchy sand facies (HG1) had distinct sediment types and distinct communities, while the dredged and undredged gravel facies (HG3 and HG4) had a similar sediment structure but supported distinctly different communities. The two ordinations have a similar spatial distribution of

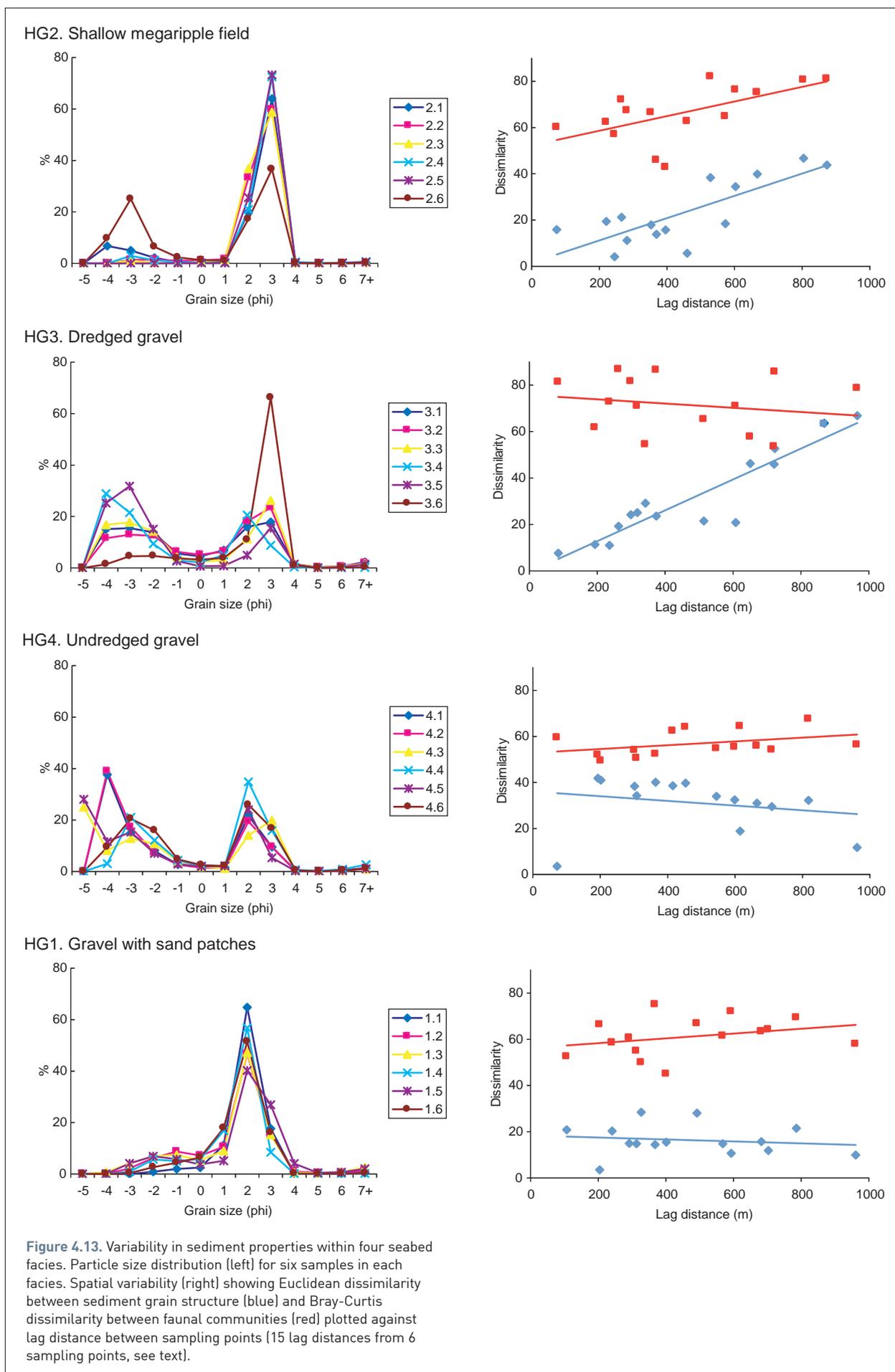


Figure 4.14. Univariate indices of faunal community structure for four seabed facies in the Hastings study site (as indicated in Figure 4.6), showing mean and 95% confidence intervals for the number of individuals per 0.1 m² (squares) and the number of species (circles). Figures indicate the mean Margalef's richness

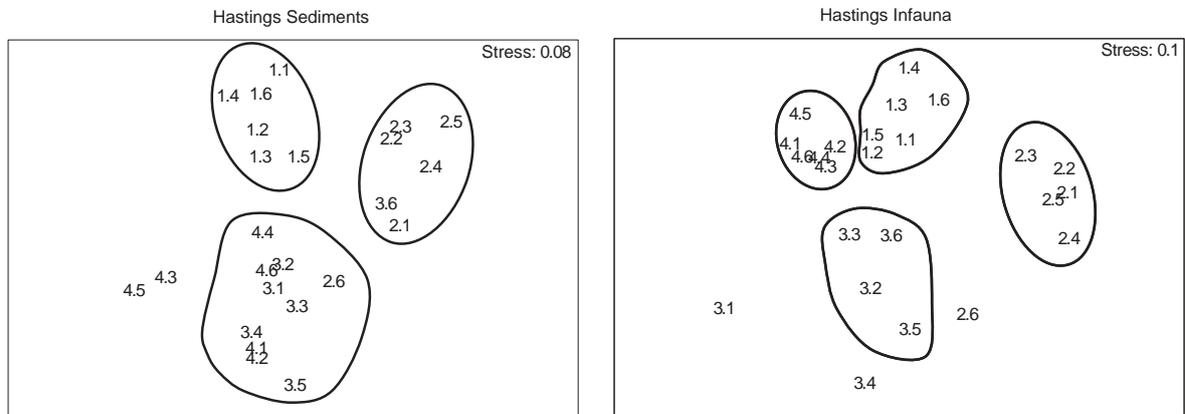
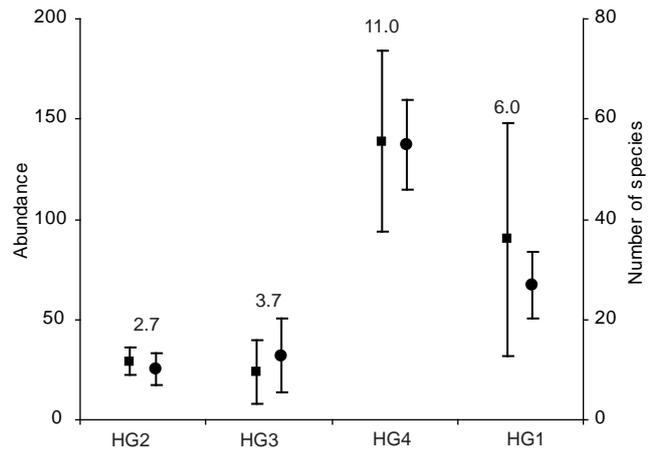


Figure 4.15. MDS plots for sediment grain size (left) and faunal abundance (right) from the same Hamon grab samples taken at four seabed facies in the Hastings study site. Major cluster groups are picked out by contours, representing Euclidean distance of 4 in the sediment samples and a Bray-Curtis similarity of 30% for the infaunal samples.

points, and a strong correlation between their underlying (dis)similarity matrices (RELATE routine in PRIMER, $\rho = 0.434$, $p = 0.1\%$) indicated a significant relationship between sediment type and community structure. Analysis of similarities confirmed a highly significant difference among the faunal communities of the four facies (ANOSIM, global $p = 0.1\%$) and that each had a recognisably different faunal community (all pair-wise comparisons having $R > 0.75$).

Species that typify and/or discriminate the different facies were determined using the PRIMER routine SIMPER, which identifies taxa that contribute most to the similarity within and dissimilarity between sample groups (Table 4.5 and 4.6). Relatively few species characterised the shallow megaripple field and the dredged gravel area, consistent with earlier observation based on univariate indices that these communities were impoverished. The other facies

supported more diverse communities, and consequently there are more characterising species and a more even spread in their contribution to the overall similarity. For species that best discriminate between facies, there are numerous examples of highly specific species that occur in one facies but not another (e.g. *Magelona johnstoni* present in HG2 but not HG3), and more generalist species whose relative abundance is markedly different between facies (e.g. *Scalibregma inflatum* in HG4 vs HG3 and HG4 vs HG2). Sample similarity was greatest in the (undredged) featureless gravel (HG4) and least in the dredged gravel (HG3), indicating respectively the most homogeneous and heterogeneous areas (Table 4.7). The greatest difference in faunal communities was between the sandy megaripple field (HG2) and the undredged gravel area (HG4) with a dissimilarity of 88.6%.

Table 4.5. Results of SIMPER analysis for infaunal samples (excluding colonial species) indicating taxa that most typify four seabed facies at the Hastings site, giving their average abundance and contribution (as % and cumulative %) to the overall similarity between replicates.

| Seabed facies | Taxon | Average abundance | % Contribution | Cumulative % |
|--|------------------------------|-------------------|----------------|--------------|
| Shallow Megaripple field (HG2) | <i>Magelona johnstoni</i> | 13.2 | 40.0 | 40.0 |
| | <i>Nephtys cirrosa</i> | 2.3 | 25.7 | 65.7 |
| | <i>Bathyporeia elegans</i> | 2.0 | 13.3 | 79.0 |
| | <i>Spiophanes bombyx</i> | 2.3 | 10.0 | 89.0 |
| | <i>Travisia forbesii</i> | 1.2 | 4.3 | 93.3 |
| Dredged gravel (HG3) | <i>Balanus crenatus</i> | 63.0 | 52.0 | 52.0 |
| | <i>Lagis koreni</i> | 2.3 | 10.4 | 62.4 |
| | <i>Spiophanes bombyx</i> | 5.5 | 10.3 | 72.7 |
| | <i>Urothoe elegans</i> | 1.2 | 9.2 | 82.0 |
| | <i>Ampelisca spinipes</i> | 1.0 | 3.8 | 85.8 |
| | <i>Lanice conchilega</i> | 0.7 | 3.2 | 89.0 |
| | <i>Cerianthus lloydii</i> | 0.7 | 2.9 | 91.9 |
| Featureless gravel (undredged) (HG4) | <i>Scalibregma inflatum</i> | 10.3 | 10.8 | 10.8 |
| | <i>Echinocyamus pusillus</i> | 8.8 | 10.1 | 20.9 |
| | Nemertea | 4.5 | 8.0 | 28.9 |
| | <i>Lumbrineris gracilis</i> | 4.2 | 7.8 | 36.8 |
| | <i>Timoclea ovata</i> | 6.0 | 7.8 | 44.6 |
| | <i>Notomastus</i> sp. | 4.0 | 5.8 | 50.4 |
| | <i>Polycirrus</i> sp. | 2.7 | 5.4 | 55.8 |
| | <i>Pisidia longicornis</i> | 2.7 | 5.2 | 61.0 |
| | <i>Lagis koreni</i> | 2.7 | 4.9 | 65.8 |
| | <i>Ophiura</i> juv. | 3.2 | 4.7 | 70.6 |
| | <i>Balanus crenatus</i> | 5.3 | 3.5 | 74.1 |
| <i>Ampelisca spinipes</i> | 3.3 | 3.4 | 77.5 | |
| Gravel with sand patches (HG1) | Nemertea | 3.0 | 12.7 | 12.7 |
| | <i>Echinocyamus pusillus</i> | 17.5 | 12.2 | 24.8 |
| | <i>Spiophanes bombyx</i> | 5.2 | 12.2 | 37.0 |
| | <i>Lagis koreni</i> | 19.8 | 10.6 | 47.6 |
| | <i>Scalibregma inflatum</i> | 7.5 | 8.7 | 56.3 |
| | <i>Spisula</i> juv. | 2.3 | 7.9 | 64.2 |
| | <i>Ophelia borealis</i> | 1.8 | 7.1 | 71.3 |
| | <i>Polycirrus</i> sp. | 1.2 | 7.0 | 78.3 |

Table 4.6. Results of SIMPER analysis for faunal samples (excluding colonial species) indicating taxa that most discriminate between four seabed facies at the Hastings site, giving their average abundance and contribution (as % and cumulative %) to the overall dissimilarity between samples.

| Seabed facies | Taxon | Average abundance | Average abundance | % | Cumulative % |
|----------------------------|------------------------------|-------------------|-------------------|------|--------------|
| HG2 vs HG3 | | HG2 | HG3 | | |
| | <i>Magelona johnstoni</i> | 13.2 | 0.0 | 11.7 | 11.7 |
| | <i>Balanus crenatus</i> | 87.2 | 63.0 | 11.5 | 23.2 |
| | <i>Nephtys cirrosa</i> | 2.3 | 0.3 | 6.8 | 30.0 |
| | <i>Bathyporeia elegans</i> | 2.0 | 0.0 | 5.9 | 35.9 |
| | <i>Urothoe elegans</i> | 0.0 | 1.2 | 5.3 | 41.1 |
| | <i>Spiophanes bombyx</i> | 2.3 | 5.5 | 4.9 | 46.0 |
| | <i>Lagis koreni</i> | 0.2 | 2.3 | 4.4 | 50.5 |
| HG2 vs HG4 | | HG2 | HG4 | | |
| | <i>Magelona johnstoni</i> | 13.2 | 0.0 | 7.1 | 7.1 |
| | <i>Echinocyamus pusillus</i> | 0.0 | 8.8 | 5.5 | 12.5 |
| | <i>Scalibregma inflatum</i> | 0.2 | 10.3 | 5.1 | 17.6 |
| | <i>Nephtys cirrosa</i> | 2.3 | 0.0 | 4.6 | 22.2 |
| | <i>Timoclea ovata</i> | 0.0 | 6.0 | 4.5 | 26.7 |
| | <i>Lumbrineris gracilis</i> | 0.0 | 4.2 | 4.3 | 31.0 |
| | <i>Notomastus</i> sp. | 0.0 | 4.0 | 4.1 | 35.1 |
| | <i>Balanus crenatus</i> | 87.2 | 5.3 | 3.9 | 39.0 |
| | <i>Pisidia longicornis</i> | 0.0 | 2.7 | 3.5 | 42.6 |
| | <i>Polycirrus</i> sp. | 0.3 | 2.7 | 3.4 | 46.0 |
| | <i>Ophiura</i> juv. | 0.0 | 3.2 | 3.4 | 49.4 |
| <i>Bathyporeia elegans</i> | 2.0 | 0.2 | 3.4 | 52.7 | |
| HG2 vs HG1 | | HG2 | HG1 | | |
| | <i>Magelona johnstoni</i> | 13.2 | 0.0 | 9.8 | 9.8 |
| | <i>Echinocyamus pusillus</i> | 0.0 | 17.5 | 8.0 | 17.8 |
| | <i>Lagis koreni</i> | 0.2 | 19.8 | 6.4 | 24.2 |
| | <i>Spisula</i> juv. | 0.0 | 2.3 | 5.7 | 29.9 |
| | <i>Scalibregma inflatum</i> | 0.2 | 7.5 | 5.3 | 35.2 |
| | <i>Bathyporeia elegans</i> | 2.0 | 0.0 | 4.9 | 40.1 |
| | Nemertea | 0.3 | 3.0 | 4.5 | 44.6 |
| | <i>Polycirrus</i> sp. | 0.3 | 1.2 | 4.4 | 49.0 |
| <i>Ophelia borealis</i> | 0.5 | 1.8 | 4.3 | 53.3 | |
| HG3 vs HG4 | | HG3 | HG4 | | |
| | <i>Echinocyamus pusillus</i> | 0.0 | 8.8 | 6.5 | 6.5 |
| | <i>Balanus crenatus</i> | 63.0 | 5.3 | 5.7 | 12.2 |
| | <i>Timoclea ovata</i> | 0.0 | 6.0 | 5.4 | 17.6 |
| | <i>Scalibregma inflatum</i> | 1.3 | 10.3 | 5.2 | 22.8 |
| | <i>Polycirrus</i> sp. | 0.0 | 2.7 | 4.4 | 27.2 |
| | <i>Pisidia longicornis</i> | 0.0 | 2.7 | 4.2 | 31.4 |
| | Nemertea | 0.3 | 4.5 | 4.1 | 35.6 |
| | <i>Notomastus</i> sp. | 0.3 | 4.0 | 4.1 | 39.6 |
| | <i>Ophiura</i> juv. | 0.0 | 3.2 | 4.1 | 43.7 |
| | <i>Lumbrineris gracilis</i> | 0.5 | 4.2 | 4.0 | 47.7 |
| <i>Mysella bidentata</i> | 0.2 | 9.8 | 3.6 | 51.3 | |
| HG3 vs HG1 | | HG3 | HG1 | | |
| | <i>Balanus crenatus</i> | 63.0 | 0.0 | 11.1 | 11.1 |
| | <i>Echinocyamus pusillus</i> | 0.0 | 17.5 | 7.9 | 19.0 |
| | <i>Spisula</i> juv. | 0.2 | 2.3 | 5.2 | 24.2 |
| | <i>Ophelia borealis</i> | 0.0 | 1.8 | 5.1 | 29.3 |
| | Nemertea | 0.3 | 3.0 | 4.9 | 34.1 |
| | <i>Scalibregma inflatum</i> | 1.3 | 7.5 | 4.8 | 38.9 |
| | <i>Polycirrus</i> sp. | 0.0 | 1.2 | 4.5 | 43.4 |
| | <i>Lagis koreni</i> | 2.3 | 19.8 | 4.5 | 47.9 |
| <i>Urothoe elegans</i> | 1.2 | 0.0 | 4.3 | 52.2 | |

Table 4.6. continued.

| Seabed facies | Taxon | Average abundance | Average abundance | % | Cumulative % |
|--------------------------|----------------------------|-------------------|-------------------|------|--------------|
| HG4 vs HG1 | | HG4 | HG1 | | |
| | <i>Timoclea ovata</i> | 6.0 | 0.0 | 6.2 | 6.2 |
| | <i>Ophelia borealis</i> | 0.0 | 1.8 | 5.1 | 11.3 |
| | <i>Pisidia longicornis</i> | 2.7 | 0.0 | 4.9 | 16.2 |
| | <i>Balanus crenatus</i> | 5.3 | 0.0 | 4.7 | 20.9 |
| | <i>Spisula juv.</i> | 0.5 | 2.3 | 4.6 | 25.5 |
| | <i>Notomastus sp.</i> | 4.0 | 0.5 | 4.5 | 30.0 |
| | <i>Ampelisca spinipes</i> | 3.3 | 0.0 | 4.2 | 34.2 |
| | <i>Lagis koreni</i> | 2.7 | 19.8 | 4.1 | 38.2 |
| | <i>Gibbula tumida</i> | 3.2 | 0.0 | 4.0 | 42.3 |
| | <i>Galathea intermedia</i> | 3.0 | 0.2 | 3.7 | 46.0 |
| | <i>Ophiura juv.</i> | 3.2 | 1.8 | 3.7 | 49.7 |
| <i>Mysella bidentata</i> | 9.8 | 0.8 | 3.5 | 53.1 | |

Table 4.7. Results from SIMPER analyses for the faunal samples from four facies at the Hastings site, showing the average % similarity for six replicates within each facies (shaded cells) and the average % dissimilarity between facies.

| | Shallow megaripple | Dredged gravel | Featureless gravel | Gravel with sand patches |
|---------------------|--------------------|----------------|--------------------|--------------------------|
| Shallow megaripple | 42.0 | | | |
| Dredged gravel | 84.9 | 37.3 | | |
| Featureless gravel | 88.6 | 70.8 | 62.4 | |
| Gravel/sand patches | 79.3 | 77.4 | 53.4 | 59.5 |

4.4.2 Broadscale study area

Interpolated facies maps

The broadscale study covered an area of ~ 400 sq km, with the Hastings study site lying in the westernmost third of the area (Figure 4.1). A pattern of 13 parallel sidescan lines were surveyed in a SW-NE orientation over a maximum distance of 40 km, though some were foreshortened due to navigation hazards (static fishing gear) being encountered due south of Dungeness. Figure 4.16 presents the results of the individual interpretations for each of the sidescan sonar tracks, showing the subsets of data used to derive the four corresponding interpolated facies maps. With a total swathe width of 400 m for each track, line spacings of 4, 2 and 1 km represented 18, 33 and 57% density coverage of the area respectively, leaving 82, 66 and 43% of the facies map to be completed by interpolation. At 4 km spacing, few of the facies in adjacent lines appeared to match and the resulting map was considered to be highly speculative. At 2 km spacing, matching between adjacent lines improved, but remained poor in some areas. At 1 km line spacing, data density had improved to the point where the underlying facies pattern could be recognised allowing the majority of interpolation between lines to be made

with a high degree of confidence. In the final interpolation based on all the available lines, a coverage of nearly 100% had been achieved along a central corridor having five lines spaced at 0.5 km, but this additional coverage gave only marginal improvements to the interpolation for that area achieved with 1 km line spacing. Two cross lines running N-S were also available and proved valuable in confirming some of the interpolated areas.

Ground-truthing – sediment samples

The physical nature of the sediments was determined by particle size analysis (PSA) on the samples collected by Hamon and Shipek grabs (Figure 4.7). A rapid analysis technique was used (no laser sizing), giving the sample composition classified by five particle size groups, namely gravel (G), coarse sand (cS), medium sand (mS), fine sand (fS) and mud (M). There were notable differences in composition of samples collected by the different gears (Figure 4.17), those from Hamon grabs showing three major sediment forms (well sorted fine sands, moderately sorted medium sands and poorly sorted medium/fine sands) while those from Shipek grabs showed only one (well sorted fine sands). This was evident even between paired Hamon and Shipek samples (i.e. taken from the

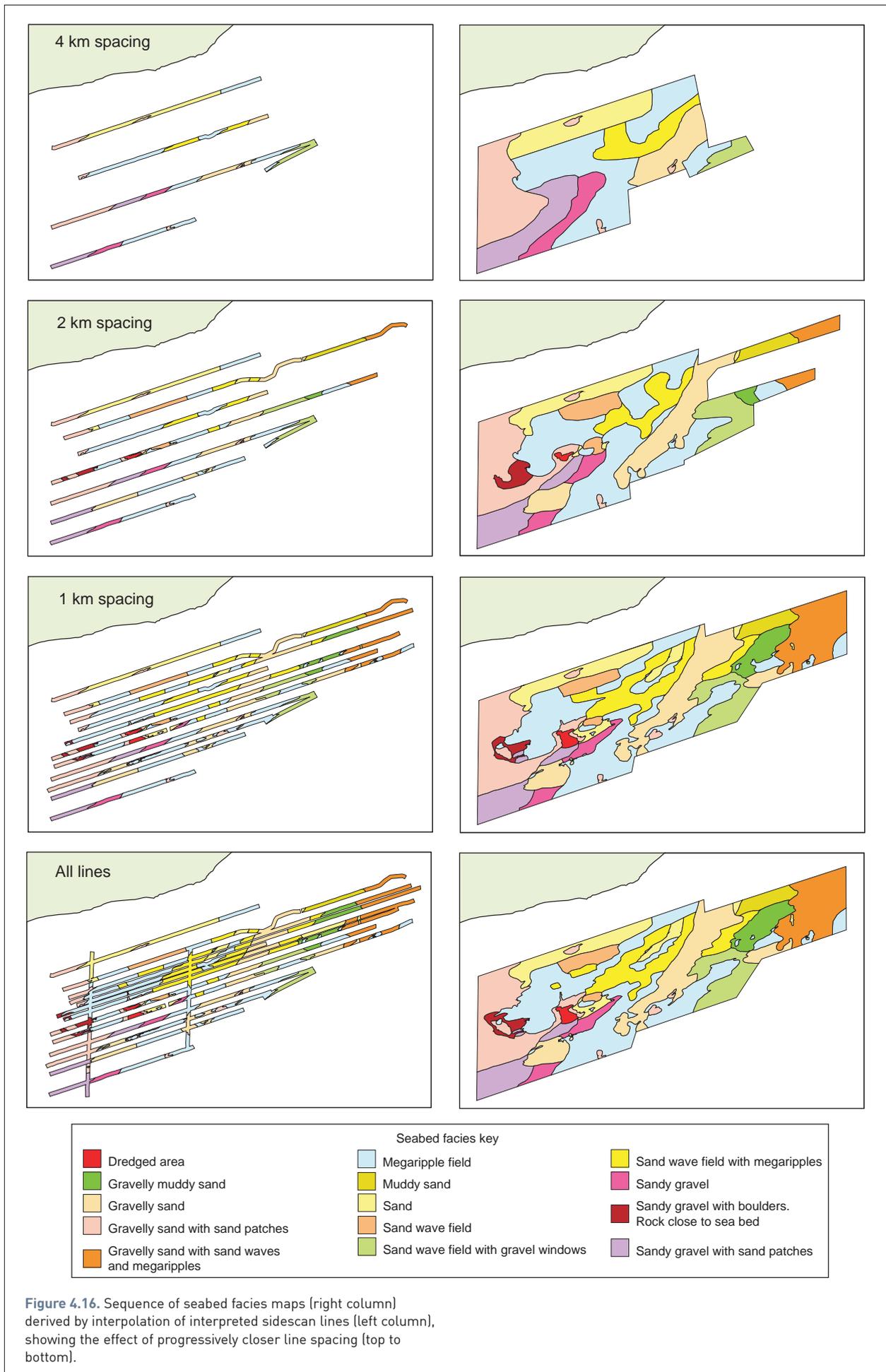
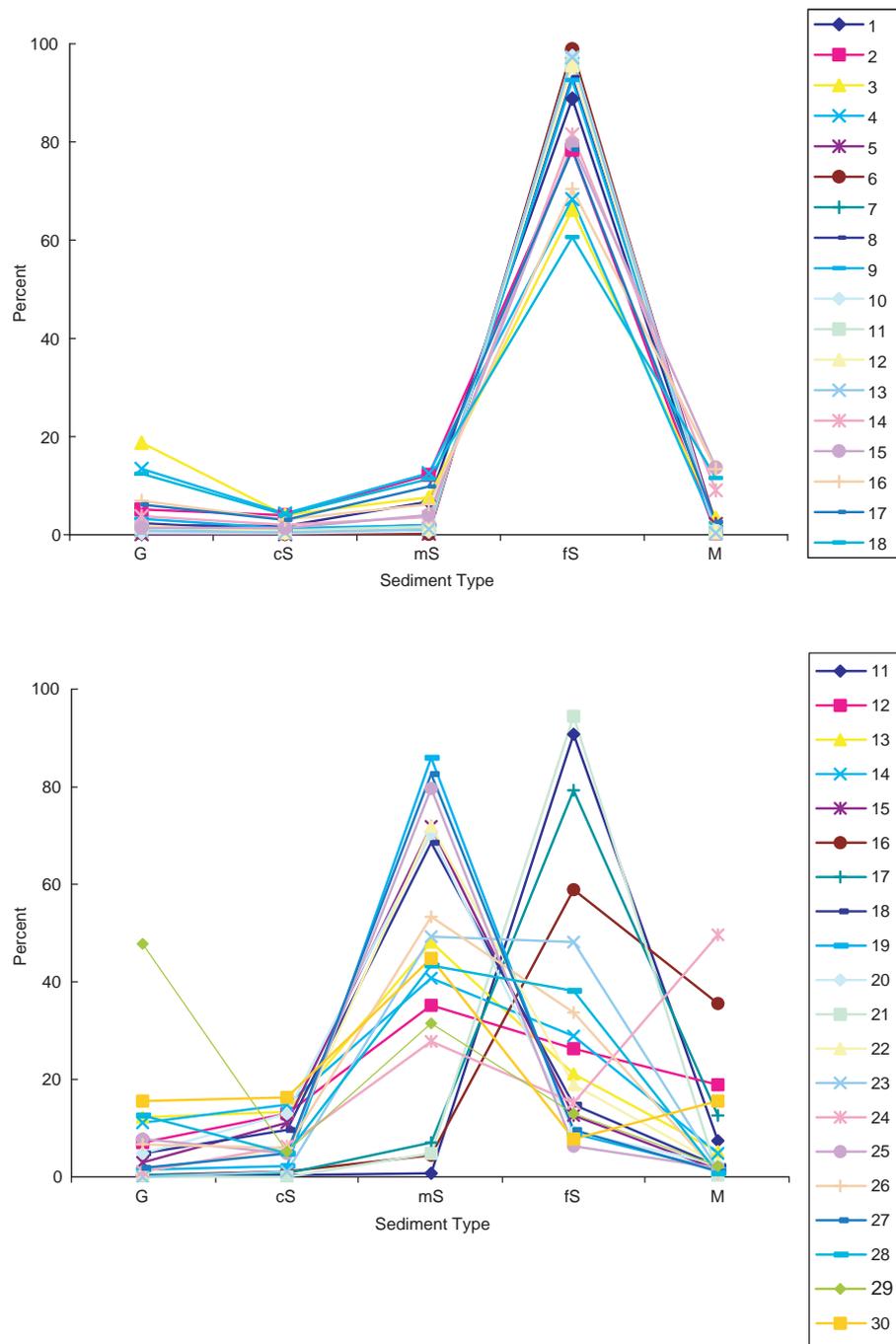


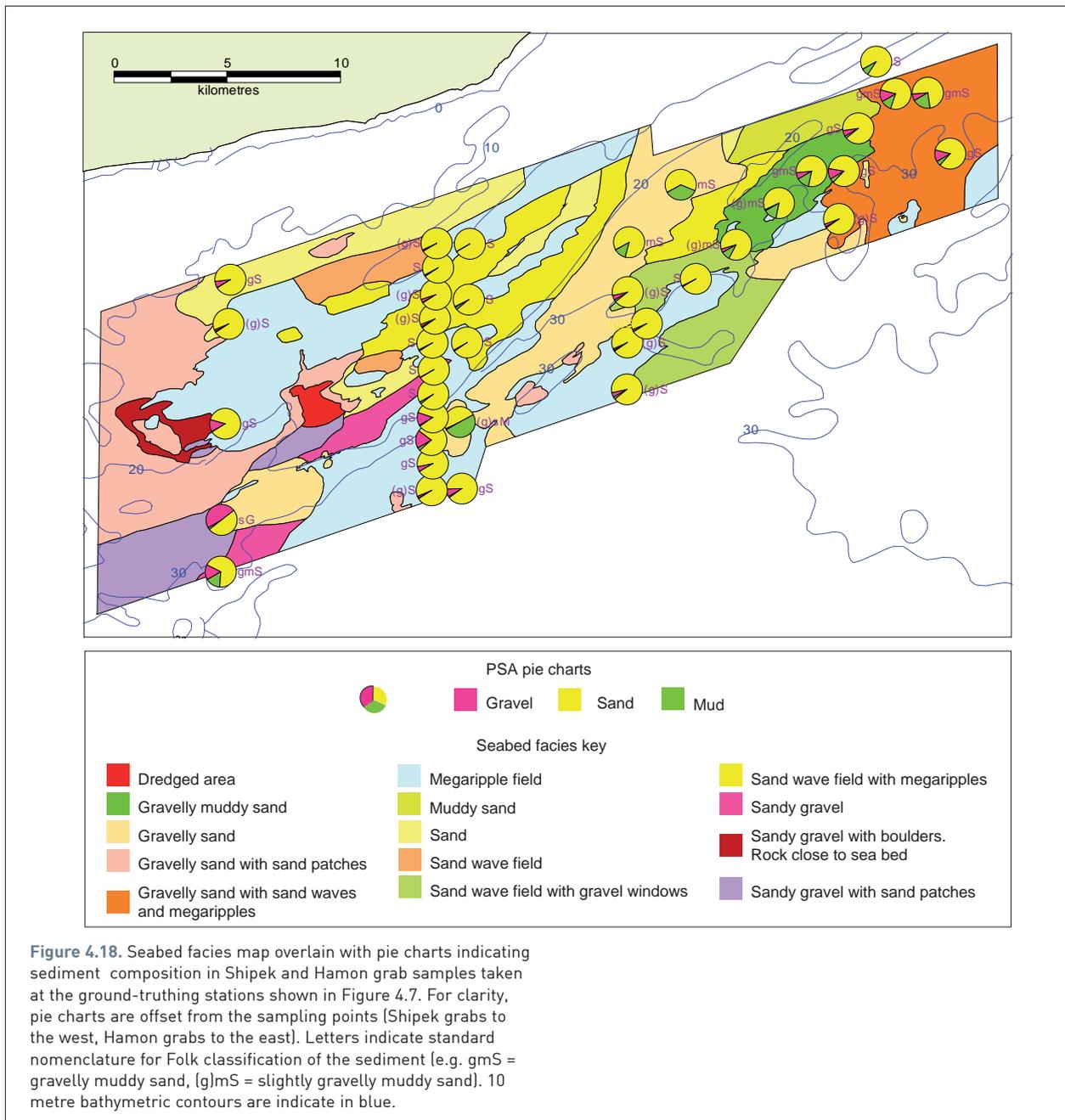
Figure 4.17. Particle size distribution of sediments from Shipek grab (top) and Hamon grab (bottom) sampling stations (as in Figure 4.7). Sediment types are gravel (G), coarse sand (cS), medium sand (mS), fine sand (fS) and mud (M).



same site; not illustrated here) and is attributed to the different penetration depth of the two sampling devices, being ~10 cm for Shipek grabs and ~30 cm for the 0.1 m² Hamon Grab. These discrepancies indicate some vertical stratification of sediments that may be important in ground-truthing the seabed facies map and highlights the importance of understanding the characteristics of different sampling devices.

PSA data were re-classified according to the Folk classification (gravel, sand, mud) to enable a more equitable comparison with the descriptions of the seabed facies, which use this same terminology (Figure 4.18). Generally, there was good agreement, apart from a central band

running SSW-NNE which was shown on the facies map as gravelly-sand, but samples indicated was muddy-sand (mS at HG16 and 17) and slightly gravelly, sandy-mud ((g)sM at HG24). The original PSA data for these stations show the sand component was almost exclusively fine sand, and the noted discrepancy would be consistent with the presence of a veneer of sand. Alternatively, gravelly-sands and muddy-sands may have a very similar acoustic reflectance, so would be difficult to differentiate on the sidescan image. The facies descriptor 'megaripple field' does not give any reference to sediment type, but infers a predominantly sandy substrate. Figure 4.18 indicates the presence of some gravel in this facies. Video observations of similar



facies in the Hastings area showed that gravel particles may be scattered among the sand and can accumulate in the troughs of the megaripples, so the facies map and the PSA analyses are consistent in this respect. The two samples in the NW area (HG 26 and 27) indicate a gravel component to the sediment not suggested by the facies map; again this could be due to some degree of patchiness which seems likely as a patchy, gravelly-sand facies lies just to the west of the two sample points. At HG 28 it took 5 attempts to obtain even a small sample (0.5 l), indicating hard ground, which is again consistent with the facies description (sandy-gravel with boulders, rock close to seabed). The sandy-gravel at HG29 is consistent with the facies description, but at HG30 the sample comprised less gravel and a greater amount of sand than indicated by the facies map. This is most likely due to local patchiness and indicates that for optimal analysis several replicates per facies are required.

Ground-truthing - Hamon grab samples

A total of 236 taxa were recorded from the Hamon grab samples taken in the broadscale study area, including 16 colonial taxa that were recorded as 'present' but excluded from the analysis. Many of the taxa were present in low frequencies, so a data subset was selected using the criteria that the total number of individuals across all 20 samples was ≥ 10 ; this subset comprised 52 taxa. Station HG28 was omitted from the analysis due to the low sample volume (0.5 l). Similarities between samples were investigated in PRIMER, using cluster analysis and MDS ordination (Figure 4.19) based on the Bray-Curtis similarity index applied to square root transformed abundance data. There were three major clusters (i-iii below), two from shallow waters (<20 m) and one from deeper water (>20 m).

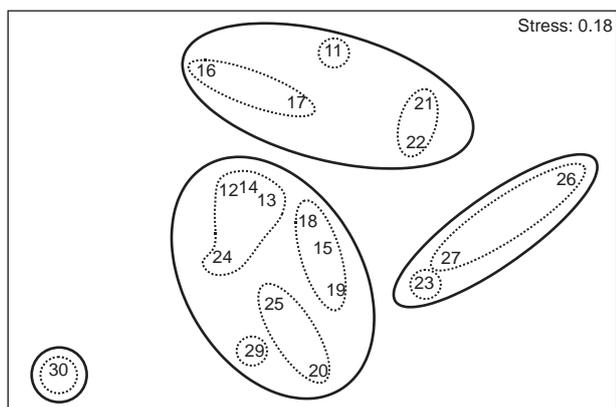


Figure 4.19. Multi-dimensional scaling (MDS) ordination of similarities between macro-infaunal assemblages at ground-truth stations sampled by Hamon grab (HG11 – 30 as in Figure 4.16), with similarity contours at ~30% (solid line) and 50% (dotted line). Bray-Curtis similarity index on square root abundance data, where $n \geq 10$ across all samples, excluding colonial taxa.

- i) Fine shallow water sands, comprising muddy fine sands (samples HG11, 16 and 17), a fine sand (HG21) and a slightly muddy medium sand (HG22). Faunal density was typically high (a mean of 2874 individuals m^{-2} ; SD = 197.5), the samples having an average similarity of 39.5% (SIMPER analysis in PRIMER) and were characterised by polychaetes, typically having some form of sand or mucous tube (*Lagis koreni*, *Magelona johnstoni*, *Poecilochaetus serpens*, *Spiophanes bombyx* and *Euclymene oerstedii*), and the small bivalves *Mysella bidentata* (~3 mm long, frequently commensal in tubes and burrows), *Abra alba* and *Phaxus pellucidus*.
- ii) Shallow medium sands, two with approximately equal proportions of medium and fine sand (HG23 and 26) and the other (HG27) with > 80% medium sand. Faunal density was notably low (mean 230 individuals m^{-2} ; SD = 55.7), the samples having an average similarity of 43.9%, with two active errant species (the amphipod *Bathyporeia elegans* and the polychaete *Nephtys cirrosa*) contributing >20% each to this similarity.
- iii) Deeper water sands and coarse sediments, with some sub-clusters formed by the gravelly muddy sands (HG12, 13, 14 and 24) and slightly gravelly sands (HG15, 18 and 19) and the deepest sandy gravel/gravelly sands (HG20, 25 and 29). Fauna density was typically moderate (mean 1131 individuals m^{-2} ; SD = 621.5), with the gravelly sands/sandy gravels showing the greatest richness. Samples had an average similarity of 47.0%, with the first four characterising species being polychaetes, including the deep-burrowing species, *Scalibregma inflatum*, which was common at all but the deepest sites (HG20, 25, 29) and *Lumbrineris gracilis* which is known to be characteristic of muddy sands or gravels. The fifth characterising species was the small urchin *Echinocyamus pusillus* which is typically found in coarse sands/fine gravels in deep water.

Dissimilarities between these three main clusters were of the order of 70%. The fauna at station HG30 appeared markedly dissimilar to that at other stations (range 84 to 90%), with 93% of individuals being barnacles (*Balanus crenatus*) attached to cobbles.

Ground-truthing - Beam trawl samples

Beam trawl samples were collected at all stations except 25 and 28, and a total of 112 epifaunal taxa were recorded, including 17 colonial organisms. Data analysis followed the same procedures used for the Hamon grab samples, with a data subset of 51 taxa (having n across all samples ≥ 10), but employing a 4th root transformation of abundance data, as some taxa were highly numerous (maximum 9,104 *Ophiura albida* in JB14).

The MDS ordination (Figure 4.20) showed two major clusters. The first contained four stations (11, 17, 21 and 14) where epifauna were typically very abundant (max. 11,204 individuals in sample JB17) being dominated by the gastropod *Hinia* sp., the hermit crab *Pagurus bernhardus* and two species of brittle star, *Ophiura ophiura* and *O. albida*, which accounted for 39% of the similarity between the samples (Table 4.8). Three of these stations (11, 17 and 21) were relatively shallow and had strikingly similar sediments, comprising ~80% or more fine sand (Figure 4.17). The second cluster contained 13 stations where the epifaunal community appeared to be far less abundant (normally in the order of 10^2 individuals per sample) but was characterised by many of the same species as the first cluster, with the notable addition of the small hermit crab *Anapagurus laevis* in place of the brittle star *O. ophiura* (Table 4.8). Sediments at these stations were typically the coarser or mixed substrates and three minor clusters were evident (Figure 4.20 - 60% similarity contour), one containing the three sites that had >10% gravel content (13, 29 and 30). Epifauna at station 16 were quite dissimilar from other stations, having the lowest number of taxa (12) but the fourth highest total abundance ($N = 2,322$), 78% of these being the tube-building polychaete *Lagis koreni*. This was the only station where the ophiuroid *Amphiura filiformis* was recorded ($n=308$).

SIMPER analysis indicated the two main clusters were separated largely on the basis of the relative abundance of the same set of dominant species (as listed above), which tend to be ecological generalists, capable of living in many types of habitat. Such species are not particularly helpful in mapping habitats, and it is more useful to identify species that have greater habitat fidelity or specificity, high fidelity meaning a species is always present in a particular

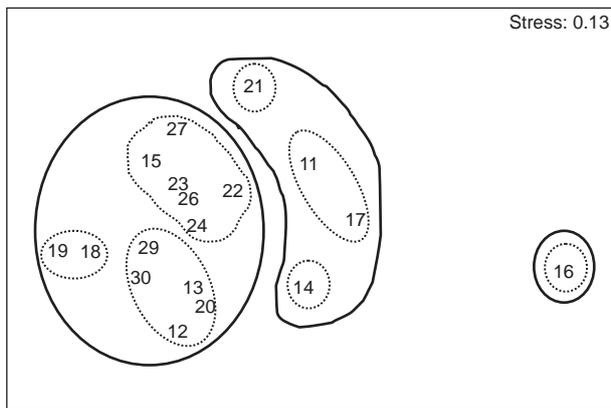


Figure 4.20. Multi-dimensional scaling (MDS) ordination of similarities between macro-epifaunal assemblages at ground-truth stations sampled by beam trawls at Hamon grab stations (HG11 – 30, as in Figure 4.16), with similarity contours at ~50% (solid line) and 60% (dotted line). Bray-Curtis similarity index on 4th root abundance data, where $n = 10$ across all samples, excluding colonial taxa.

Table 4.8. Results of SIMPER analysis for epifauna from beam trawl samples in the broadscale study, grouped as per the two major clusters indicated in Figure 4.20, listing the top ten taxa, their average abundance, the % and cumulative % contribution to average similarity, and the average similarity between samples in a cluster.

| Cluster | Taxon | Average abundance | % contribution | Cumulative % | Average similarity |
|----------|--------------------------------|-------------------|----------------|--------------|--------------------|
| 1 | <i>Hinia</i> sp. | 1071.00 | 14.57 | 14.57 | 51.48% |
| | <i>Pagurus bernhardus</i> | 256.25 | 11.11 | 25.68 | |
| | <i>Ophiura ophiura</i> | 214.25 | 7.63 | 33.31 | |
| | <i>Ophiura albida</i> | 3137.50 | 5.97 | 39.28 | |
| | <i>Callionymus</i> sp. | 9.00 | 4.86 | 44.13 | |
| | <i>Macropodia</i> sp. | 16.75 | 4.63 | 48.76 | |
| | <i>Pagurus prideauxi</i> | 5.50 | 4.30 | 53.06 | |
| | <i>Aphrodita aculeata</i> | 8.50 | 4.13 | 57.19 | |
| | <i>Corbula gibba</i> | 71.25 | 4.10 | 61.29 | |
| | Gobiidae | 25.25 | 3.96 | 65.24 | |
| 2 | <i>Pagurus bernhardus</i> | 92.54 | 12.50 | 12.50 | 58.16% |
| | <i>Anapagurus laevis</i> | 31.85 | 8.90 | 21.40 | |
| | <i>Ophiura albida</i> | 123.92 | 7.74 | 29.14 | |
| | <i>Hinia</i> sp. | 32.00 | 6.77 | 35.91 | |
| | <i>Callionymus</i> sp. | 5.92 | 5.47 | 41.38 | |
| | <i>Macropodia</i> sp. | 10.69 | 4.76 | 46.14 | |
| | <i>Aequipecten opercularis</i> | 7.38 | 4.60 | 50.74 | |
| | <i>Pagurus prideauxi</i> | 6.69 | 4.49 | 55.23 | |
| | <i>Liocarcinus holsatus</i> | 3.92 | 4.25 | 59.48 | |
| Gobiidae | 4.00 | 3.99 | 63.47 | | |

habitat and high specificity meaning it is only found there. Consequently, a second SIMPER analysis was performed using presence/absence data, which removed the influence of abundant species and highlighting those showing high specificity and/or fidelity to the two main clusters (Table 4.9). Some taxa were unique to each cluster; the bivalves *Phaxus pellucidus* and *Acanthocardia* sp. in the first cluster and the urchin *Psammechinus miliaris* in the second.

Two further analytical steps were informative. The similarity matrices underlying the MDS plots for Hamon grab and beam trawl samples (Figures 4.19 and 4.20) were compared to see if their patterns were similar, but no significant correlation was found (RELATE routine

in PRIMER, Spearman's rank correlation, $\rho = 0.18$, $p = 11.9\%$). However, there were significant correlations between the pattern in each of these faunal elements and the measured environmental variables of sediment type and water depth (Hamon grab: $\rho = 0.438$, $p = 0.4\%$; Beam trawl: $\rho = 0.457$, $p = 0.1\%$). This suggests little linkage between the distribution of fauna obtained from Hamon grab and beam trawl samples, but that both are significantly influenced by environmental factors. The particular suite of environmental variables that best explained the biotic pattern for Hamon grab samples was the combination of water depth, % gravel, % fine sand and % mud (BIO-ENV routine in PRIMER, Spearman's

Table 4.9. Results of SIMPER analysis showing dissimilarity between epifaunal samples in the two major clusters indicated in Figure 4.20, using a presence/absence transformation of abundance data (see text). Listing taxa contributing to the first 40% of the overall dissimilarity (42.21%), their average abundance in each of the sample clusters and the % and cumulative % contribution to the overall dissimilarity between clusters.

| Taxon | Cluster 1 Average abundance | Cluster 2 Average abundance | % Contribution | Cumulative % |
|--------------------------------|--------------------------------|--------------------------------|-------------------|-----------------|
| <i>Aphrodita aculeata</i> | 8.50 | 0.31 | 4.19 | 4.19 |
| <i>Phaxus pellucidus</i> | 4.00 | 0.00 | 3.61 | 7.80 |
| <i>Acanthocardia</i> sp. | 7.00 | 0.00 | 3.61 | 11.41 |
| <i>Limanda limanda</i> | 7.50 | 0.08 | 3.53 | 14.94 |
| <i>Abra</i> sp. | 113.25 | 0.08 | 3.41 | 18.35 |
| <i>Echinocardium cordatum</i> | 9.75 | 0.15 | 3.22 | 21.57 |
| <i>Liocarcinus pusillus</i> | 0.75 | 2.08 | 3.10 | 24.68 |
| <i>Buglossidium luteum</i> | 5.75 | 0.92 | 2.78 | 27.46 |
| <i>Echiichthys vipera</i> | 0.25 | 1.15 | 2.72 | 30.18 |
| <i>Ophiura ophiura</i> | 214.25 | 2.31 | 2.68 | 32.86 |
| <i>Aequipecten opercularis</i> | 1.50 | 7.38 | 2.53 | 35.39 |
| <i>Crangon allmanni</i> | 0.50 | 3.46 | 2.51 | 37.91 |
| <i>Psammechinus miliaris</i> | 0.00 | 5.15 | 2.45 | 40.36 |

rank correlation, $\rho = 0.502$). Similar analysis was not considered valid for epifauna, as the beam trawl integrates samples over a strip of seabed where as the environmental data refer to point samples.

4.5 Discussion

4.5.1 Hastings study area

Results of the studies in the Hastings site show that seabed facies maps are a reliable spatial representation of the physical nature of the seabed. Video observations confirmed the distinctness of boundaries between facies and justified their depiction as discrete polygons. They also confirmed the accuracy of the facies descriptions and the underlying interpretation of sidescan sonar mosaics. Some minor differences were noted in bedform between the shallow and deeper occurrences of the short wavelength megaripple fields (coloured green on the facies map), indicating some need to 'fine-tune' the facies descriptions as this method of interpreting sidescan sonar images is developed. A reference catalogue of facies interpretations would provide a valuable asset in standardising this process and training others in rendering facies maps. The map produced in this study represents a significant advance over the coarser interpretation of the earlier studies (Brown *et al.*, 2001, 2004), providing far greater detail and resolution yet retaining clarity of presentation at this spatial scale.

Epifaunal communities differed between major sediment types in a manner that was consistent with the earlier study of Brown *et al.* (2001, 2004). Greater sample replication is required to fully test the difference in epifaunal communities between facies, but the similarity between three samples collected from sandy gravel facies at different depths (JB4, 5 and 8 in Figure 4.5, 4.11

and 4.12) indicates that substrate type is an important controlling factor in structuring epifaunal communities.

The novel spiral sampling pattern based on the Fibonacci number series also proved successful, proving a structured approach to assessing physical and biotic variability within a facies and sufficient replication to enable robust comparison between them. Spatial analysis identified facies having distinct spatial trends in grain size and macrofaunal community structure and provided a means to assess the degree of heterogeneity and/or patchiness within facies. The sampling pattern can easily be extended to cover larger spatial areas, and further trials would be valuable to investigate the properties of this sampling design. The analysis of particle size and faunal abundance data showed a clear relationship between different sediment types (grain structure) and their associated faunal communities. It was further established that macrofaunal assemblages were significantly different between each of the four facies sampled. Together, these results demonstrate that seabed facies are ecologically significant units and validate their use in mapping seabed habitats.

4.5.2 Broadscale study area

In the series of interpolated facies maps, low density coverage produced some distinctly linear features running parallel with the survey track (e.g. the most northerly sand facies in the central sector, Figure 4.16). The resolution of the facies map increased with density of sidescan sonar coverage, identifying more discrete facies and improving confidence in boundary definition. The dredged area due south of Hastings first appeared at 2 km line spacing and was more accurately represented at 1 km spacing, while a significant area of sand lying 12 km NE of the dredged area only became apparent at 1 km line spacing. Confidence in the interpolation therefore increases from low, to

moderate, to high for the 4, 2 and 1 km interpretations. The last of these represents approximately 50% density coverage. Further 'in-fill' lines giving 100% coverage resulted in only marginal increase in resolution that would not appear to justify the doubling of survey time and cost when mapping over this broad spatial scale. At this site, a 50% density coverage appears optimal, which equates to 1 km line spacing for a sidescan system with 400 m total swathe width.

Particle size analysis from sediment samples provided a valuable means of cross-checking the broadscale facies map and confirming that the sediment type had been correctly assigned. A few samples contained more gravel or mud than was anticipated from the facies map, and served to highlight specific areas that might need more detailed investigation, possibly using a complementary method such as video observation to verify the true nature of the sediment. The different sampling characteristics of the Shipek and Hamon grabs led to some disparity in granulometric analysis, and it appeared that Hamon grab samples were generally more representative as the Shipek grab tended to under-sample the larger size fractions of the sediment (i.e. the gravel).

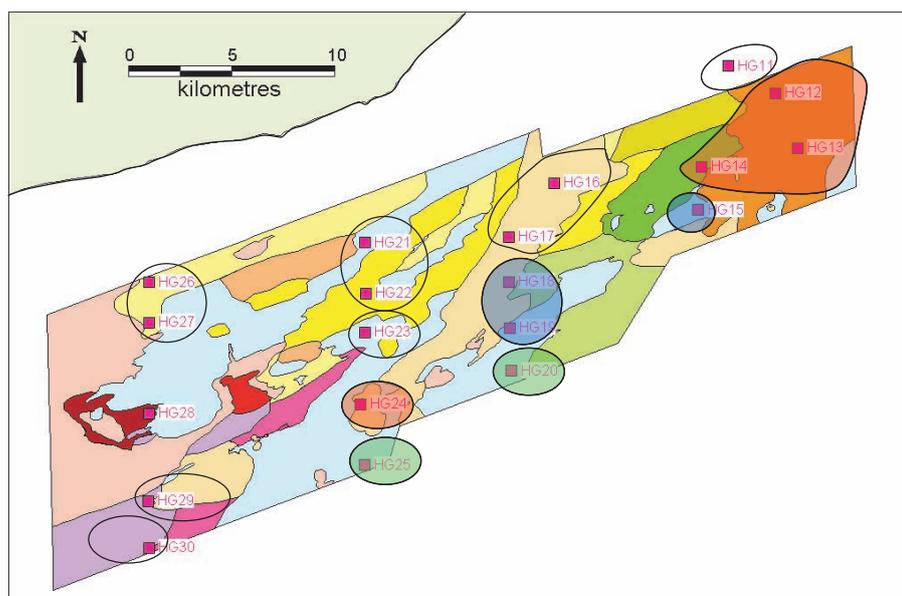
The pattern of grab and beam trawl sampling used for the broadscale study followed a strategy that would normally be employed in a pilot survey, selecting a regular grid of sites to cover the survey area with a view to providing preliminary information on the nature of the site. It would not be valid to rely solely on these samples to provide sufficient data for a habitat map, due to the wide spatial separation of the sampling sites and the lack of replication. However, the knowledge gained from this 'pilot' sampling is invaluable in planning and designing the full ground-truth survey, the purpose of which is to target and characterise the distinct areas identified by the facies map (as per the current Hastings study). The pilot survey revealed a range of sediment types over the broadscale area that require different sampling techniques. Most of the area would appear to be amenable to sampling by Hamon grabs, but Day grabs or corers may be more suitable for the areas of sandy mud and drop-down video for the rock outcrops.

Faunal analysis identified some species that are common to a variety of habitats and others that show a higher degree of specificity and fidelity and will therefore be more important in discriminating between habitats. Three major cluster groups were evident for the Hamon grab samples,

separating shallow from deep sites and splitting the shallow sites into fine sands and medium sands. There was clear evidence of further grouping within these clusters, particularly where there was a mud or gravel component in the sediment and mapping these minor clusters onto the facies map gives a first indication of how the spatial relationships between habitats might appear once the full ground-truthing data are available (Figure 4.21). As there was not a close linkage between the distribution patterns of Hamon grab and beam trawl samples, the two elements of the biota will require separate consideration when constructing a habitat map. Epifaunal assemblages were characterised by motile carnivorous species whose habit has little dependence on sediment properties (e.g. hermit crabs, shrimps, starfish) and so show very low specificity to sediment type. Other environmental variables such as depth and current speed will have a more dominant influence in shaping their distribution, along with the basic habitat requirement for provision of food and shelter. As the majority of species sampled using Hamon grabs are infaunal (i.e. living within the sediments), their physical characteristics are likely to be the principal environmental factor in structuring such assemblages.

This structured approach to surveying the physical and biological conditions of the seabed can be adapted to suit a range of spatial scales and is suitable for both local and regional application. It is recommended that facies maps are constructed using acoustic and sediment data prior to undertaking a directed ground-truth sampling programme which is targeted at each of the apparent seabed facies. Existing acoustic data may be suitable for the basis of the facies map, but if it is not available a dedicated acoustic survey will be required. Directed ground-truth sampling provides more efficient use of available resources, leads to higher confidence in the resulting maps and ensures they are fit for the purpose of marine monitoring and spatial planning. It is recognised that logistical constraints can influence the timing of surveys and it may be impractical to undertake the acoustic survey prior to faunal and sediment sampling. Under these circumstances, a more intensive sampling programme is recommended to ensure adequate density and replication of samples. In the absence of any knowledge about the distribution of sediments within the area of interest, the sampling programme should be based in a conventional grid design, with a maximum spacing of 1 km between sampling points.

Figure 4.21. Preliminary differentiation of faunal habitats for the broadscale study site, grouping sampling sites that lay within the 50% similarity contours of Figure 4.19. Where stations are not adjacent to each other, similarity is also indicated by colour coding (e.g. stations 15, 18 and 19 all lie within the same 50% similarity contour).



4.6 Scope for linkage between surveys conducted at different spatial scales

4.6.1 Introduction

Earlier chapters of this report have described the effectiveness of a number of biological seabed sampling techniques in the context of ground-truthing remotely-sensed acoustic data, with the aim of arriving at a set of guidelines for future biotope mapping work. Direct biological sampling is an expensive process, forcing mapping studies to try and be parsimonious when selecting sites for biological characterisation. The ideal for any newly initiated survey would be to incorporate additional biological data collected as part of previous surveys, thereby broadening the mapping dataset at little extra cost. Biotope mapping studies in UK offshore waters are generally directed at areas of focussed human activity, such as aggregate extraction and waste disposal sites (e.g. Brown *et al.*, 2004; Boyd *et al.*, 2005; Chapter 5 of this report), in which case biological samples for the sites will likely already exist. Offshore waters around the UK are also subject to annual assessments of the status of many groundfish stocks, and in principle the data collected during these surveys can be used to augment site-specific data. Groundfish surveys are no different from other biological sampling programmes in targeting specific species and assemblages. As described earlier in this report, site-specific seabed surveys generally rely on Hamon grabs to sample infauna and non-mobile epifauna, and on 2 m beam trawls for semi-quantitative estimates of structural fauna and mobile epifauna. Groundfish surveys by contrast cover a much broader area and are designed to target demersal fish communities. In the UK, surveys of adult fish are conducted with either a 4 m beam trawl or a bottom trawl, depending on the target species. Juvenile fish are sampled more effectively using a 2 m beam trawl, but young fish surveys do not typically extend far into offshore waters, as the species targeted

by the surveys generally occupy inshore waters during their early life history (Rogers and Millner, 1996). Beam trawls have the advantage over bottom trawls in being able to sample larger macrofauna relatively well, and a number of studies have described the spatial distribution of benthic epifauna from routine fisheries beam trawl surveys (e.g. Kaiser *et al.*, 1999; Ellis and Rogers, 2000). Unfortunately, samples collected by different gears often arrive at different estimates of the relative abundance of different species. Understanding the catch efficiencies of different gears is an ongoing area of study (ICES, 2004), but unless data from different gears can be compared directly, biological classifications will differ according to the source of the data, and complicate the transfer of classifications across sites.

Despite these problems, biological data from fisheries beam trawl surveys can potentially be used as an extra resource during seabed mapping studies. Unfortunately, long tow lengths of the order of 3-4 km and the use of relatively heavy sampling gear produce data on too coarse a resolution for site-specific habitat assessments. Nevertheless, the larger areas covered by fisheries surveys provide opportunities to assess whether site-specific surveys have captured sufficient information on how species respond to their environment, which in turn will affect whether species-habitat descriptions are applicable across a broader area. In general, a survey covering a limited spatial extent would be less likely to detect species-habitat associations compared to a survey covering a much broader spatial area, the rationale being that surveys conducted over a much broader area have a greater chance of sampling environmental extremes representative of the upper and lower limits of tolerance for population viability (Huston, 2002). In this case, species-habitat relationships should be easier to detect. Leading on from this, it would be useful to know whether site-specific surveys can be used to characterise habitats at a broader scale (scaling-up), and similarly whether broader scale surveys can be

used to characterise more localised, site-specific habitats (scaling-down). Previous studies have demonstrated that scaling-down generally yields more accurate habitat assessments than vice versa (Collingham *et al.*, 2000; Aspinall, 2001), confirming the view that species-habitat relationships become better defined as the spatial extent of the study area increases.

Disparity between the sampling gears used for site-specific epibenthic surveys and broader scale groundfish surveys precludes thorough assessments of transferability of modelled species-habitat relationships, of the kind described in Chapter 7. Comparisons would also be confounded by spatial and temporal mismatches between the sampling programmes. This is the situation when comparing seabed biological sampling studies in the eastern English Channel (EEC). Site-specific epifaunal sampling with 2 m beam trawls described earlier in this report was generally conducted in spring and summer, whilst the 4 m beam trawl groundfish survey is undertaken in late summer and early autumn. In addition, very few 4 m and 2 m beam trawl sites are spatially coincident (Figure 4.22), and epifauna from the groundfish survey were not enumerated in the same years as the site-specific investigations undertaken as part of the current and previous studies (Brown *et al.*, 2001).

Nevertheless, it is still possible to use these data to investigate whether site-specific surveys are able to detect species-habitat associations that in turn are broadly applicable over a wider area, and by doing so assess whether surveys conducted over different spatial scales can be linked. The objective of this study was therefore to examine whether associations between key environmental variables and patterns of species distributions strengthen as the spatial extent of the area surveyed increases. We use associations between species and environmental factors from the broad coverage 4 m beam trawl groundfish surveys to provide a baseline against which species-habitat associations developed from the more localised 2 m beam trawl sampling can be compared.

It is worth first defining the term 'scale' in the context of this study. In strict terms, scale comprises both resolution and extent (Morrison and Hall, 2002). Here we restrict its use to describe the spatial extent of the survey area rather than the resolution of the data being used. A broadscale survey therefore covers a larger area than a small-scale survey.

4.6.2 Materials and methods

4.6.2.1 Data sources

Biological data were extracted from 6 separate datasets representative of surveys covering different areas, spatial extents, and time periods, and using different sampling gears (Figure 4.22). There were:

- i) 4 m beam trawl survey dataset of the EEC. The survey is conducted annually but data suitable for comparison with the 2 m beam trawl data were only available for 3 years. Of these, only data for 1999 and 2002 were used to reduce the temporal mismatch with the 2 m beam trawl data. The data from the two years were pooled as the location of survey stations remained relatively constant between years.
- ii) Five 2 m beam trawl survey datasets collected at specific locations in the UK sector of the EEC as part of this and previous studies (Brown *et al.*, 2001). Data from the sites covered a number of years from 2000 to 2004.

From these datasets, two taxa were selected that were relatively well represented in the catches of both gear types: hermit crabs (*Pagurus spp.*), and queen scallop (*Aequipecten opercularis*). All counts were standardised by the swept area of the gear and represented as numbers per 1000 m². Table 4.10 provides mean densities for these two taxa by survey along with other summary statistics.

Data for water column depth and near-bed shear stress were added to the trawl survey datasets by overlaying the trawl stations onto digital maps held in a GIS (ArcGIS v.9) and extracting spatially coincident values. Both these parameters may act to limit population densities of *Pagurus* and *Aequipecten*, and this relationship may be detectable if a broad enough environmental range had been measured by the sampling regime. Water column depth was not added to the 4 m beam trawl stations as *in situ* measurements were available. Digital depth data in metres below lowest astronomical tide were provided by the UK Hydrographic Office, whilst near-bed shear stress was estimated from an 8 km resolution hydrodynamic model of the UK shelf originally developed by Proudman Oceanographic Laboratory. Units of measurement for shear stress were Newtons (N) per m² and represent pressure exerted on the seabed from tidal forcing.

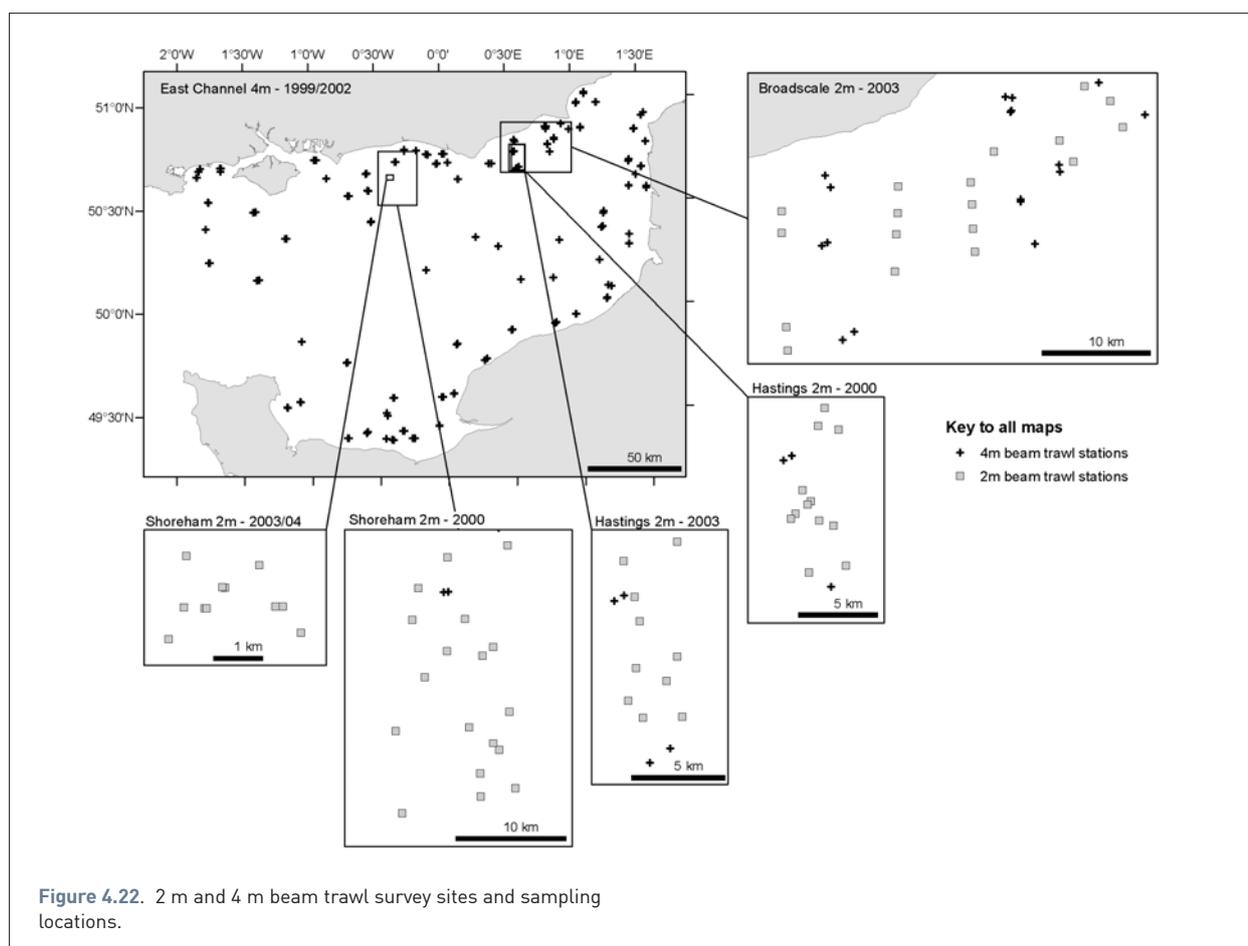


Figure 4.22. 2 m and 4 m beam trawl survey sites and sampling locations.

Table 4.10. Summary data for 4 m and 2 m beam trawl survey datasets used in this study.

| Survey | Year | No. of stations | Approx. area (km ²) | Depth range (m) | Shear stress range (N m ⁻²) | <i>Pagurus</i> mean density (no. 1000 m ⁻²) | <i>Aequipecten</i> mean density (no. 1000 m ⁻²) |
|---------------------------|-----------|-----------------|---------------------------------|-----------------|---|---|---|
| EEC 4 m beam trawl | 1999/2002 | 147 | 32400 | 68.5 | 2.86 | 0.9 | 5.9 |
| Broadscale 2 m beam trawl | 2003 | 18 | 331 | 57.3 | 0.78 | 305.9 | 20.7 |
| Shoreham 2 m beam trawl | 2000 | 18 | 223 | 28.6 | 0.29 | 112.7 | 66.7 |
| Hastings 2 m beam trawl | 2003 | 10 | 29 | 27.7 | 0.29 | 67.3 | 11.5 |
| Hastings 2 m beam trawl | 2000 | 12 | 27 | 23.6 | 0.62 | 132.8 | 0 |
| Shoreham 2 m beam trawl | 2003/04 | 11 | 4 | 10.6 | 0.00 | 127.9 | 111.0 |

4.6.2.2 Analysis

As noted earlier, the basis for the analysis was an assessment of whether associations between key environmental variables and patterns of species distributions strengthen as the spatial extent of the area surveyed increases. Associations between the two environmental factors, depth and shear stress, and the two representative taxa, *Aequipecten* and *Pagurus*, were tested by way of pairwise correlations given by Spearman's rank (r_s), with P -values computed using degrees of freedom corrected for spatial autocorrelation (Dutilleul, 1993). Regression quantiles from

the 50-99th were also estimated for univariate models of *Aequipecten* and *Pagurus* catch densities ($\log_e + 1$ transformed) as dependent variables against the two environmental factors as independent variables, in order to examine whether the sign of the relationship given by the correlation coefficients remained stable across a broader range of each species-habitat data distribution. Regression quantile models were estimated for two aggregated datasets: combined 2 m beam trawl data and combined 4 m beam trawl data, the purpose being to estimate the overall response of both taxa to the two environmental

factors. In principle, regression quantiles fitted to the upper regions of the species-habitat distributions (> 75th) would also be able to detect the shape and form of any potential limiting effects caused by depth and shear stress on catch densities of the two taxa. Regression quantiles are described in more detail in Chapter 7 and also in Cade and Noon (2003) and Eastwood and Meaden (2004). Tests of significance for Spearman's rank correlation were computed using the freely available MODTTEST program of P. Legendre and P. Casgrain of the University of Montréal, while regression quantiles and tests of significance were computed using the freely available BLOSSOM software program of B. Cade and J. Richards of the US Geological Survey.

Correlation coefficients were plotted against the area at each survey site to assess whether a relationship existed between the species-habitat correlations and the size of the survey area. Area was \log_{10} transformed to reduce the large difference in area covered by the 4 m and 2 m beam trawl surveys. 50th regression quantiles were estimated for these data to provide an indication of whether the correlation coefficients followed an increasing or decreasing trend.

4.6.3 Results

In general, as the area surveyed increased in size, so did the range of the two environmental variables (Table 4.10). Mean densities of both *Pagurus* and *Aequipecten* were noticeably lower in the 4 m beam trawl survey but this might be expected given the broader spatial area covered and the presence of a larger proportion of zeros, of which there were approximately 40% and 60% in the 4 m beam trawl surveys for *Pagurus* and *Aequipecten* respectively, compared to 0% and 40% in the 2 m beam trawls. *Pagurus* appeared to be sampled more effectively by the 2 m beam trawl, less so for *Aequipecten*.

Scatterplots of aggregated catch densities against the two environmental parameters suggests a general decline in *Pagurus* catch densities with increasing depth and shear stress, whilst the opposite appears true for *Aequipecten* (Figure 4.23). Firm conclusions on the form of the relationships for the 4 m beam trawl survey are more difficult to draw compared to the 2 m beam trawl survey. For *Pagurus*, the association with depth is ill-defined, while for *Aequipecten* the large number of zeros and low catch densities tends to obscure any noticeable trend.

Regression quantiles estimated for models of aggregated catch densities against the two environmental parameters confirmed any general trends seen in the scatterplots (Figure 4.24). The signs of the coefficients for depth and

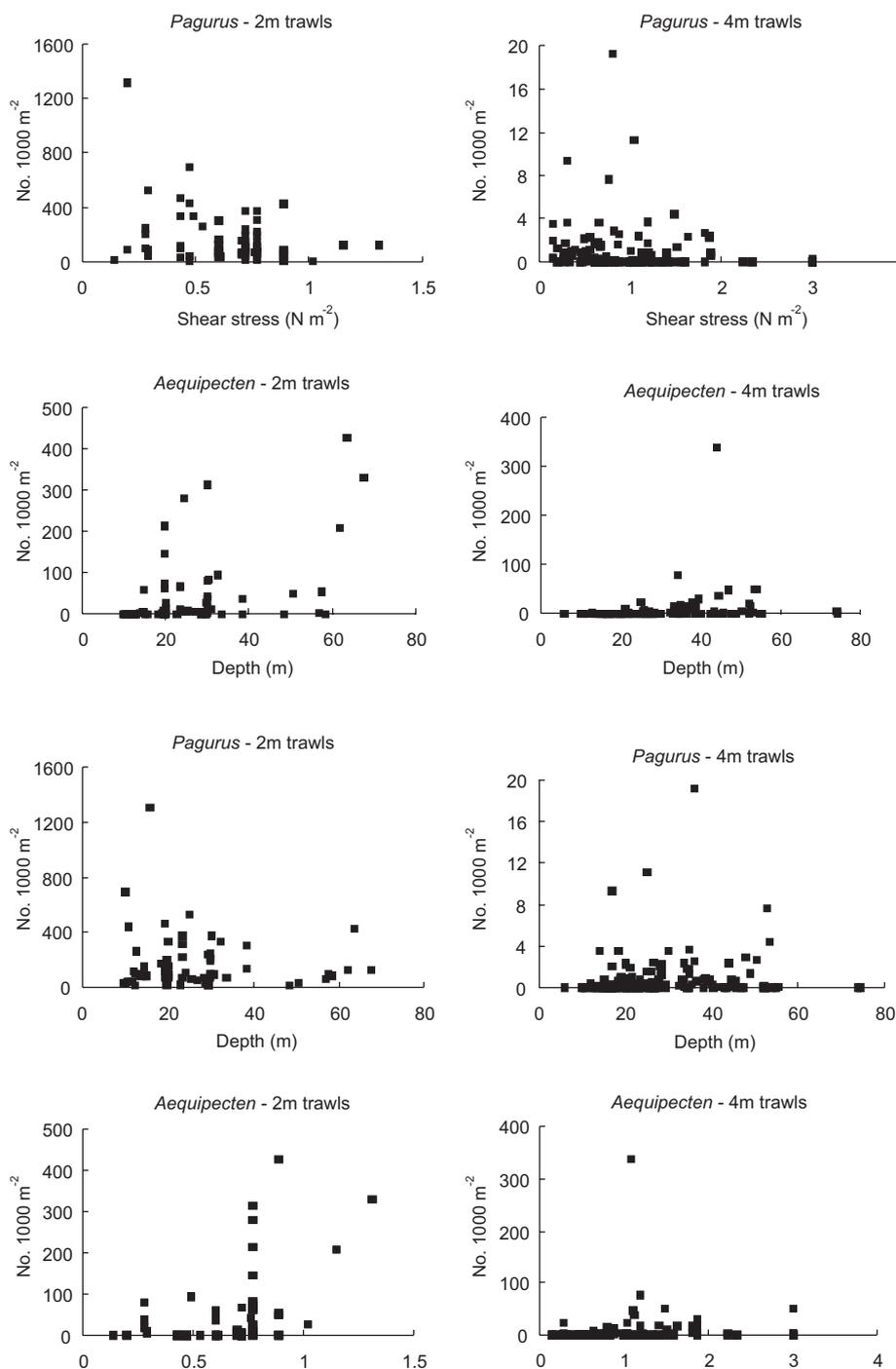
shear stress in models of *Pagurus* catch densities were generally negative, although the majority of the models were found to be non-significant ($P < 0.05$). *Pagurus* and depth were positively related according to the 4 m beam trawls, but the coefficients were weak and non-significant. Quantile models for *Aequipecten* comprised of coefficients for depth and shear stress that were both positive and significant ($P < 0.05$) for the majority of quantiles tested. This suggests that *Aequipecten* was more strongly related to the two environmental factors compared to *Pagurus*. Comparable relationships were given by both 2 m and 4 m beam trawl data. Therefore despite their potentially different catch efficiencies, the two gears yielded similar species-habitat associations for both taxa, where they were found to be significant.

Correlations between *Pagurus* and both depth and shear stress generally followed a trend of having positive signs for the smaller surveys but then decreasing in strength and having negative signs as the size of the survey area increased (Figure 4.25). None of the correlations were found to be significant except for *Pagurus* and depth in the 4 m beam trawl survey, and even then the coefficient was only weakly positive. In contrast, correlation coefficients for *Aequipecten* all had positive signs and the fitted trend line suggested a strengthening of the correlations as the survey area increased, despite a considerable amount of variability. It should be noted that the plots in Figure 4.25 include correlation coefficients for aggregated 2 m and 4 m beam trawl surveys as well as for individual 2 m beam trawl surveys. Correlations could not be computed for all pairwise comparisons due to missing or uniform data in some cases, hence some plots contain fewer than 7 points. To summarise, for *Aequipecten* the general form of the species-habitat relationships appeared to be sufficiently clear to be detectable by even the smallest survey. Habitat relationships for *Pagurus* were, by contrast, less obvious and more difficult to detect.

4.6.4 Discussion

It is difficult to draw firm conclusions on whether a positive relationship exists between the strength of the species-habitat associations and the size of the survey area. For *Aequipecten*, the form of the species-habitat relationships was relatively invariant to the size of the survey area given the large degree of variability in the correlation coefficients around the fitted trend line. This suggests that even surveys covering relatively small spatial extents ($< 10 \text{ km}^2$) were able to detect the general form of the relationships between *Aequipecten* and the two physical environmental parameters. The 4 m beam

Figure 4.23. Scatterplots of *Pagurus* and *Aequipecten* catch densities against depth and bed shear stress for aggregated 2 m and 4 m beam trawl surveys.



trawl surveys covering a much larger spatial extent (> 1000 km²) detected similar relationships to the 2 m beam trawl surveys but were obscured by a high degree of variability, probably due to a lower catch efficiency. For *Pagurus*, the most interesting feature was a shift in the association with shear stress from being positively related to negatively related as the size of the survey area increased. Overall, however, both 2 m and 4 m beam trawl surveys were poor at being able to detect the form of the relationship between *Pagurus* catch densities and the two habitat variables despite the taxa being relatively

well represented in the trawls. It may be that depth and bed stress are not important predictors or proxies for describing *Pagurus* habitat, but statistical significance aside this is unlikely given the form of the relationship described by the scatterplots and confirmed by the fitted regression quantile models.

For the two taxa considered here, there is little firm evidence to suggest that species-habitat correlations strengthen as the spatial extent of the area surveyed increases. Correlations remained relatively invariant for one taxon and were difficult to detect for the other regardless of

Figure 4.24. Regression quantiles (50-99th, represented on a scale of 0.5-1.0 on the x-axis of each graph) estimated for univariate models of aggregated 2 m and 4 m beam trawl catch densities ($\log_e + 1$ transformed) of *Aequipecten* and *Pagurus* as dependent variables against bed shear stress and depth as independent variables. Red portions of the graph represent quantiles found to be significant ($P < 0.05$) according to rank-score tests.

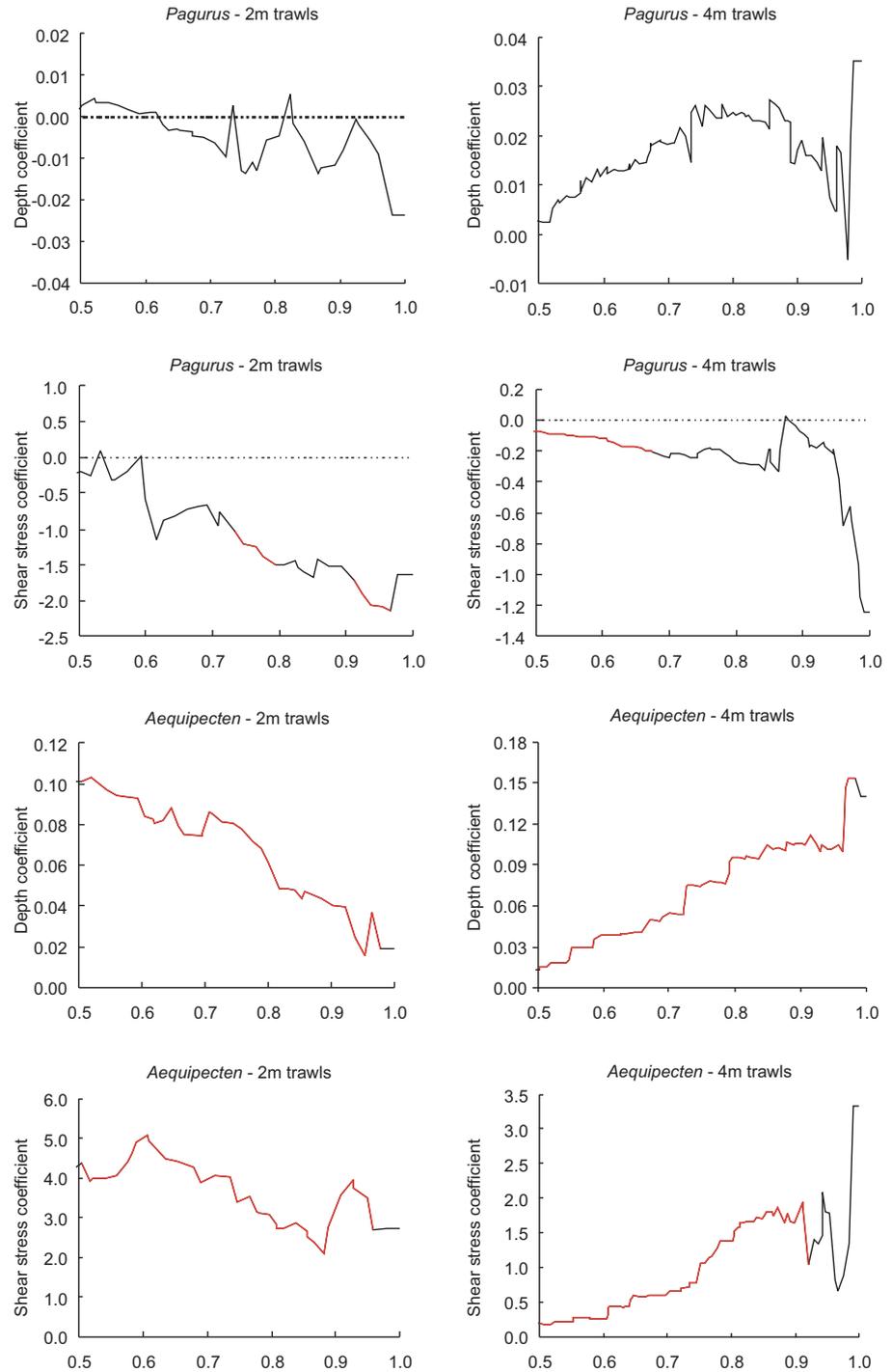
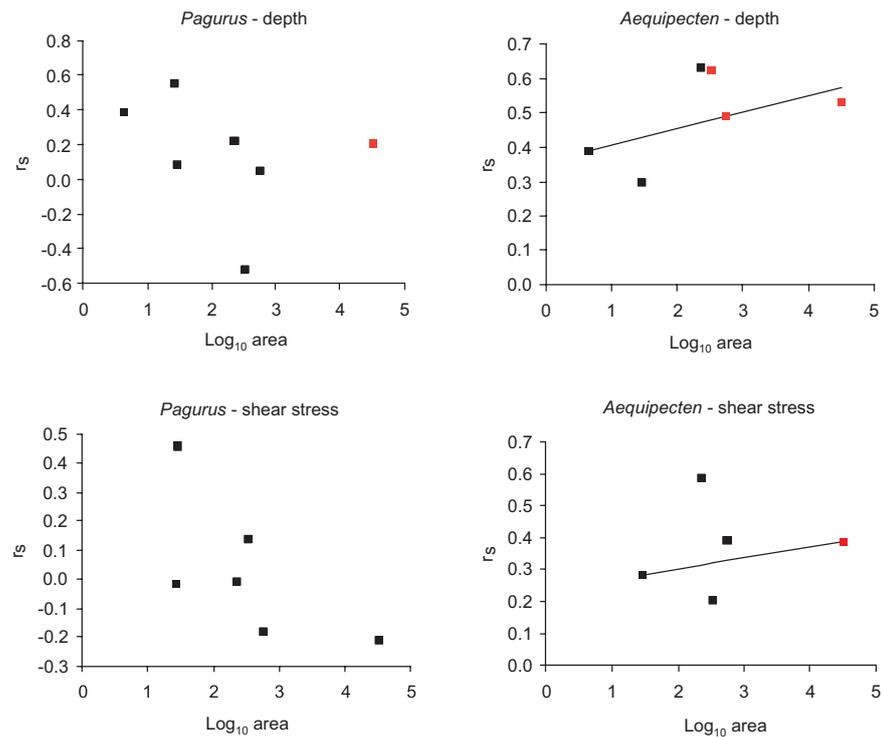


Figure 4.25. Spearman's rank correlation (r_s) for pairwise species-habitat associations, plotted against survey area, and fitted 50th regression quantile. Correlations found to be significant ($P < 0.05$) are shown in red.



the survey size. The importance of this outcome for mapping studies is that species-habitat relationships quantified at one spatial scale may not necessarily be transferable to another. Notions of habitat drivers for patterns of species distributions may therefore be dependent on the spatial scale of the investigation. The large degree of uncontrolled spatial and temporal mismatch between surveys is likely to have contributed to our inability to draw firm conclusions.

5. Utility of mapping techniques for assessing/monitoring temporal changes

5.1 Introduction

Determination of spatial patterns of benthic assemblages in relation to the seafloor attributes dates back to the early work of Petersen (1914). Since then, researchers have employed different types of sampling design (i.e. grids, transects) to explore relationships between biological, chemical and physical characteristics of the seafloor over various spatial scales (Thrush *et al.*, 1989). Difficulties arise from the adoption of such approaches, for defining the spatial distribution and characteristics of benthic assemblages over wider areas. This is because in the past, scientists have relied on traditional sampling tools (e.g. grabs, corers and dredges) to quantify the benthic fauna (macrofauna and meiofauna) and its associated sediments (Boyd *et al.*, 2002; Buchanan, 1984). This information only relates to a specific point on the seabed from which the sample was collected and, therefore, inferences regarding the wider distribution of substrata and the associated fauna may be unrealistic, especially in patchy environments (Brown *et al.*, 2002). Whilst there are sound reasons for the application of such approaches (e.g. Rees *et al.*, 1990), with improvements in technology there is an increasing interest in using acoustic and optical techniques for assessing anthropogenic effects, particularly in areas of known habitat heterogeneity.

A number of acoustic techniques (especially sidescan sonar) have been widely employed to monitor physical disturbance of seabed habitats (e.g. Brown *et al.*, 2004, 2001, 2002; Limpenny *et al.*, 2002; Boyd *et al.*, 2004). However, an ongoing challenge is to establish the extent to which such techniques, used in conjunction with appropriate ground-truthing methodology and optical methods, can be used to map both the distribution and status of benthic communities in relation to natural and man-made influences. Such techniques include: i) acoustic methods, for example, sidescan sonar, multibeam bathymetry and acoustic ground discrimination systems (e.g. QTC™ and RoxAnn™); ii) underwater remote sensing techniques (e.g. video and digital stills photography) and; iii) Sediment Profile imagery (SPI). There are few studies where a combination of different approaches (optical, acoustic and traditional methods) has been employed (Zajac, 1998). Therefore, the aim of this Chapter is to assess the utility of these techniques (or combination of) for monitoring, and to establish the extent to which such an integrated approach can be routinely applied. The first case study is a dredged material disposal site, (TY070 hereafter), off the Tyne, North Sea and the second scenario is an aggregate extraction site, off Shoreham in

the eastern English Channel. The use of acoustic ground discrimination systems (AGDS) and their application to the detection and monitoring of anthropogenic disturbance of the sea floor are also explored in some detail in this Chapter.

Many questions remain over the suitability of AGDS for detecting and tracking changes in habitats, in particular:

- Can AGDS detect ground types that can be ascribed to anthropogenic disturbance?
- Are different AGDS comparable, i.e. can they discriminate the same ground types despite their inherent differences?
- Can seabed samples be used to adequately ground-truth the AGDS data and what constraints does this function of sampling impose on survey strategy?
- Are the data from AGDS sufficiently robust to be able to monitor change?
- How do maps based on AGDS classification compare with maps based on other acoustic systems?
- Does the use of a combination of acoustic systems provide a better understanding of habitat distribution than using one system alone?

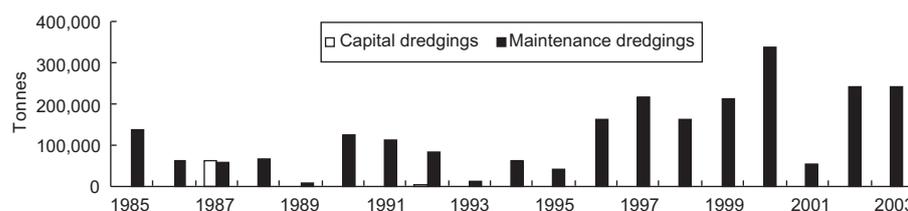
5.2 Site descriptions

5.2.1 Dredged material disposal site (TY070)

Over the past three decades large amounts of solid industrial waste (e.g. colliery waste, fly ash) and sewage sludge from a number of sources were disposed of at licensed sites off the north east coast of England (e.g. Eagle *et al.*, 1979; Bamber, 1984; Khan and Garwood, 1995; Frid *et al.*, 1996; Herrando-Pérez and Frid, 1998, 2001; Bustos-Báez, 2003; Bustos-Báez and Frid, 2003). In most cases disposal of these materials started well before statutory controls for the protection of the marine environment were enforced (Eagle *et al.*, 1979). However, with the exception of dredged material, the disposal of these materials to sea has been phased out over time.

Dredged material can be defined as the material excavated from a sea, river or lake bed. It can also be further de-fined as maintenance dredging (typically consisting of sand, silt and gravel arising from estuarine ports) and capital dredging (soft clay, sand, silt and in some cases rocks and boulders from channel, harbour and civil engineering work) (MEMG, 2003). Since dredged material disposal at sea is the only material currently released into the marine environment, this activity has been the focus of increasing attention from government, the general public and industry (for review see Bolam and Rees, 2003).

Figure 5.1. Quantities of capital and maintenance dredged material licensed for offshore disposal at Dredged Material Disposal Site (DMDS, thereafter) (Defra unpublished data).



The disposal of maintenance dredged material from the Tyne Estuary has increased over recent years. Quantities of over 1.5 million wet tonnes (Figure 5.1) are annually disposed of at a licensed area (TY070) located 5.7 km off the Northumberland coast. Cefas has periodically surveyed environmental conditions as part of routine monitoring programmes undertaken on behalf of Defra at various disposal sites in the region (e.g. Maff, 1994; Eagle *et al.*, 1979). Early studies (Buchanan, 1963) have helped to characterise the sediments of the wider area encompassing the TY070 disposal site and these studies indicate that they represent the buried landscape of late a Pleistocene land surface with the sediments resorted to some extent by waves and tidal current. The sediments of the north east coast of England are generally regarded as being North-English and Scottish glacial and fluvoglacial origin (Eagle *et al.*, 1979). The resorting of these sediments began in the sub-boreal period when the connection between the Dogger Bank and England was severed and the characteristics of the present tidal current system were initiated alongside the present trends of coastal accumulation (Olsen and Olsen, 1993).

5.2.2 Aggregate extraction site (Shoreham)

Brown *et al.* (2001, 2002) and James and Brown (2002) investigated the habitats off Shoreham in the eastern English Channel. The area studied by these authors, termed the 'Shoreham Box' lies on the northern margin of the English Channel and covers a relatively shallow coastal platform which declines gently across 10 to 15 km of seabed from a depth of just less than 10 m in the north west corner of the area to a depth of 30 to 35 m. At this depth there is an abrupt break of slope down to a narrow step at about 45 m, before another break of slope down to 60 m. The slope breaks range over a distance of <2 to 3 km and occur on the northern margin of the Northern Paleovalley, a major open depression within this sector of the English Channel. Three principal morphological units were identified by James and Brown (2002) within the 'Shoreham Box' namely, coastal platform, palaeovalley margin and palaeovalley floor. A seabed facies interpretation from the sidescan sonar data separated the seabed into seven areas having distinctive primary facies.

The current study builds upon previous findings from these studies, exploring further the presence of marine habitats over a smaller area within the 'Shoreham Box' which contains a licensed marine aggregate extraction site. The dredged area lies on a feature which is slightly elevated on the eastern margin of the coastal platform.

This area lies within the Owers Bank licensed dredging area. Both Brown *et al.* (2001, 2002) and James and Brown (2002) noted that the gravel from this area had been excavated using static suction hopper dredgers. Dredging using such vessels is conducted by anchoring the dredger over the seabed and extracting the sand and gravel in a virtually stationary position. This results in the creation of a patchwork of extraction pits at the seabed which were distinctive from sidescan sonar records obtained within the 'Shoreham Box'. Video footage obtained from this site indicated that the dredged depressions contained fine sediment and this was attributed by James and Brown (2002) to be due to the release of and then deposition of material during the dredging process. Brown *et al.* (2001, 2002) also noted the presence of mussels within the confines of the dredged pits, although the extent of their coverage within the dredged area was difficult to ascertain from the limited video footage. It was suggested that the mussels had settled in this unique anthropogenic environment following the cessation of dredging. Although the video footage appeared to indicate differences in both the fauna and sediments within the confines of the pits compared to outside, this was not borne out by the results of sediment particle size and macrobenthic analysis of Hamon grab samples. This was probably a consequence of sampling within a patchy environment. This site was selected along with TY070 in order to further assess the scope and application of a range of conventional and novel tools for evaluating the impacts of anthropogenic disturbance in heterogeneous environments.

5.3 Methods – acoustic surveys

Since the methodological focus of this Chapter is on AGDS, there follows a detailed description of the ways in which they were applied to the TY070 and Shoreham surveys and an outline of the analysis and interpretation of the data collected.

5.3.1 AGDS

There are a number of commercially available AGDS and there was the opportunity to use three systems within this study: QTC-View™ (Questor Tangent Corp – Sidney BC Canada), RoxAnn™ (Sonavision Ltd, Aberdeen) and Echo Plus™ (SEA Ltd, Bath). QTC was used throughout this study on all sites whilst the latter two systems were used once, in 2001, at TY070. The datasets available from AGDS between 2001-2003 for TY070 and the Shoreham sites are summarised in Table 5.1.

Table 5.1. AGDS datasets used at different areas over time.

| Year | Site | System | Frequency kHz | Track spacing |
|------|------------|----------|---------------|---------------|
| 2001 | North Tyne | QTC | 200, 50 | 150 m |
| | | RoxAnn | 200, 38 | 400 m |
| | | EchoPlus | 200, 50 | 400 m |
| 2002 | Shoreham | N/A | N/A | N/A |
| | North Tyne | QTC | 200 | 360 m |
| 2003 | Shoreham | QTC | 200 | 200 m |
| | North Tyne | QTC | 200 | 350 m |
| | Shoreham | QTC | 200 | 350 m |

The RoxAnn™ system uses analogue signal processing hardware to select two elements from the echo (Burns *et al.*, 1985; Chivers *et al.*, 1990). The first selected segment of the echo is the decaying echo after the initial peak (termed E1 or G1) and is taken to be a measure of roughness of the ground. The second segment is the whole of the first multiple echo (termed E2 or G2) and is a measure of hardness. EchoPlus™ is essentially a digital version of this system but offers potential benefits of avoiding variability inherent in the analogue signal processor. QTC View™ operates in a very different way to RoxAnn™. The echo is converted from analogue to digital form and is then subjected to analysis using a large number of algorithms for wave-form analysis (Collins *et al.*, 1996; Collins and McConnaghey, 1998). The variables are logged for subsequent principle components analysis to be applied to the complete dataset. The bespoke software package QTC Impact™ is then used to identify 'natural' clusters which are acoustically different, within the dataset, which can then be attributed to ground types as dictated by the field sample data. The clusters can be further split by running QTC Impact™ again. This process of finding 'natural' clusters is termed 'unsupervised classification' and is covered in greater detail below.

Quality assurance and data editing

Quality assurance was undertaken following the guidelines given in Foster-Smith and Sotheran (2003). Spurious depth data were highlighted and removed using plots of depth against time to re-run the depth profile of the data. All zero values for depth were also removed. The datasets were also projected in non-earth coordinates (E1/E2 or Q1/Q2; Q1/Q3; Q2/Q3) to check for outlying data that might be suspect. These data points were tagged and all the data were plotted geographically and displayed showing incremental values in E1/E2 or Q1, 2 and 3 to visually check for any conspicuous disparity between adjacent tracks. In all, less than 2% of the data from any of the datasets were removed and the remaining data were considered of sufficient quality for further analysis.

Unsupervised classification of point data

All AGDS are designed to have the capability of real-time discrimination of sediments. For RoxAnn™ and EchoPlus™, two paired variables, E1 and E2 (or G1 and G2) can be displayed on a Cartesian XY plot, and this is the basis of the real-time display as used in the data logging and display systems. QTC View™ applies a number of algorithms to the echo, reduces these variables using principal components analysis and displays a three-dimensional plot of the first three principal components, termed 'Q space'. The points in Q space are then divided up into a number of natural clusters. The number of clusters and their centroids in Q space are determined 'objectively' within the Impact™ software. This basic cluster analysis was performed on some of the datasets and the points labelled by cluster number. An alternative route for analysis, and one which was used more extensively in this study, was to process the data in Idrisi™ after interpolation, which allows a wider range of classification techniques to be performed (see below).

Interpolation

Interpolating between AGDS track point data creates a regular grid of values calculated from the real data. Perhaps one of the most compelling reasons for interpolation is that it opens up the use of proprietary image processing software for further analysis (Sotheran *et al.*, 1997). A grid of interpolated values can be represented as a digital image with each grid node becoming the centroid of a pixel. Variogram analysis of the track point data was carried out using Surfer™ to determine if interpolation was appropriate. Interpolation was also performed in Surfer™ using a simple inverse distance algorithm. The geographic boundaries, search and display radius and grid spacing were standardised within each dataset during interpolation. The grid data were saved in ASCII grid format, which was imported into Idrisi™.

Unsupervised classification of interpolated data

Idrisi™ has an unsupervised classification procedure (Isoclust™), which is an iterative self-organizing classifier in which the operator selects the number of clusters to be identified. It is often difficult to assign these clusters to particular sediment types and the usefulness of unsupervised techniques in general has been (1) to identify possible acoustically different ground types for sampling and (2) to reinforce the confidence in supervised classification in situations where there is some coincidence between the distribution of acoustic ground types and supervised classification outputs. Unsupervised classification has been applied to all the available AGDS data sets from TY070 and Shoreham sites.

Supervised classification

Supervised classification establishes statistical links between categorical ground-truth data and the acoustic data. For AGDS data, these acoustic images are generated by interpolation. The grids for the AGDS data were imported into Idrisi™ for classification. The training sites were created from the final biotope list to be used for classification in MapInfo™. Buffers were created for each of the sample points with a radius of 75 m and these polygons imported into Idrisi. The training sites were used to create signatures for each of the biotopes and the signatures were used to classify the acoustic images using the maximum likelihood classifiers in Idrisi™.

Supervised classification of the RoxAnn™ data using maximum likelihood is a very convenient route for analysis since it is well supported by proprietary software and gives good results. This method of classification can also be applied to QTC data, using the three Q values and depth in the classification procedure.

The main steps in supervised classification are (1) selecting training sites for categories of habitats or biota, (2) developing acoustic signatures for those categories and, (3) classification of the whole area in terms of the categories. Training sites were created from point data by creating a circular buffer zone around each point of 100 m diameter in MapInfo™ and exporting these into Idrisi™. This size was selected to be large enough to capture sufficient acoustic data to complete the next stage successfully, but not too large that data are wrongly attributed to the biotope.

Training sites were also created for different areas of bedform features identified from sidescan sonar images. These sites were digitised well within features to avoid boundary conditions. These training sites are converted into a ground-truth image by Idrisi™ with the same dimensions as the acoustic images.

Signatures were created using the module MAKESIG in Idrisi™ and these were applied to the acoustic images using the maximum likelihood classifier. Note that since each survey was treated independently only the final outputs can be compared. The performance of the classification process was assessed by comparing the ground-truth image (actual) with the corresponding classified acoustic image (predicted). It is usual to measure the success of classification by comparing the classified image with the ground-truth data and calculating either the percentage correctly predicted or through the use of the Kappa index (proportion correct over and above that proportion that might be expected by chance). However, these measures have not been included in the analyses. This is because the same data would be used for classification AND accuracy assessment, thus the apparent fit would give a very incorrect impression of predictive power. This is especially the case when only a few samples are used for classification – the fit is almost always good in that they match the map, but the predictive power (if matched against an outside dataset) would probably be very poor. More samples often results in a poorer fit because there is more scope for a mismatch, but the predictive power is better.

5.3.2 Sidescan sonar

Surveys were conducted at both TY070 and Shoreham aggregate extraction site during 2001-2004 using a Datasonics SIS 1500 digital chirps sidescan sonar with a Triton Isis logging system. Delphmap post-processing software was used to mosaic the imagery and classify texturally different areas of the seabed. The system was operated on a 400 m swathe range, and survey lines were spaced at 400 m intervals in order to ensonify approximately 100% of the survey area. Vessel positioning was provided by Differential Global Positioning System (DGPS) and towed sensor position calculated by vessel heading, cable layback and towfish depth, all of which were logged in a real time by the Isis system.

5.3.3 Multibeam bathymetry

In 2003, multibeam bathymetry surveys were carried out at TY070 and the Shoreham site (see Chapter 3 for methodology). Multibeam technology allows the simultaneous collection of acoustic backscatter information (similar to sidescan sonar data) and also very detailed bathymetric information. The output is then used to generate very detailed maps of the seabed showing the distribution of sediment in relation to seabed topography and allows the discrimination of comparatively small seabed features such as disposal mounds or dredge tracks.

5.4 Methods – biological surveys and ground-truthing

The design of benthic surveys was based on the methods developed by Brown *et al.* (2001). This involved dividing the sidescan sonar mosaic into acoustically distinct regions which, following ground-truthing using conventional techniques (grabs and trawls) and optical techniques, results in the physical and biological characterisation of the acoustic regions. At this stage, the output from sidescan sonar surveys (and other acoustic systems) can also be used to assess any anthropogenic effects on the seabed. Benthic surveys (for macrofauna and sediments) were designed to encompass the total area ensonified by the sidescan sonar surveys. Stations were randomly positioned within each of the acoustic regions, and the numbers of stations within each region were allocated in relation to the size of the area. The main sampling tool was a 0.1 m² Hamon grab fitted with a video camera and light (Boyd, 2002). This device was employed since it has been shown to be particularly effective on coarse substrata (Kenny and Rees, 1996; 1994; Seiderer and Newell, 1999). It was therefore considered suitable for sampling the heterogeneous sediments and deposited materials (e.g. colliery waste, fly ash and dredged materials) known to be present at TY070 as well as the coarse sediments previously noted by Brown *et al.* (2001, 2002) which are located at the Shoreham site. The grab was fitted with a video camera to record an image of the seabed adjacent to the collection bucket of the grab, thus providing additional visual information of the undisturbed surface of the sediment at each sampling station. A sub-sample was taken from each grab sample for sediment analysis (particle size analysis-PSA thereafter, for methodology employed see Chapter 3). The use of a standard 2-metre 'Jennings' beam trawl was used to generate epifauna samples from specific acoustic areas. Samples were processed according to the guidelines given in Boyd (2002) and following the methods described in Chapter 3. In 2003, a Sediment Profile Imagery (SPI) survey was also undertaken to obtain in situ profile images to assess the status of the centre of TY070 and surrounding areas. In addition, a drop camera frame was deployed at several stations across both surveyed areas to provide ground-truth data to help the interpretation of the sidescan sonar datasets.

5.4.1 Data analysis

Univariate analyses based on the total number of individuals (excluding colonial species) and the total

number of species were calculated from the Hamon grab samples to provide a quantitative assessment of the benthic fauna from within each acoustic region over time. Additionally, a number of multivariate techniques were used employing the software PRIMER version 6 for Windows (Plymouth Routines in Multivariate Ecological Research. Non-parametric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure was applied to species abundance data following square root transformation of the data (excluding colonial taxa) to assess changes in species composition (Clarke and Warwick, 1994). Analysis of similarities (ANOSIM, Clarke, 1993) was performed to determine whether there were any significant differences in macrobenthic assemblage composition over time and between different acoustically distinct regions. The nature of groupings identified in the MDS ordinations was explored further by applying the similarity percentages programme (SIMPER) to determine the contribution of individual species towards the dissimilarity between years and stations. PSA data was analysed using Principal Component Analysis (PCA) applied to the percentage of mean particle size, median particle size, sorting coefficient, graphic skewness and kurtosis of individual sediment samples. The relationships between multivariate community structure and environmental variables were assessed using the BIO-ENV routine. In this procedure, rank correlations (ρ_w) between a similarity matrix derived from the biotic data and matrices derived from various sub-sets of environmental data are calculated, thereby defining suites of environmental variables which best explain the biotic structure. Finally, the ground-truth data (biotic and sediment data) were analysed in terms of lag distances between samples in order to assess whether there was any overall spatial association in the data.

5.4.2 Characterisation of grab samples

The PSA data were used to generate sediment categories according to the modified Folk classification system (Folk, 1974) as adopted by the BGS for seabed sediment maps. Similarly, biotic categories were established and these were defined by the main characteristics of the dominant taxa based on their presence or absence. This categorisation was largely based on the characteristics of the infaunal data but data from other sources were also used, as appropriate (see also Section 5.5.6 and 5.6.6). Once erected these categories were used to classify the AGDS data.

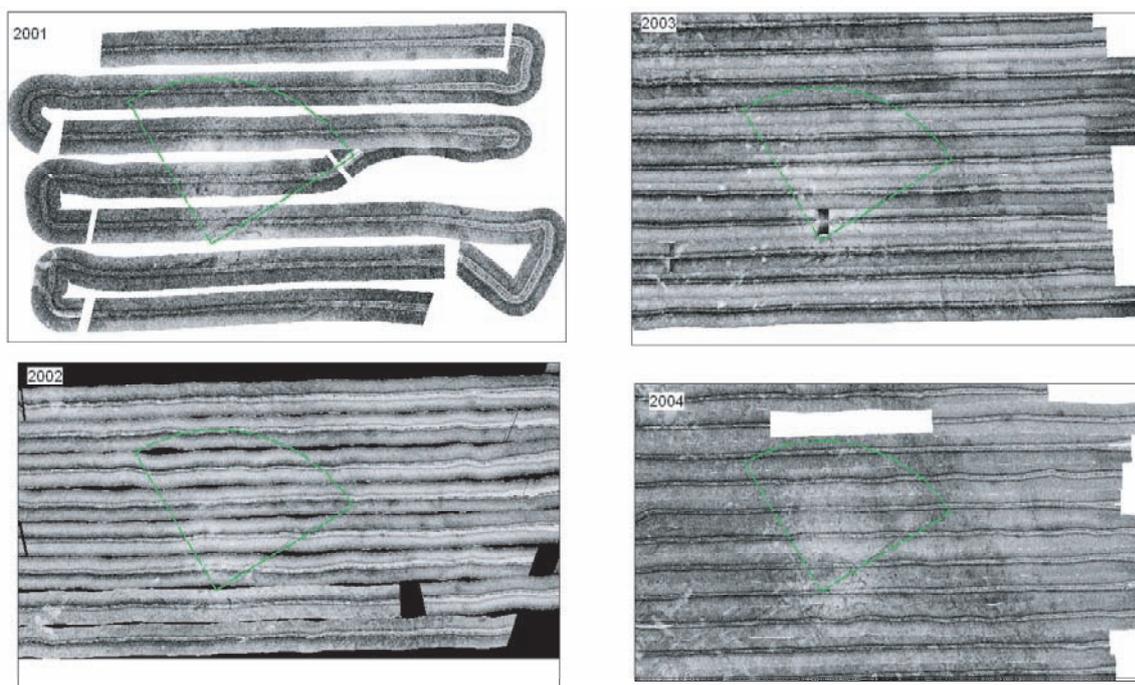


Figure 5.2. Temporal (2001-2004) images of sidescan sonar mosaic at Dredged Material Disposal Site (TY070).

5.5 Results (TY070)

5.5.1 Sidescan sonar

Sidescan sonar surveys were carried out at TY070 in 2001-2004. The mosaiced data from each of these surveys is shown in Figure 5.2. The sidescan sonar survey conducted in 2001 was spatially less extensive and also provided less percentage swathe coverage, than the surveys carried out in later years. Interpretation of the data from all surveys shows that there are some persistent general patterns of sediment distribution over the survey area. Offshore, surficial sediments are soft in nature and are dominated by fairly featureless, homogenous sandy muds with small amounts of shell material at the surface (Figure 5.3(a)). Photographic evidence shows that burrowing and tube forming fauna inhabit these sediments. Occasional harder linear features, possibly caused by the impacts of demersal fishing activity, are apparent over this substrate. Moving further inshore, the sediments become coarser and more heterogeneous with a band of shellier muddy sands and sandy muds, intermixed with coal and clay, dominating the central part of the survey area (Figure 5.3(b)). This change in sediment composition appears to follow the bathymetric contours.

Equally spaced, rectangular, low backscatter features were recognised from the sidescan sonar records. These were even more marked on the output from multibeam surveys of the area and are depicted as depressions. The location of these features coincides with coal mine galleries on the mining plans of the Coal Authority (Denton, 2005). It is therefore considered that the depressions are the result

of subsidence due to coal mining 300 m below the seabed surface. It also appears that the low backscatter is a result of infill of the depressions with fine material.

At the disposal site itself sediments were extremely mixed. The centre is characterised by a lower acoustic backscatter and sediments consist mainly of sandy muds and muddy sands. The southern and central part of the site seems to be generally muddy in nature, with some coarse sand present. The sidescan sonar imagery portrays this as a patch of predominantly finer sediment with areas of coarser, mixed material at the periphery, which seems to represent the acoustic footprint of the deposited sediments. The remainder of the site is mainly shelly, muddy sand with varying quantities of colliery waste present (Figure 5.3(c)). The sidescan mosaics suggest that disposal operations have modified the sediments to the south, south west and west of the disposal site. It also appears that the footprint of deposited sediments extends beyond the boundary of the site to the south. This may represent southerly transport of dredged material deposited within the licensed area or it may be a result of the disposal of dredged material outside the confines of the site. The presence of what appear to be discrete patches of soft material to the south and west of the licensed area also suggest that disposal may have occurred outside of the licensed area (Figure 5.3(d)).

Underwater photography was used to ground-truth an area of mixed sediment extending away from the southwest boundary of the licensed area (Figure 5.3(d)). It was apparent that the coarser component of this substrate consisted of gravel and cobble sized coal particles within

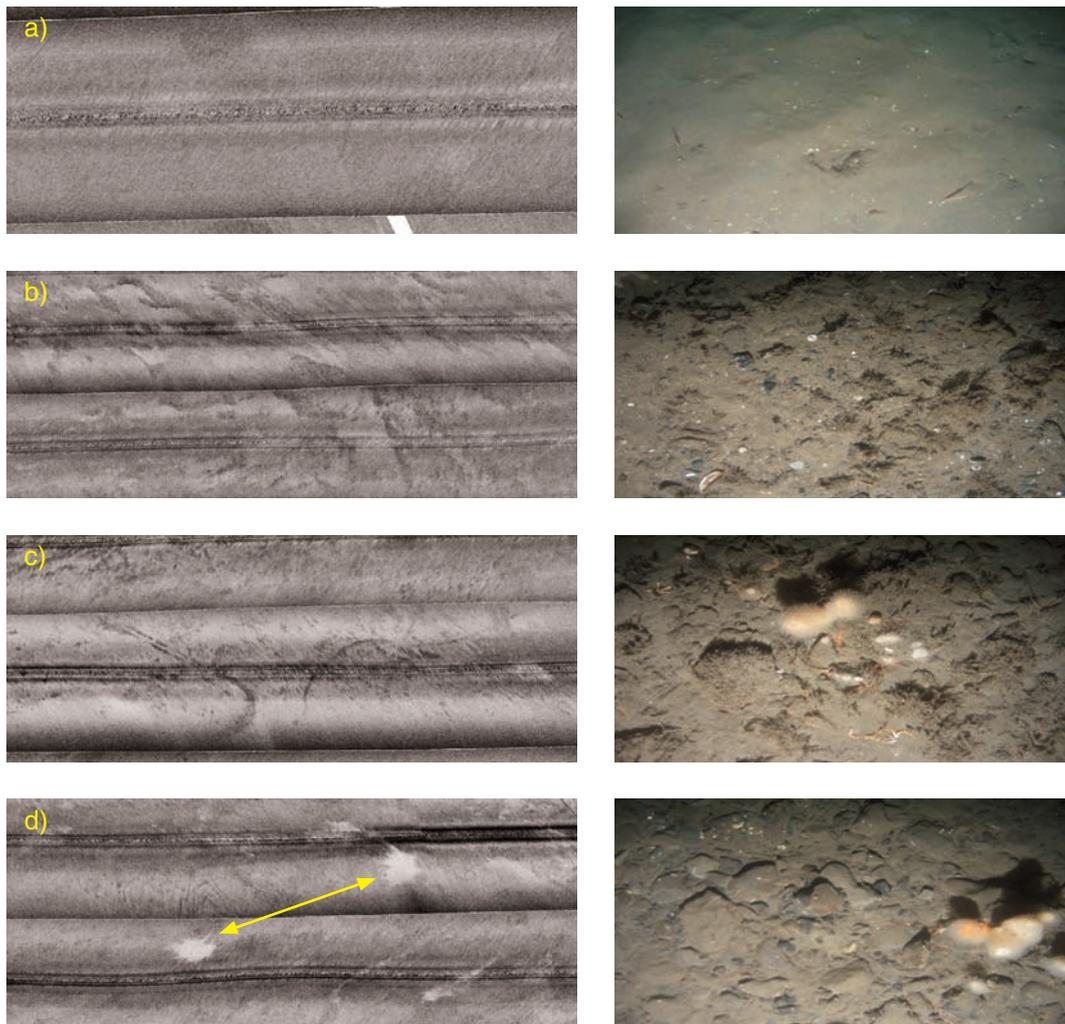


Figure 5.3. Sidescan sonar and video images showing seabed types, a) Homogeneous sandy mud in the offshore part of the survey area (Area shown is approx 200 m x 400 m); b) Heterogeneous sediments composed of shelly muddy sand, sandy mud, coal and clay (area shown is approx 800 m x 1600 m); c) Shelly muddy sand with colliery waste, present inside the disposal site. Also evident are linear trawling marks and possible anchor drag scars (area shown is approx 300 m x 600 m) and d) Discrete patches of soft material (Arrowed) to the west of the disposal site (area shown is approx 600 m x 1200 m).

a muddy sand matrix. Patches of finer sediment (muddy sand/sandy mud) also appear within this area. In contrast, sediments at the extreme western part of the survey area are a mixture of sand, mud, coal and rocks (Figure 5.4). It is not certain if either these rocks, or those found to the south of the disposal site, are a result of disposal operations or natural coal deposits which are exposed at the seabed.

Temporal comparison of the sidescan sonar records shows that there was little change in the broad distribution of sediments and features within the survey area between 2001 and 2003. A multibeam survey conducted over the site in 2003 does not show a significant shallowing of the water depth as a result of accumulations of material. This would suggest that the site is dynamic in nature and that a proportion of the dredged material placed at the site is transported away via natural processes. A number of

harder linear features, identified within and close to the licensed site in 2001, remained apparent on the sidescan sonar record in 2002 and 2003 providing further evidence that widespread long-term accumulation of fine material is not occurring. Examination of the sidescan sonar record from 2003 shows the presence of discrete patches (~50 m diameter) of fine material to the west of the site. These features were not apparent in 2001 or 2002 and consequently may be the result of ongoing disposal operations occurring between 2002 and 2003.

Figure 5.5 shows a sidescan sonar mosaic overlain with the output from a QTC survey conducted during 2002, which shows the differences in hardness and roughness of the sediments present in the area. It also shows the location of the five acoustically distinct areas, A-E, which were delineated based on expert interpretation.

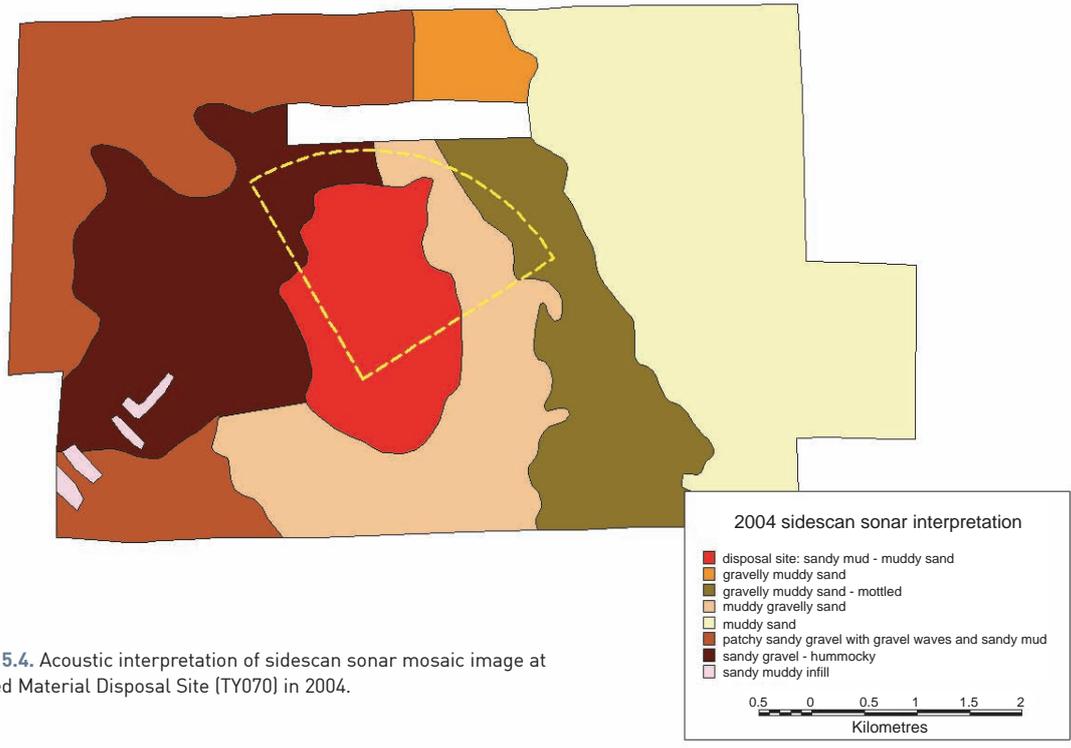


Figure 5.4. Acoustic interpretation of sidescan sonar mosaic image at Dredged Material Disposal Site (TY070) in 2004.

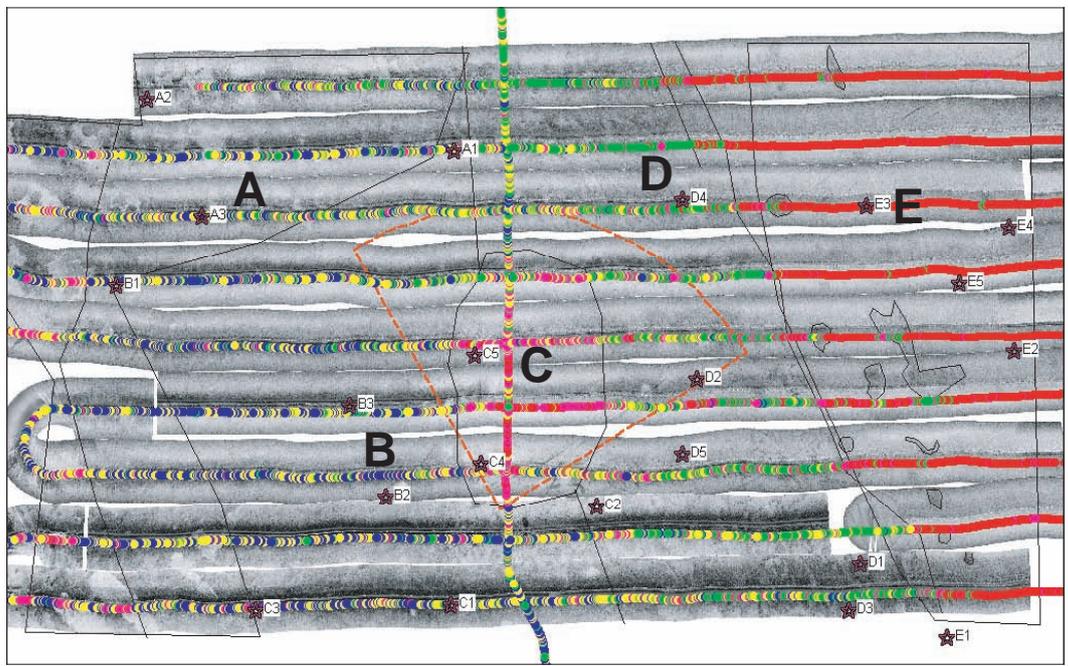


Figure 5.5. Sidescan sonar image overlaid with QTC data showing the delineation of acoustically distinct areas at Dredged Material Disposal Site (TY070).

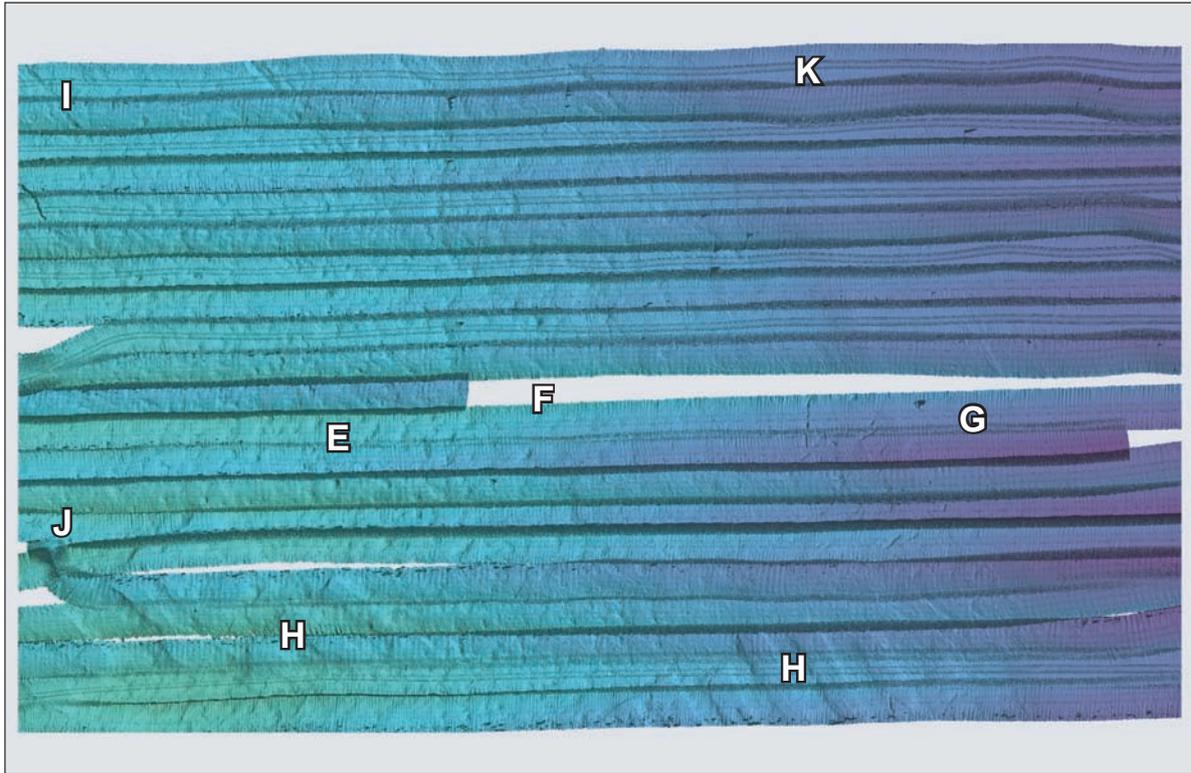


Figure 5.6. Multibeam image for Tyne dredged material disposal site.

5.5.2 Multibeam bathymetry

The output from a multibeam survey conducted at TY070 is shown in Figure 5.6. Water depths increase steadily from west to east, resulting in a gently sloping seabed. The western half of the survey area has a hummocky fine-scale topography (E) which becomes less pronounced towards the central part of the region. There is no evidence of a 'mound' of dredged material within the disposal site although the smoother seabed could be the result of infilling of the hummocky topography. Some anchor scars are evident in the south west of the survey area (G) and along the southern border a geometric series of linear trenches is visible (H). These align on a NW to SE bearing and similarly fault-lines (I) can be seen in the north west running in a similar orientation. These features could be the result of past mining activity as they bear striking resemblance to the charted extent of coal mine galleries.

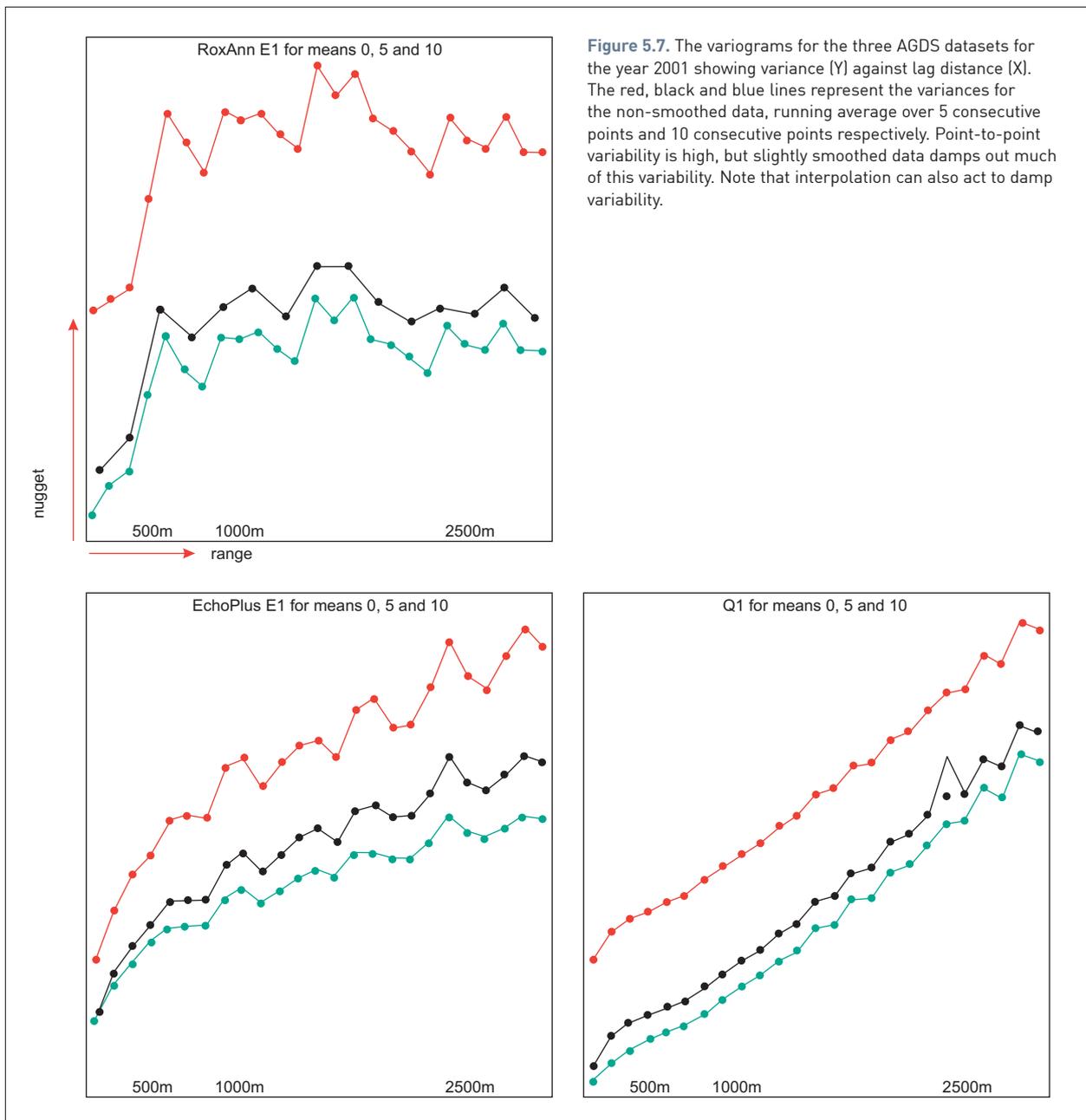
5.5.3 AGDS classification

Data editing and preliminary analysis

Editing of the AGDS data highlighted a number of points and sections of tracks in most datasets that were dubious, usually because of an abrupt but short-lived change in values or depths. However, the rejected data was never more than 5% of the total data covering TY070 and all datasets were considered of sufficient quality to proceed with the next stage in analysis. The track spacing (Table 5.1) was not consistent between datasets within the same

site. However, the variograms (Figure 5.7) would suggest that, although the inherent fine scale variability (nugget effect) is high, there is a sill at a range of about 500 m for the RoxAnn™ and EchoPlus™ datasets whilst the variance in the QTC-View data rises linearly: the closer points are to each other, the more likely they are to be similar. This is basic to successful interpolation. The variability between neighbouring points is also high, as represented by the size of the nugget. However, the proportion of the variance represented by the nugget can be substantially reduced by taking a running mean of as few as 5 points. This implies that the mean of consecutive points is a more stable representation of the area than individual points. (Note that 5 points would cover about 100 m of track, depending upon vessel speed and save rate of the AGDS.) In summary, it was considered that interpolation was appropriate and that smoothing would produce a more stable image of the seabed, although at a risk of losing fine scale structure.

The interpolation algorithm used was inverse distance to a power. The parameters used were chosen to smooth the data and reduce variability. Thus, the power setting was 1.5 and a wide search radius of 250 m selected to span adjacent tracks. The maximum number of points to be considered was also set high (120) and a quadrant search selected to enforce a spread of data across tracks. A high smoothing coefficient was also selected so that estimated grid values close to real data were allowed to depart from real values to reflect the local mean. The result was a smooth map reflecting local means centred within



the 250 m search radius, but with a moderate weighting towards the nearest real data. The effects of interpolation parameters can be seen in the Figure 5.8.

Unsupervised classification

The gridded data were imported into Idrisi™, one image for each variable for each dataset. The grids were stretched so values lay between 0-255. The module ISOCLUST and CLUST were used to explore the data to reveal the 'natural' acoustic classes within the data. It is possible to raise or lower the number of classes and thresholds for clusters to be considered significant. However, the selection of appropriate cut-offs is subjective and the classes become somewhat arbitrary. The numbers of clusters were increased until the area encompassing the disposal site was 'detected' (Figure 5.8). The cluster numbers were 8 for EchoPlus™ and RoxAnn™ and 7

for QTC™ (Figure 5.9). The colours have been chosen to match areas by location, although this gives a false impression of concurrence between datasets and not too much should be read into them. However, there are clear northwest/south east trends in the acoustic data, which are consistent between datasets. Beyond this, there are few clearly defined acoustic ground types. Most datasets can be forced to 'detect' the approximate location of the disposal site, although the number of classes invoked to do this somewhat undermines the validity of these results. The last set of figures (Figure 5.10) show unsupervised classification of the QTC data for years 2001-2003 and there is greater consistency in the 'detection' of some areas that appear to be linked to the disposal activity. Supervised classification of the AGDS data is discussed following consideration of the results of sediment and biological analysis.

Figure 5.8. The effects of smoothing through interpolation can be seen by comparing the two maps. Interpolation used in the top map used a small maximum number of points, heavily weighted to the nearest real point (power 2). The effect is the inclusion of a large number of 'bulls eyes' around track points. In the second, the number of points to be included in the calculation of grid values was increased and the weighting towards the nearest real data point reduced (power 1.5). The general distribution of values is preserved, but the 'bulls eyes' reduced.

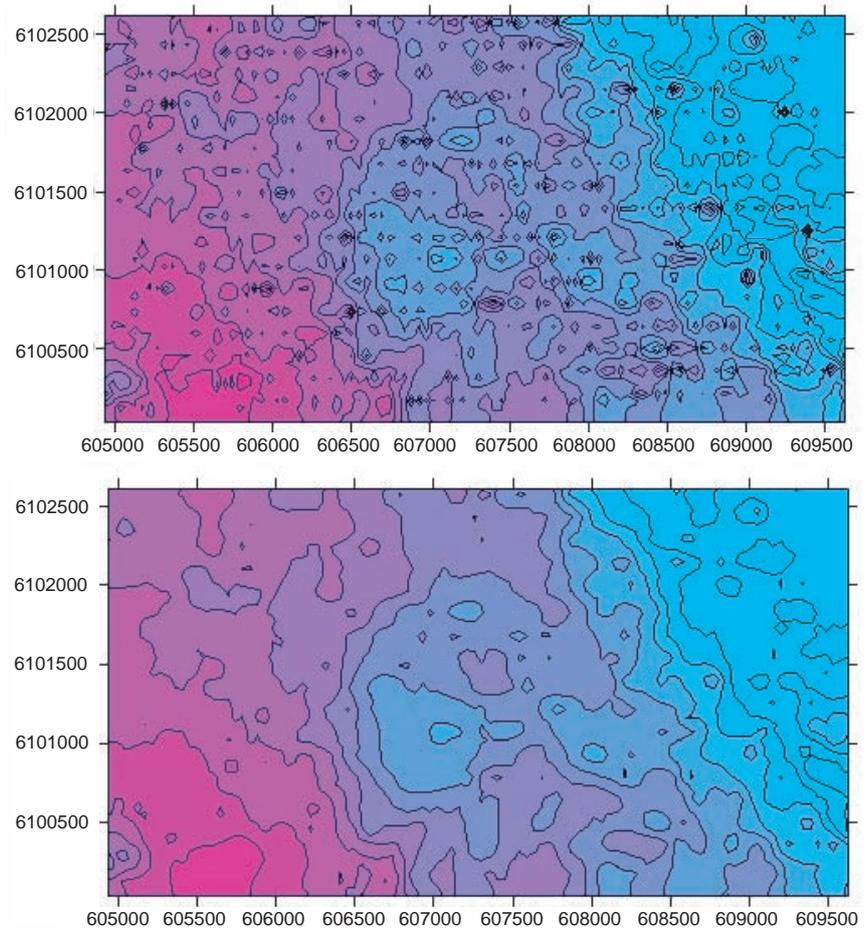


Figure 5.9. Unsupervised classification of QTC datasets from the three years 2001–2003. Seven clusters were selected from the data in each year. Note that they are represented to the same scale and that the areas covered differed in each year. The approximate location of the dredged material disposal site and the northwest/southeast orientation of the sediment types have been indicated in each year.

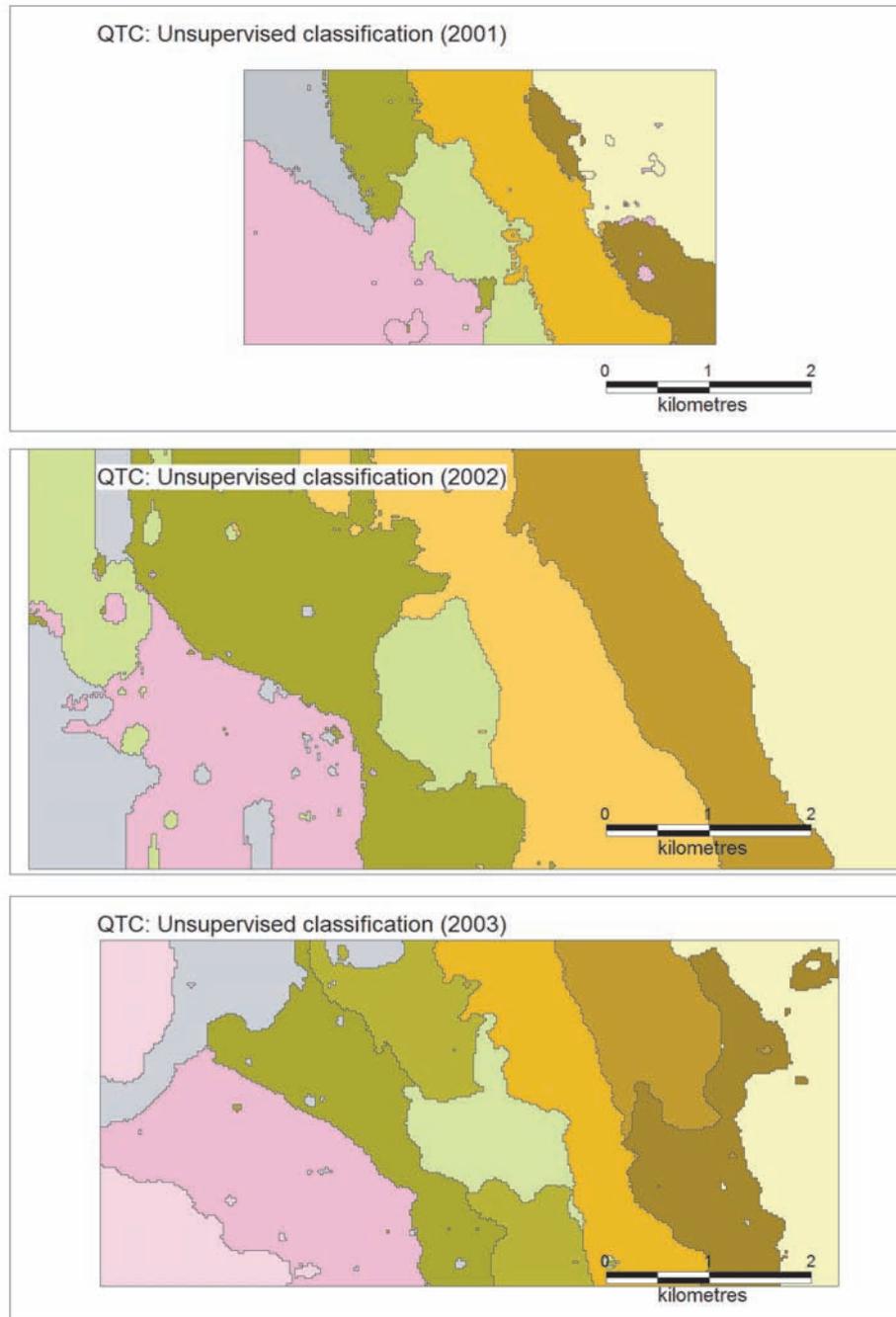
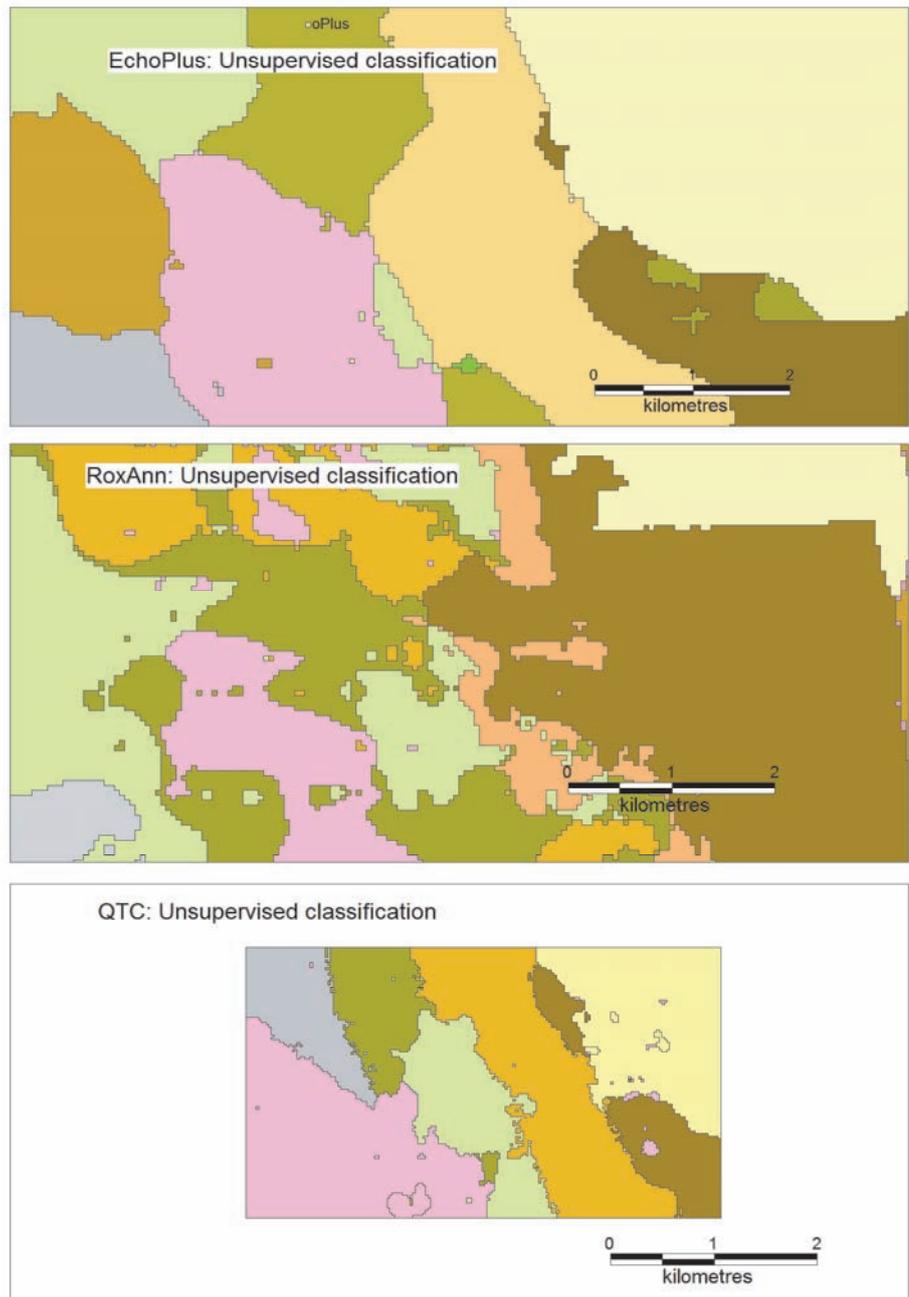
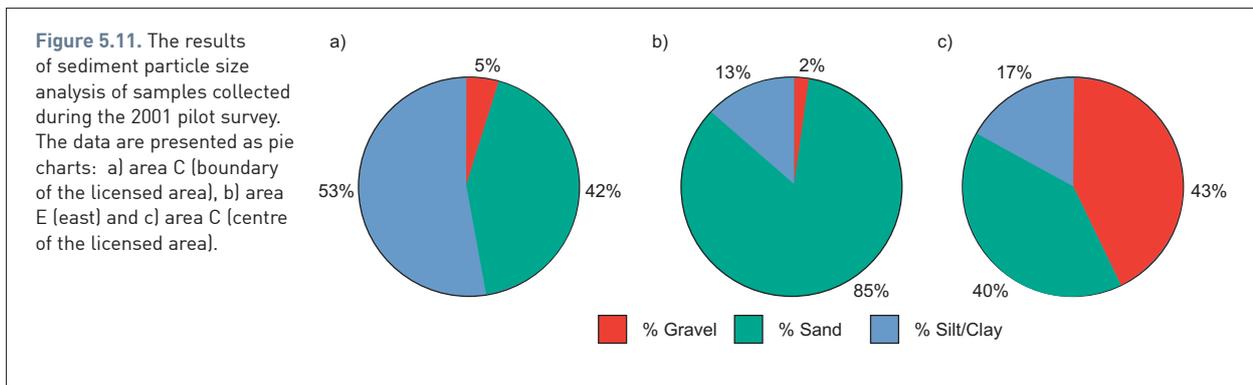


Figure 5.10. Unsupervised classification of datasets from three AGDSs, EchoPlus, RoxAnn and QTC for the year 2001. Although the northwest/southeast orientation of the sediments is broadly consistent between AGDSs, the finer patterns of acoustic properties are quite different. This is despite the fact that EchoPlus and RoxAnn were run concurrently using the same echosounder.





5.5.4 Sediments characteristics

During the pilot survey (2001) the sediment composition was observed to be an admixture of sand, silt/clay and gravel at all sampled stations (Figure 5.11). In the centre of the dredged material disposal site (area C) the sediments were mainly gravel (43%) and sand (40%). At the boundaries of the licensed area the sediment composition was silt and clay (53%) and sand (42%), whereas at area E, located east of the licensed area, sediments were predominantly composed of sand (85%) with a lesser amount of silt/clay (13%). Figure 5.12 shows the distribution of sediments over 2001-2004. The centre of the licensed area is characterised by the presence of sandy muds and muddy sands.

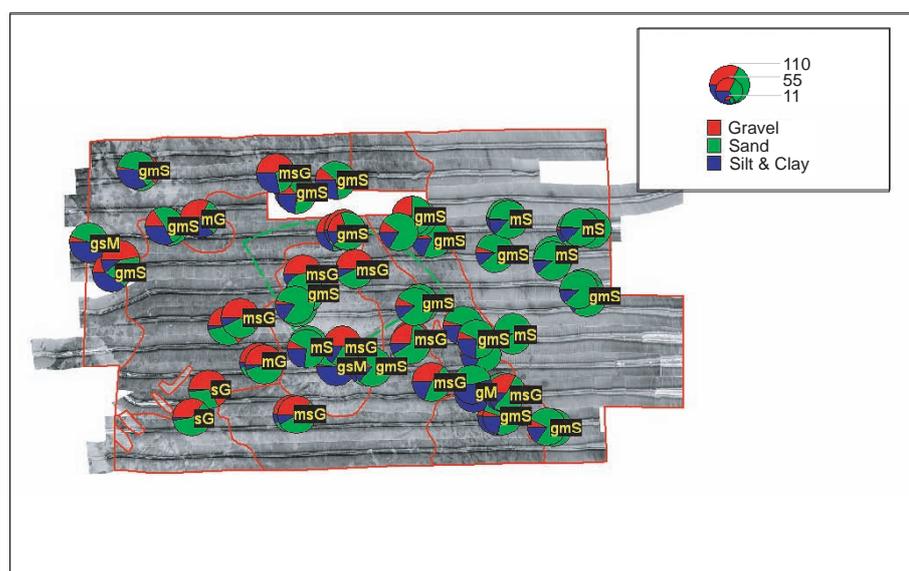
A Principal Components Analysis (PCA) of the particle size data was undertaken. The median particle size (mm), % sand and % gravel were highly correlated with PC axis 1, which accounted for 66.4% of the variation in the data. PC axis 2, in contrast, was highly correlated with the % sand and % silt/clay (both with negative values), accounting for a further 30.6% of the variation (Table 5.2). Plotting the sediment samples in PCA space (Figure 5.13-A) reveals two main groups (with 4% similarity) and also four subgroups (with 2% similarity). The first group, located in the bottom right of the ordination, is formed

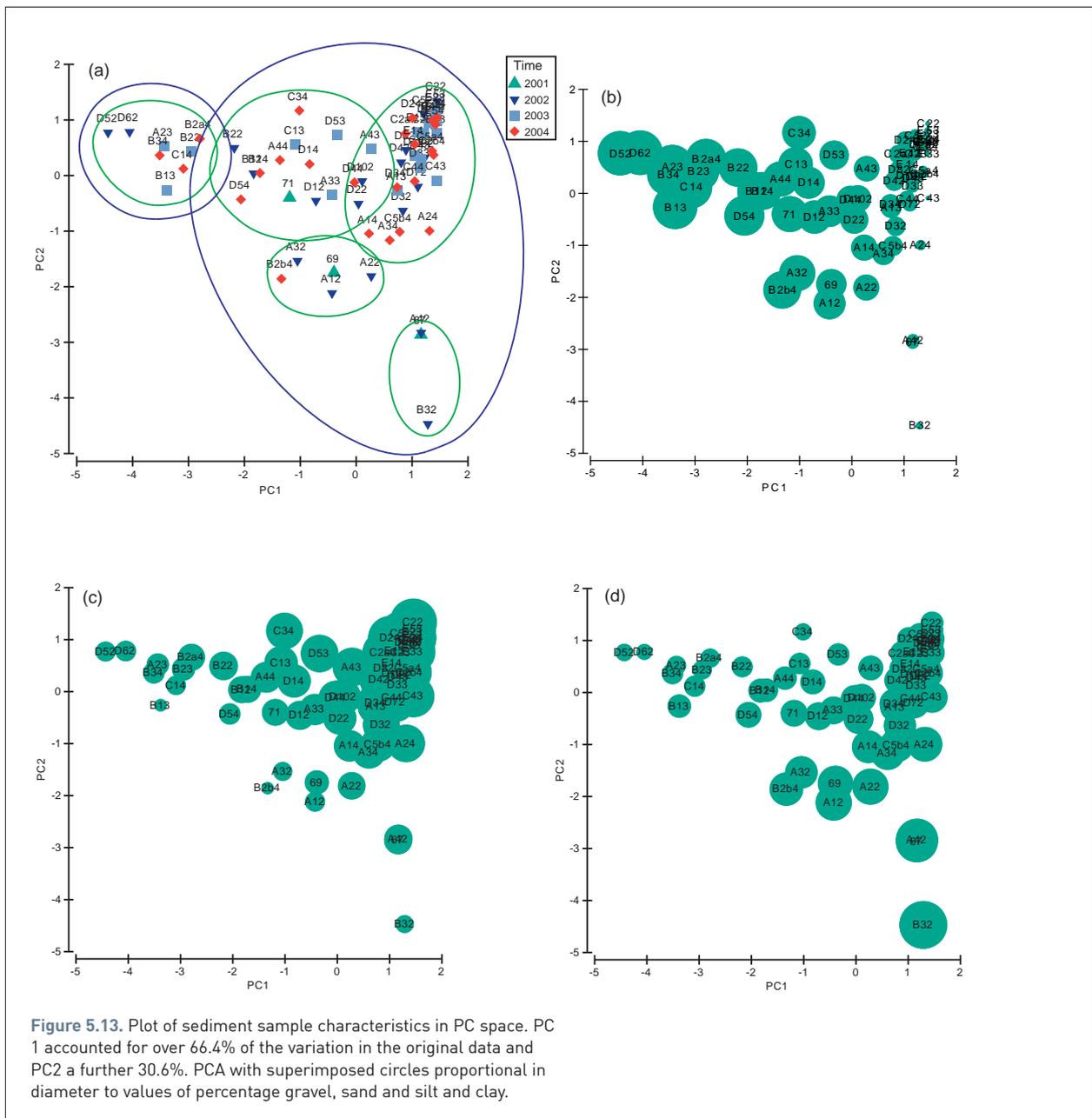
Table 5.2. Principal components analysis of sediment characteristics (mean particle size, percentage of gravel, percentage sand and percentage silt & clay) for ground-truth samples (2001-2004) at TY070.

| Variable | Weighting | |
|-------------------------|-----------|--------|
| | PC1 | PC2 |
| Mean particle size (mm) | -0.579 | 0.162 |
| % Gravel | -0.606 | -0.048 |
| % Sand | 0.489 | 0.54 |
| % Silt & Clay | 0.242 | -0.824 |
| Eigenvalues | 2.66 | 1.22 |
| Percentage of variance | 66.4 | 30.6 |
| Cumulative percentage | 66.4 | 97 |

by two stations which are characterised as having a high silt/clay content. The second group, (top right of the plot), includes a number of samples collected from 2002 to 2004 from several areas (i.e. A, D, C and E). This group is characterised by samples having a high proportion of sand

Figure 5.12. Trends of particle size of sediments at Dredged Material Disposal Site (TY070) for 2001-2004.





and a moderate amount of silt/clay. There is also evidence of a gradient of increasing gravel content moving from the third cluster (top middle) to the fourth cluster (see Figure 5.13 B-D), and this group consists of samples taken from within areas B and D (both outside of the disposal site). Finally, the fifth cluster is a group of samples from areas A and B, and these are composed of a mixture of gravel and silt/clay.

5.5.5 Biological characteristics

A total of 172 taxa were identified over the four years of the study. Figure 5.14 shows all the ground-truth samples collected for the TY070 area. In 2001, the exploratory survey of the area was designed to assess differences between the centre of the licensed disposal site and adjacent areas in order to provide an initial indication of the status of macrobenthic assemblages. Samples were collected from within 4 acoustic areas (i.e. areas B, C, D

and E). Over these 4 distinct acoustic areas densities of macrofaunal organisms ranged from 116 to 374, whereas the total number of species varied from 30 to 50 taxa. Lower values of both univariate metrics were observed at area C (located in the centre of the disposal site). This reflects the impact of recent disposal activity in this area. In contrast, highest densities and numbers of species were recorded from within area E.

Figure 5.15 shows the values of total abundance of individuals and total number of species for the different acoustic areas sampled over the 4 years of the study. Overall between 2002-2004, the total abundance of organisms was similar between areas, with the exception of area B, which was always found to present the lowest abundance and species richness over these years. Univariate analysis revealed that areas A, D and E had the highest number of individuals and higher values of species richness over time in comparison with other areas.

Figure 5.14. Sampling positions used to ground-truth the Dredged Material Disposal Site (TY070) over 2001-2004.

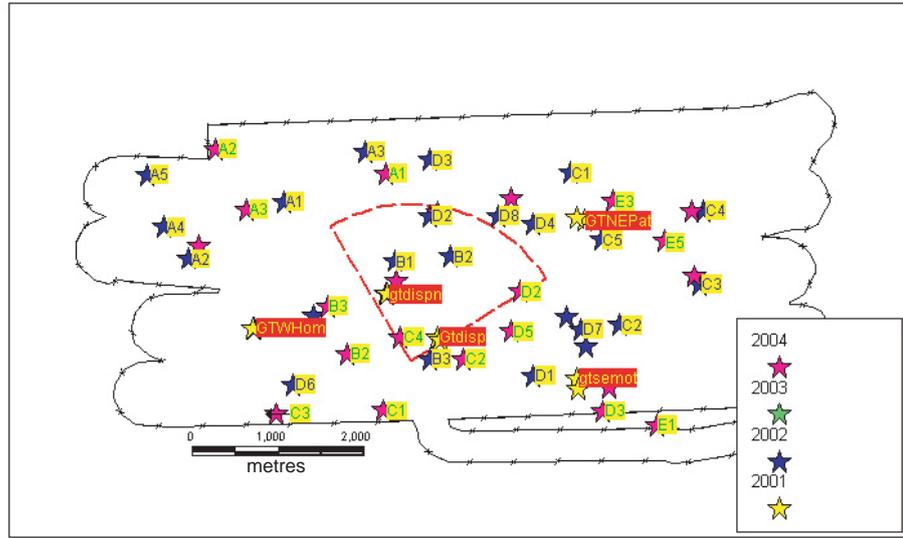
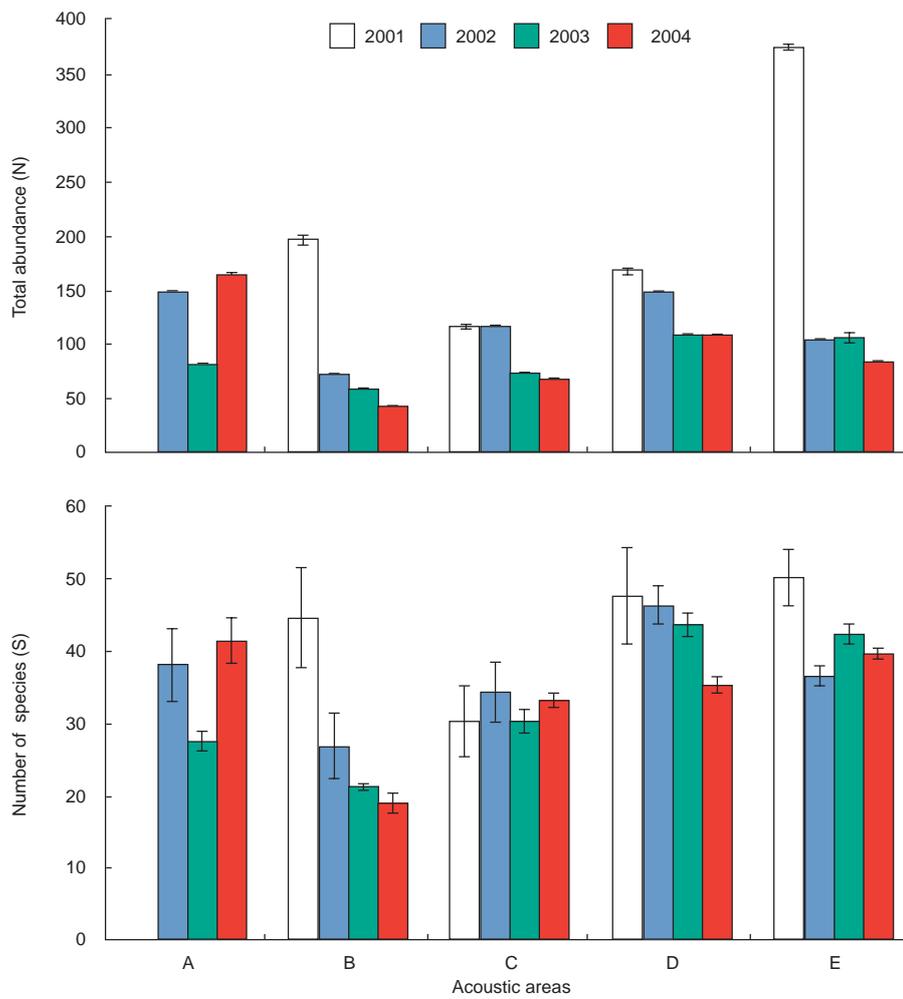


Figure 5.15. Summary of univariate measures (Mean number of individuals and number of species per 0.1 m²) from within each acoustic area over 4 years of study at Dredged Material Disposal Site (TY070).



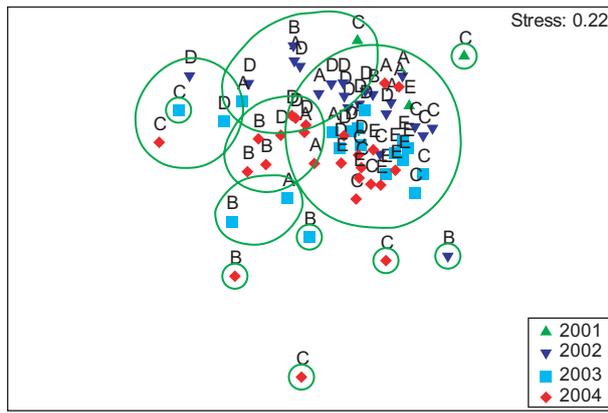


Figure 5.16. Multidimensional scaling plot based on Bray-Curtis similarity abundance for infauna samples over 2001-2004 at Dredged Material Disposal Site (TY070).

Results of multidimensional scaling using Bray-Curtis similarity coefficients indicated the presence of 5 clusters for macrofaunal samples taken during 2001-2004 (Figure 5.16). The majority of samples from acoustic regions A, D, E, and C collected over 2002-2004 have formed one cluster to the right of the plot. There was, however, a degree of overlap between clusters for areas A, B and D for 2004 (left side cluster) and 2002 (top cluster). A number of samples collected within and in the vicinity of the disposal site, from areas B and C, are slightly set apart from the other samples on the MDS ordination suggesting that the effects of disposal activity are not confined to the licensed site.

The second MDS ordination (Figure 5.17) is based on epifaunal data for TY070 from 2003 and 2004. Samples collected during 2003 appear to be similar for areas outside the disposal site. Interestingly, sample C4, which corresponds to the disposal site itself appears to be distinct in comparison to the rest of samples in terms of its community composition. Additionally samples collected in the 2004 survey, which concentrated on the disposal site were very similar to each other and differed from samples collected in the surrounding areas.

The Hamon grab data was also analysed in relation to physical variables using the BIO-ENV routine. Results showed that the community composition was best explained ($r=0.479$) by the mean particle size (mm), % of gravel and % of silt/clay. Figure 5.18 provides a visual expression of the relationships between the macrofaunal data and the sediment particle size characteristics. Samples obtained from the areas surrounding the disposal site are clustered on account of a greater proportion of % gravel and less silt/clay. There also appears to be a higher proportion of silt/clay within the disposal site and also at area A (located further inshore) compared to other sampled sediments elsewhere.

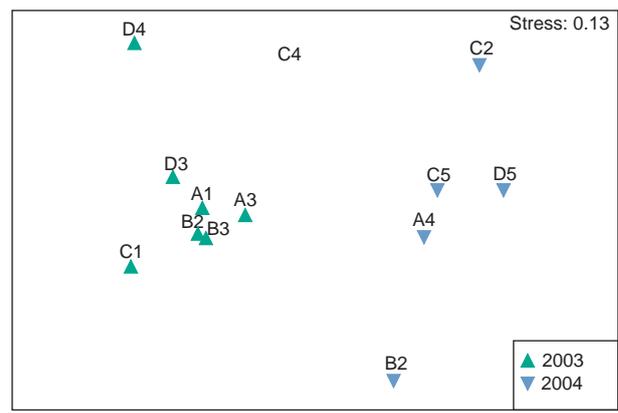


Figure 5.17. Multidimensional scaling plot based on Bray-Curtis similarity abundance for epifauna samples over 2003-2004 at Dredged Material Disposal Site (TY070).

The community groupings were explored further using the similarity percentages (SIMPER) analysis. Results revealed the taxa that were responsible for characterizing and/or differentiating the community composition over time (Annex I and II) and from the acoustically distinct regions (Annex III and IV). The community composition over time revealed that the average similarity between samples collected over time was low, particularly in 2001 and 2004 (Annex 1).

SIMPER results also revealed which taxa contributed the most towards the dissimilarity over time during the full period of this study. The highest values for overall dissimilarity can be seen in the comparison of year 2001 v/s 2002 (72.11%) and 2001 v/s 2004 (73.72%) (Annex II). Differences observed over time are attributed to the changes in abundance of the taxa present/absent over time. For example, the polychaete *Lagis koreni* is present in high densities during the first year of study and in lower numbers thereafter. SIMPER was also employed to assess the similarities and dissimilarities between the acoustically distinct regions. The highest similarity values were found at areas D and E. Overall, the community groupings were fairly consistent in their distribution over time. The main numerically dominant species i.e. *Lumbrineris gracilis*, *Thyasira flexuosa*, *Peresiella clymenoides*, *Amphiura filiformis*, *Nuculoma tenuis* and *Mysella bidentata* were consistently found at all of the 5 acoustically distinct regions (Annex III). The dissimilarity between the acoustically distinct regions were also analysed (Annex IV). The highest overall dissimilarity values were encountered at areas C v/s B (73.62%) and B v/s E (72.80%).

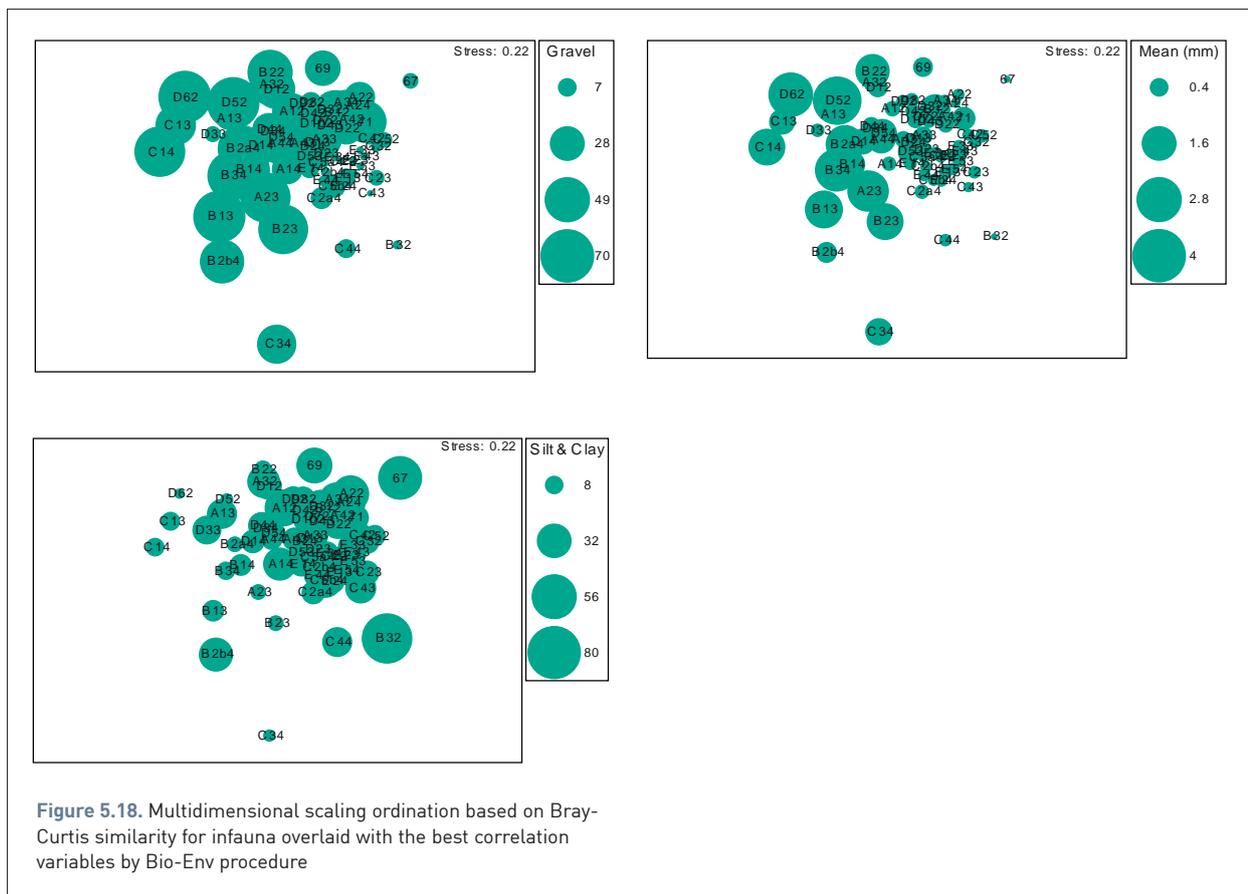


Figure 5.18. Multidimensional scaling ordination based on Bray-Curtis similarity for infauna overlaid with the best correlation variables by Bio-Env procedure

5.5.6. Categorisation of grab samples

The biota collected from the Hamon grab samples were used to create a classification system. This was annotated using group codes. The allocation of the categories was based on the 4 main clusters observed from the MDS ordination. The group codes were assigned based on the abundance of numerically dominant species whilst also considering the presence (or absence) of other species. Visual information provided by video and SPL was also used to corroborate the selection of the classes. The resulting codes were:

- A** = High abundance of *Lumbrineris gracilis* and low abundance of all other species within the remainder of the sample.
- B** = Low abundance of *Lumbrineris gracilis* and low abundance all other species within the remainder of the sample.
- D** = Moderate abundance of *Lumbrineris gracilis* and high abundance of *Thyasira flexuosa*, low *Nucula tenuis* and rich abundance of all other species within the remainder of the sample.
- E** = *Mysella bidentata* moderately rich.

Figure 5.19 shows changes in similarity over lag distances (0-500, 500-1000 and 1000+ metres) for different years. The changes in similarity were small (55% similarity at smallest lag distance falling to 45% for large lag distances). This shows weak spatial associations, i.e. a high level

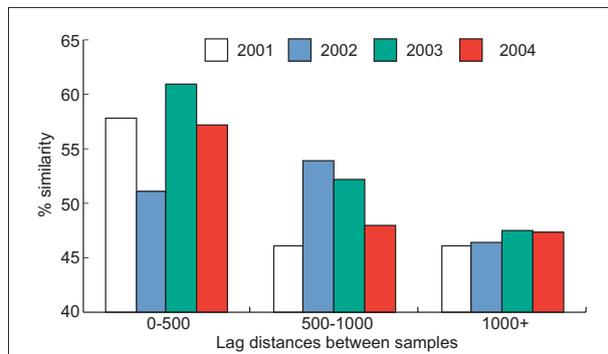


Figure 5.19. Changes in percentage of similarity compared with lag distances (0-500, 500-1000, 1000+) between samples collected at dredged material disposal site (TY070) over 2001-2004.

of 'noise' and a heterogeneous habitat. The spatial data was also analysed using multivariate similarity analysis, using Euclidean distance to transform the abundance data. The classes created above were used as a factor to structure the assemblages. The analysis showed the presence of very distinct clusters (Figure 5.20) based on the categories created (A, B, D, E) for the faunal data. The faunal categories were also plotted over the geographic

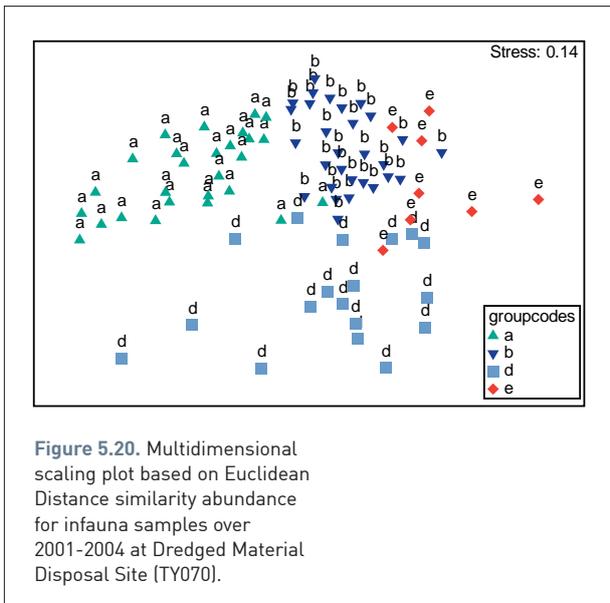


Figure 5.20. Multidimensional scaling plot based on Euclidean Distance similarity abundance for infauna samples over 2001-2004 at Dredged Material Disposal Site (TY070).

space to assess their distribution over time (Figure 5.21). The results indicate that there were fewer categories in 2001 than any other year and this was the result of less extensive sampling in this year. Faunal classes clustered (Figure 5.21) in 2002 and 2003, whereas in 2004 the group classes identified previously, changed completely. This apparent change in the distribution of biological classes may be related to the spatial heterogeneity of sediments. The change in faunal classes over time was also assessed

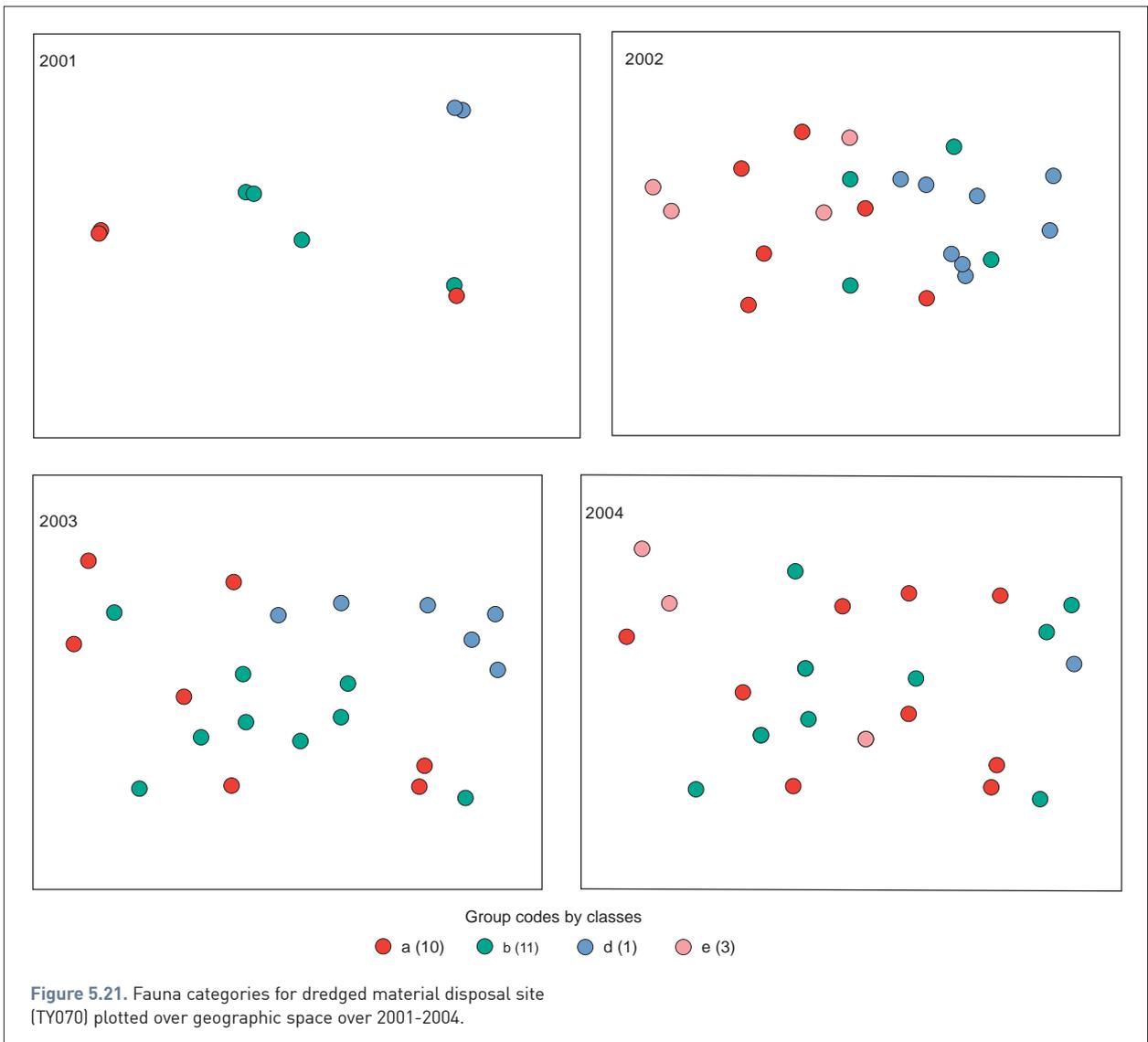
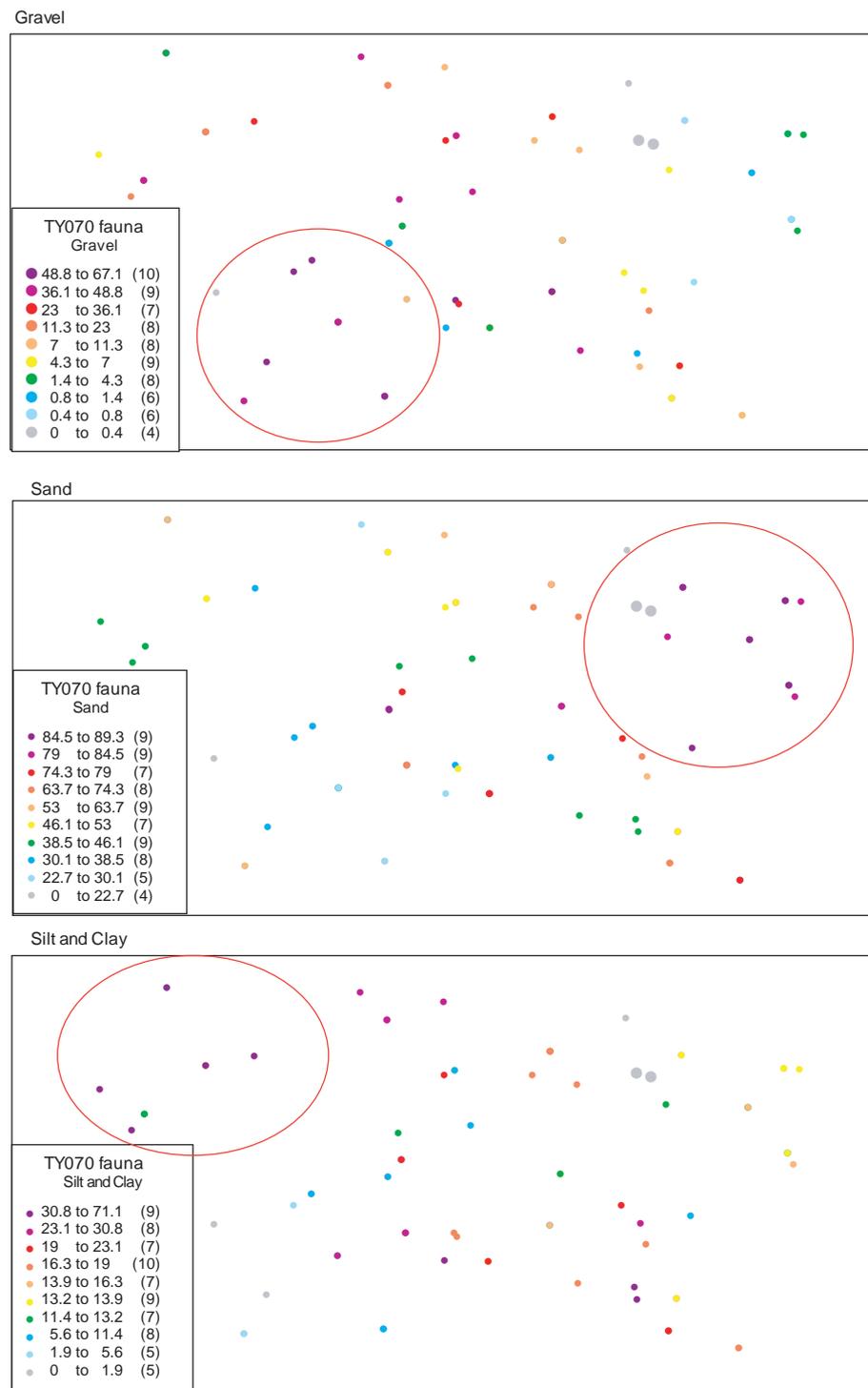


Figure 5.21. Fauna categories for dredged material disposal site (TY070) plotted over geographic space over 2001-2004.

Figure 5.22. Sediment classes over geographic space for dredged material disposal site (TY070) over 2001-2004.

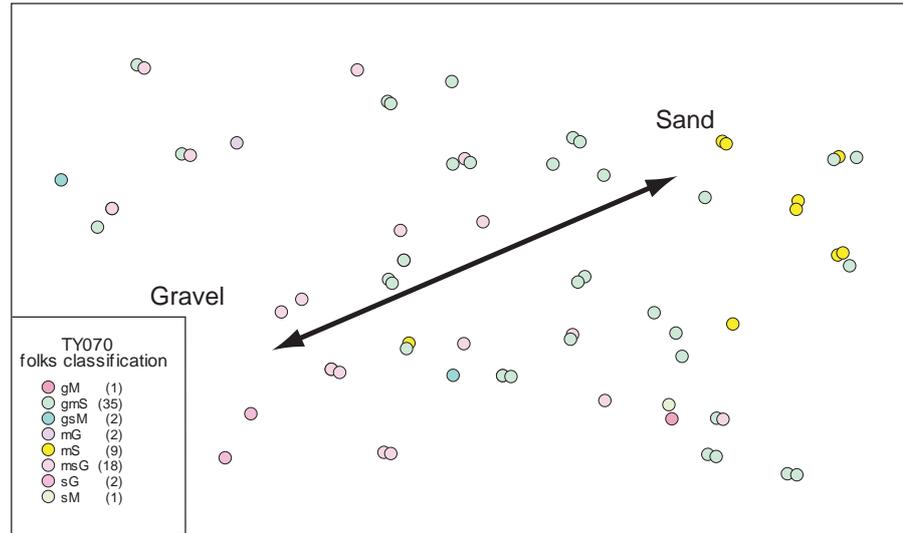


in order to establish the temporal variability of biological assemblages within the areas surveyed. An analysis of this data suggested that 2002-2004 data could be compared with a good degree of confidence.

The Folk classification system was employed to categorise sediment classes. The three main categories (i.e. gravel, sand and silt/clay) were used initially to characterise the sediment data for 2001-2004. Results are shown in Figure 5.22, and this clearly identifies the presence of the three classes. Figure 5.22A-C shows that

predominantly gravelly sediments are located in the southwestern part of the survey area whereas sandy sediments are found to the east, with the majority of fine material found to the northwest. Figure 5.23 shows the spatial distribution of sediments across the survey area over the four years of study. This confirms that generally sandy sediments are located east of the disposal site and these are replaced by the presence of a greater proportion of gravel to the west.

Figure 5.23. Temporal changes in sediment trends over geographic space for dredged material disposal site (TY070) over 2001-2004 for the sediment classes.



5.5.7 Supervised classification of AGDS data

Supervised classification of the AGDS data was carried out using different categories derived from an analysis of the faunal, sediment and sidescan sonar datasets. The results of this classification are briefly described below:

1. Sediment: The classified distribution of sediments show very little apparent consistency between 2001-2003 except that sand was always predicted in the north east sector. The limited range of sediments for 2001 simply reflects the smaller number of samples collected in this year. The apparent increase in the area of sand and muddy sand in 2003 at the expense of gravelly sand and gravelly muddy sand in 2002 may indicate a shift in sediments between the two years towards finer sediments, or may be an artefact of sample distribution in a heterogeneous environment (Figure 5.24).

2. Biota: There are few consistent patterns that span all three years. Group 'd' was more often classified in the eastern sector and Group 'a' in the west. However, Group 'c' showed no consistent pattern and Group 'd' was found only in 2002 (Figure 5.25).

3. Sidescan: The classification using training sites digitised from the sidescan sonar image has produced consistent patterns from year to year that match the sidescan interpretation. The more distinct delineation of the disposal site in 2002 corresponds well with the better quality sidescan sonar images obtained in that year (Figure 5.26).

Figure 5.24. Supervised classification of the QTC data according to sediment type (classified according to the modified Folks system as used by the BGS). Note that the outline of the area covered in 2001 has been overlain on the maps for 2002 and 2003 to aid comparison. There is little consistent in the pattern of sediment distribution between years. It is possible that the dredged material disposal site is marked out by heterogeneity, especially in 2002.

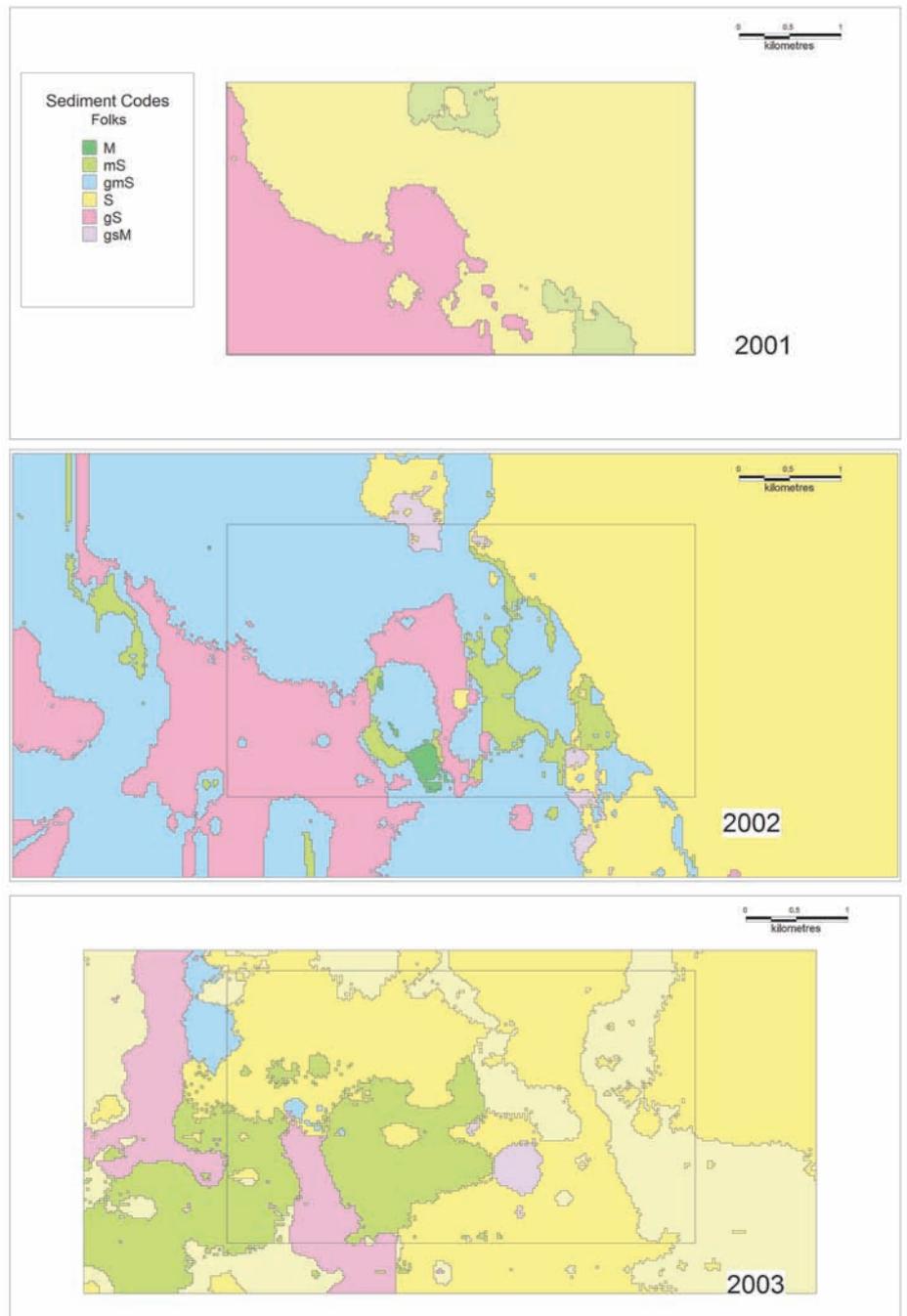


Figure 5.25. Supervised classification of the QTC data according to faunal classes. Note that the outline of the area covered in 2001 has been overlain on the maps for 2002 and 2003 to aid comparison. There is little consistency in the pattern of the distribution of the infaunal classes between years. It is possible that the dredged material disposal site is marked out by heterogeneity in 2002 but not in other years.

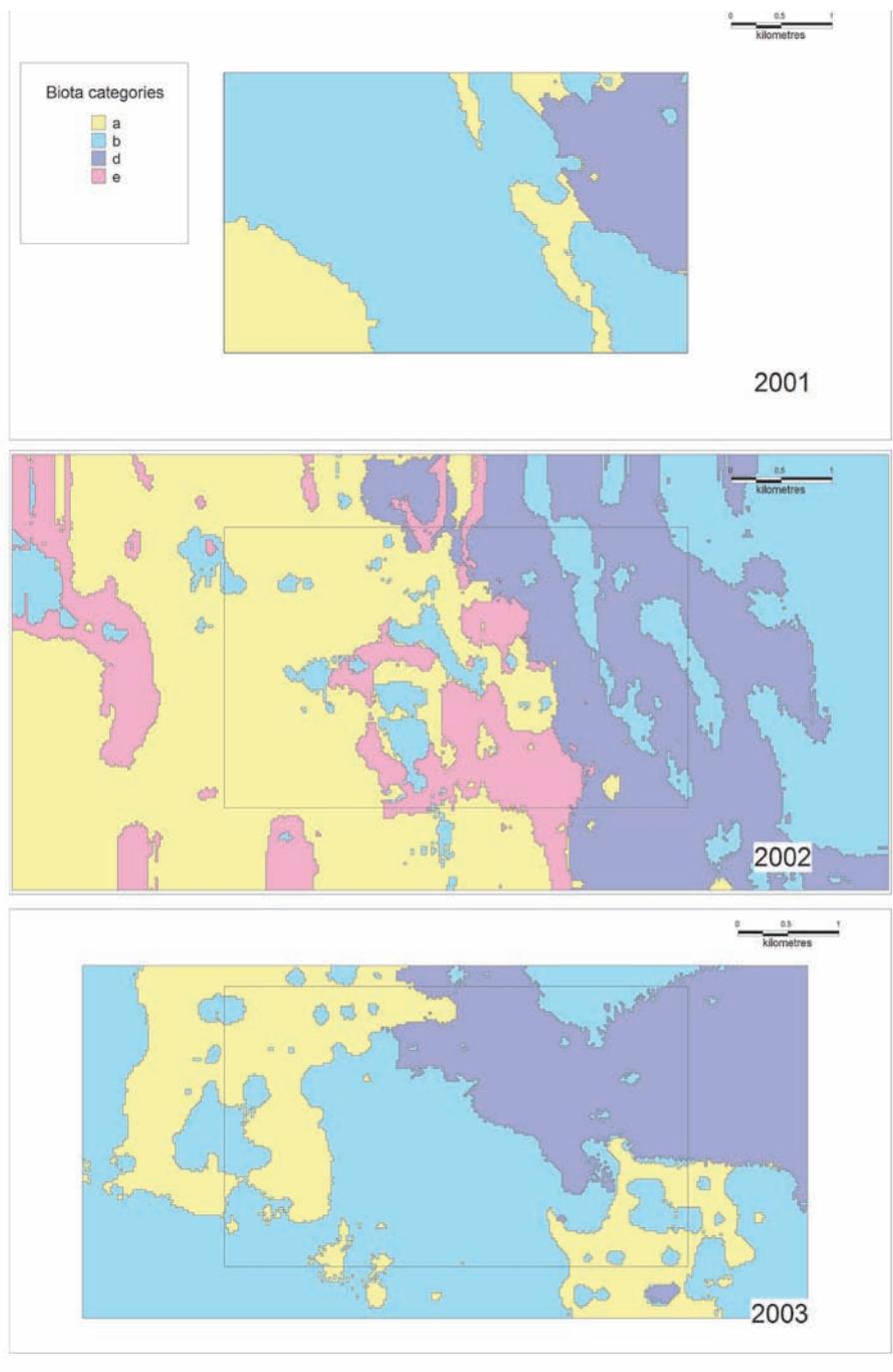


Figure 5.26. Supervised classification of the QTC data according to sediment/bedform from sidescan interpretation. Note that the outline of the area covered in 2001 has been overlain on the maps for 2002 and 2003 to aid comparison. There is a broad similarity in sediment/bedform areas between years, although the area associated with the dredged material disposal site appears to be less well defined in years 2001 and 2003.

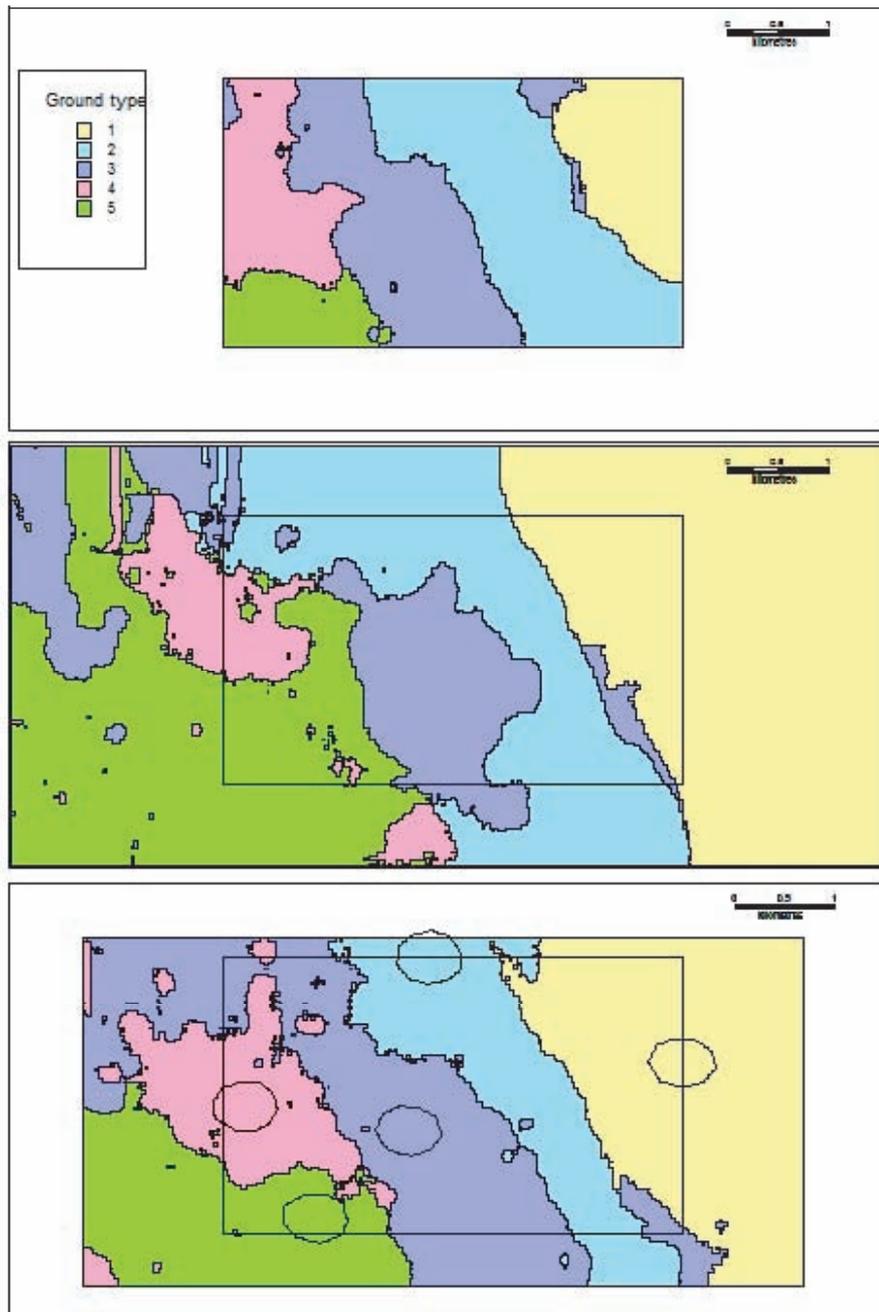
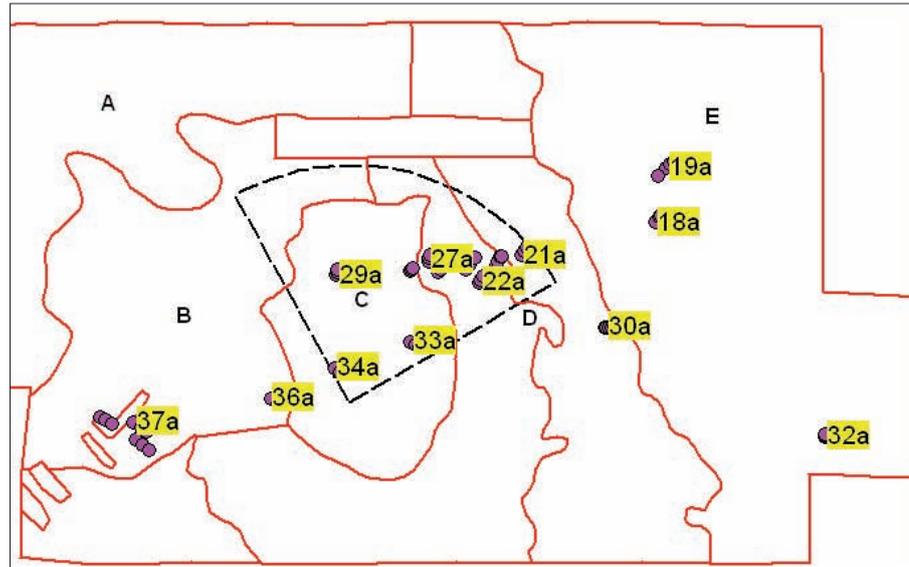


Figure 5.27. SPI survey at Dredged Material Disposal Site (TY070) during 2003.



5.5.8 Sediment Profile Imagery

The use of video images and the SPI camera collected at TY070 (see Figure 5.27) complemented the results of sidescan sonar surveys. SPI images from July 2003 are shown in Figure 5.28 for the different areas sampled. The sediment distribution appears to be predominantly composed of fine sand in the topmost layers of the sediment. Excepting stations 36, 37 and 39, sediments appeared to consist of medium sands with some fine muddy material. A varying shelly fraction is also visible at the sediment surface in many of the areas surveyed. This material is the highly reflective fragments scattered across the sediment/water interface. This is an artefact of the SPI technology. The presence of coarse sediment was also observed at stations 36, 37 and 39.

Surface boundary roughness is a measure of the unevenness of the sediment surface as a result of physical activity and bioturbation processes (Rhoads and Germano, 1986). Values ranged from a low of 0.33 (station 33 the very flat sediment surface present at area C in the disposal area) to a high value of 14.40 (station 34 a biogenically-roughened sediment water interface at area C located on the margins of the disposal site). Where high roughness values were recorded, it is clear that these are largely attributable to biogenic features, for example, in photographs taken at area E. This is mainly due to the burrowing activities of decapods whose burrows are evident in several SPI photographs (area E: stations 18-19 A and also at the margins of the disposal site- station 22) or due to tube formation and bioturbating activity of infaunal animals e.g. polychaetes and holothurians. Evidence of physical disturbance (as distinct from biogenic disturbance) is also present in seafloor sediments at stations 25 and 34 located within the disposal site. The presence of relatively irregular mud clasts composed of reduced sediment at the sediment surface is indicative of such disturbance (Figure 5.28).

The apparent redox potential discontinuity (ARPD) depths (the visible line between oxygenated and reduced sediment) recorded from the SPI images are presented in Table 5.3. It is evident that ARPD depth is greatly dependant on the presence/absence of bioturbating fauna; the presence of which can be gauged using the information from the profile images. Where such animals are present (areas E and D), the ARPD layer is relatively deep and uneven, mixing of sediment types is good throughout the sediment profile and oxygenated voids are generally present at depth within the sediment.

At stations where the excavating, irrigation, burrowing and feeding activities of such animals are absent (centre of area C and area B), a shallower ARPD layer is found with a thin veneer of oxygenated sediment overlying an otherwise oxygen-depleted substratum. Area B is a good example of this: the profile image reveals a very limited amount of oxygenated sediment present, with an associated low level of biological activities. Due to the presence of coarse/rocky substrata, it was not possible to gauge the depth of the ARPD layer at all stations (specifically, area B-stations 36, 37 and 39) (Figure 5.29, image 36). It is important to highlight the variation in different ARPD depths within the disposal site itself, with both relatively high and relatively low values recorded. This may reflect, to some degree, the history of disposal at the site. All areas located outside the disposal site returned consistently high ARPD values (Table 5.3). The Benthic Habitat Quality Index was calculated, following the methodology proposed by Nilsson and Rosenberg (1997), and the results are presented in Table 5.3. Successional stages varied from stage I environments namely, areas C and B (all inside or in the vicinity of the disposal site), which are largely characterised by shallow ARPDs and the absence of discernible biogenic features to stage III, namely stations E and D, (both outside the disposal area) with their characteristically deep ARPDs, well developed faunal communities and prominent biogenic features, such as burrows and feeding mounds.

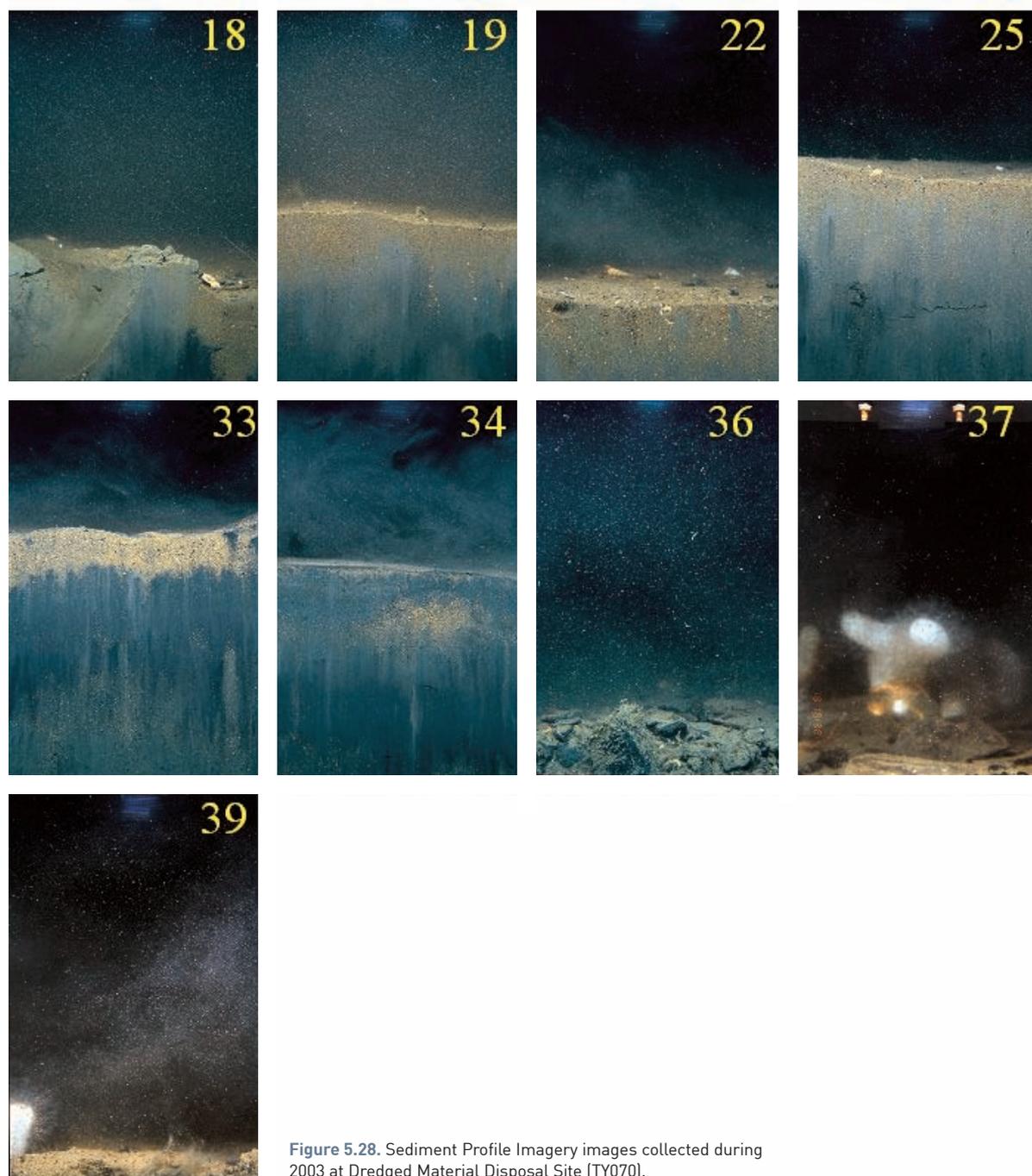


Figure 5.28. Sediment Profile Imagery images collected during 2003 at Dredged Material Disposal Site (TY070).

Table 5.3. Results from the analysis of SPI images, including sediment type, penetration, Sediment Boundary Roughness (SBR), apparent redox discontinuity depth (ARPD), Stage (calculated from the Benthic Quality Index) and Organism sediment index (OSI)

| Stations | Sediment type | Penetration (cm) | SBR | ARPD depth | Stage | OSI |
|----------|---------------|------------------|------|------------|--------|-----|
| 22 | >3-2 phi | 5.80 | 1.00 | 4.93 | II-III | 10 |
| 25 | >4-3 phi | 13.43 | 0.69 | 5.62 | II | 9 |
| 33 | > 4phi | 15.39 | 1.63 | 2.58 | I | 5 |
| 34 | > 4phi | 12.96 | 1.00 | 1.96 | Azoic | 2 |
| 36 | > 4phi | --- | --- | --- | I-II | 2 |
| 37 | >4-3 phi | --- | --- | --- | I-II | 2 |
| 39 | >3-2 phi | --- | --- | --- | I-II | 2 |

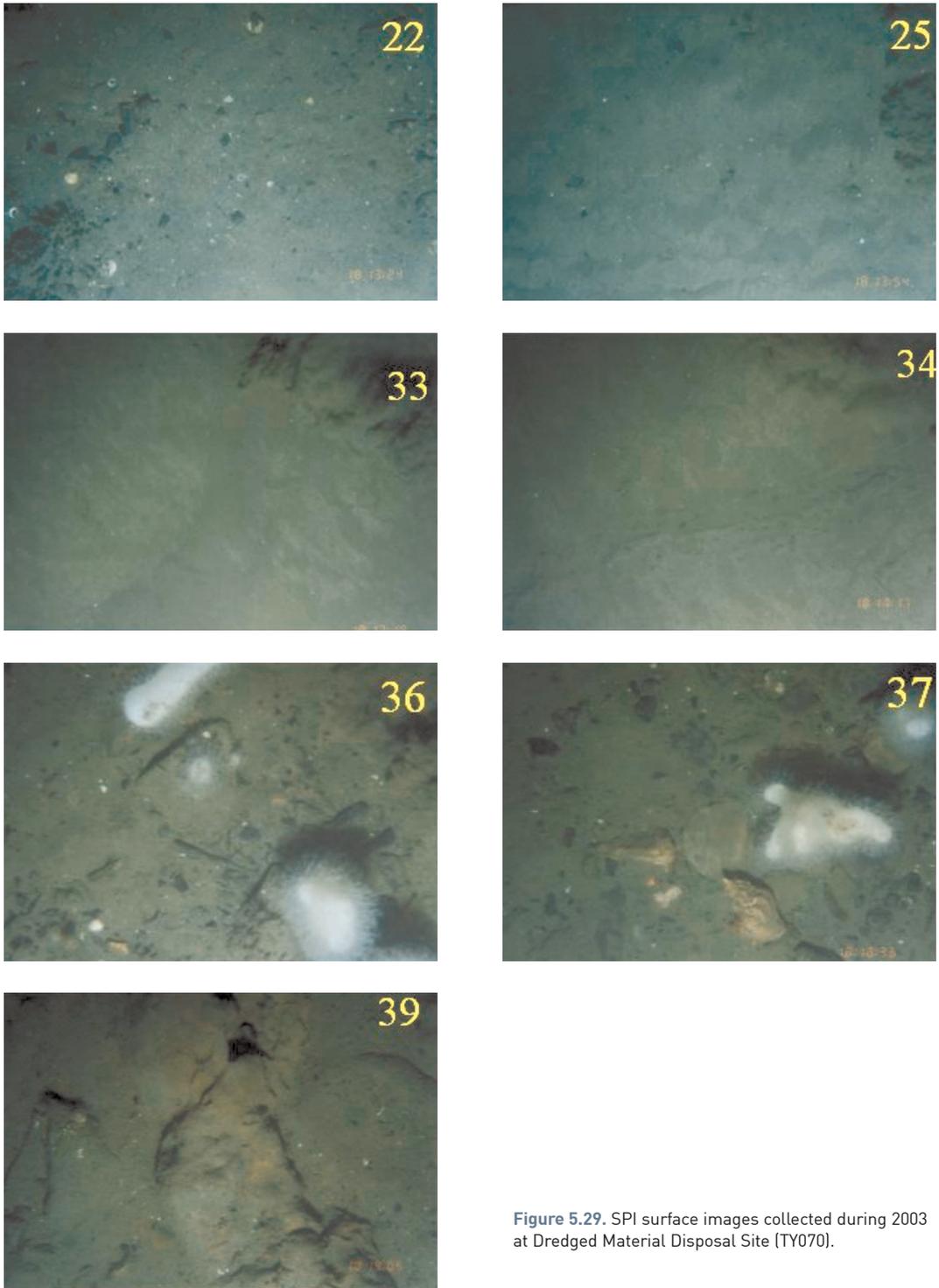


Figure 5.29. SPI surface images collected during 2003 at Dredged Material Disposal Site (TY070).

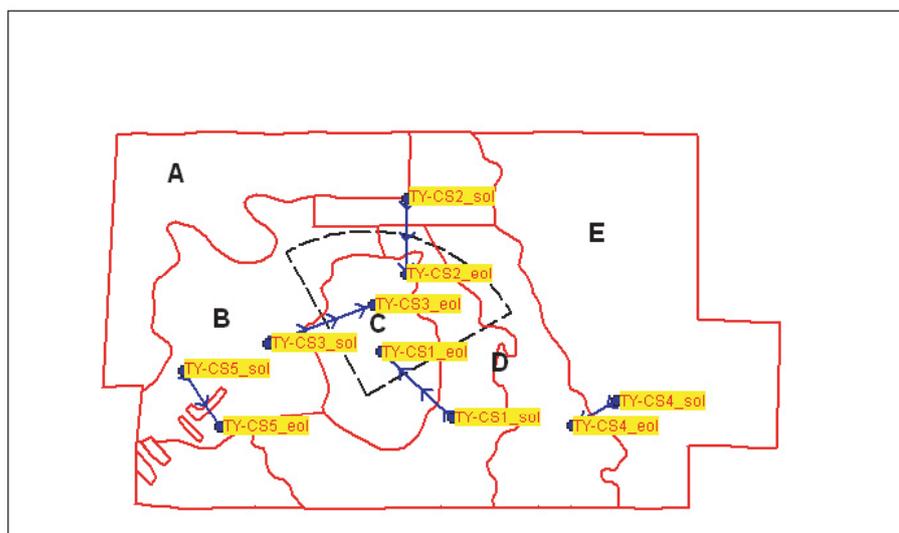
There was also evidence of bioturbation and this activity has affected the oxygenation of some of the surveyed sediments, although these effects were mainly observed at areas outside the disposal site. Burrows attributable to the excavating activities of several infaunal species were observed in many of the profile images, in some cases substantial sections of these burrows are visible (Figure 5.28, image 25).

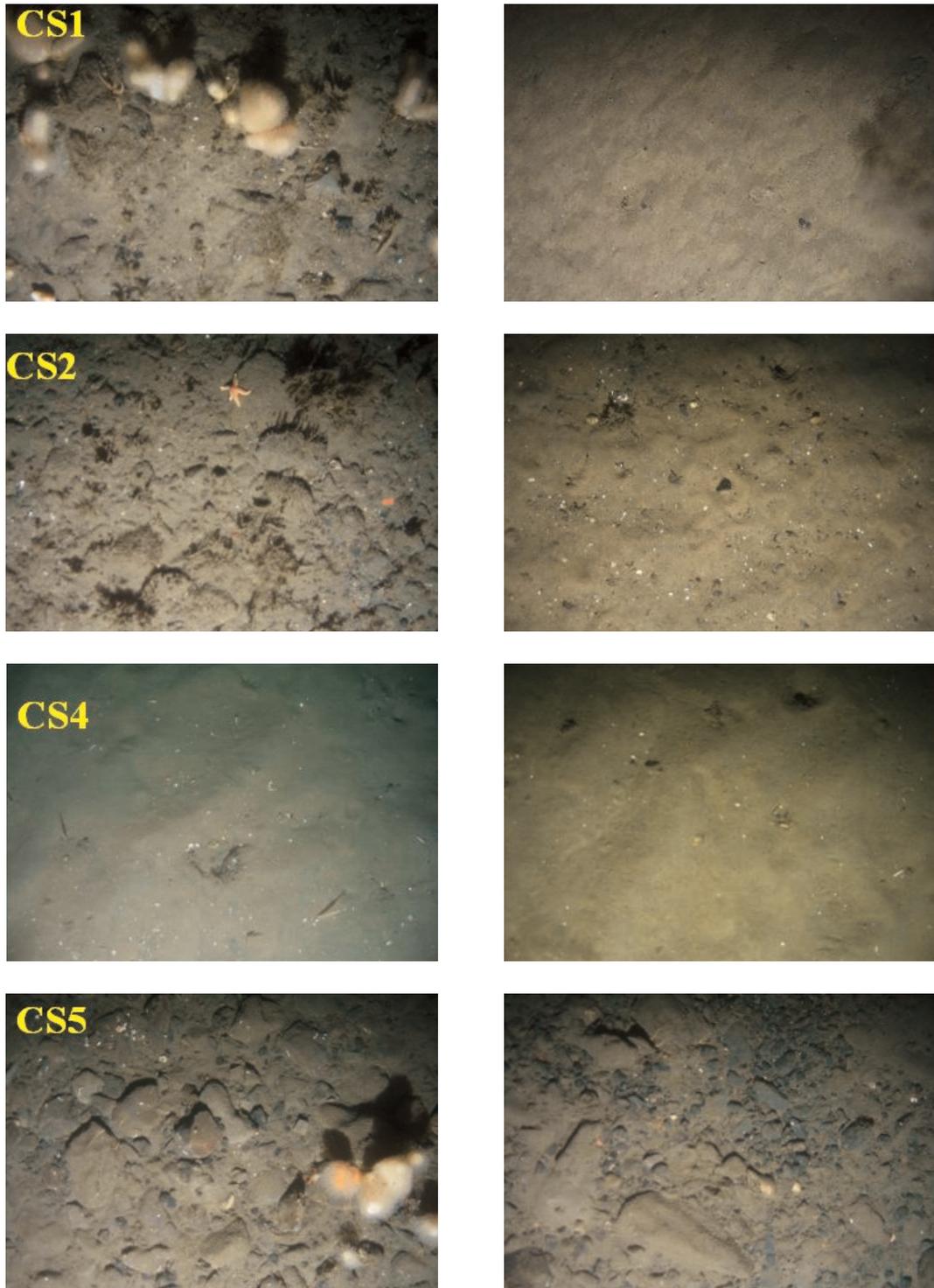
Organism sediment index (OSI) values are presented in Table 5.3. Lowest values were recorded at those stations with a shallow RPD layer and which are best described as Stage I-II or II-III of the Benthic Habitat Quality Index. The OSI values for areas E, D and the northern part of area C correspond to values of 9, 10 and 11 respectively, which indicates a high quality habitat with an aerobic sediment at depth, a deeply depressed ARPD and a mature benthic community. For areas C (centre and margins of the disposal site) and B the OSI values were 3, 5 and 2 respectively, indicating a partially degraded habitat, perhaps reflecting the history of disposal activity at the site.

5.5.9 Video information

The use of underwater video and still images in this study provided an instant qualitative description of in situ epifauna communities, and helped complement other ground-truthing techniques (Figure 5.30). Underwater video images were collected with a camera sledge (see Chapter 3). Inside the disposal site the sediments were observed in some areas to be shelly muddy sands with the presence of coal fragments and other coarse particles which hosted the presence of *Alcyonidium digitatum* (dead man's fingers), the brittlestars: *Amphiura* sp., and *Ophiura* sp., hydroids, bryozoan and the starfish (*Luidia ciliaris*) (Figure 5.31; CS1). Outside the disposal site within areas D and E (Figure 5.31; CS2, CS4), the presence of fine and medium sands, which hosted burrowing organisms such as *Turritella*, sp., as well as hydroids, bryozoans, *Antalis* sp. and *Aporrhais* sp. Area B (Figure 5.31; CS5) was characterised by coarser material, supporting the presence of *Alcyonidium digitatum* (dead man's fingers), *Amphiura* sp and *Ophiura* sp.

Figure 5.30. Camera sledge collected at Dredged Material Disposal Site (TY070) over acoustic areas.





5.6 Results (Shoreham)

5.6.1 Sidescan sonar

This area could be generally divided in three broad regions: a deep west-southwest area, the central and southeast dredged area, and a northeast gravelly area. In the west-southwest area water depths exceed 30 m and the sediments are mainly gravelly sands. A field of megaripples covers the western edge of the dredged area (Figure 5.32). As noted previously (see Brown *et al.*, 2001, 2002; James and Brown, 2002), the effects of dredging activity were clearly discernible from the sidescan sonar mosaic. The dredged area could be further subdivided into two areas consisting of an area dredged using static suction and an area dredged using trailer suction hopper dredgers. The area disturbed by static suction hopper dredger was characterised by deep depressions that were obvious from the sidescan sonar record as a distinctive mottled tone. In contrast, the area disturbed by trailer suction hopper was typified by southwest-northeast running furrows caused by the draghead of the dredger. The sediments in the area were predominantly gravelly, although locally sandy sediments were also present. The sandy sediment may have been associated with the retention of fine sediments in the dredged depressions. Northeast of the area has a very gravelly floor without any major bedforms. From the sequence of acoustic mosaics the development of a surficial sandy feature with a southwest-northeast direction is evident. The extent of this feature increased in size from 2001 to 2004. It also emanates from the most intensive area of dredging, suggesting a link between the aggregate extraction activities and the development of this feature over time.

5.6.2 Multibeam bathymetry

The effects of dredging activity were clearly depicted from the output from the multibeam bathymetric survey. The data was assessed under 1 metre horizontal grid and 0.001 metre vertical grid. At this resolution, the impacts of static suction hopper dredging can be discerned as areas of rough uneven topography (Figure 5.33C). Dredged pits cover an area of approximately 1600 by 900m within the licensed area. These pits are interlinked and overlapping in the most intensively dredged area. Individual pits can be measured at the boundary of the disturbed area and range from 2 to 5 m deep and approximately 30 m across. Elongated furrows characteristic of trailer suction hopper dredging activity were also evident on the multibeam record. These tracks are of approximately 3-4 metres wide and 0.2 to 0.3 metres deep. Natural features such as megaripples (A) and the edges of paleovalleys (B) were also visible.

5.6.3 AGDS classification

Data editing and preliminary analysis

The datasets available for the Shoreham site were obtained in 2002 and 2003. The 2002 dataset consists of 10 tracks with a spacing of 200 m. The 2003 dataset, however, consists of only 5 tracks with a spacing of 350 m. Only QTC was used in these surveys. The variograms show that the QTC-View data rise linearly, as for the TY070 datasets. The nuggets were quite small, indicating a strong local similarity between values. This is supported by the strong patterns in Q1. The data were therefore considered suitable for interpolation. The interpolation algorithm used was inverse distance to a power 1.5. A search radius of 250 m was selected and the maximum number of points set at 64 within a quadrant search. A high smoothing coefficient was also selected and the grid size was set at 25 m.

Unsupervised classification

The gridded data were treated in the same manner as the TY070 data. The cluster numbers were set to the number of sediment types found through sampling: 5 for 2002 and 4 for 2003. The colours have been chosen to match the predominant point sediment data that fell within the cluster polygons, although this gives a false impression of concurrence between datasets. However, in marked contrast to the TY070 data, the pattern of acoustic ground types appears to match the pattern of the sidescan interpretations for the two years. In particular, the area associated with the extraction site accords well with the sidescan sonar image (Figure 5.34).

5.6.4 Sediment characteristics

Results of particle size analysis revealed that sediments in the dredged area consisted of gravel and gravelly sands. In contrast, the sediments surrounding the dredged area were composed of sands occasionally interspersed with sandy gravels. Interestingly, between 2003-2004 there appears to have been a change from gravel to sandy gravels at both the dredged and surrounding areas (Figure 5.35). A principal components analysis (PCA) of the sediment particle size data showed the % gravel and % sand to be highly correlated with PC 1, accounting for 69.7% of the variation in the data. PC axis 2 was also highly correlated with % silt/clay, accounting for an additional 30.3% of the variation (Table 5.4). The sediment samples plotted in PCA space (Figure 5.36, A) show several groups (with 3% similarity).

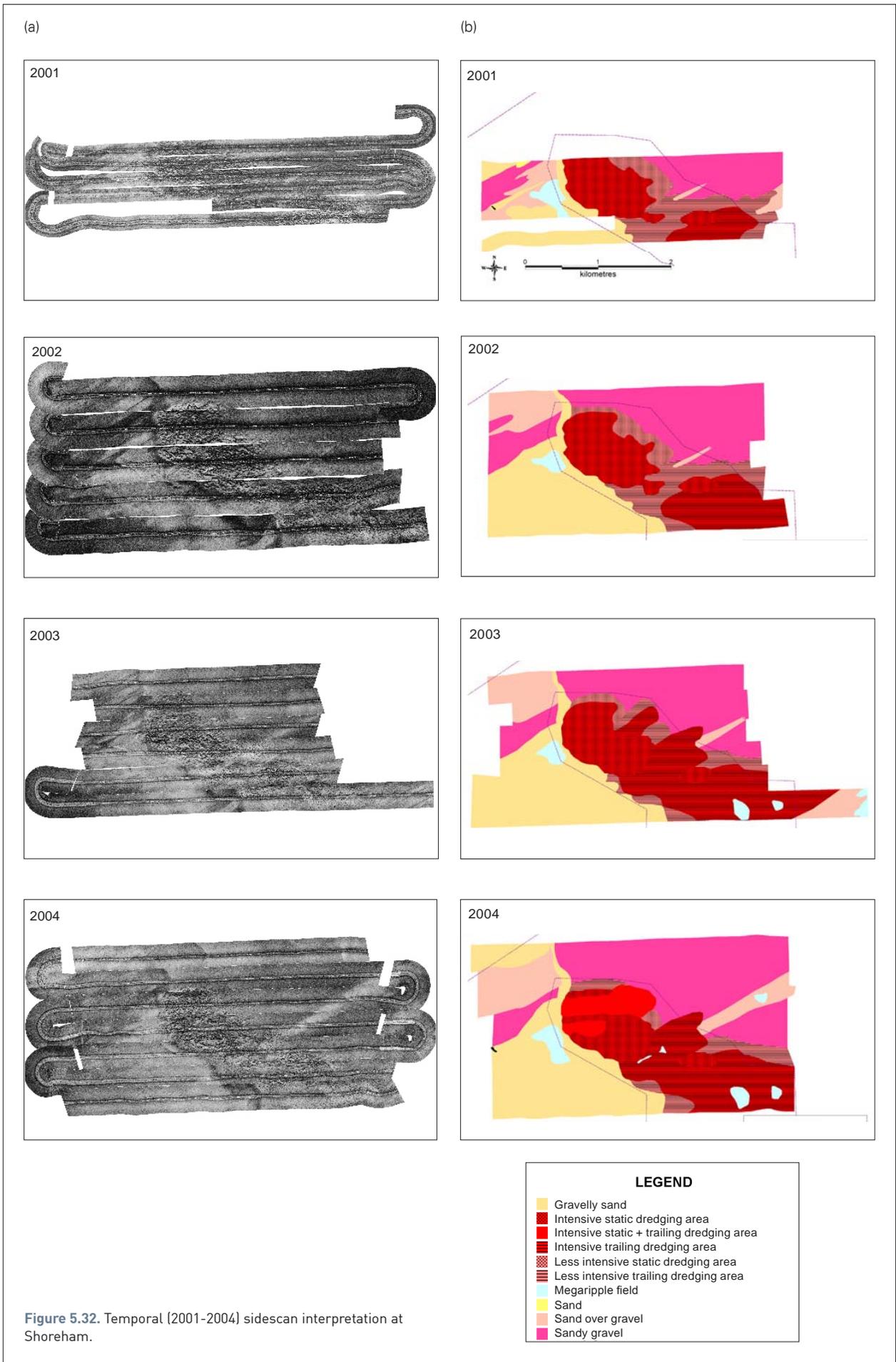


Figure 5.33. Multibeam image for Shoreham aggregate extraction site.

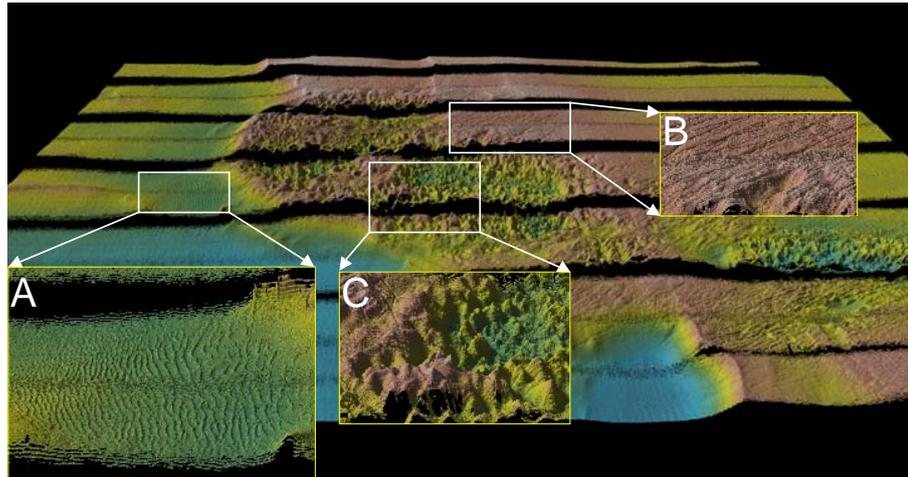
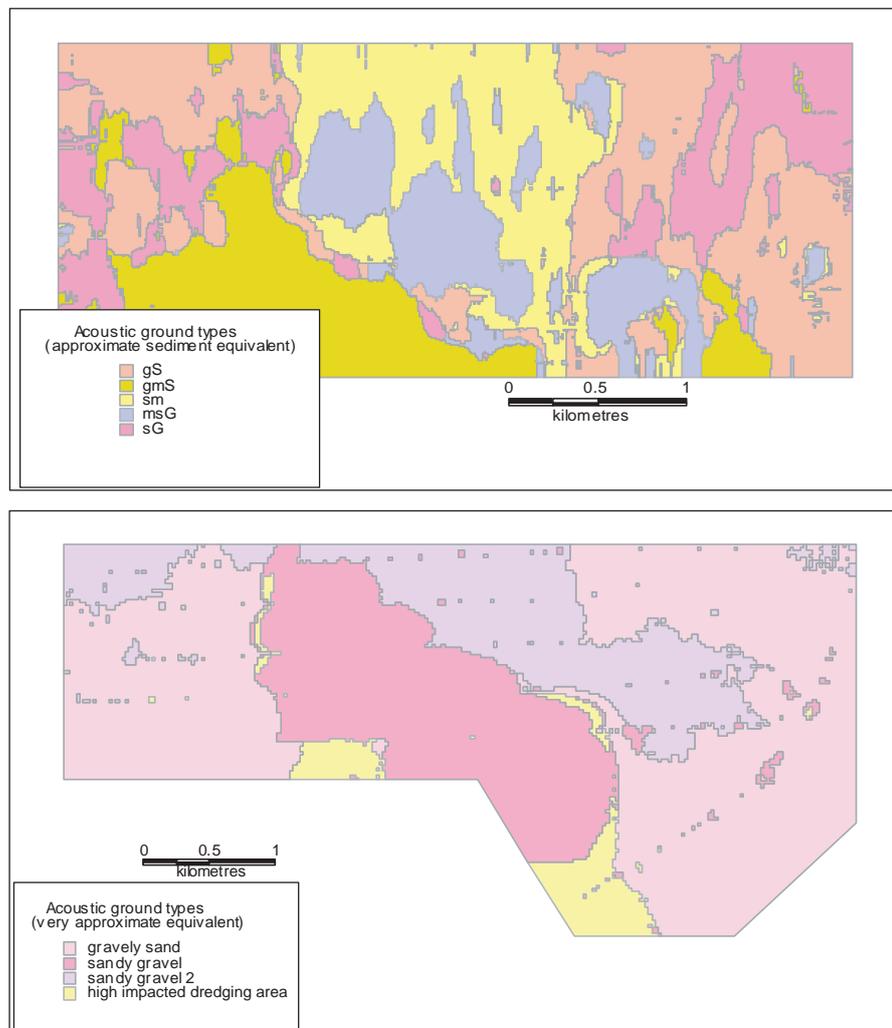


Figure 5.34. Unsupervised classification of QTC datasets for the three years 2002 and 2003. The same number of clusters were selected as the sediment classes and an attempt has been made to match acoustic ground types to sediment class.



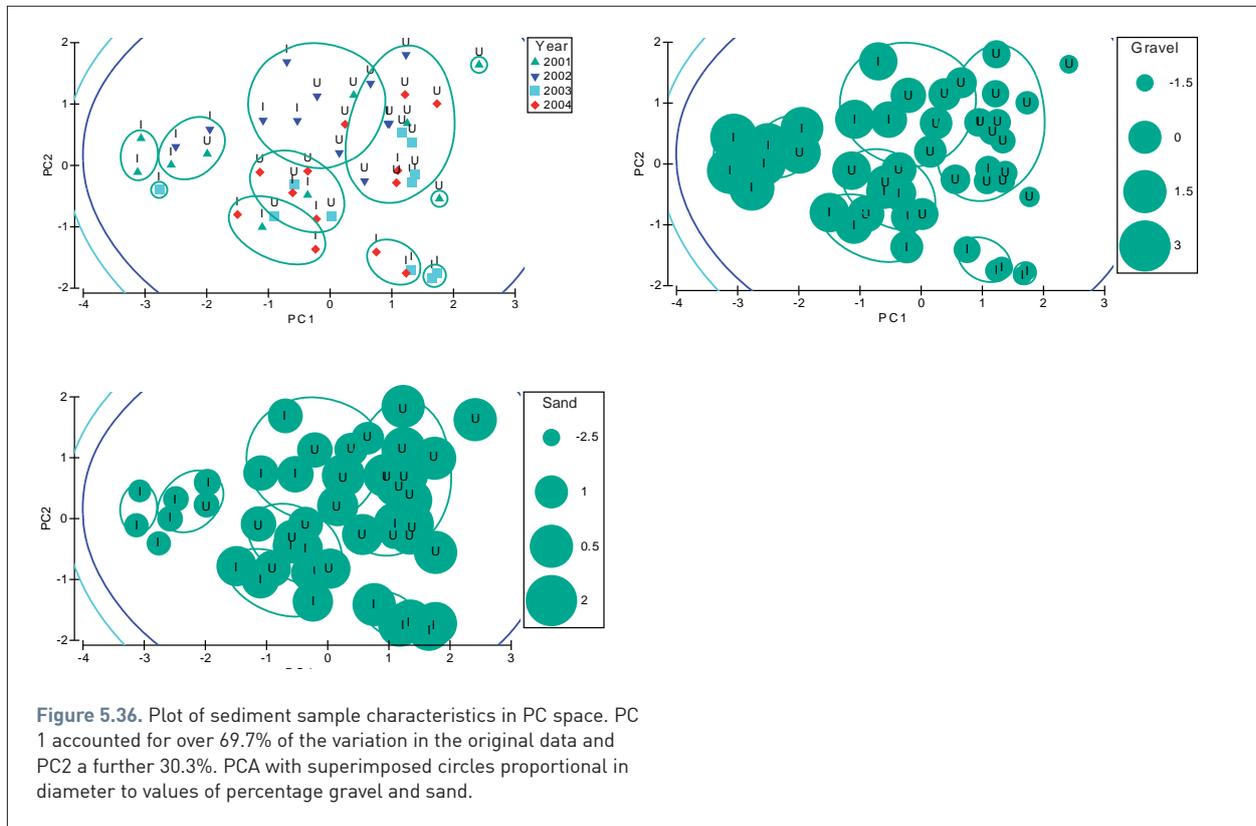
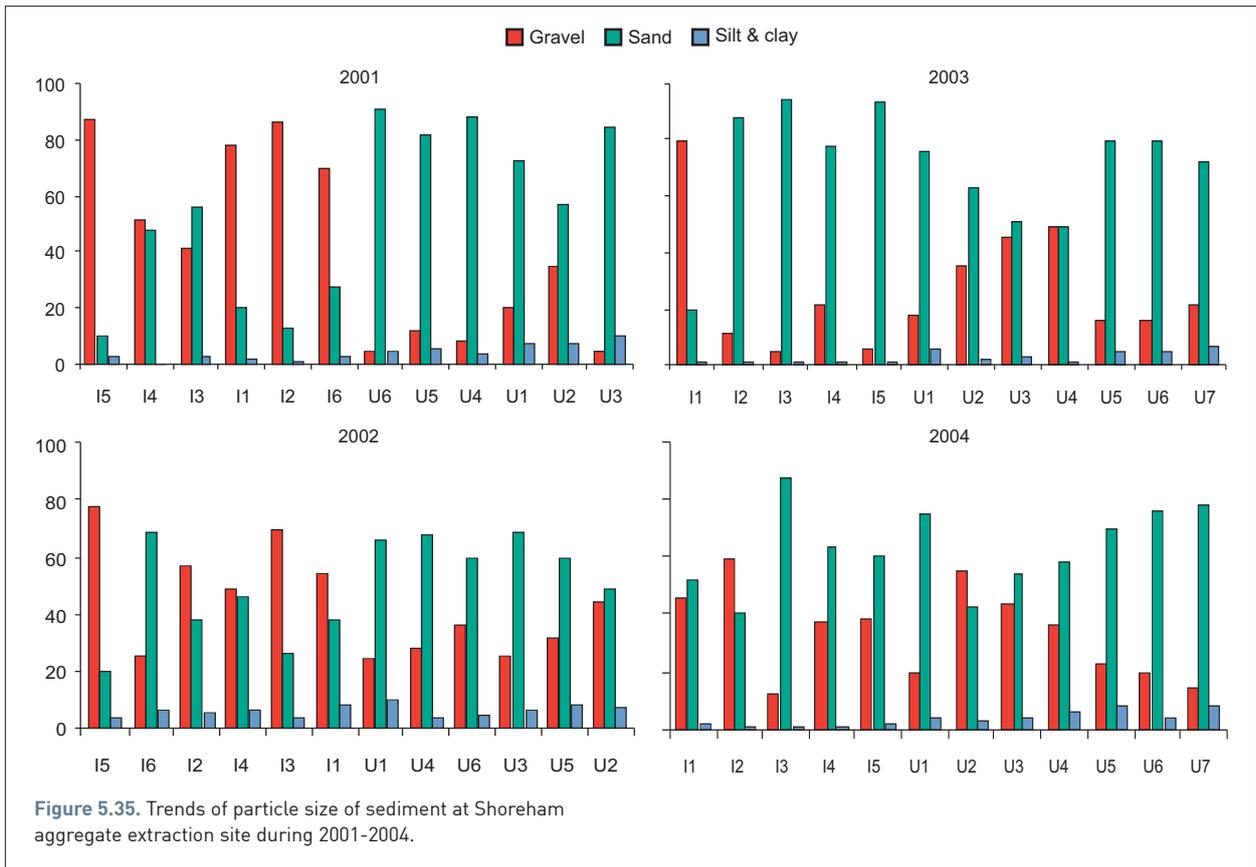


Table 5.4. Principal components analysis of sediment characteristics (percentage of gravel, percentage sand and percentage silt and clay) for ground-truth samples (2001-2004) at Shoreham.

| Variable | Weighting | |
|------------------------|-----------|--------|
| | PC1 | PC2 |
| % Gravel | -0.685 | 0.143 |
| % Sand | 0.669 | -0.263 |
| % Silt & Clay | 0.287 | 0.954 |
| Eigenvalues | 2.09 | 0.909 |
| Percentage of variance | 69.7 | 30.3 |
| Cumulative percentage | 69.7 | 100 |

5.6.5 Biological characteristics

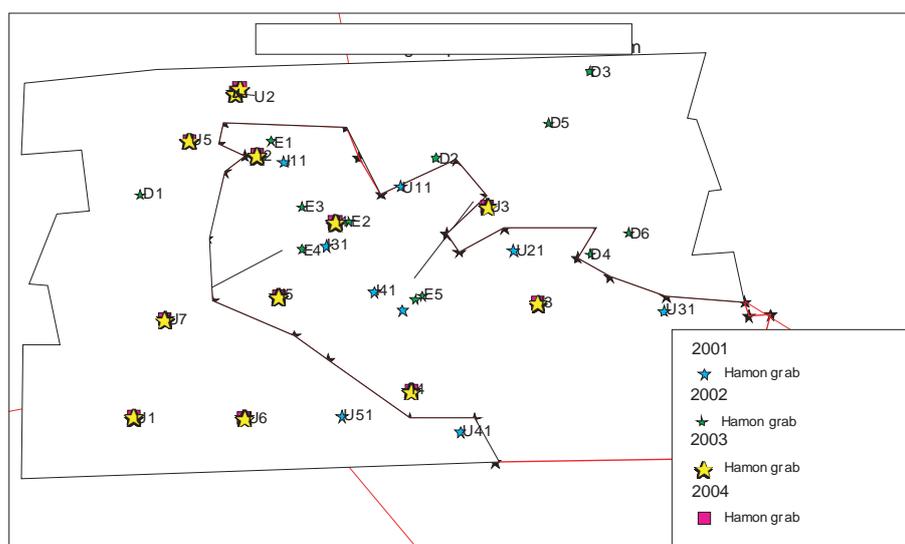
A total of 252 taxa were identified from the 0.1 m² Hamon grab samples collected over the four years of study. Figure 5.37 shows the location of all ground-truth samples collected at the Shoreham site. Figure 5.38 shows the results of univariate analysis for the 2 main acoustic regions (dredged and surrounding area) sampled over the 4 years. In summary, the results of univariate analysis reveal that whilst the dredged area and surrounding areas are acoustically different they were very similar in terms of their faunal characteristics. Results

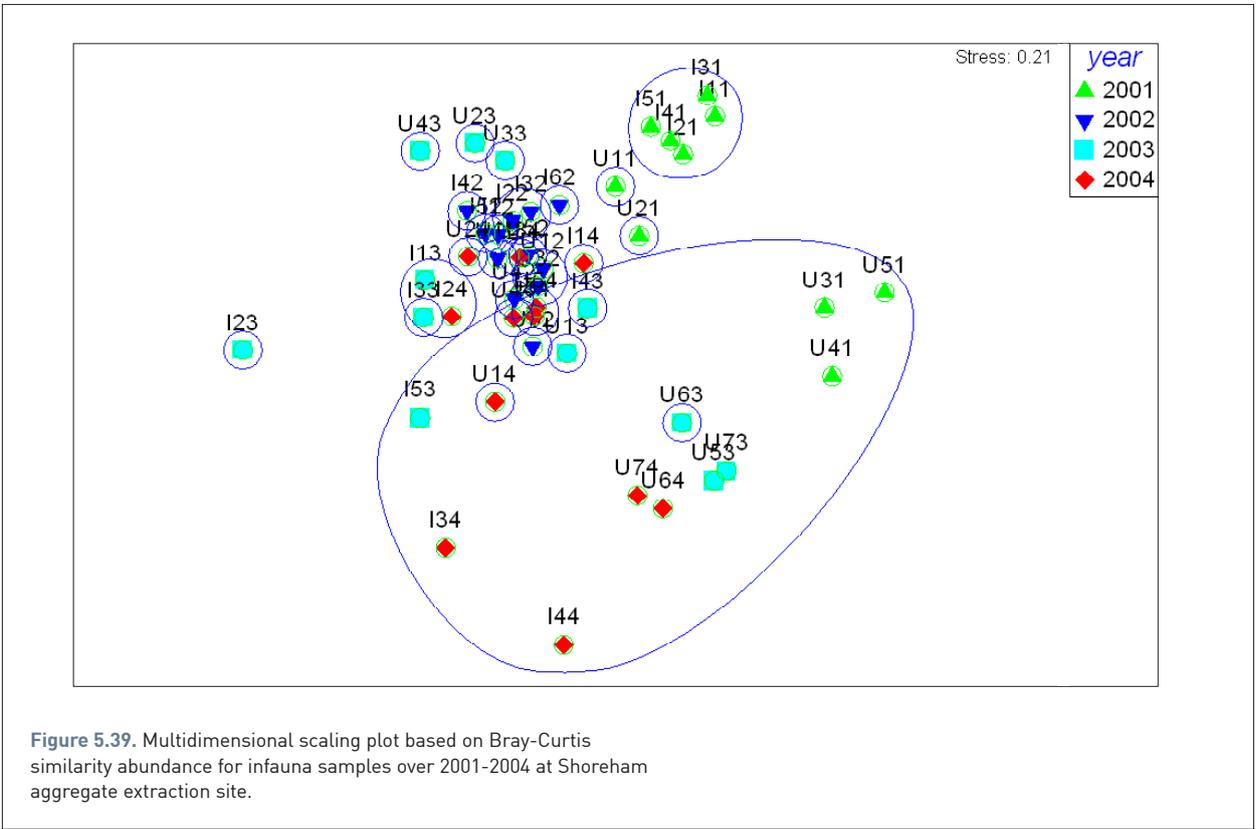
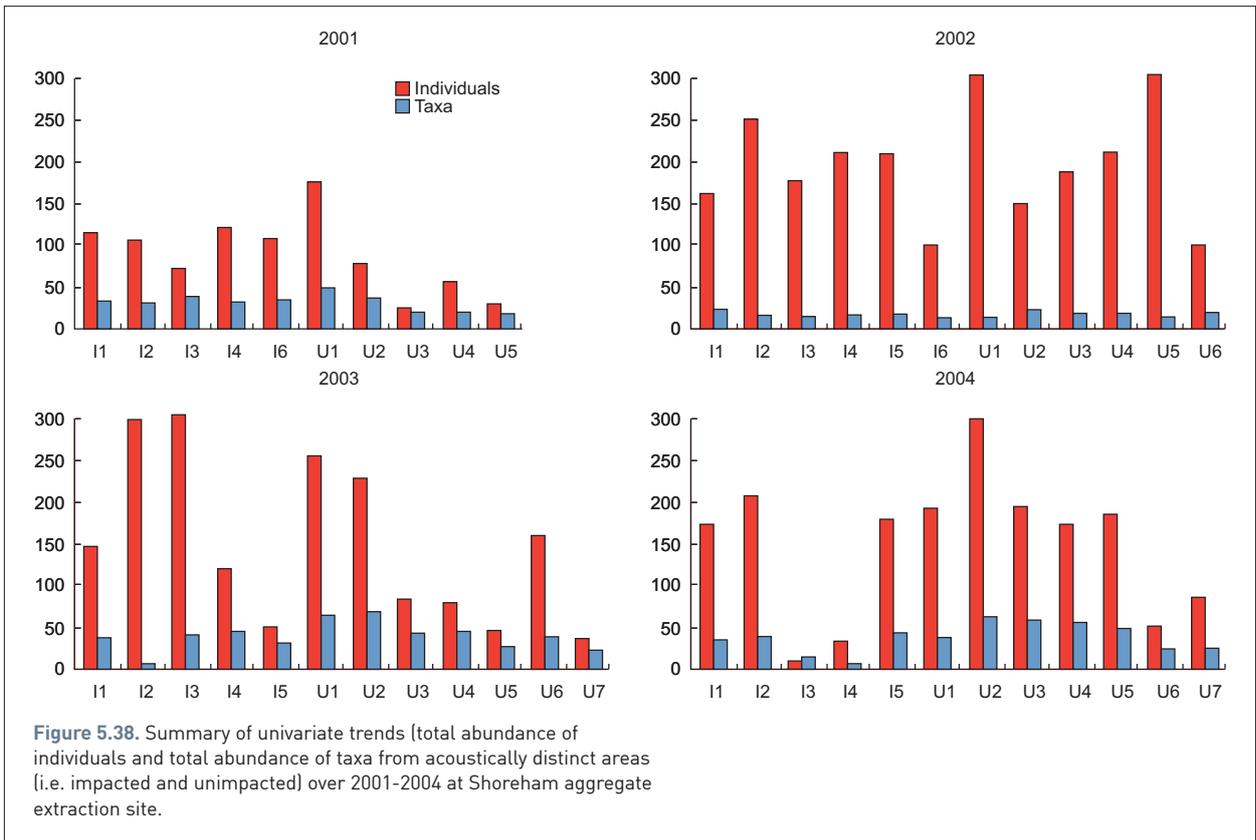
of multidimensional scaling using Bray-Curtis similarity coefficients indicated the presence of 3 main clusters (with 50% similarity) and also several minor clusters (Figure 5.39). However, there is no clear difference in species composition between the dredged and non-dredged areas. The results of BIO-ENV analysis indicated that the best fit between macrofaunal species composition and sediment characteristics ($\rho_w=0.195$) is obtained with percentage sand and percentage silt/clay content. Figure 5.40 shows the faunal data overlaid with the environmental variables (i.e. PSA data).

Results from SIMPER analysis revealed the taxa responsible for characterising and/or differentiating the community composition over time (Annex V and Annex VI) and at acoustically distinct areas (Annex VII and Annex VIII). The results from SIMPER analysis confirmed that the community composition of the dredged area was very similar to that of the surrounding sediments. This accords with the findings of Brown *et al.* (2001, 2002).

The second MDS ordination (Figure 5.41) is based on epifauna data from 2003-2004. Samples collected over these two years appear to form distinct clusters. Interestingly, samples from 2003 do indicate a clear separation of the dredged and non-dredged sites within the same cluster. However, samples collected in 2004 from both acoustic regions were judged to be similar.

Figure 5.37. Sampling positions used to ground-truth the Shoreham aggregate extraction site over 2001-2004.





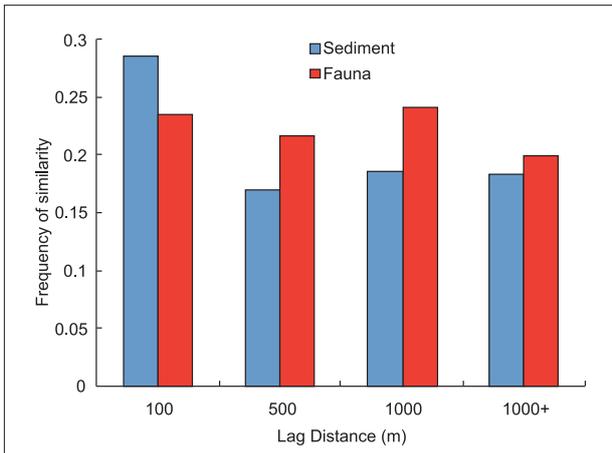


Figure 5.42. Changes in percentage of similarity compared with lag distances (100, 500, 1000 and >1000) for sediment and faunal samples collected at Shoreham aggregate extraction site over 2001-2004.

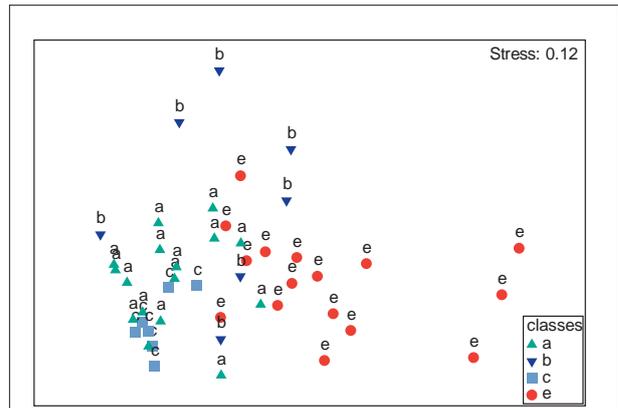


Figure 5.43. Multidimensional scaling plot based on Euclidean Distance for infauna samples over 2001-2004 at Shoreham aggregate extraction site.

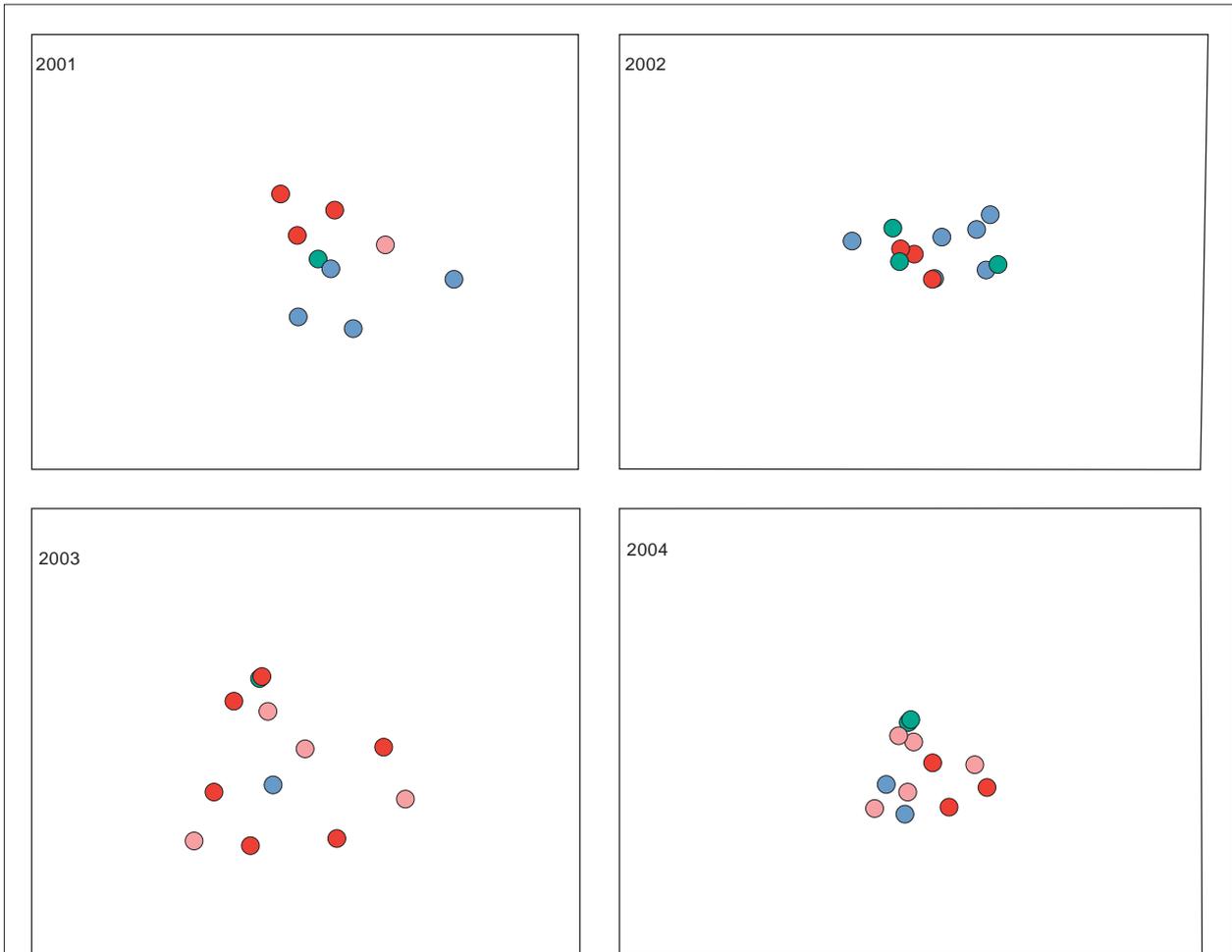
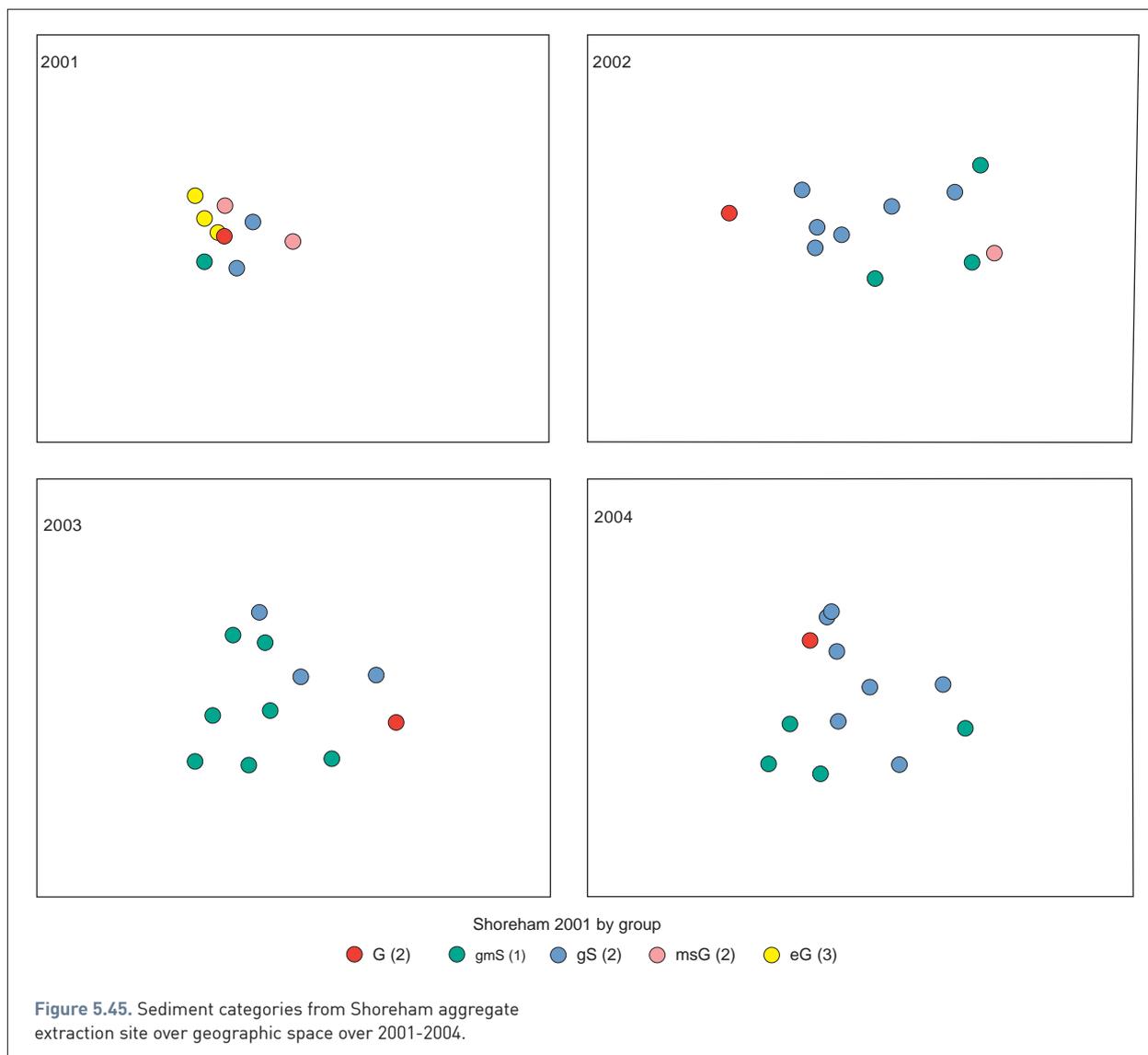


Figure 5.44. Fauna categories from Shoreham aggregate extraction site over geographic space over 2001-2004.



5.6.7 Supervised classification of AGDS

Supervised classification of the AGDS data was carried out using different categories derived from an analysis of the faunal, sediment and sidescan sonar datasets. The results of this classification are briefly described below:

1. Sediment: The classified distribution of sediments show very little consistency between years 2002-2003. However, it should be noted that there was a substantial change in the sample data (both in terms of sediment classes identified and location of samples) between these years. For example, there was a shift away from silty sands and gravels in 2003. Bearing in mind the constraints of supervised classification, it is not surprising that the distribution maps show little coincidence (Figure 5.46).

2. Biota: Once again, there are few consistent patterns between 2002 and 2003. The results show that the extraction site supported different classes of biota from the surrounding area, but with quite contradictory classes involved: In 2002 the extraction site was characterised by Group 'a' with Group 'e' being commonly found outside the extraction area. In 2003 the situation is completely reversed and the extraction site had a class not found anywhere in 2002 (Figure 5.47).

3. Sidescan: The classification using training sites digitised from the sidescan image has produced consistent patterns from year to year that match the sidescan sonar interpretation (Figure 5.48).

Figure 5.46. Supervised classification of the QTC data according to sediment type (classified according to the modified Folks system as used by the BGS).

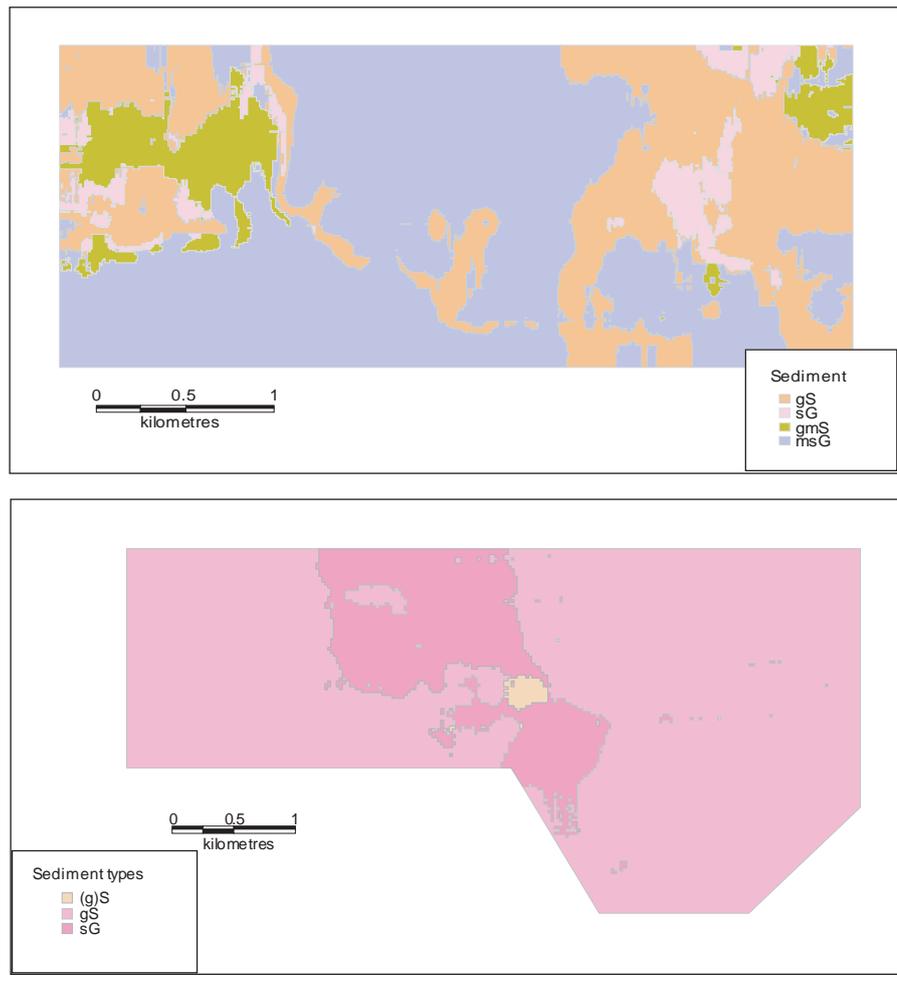


Figure 5.47. Supervised classification of the QTC data according to faunal classes. The distribution of the faunal classes change radically between years, although the area of extraction is approximately delineated.

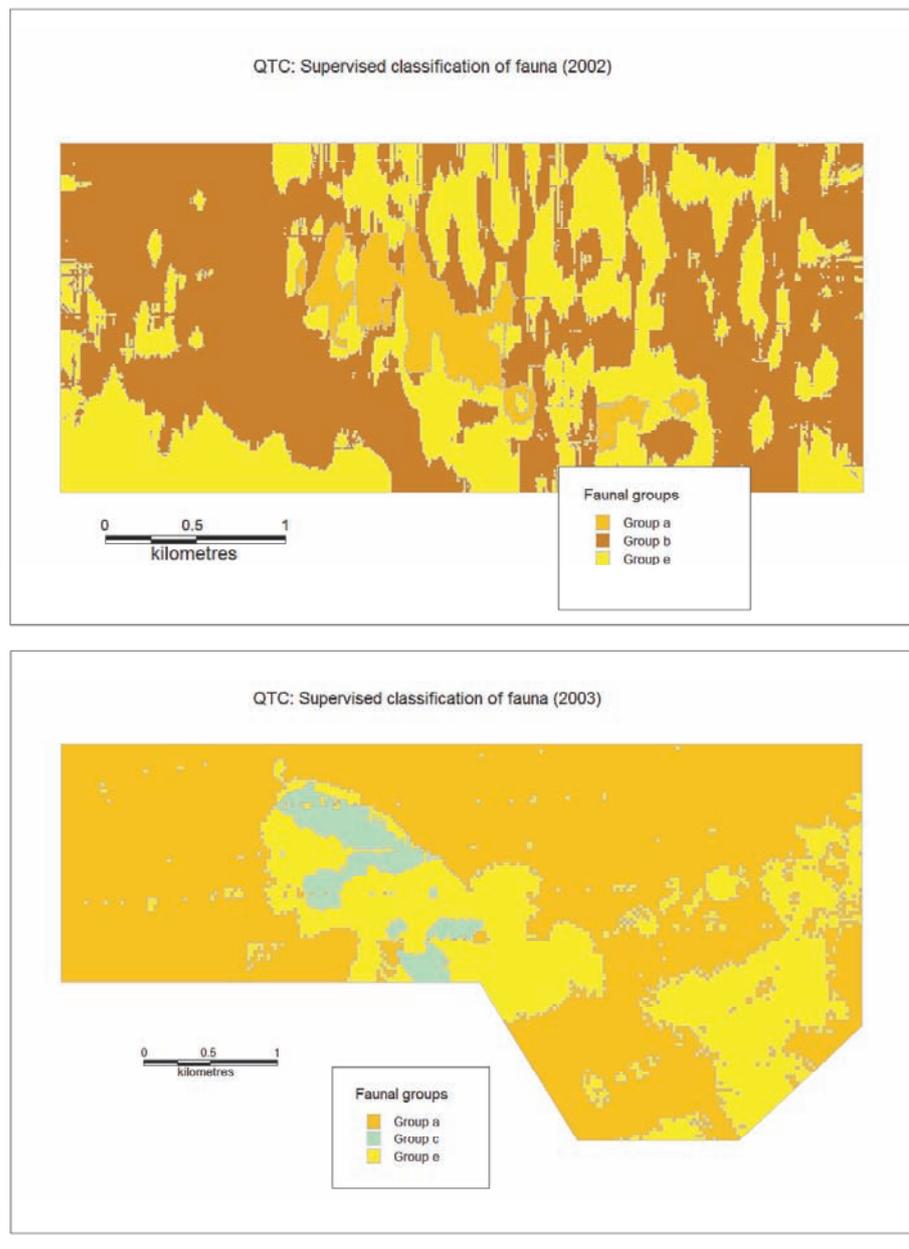
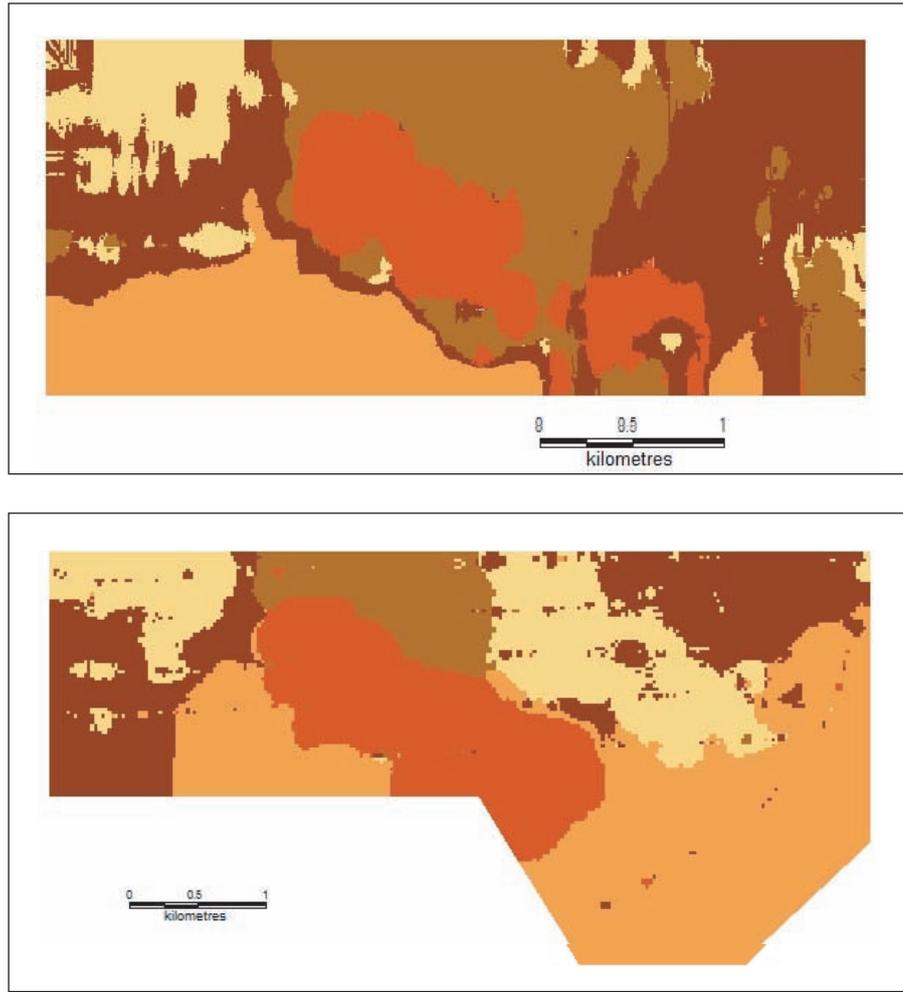


Figure 5.48. Supervised classification of the QTC data according to sediment/bedform from sidescan interpretation. The map accords well with the sidescan interpretation.



5.6.8 Optical techniques

Images from video and camera stills were used to characterise the two acoustically distinct areas (i.e. dredged and surrounding area) over time. Initial surveys of images collect in 2001 (Figure 5.49-A) showed the status of the central part of the dredged area. The presence of coarse sediment, clumps of hydroids and aggregations of slipper limpet *Crepidula fornicata* were clearly observed. (Figure 5.49-A). The area was also sampled in 2004, where the increased presence of the limpet *Crepidula fornicata* dominated the central dredged area in conjunction with clumps of hydroids (Figure 5.49-C). In the surrounding area the image showed the presence of megaripples in the first year of the study (Figure 5.49-B). During 2004

the video image also confirmed the characteristics of the site, which showed the same sedimentary features previously observed in the surrounding area. (Figure 5.49-D). Video images were also collected from the west of the dredged area. The sediments here showed the presence of slightly muddy sand with the presence of mussels clumps (*tentative identification from video footage *Mytilus edulis*), *Flustra foliacea* and *Pagurus* sp.

South of the dredged area, slightly gravelly muddy sand sediments with presence of *Crepidula fornicata* were observed. (Figure 5.49-F). Finally, a mixture of sand and gravelly sediments with a high density of *Crepidula fornicata* and empty mussels shells was observed at the southern edge of the dredged area (Figure 5.49-G).

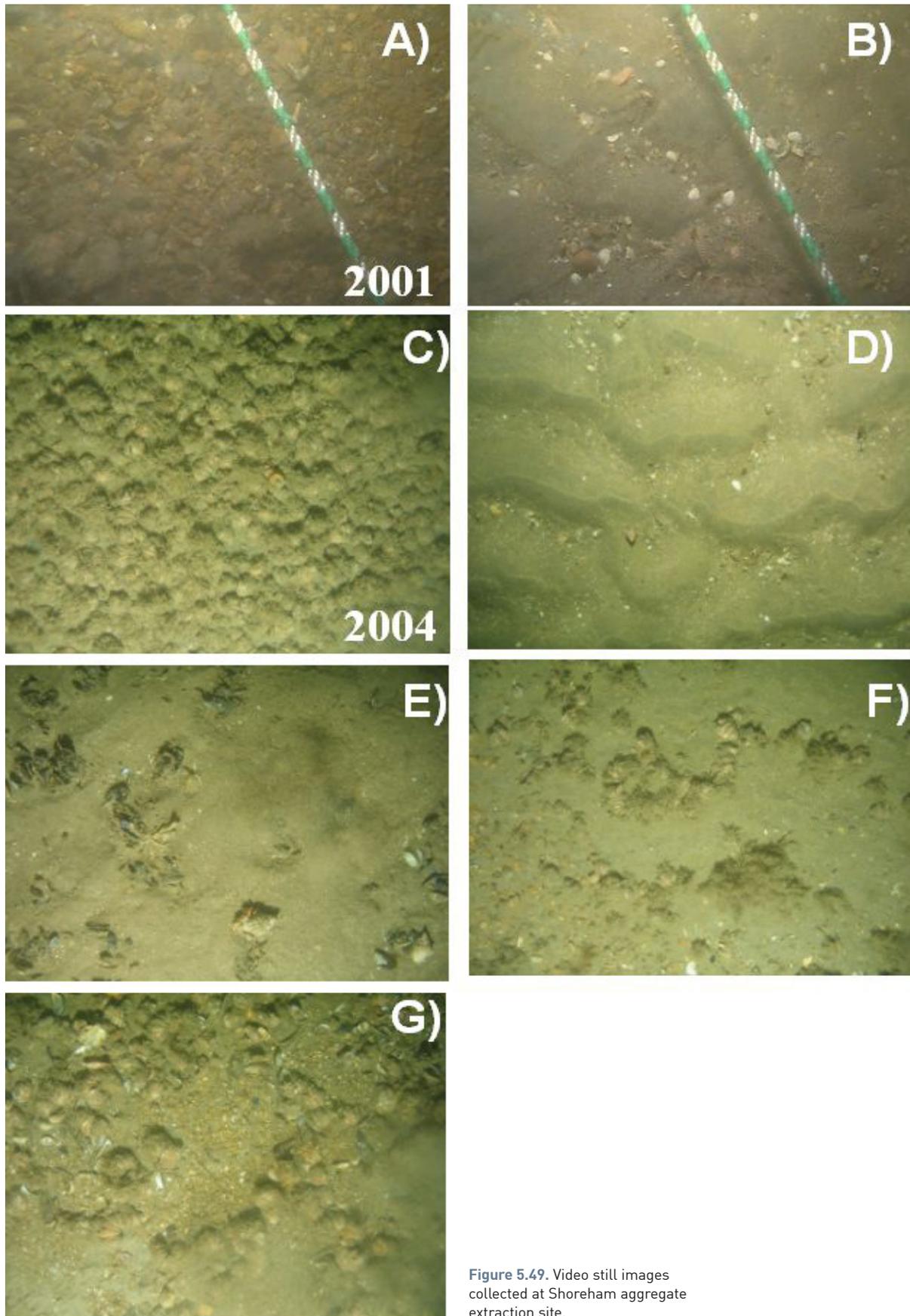


Figure 5.49. Video still images collected at Shoreham aggregate extraction site.

5.7 Discussion

Marine benthic habitats are vulnerable to the influence of a wide range of anthropogenic activities (e.g. dredged material disposal, aggregate extraction, windfarm developments, oil and gas exploitation and fishing impacts). Recent developments in seabed mapping techniques driven by continuous improvements in acoustic systems offer the potential to radically alter approaches to monitoring the impacts of such activities. This study aimed to establish the extent to which such techniques could be routinely applied in environmental monitoring programmes. For this, two scenarios were selected for testing the same suite of techniques (i.e. grabs, trawls, acoustic and optical methods) over a period of 4 years.

5.7.1. Utility of individual techniques

The utility of sidescan sonar

In this study, the use of the sidescan sonar was used primarily to map at high-resolution the distribution of sediments and physical features (e.g. dredged material deposits, sand waves and rock outcrops) in different areas and to provide an indication of the effects of time-dependant variations in the nature and intensity of impacts associated with the disposal of dredged material and extraction of sand and gravel. The results indicate that the output from the sidescan sonar surveys was useful for identifying the footprint of the disposal activity and for discriminating changes in topography associated with marine aggregate extraction.

The use of sidescan sonar techniques has been widely used for: i) benthic habitat mapping, ii) identifying seabed features of observation or resource interest (Van Lancker *et al.*, 2003), iii) determining the spatial relationships between biota and bed-forms and iv) assessing whether organisms influence sediment-transport (Sisson *et al.*, 2002). Limpenny *et al.* (2002) also highlighted the utility of sidescan sonar techniques in areas affected by aggregate extraction sites for assessing the spatial extent and temporal changes to the seabed. In addition, such techniques have been employed as exploratory tools to facilitate the generation of effective site-specific sampling designs (Brown *et al.*, 2002), for example, as part of a pilot study, or in determining the location of representative reference sites against which changes at impacted locations may be compared as part of long term monitoring programmes (Boyd *et al.*, 2004).

One fundamental issue was raised in this study by the conflicting results obtained from the sidescan sonar surveys and benthic sampling. It would appear that although the

bedforms were consistently detected using sidescan sonar over time reflecting disturbed conditions, the sediments and fauna associated with those bedforms are very variable both spatially (over fine scales) and temporally. Whether or not this is the case, designing a survey strategy to detect, describe and measure change (including mapping fauna and sediment distributions) is likely to be problematic in similar heterogeneous environments. With hindsight, a better strategy might have been to identify the well-defined ground types and then select locations to be sampled repeatedly over the years. Of course other combinations of conditions could apply to new survey areas and the implications of each set of conditions would need to be assessed in the initial stages of survey to ensure that the most appropriate survey design is chosen. Designing a strategy to monitor change and distribution patterns (other than fairly gross changes and very broad patterns) would require a larger number of samples to produce results with the required statistical power (see Chapter 8). There are a number of possible explanations for the discrepancy between the results of sidescan sonar surveys and benthic sampling. For example, it may be that the level of total disturbance (natural through hydrodynamics, fishing activity and so on) is high throughout the whole area and it is difficult to separate out the effects of just one source. There may also be a legacy from past disturbance that has had a long lasting effect on community structure.

The utility of SPI

The SPI camera helped to complement the ground-truth data (benthic samples) providing a detailed image of the vertical composition of sediments, the bioturbation activity of the fauna and the general “health status” of the area. The visual information helped to distinguish areas subject to the impacts of dredged material disposal. The main benefit of the SPI technique was the provision of detailed photographic information of the cross-section image of the upper 20 cm of the seafloor, with the advantage of a rapid return of data on biological and physical parameters. Our results compare favorably with those obtained by Rhoads and Germano (1990) who used *in situ* SPI technology to assess the presence of thin layers of dredged material and also to document the efficiency of faunal recolonization and diagenesis of the disposed sedimentary materials. Their findings demonstrated the utility of SPI techniques over a wide area for characterising high-energy dispersive sites, to assess project compliance, to measure short-term impacts and to create a time-series dataset allowing a visual assessment of the physical stability of sediments and infaunal responses to be monitored over time.

The utility of AGDS

In this study the use of AGDS was investigated in some detail. The approach to seabed characterisation using AGDS is pragmatic: the seabed characteristics are determined from the acoustic parameters measured by the apparatus without there being an objective and theoretically substantive link between the acoustic parameters and any particular properties of the sediment (of which there is a long list of potential candidates for affecting the echo, such as porosity, layering, organic inclusions etc). It is sufficient that the acoustic parameters give adequate discrimination between the seabed types as defined by the sampling method, such as grab and video (see Lurton, 2002). This approach is particularly true for QTC but the relationship between E1 (G1) and roughness, and E2 (G2) and hardness is only approximate. In consequence, AGDS cannot 'see' features directly in the same way as sidescan sonar and the acoustic parameters must be analysed and interpreted to reveal features. The ground-truth data are all-important for interpretation of AGDS. Even unsupervised classification of the acoustic parameters must be interpreted through ground-truthing in order to determine the significance of the acoustic ground types that might have been discriminated. It follows from the limitations of classification that AGDS cannot detect feature classes that have not been sampled adequately. The best that classification techniques can achieve under conditions of sparse ground-truthing is to assign areas as being unclassified if the acoustic properties do not match any of the signatures of the feature classes closely. This is in contrast to sidescan sonar where significant features can be discerned directly from the images without necessarily having to ground-truth. This is perhaps the most severe constraint to the use of AGDS and requires a carefully designed ground-truthing strategy. Even limitations on resolution can be accommodated for AGDS, but a low level of ground-truthing can seriously undermine interpretation.

Four main classifications were performed on the AGDS data: (1) unsupervised classification; (2) supervised classification of sediment classes; (3) supervised classification of infaunal classes, and; (4) supervised classification of sidescan sonar bedform classes. The results on the performance of the classification often appear to be contradictory between TY070 and the Shoreham site. For example, unsupervised classification was not particularly successful in discriminating the disposal site, but was moderately successful at the aggregate extraction site at Shoreham. Supervised classification using sediment classes indicated a distinct area of sediment in the dredged material disposal site (although the nature of the sediment

changed from year to year) but very poor delineation of the aggregate extraction area at Shoreham. No distinct infaunal classes seemed to be associated with the disposal site. In contrast, the aggregate extraction site, was quite well delineated by the distribution of the faunal groups although these were not consistent between years. The most successful supervised classification at both sites was obtained using the training sites digitised from the sidescan sonar records. It is significant that the use of the sidescan training sites resulted in an AGDS interpretation that agreed well with the expert visual interpretation of sidescan image. However, this begs the question as to whether the AGDS should be ground-truthing the sidescan images (adding more information to the sidescan) or the sidescan should be ground-truthing the AGDS (used to train the AGDS). Both are possible and true synergy between the techniques might involve feedback from AGDS classification into sidescan through refining boundaries and differentiating apparently similar areas of the sidescan mosaic.

Some of the classification problems must be due to the sampling strategy employed for ground-truthing. This is because the strategy used was not designed specifically to ground-truth the AGDS output, rather sidescan sonar was adopted as the primary acoustic tool for directing subsequent sampling. However, it is clear from all the sources of information (AGDS, infauna, sediment and, to some extent, the sidescan images) that the Tyne dredged material disposal site was very heterogeneous with no consistently clear delineation of the licensed disposal site whilst the aggregate extraction activity at the Shoreham site was more clearly marked. There are also remarkable apparent changes in fauna and sediment over the sampling period in both survey areas. The most consistent patterns are the bedforms. Thus, the success of AGDS combined with limited ground-truth sampling must be judged against this background of heterogeneity: It is unlikely that this strategy would successfully predict the distribution faunal or sediment classes where the ground was heterogeneous at a fine scale (although broader spatial trends might be detected).

The utility of multibeam bathymetry

This study also benefited from the use of multibeam techniques to survey both study sites. Kenny *et al.* (2003) highlighted the major advantages of multibeam echo sounders over sidescan sonar. Multibeam techniques can generate quantitative bathymetric data that are more amenable to classification and image processing. In this study, the multibeam information helped to resolve bed

slopes and clearly provided valuable corroboration of sidescan characteristics. Evidence of topographic features at the dredged material disposal site (e.g. coal galleries, anchor scars) were distinct from the multibeam imagery. Furthermore, at the aggregate extraction site the presence of natural features (e.g. megaripples and paleovalley edges) and disturbance (i.e. furrows and dredged pits) from the two methods of aggregate extraction were also obvious using this technique. Multibeam techniques are currently being widely employed both in the U.K (see for example, James *et al.*, 2005; Philpott *et al.*, 2005) and elsewhere (e.g. Kostylev *et al.*, 2001) and therefore, promising outcomes can be expected for further applications of these techniques.

5.7.2 Utility of an integrated approach.

At TY070, sidescan sonar and AGDS surveys revealed the presence of acoustically distinct areas over the study site. Examination of these data revealed an area of the seabed within the disposal site, which was characteristic of disposal activity. Ensonification of other substrata present over the survey area also demonstrated some agreement between the output of the two different acoustic systems. At the Shoreham site, the sidescan sonar record showed that, since the 2001 survey, trailer suction dredging activity in the south of the region had encroached further northward into the area of active static suction dredging. The sidescan sonar and multibeam imagery enabled rapid coverage of large areas of seafloor, providing information on the physical characteristics of the seabed and the footprint of disposal/aggregate extraction activity. At a smaller spatial scale, a video camera attached to the Hamon grab provided instantaneous information on the nature of the seabed adjacent to the sampled sediment, but gave little indication of the wider anthropogenic impact evident from the larger scale sidescan sonar mosaic. A new digital video recording system utilised during later surveys also improved the quality and ease of image capture. The combination of acoustic, optical and conventional ground-truthing techniques, proved to be successful for characterising macrobenthic assemblages and sediments within and in the vicinity of a dredged material disposal site and at an aggregate extraction site. The utility of combining the 3 approaches, in the present study, has been demonstrated by obtaining rapid, representative and accurate information for assessing the site-specific effects of both dredged material disposal and aggregate extraction operations. Humborstad *et al.* (2004) highlighted the utility of sidescan sonar and other acoustic techniques such as the RoxAnn-ground discrimination system for

providing information about the actual composition of the seabed, e.g. the presence of small features that could be targeted for ground-truthing. In this study benthic samples, surface video images and the SPI camera were all successfully employed for this purpose, providing the necessary information for characterising different acoustic areas and for determining changes in the composition of fauna and sediments over time. The use of such an integrated mapping approach appears to be of particular value when assessing anthropogenic effects in areas of known habitat heterogeneity, and for providing baseline information for future monitoring exercises in the region. Although the initial results are encouraging there is still further work needed in order to establish robust approaches for routine application as part of existing monitoring responsibilities. It is, however, clear that the integration of such tools provides a robust approach for assessing temporal changes in the nature and intensity of anthropogenic impacts. The adoption of such an approach involving acoustic and optical techniques may therefore improve the design of monitoring programmes through the provision of information concerning the physical nature of the seabed and could also aid, supplement or even replace ongoing environment assessment techniques reliant upon conventional approaches.

6. Implications of biogeographical variations in community composition for predictive mapping

6.1 Introduction

The geographical distribution of an individual species is governed by a combination of its ecological requirements (e.g. habitat, food supply) and its tolerance of physical environmental variables (e.g. temperature, salinity, desiccation, current speed etc). Closely related species usually have similar ecological requirements and so are restricted to certain habitat types (e.g. rocks or sands) but can often exhibit different environmental tolerances, so have different geographic distributions. Consequently, when similar habitats are compared across geographically separate areas, the general structure of the community may be similar in terms of the types of organism present, but the specific structure may differ in terms of the species present, and this will clearly have implications for predicting species assemblages over broader spatial scales.

Another aspect of predictive mapping relates to attempts to forecast the likely distribution of particular species of conservation importance. This requires detailed knowledge of the autecology of the species concerned, i.e. its habit, life cycle, biogeographic range and limiting environmental conditions (depth, salinity, temperature, current speed/exposure etc). A recent and well publicised example is that of the deep/cold water coral species *Lophelia pertusa* (hereafter referred to as *Lophelia*) which, under the right conditions, builds reefs that structure the local environment and provide habitat for other organisms, so forming 'pockets' of high biodiversity. ROV observations in the Porcupine Sea Bight (Irish Sea) have documented significant damage caused to *Lophelia* reefs by deep-water fisheries, such as those targeting orange roughy (*Hoplostethus atlanticus*), leading to calls for the urgent implementation of appropriate conservation measures under the Common Fisheries Policy (Greehan *et al.*, 2004). These measures need to be directed towards areas of *Lophelia* habitat, but in the absence of full and detailed knowledge of its distribution, great reliance will be placed on predictive mapping. Until recently, *Lophelia* reefs were generally considered to be restricted to deep-water sea mounts and fjords, but in the last few years the autecology of the species has become far better understood, and temperature, current and substrate type are now recognised as the major determinants of its distribution. With a preference for temperatures of 4 to 12°C in strong currents with oceanic waters and salinities of 34 to 35 ppt, the potential distribution of *Lophelia* is far wider than previously thought and such predictions have largely been borne out with the discovery of new colonies, some at depths as shallow as 75 metres (Rogers, 1999;

Roberts, 2002). This knowledge will improve the accuracy and precision of predictive mapping of *Lophelia* habitat, helping to ensure that conservation policy is applied without unduly restricting commercial fishing practices.

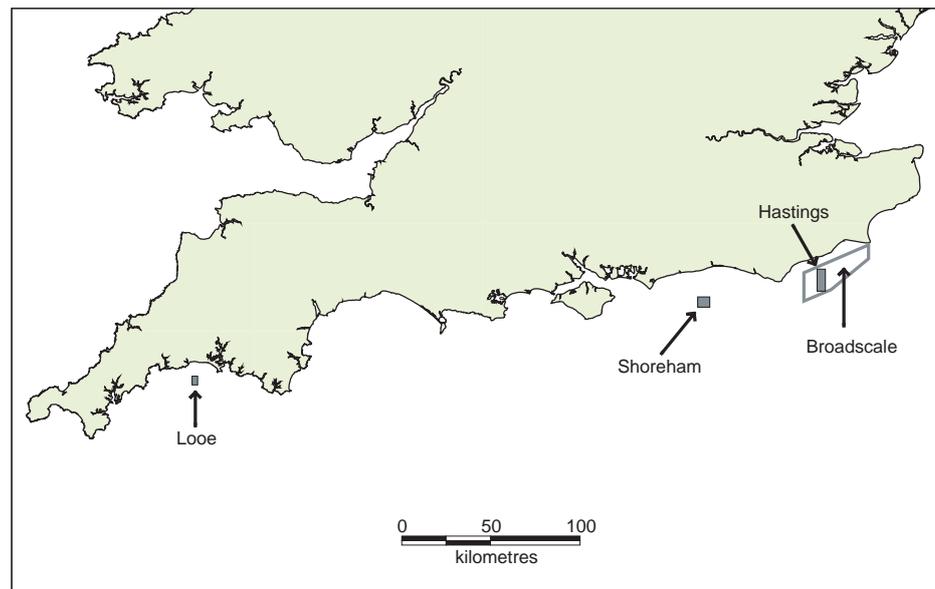
There are therefore two related but separate issues concerning predictive mapping, one focusing on the probability that a particular species of interest will exist at a nominated site and the other on a more generalised forecast of the community composition in physically similar but geographically separate habitats. We addressed the latter of these issues, taking an example of the English Channel where there is a recognised biogeographical trend from west to east reflecting changing environmental parameters (Holme, 1961, 1966). In general, the western Channel is deeper (max 100 m) with finer bioclastic sediments, while the east is shallower (40 m in the Dover Strait) with mostly coarser lithoclastic sediment (gravels). Waters in the west become stratified in the summer (weak currents), while those in the east remain well mixed due mainly to turbulence caused by stronger currents. Many benthic species are restricted to the west, and fewer restricted to the east (Holme, 1961, 1966; Pawson, 1995; Rees *et al.*, 1999; Stanford and Pitcher, 2004). This part of the project examined how this known biogeographical variability was manifest in the community structure at comparable sites in the west and eastern regions of the Channel and considered the implications this has for the approach to and efficacy of predictive habitat mapping.

6.2 Methods

Four sites in the English Channel were surveyed in 2003 (Figure 6.1). Three of these sites in the eastern Channel have been discussed in earlier sections of this report, namely those at Hastings and Shoreham, and the broadscale study area between Hastings and Dungeness. The fourth site, in the western Channel due south of Looe, was selected on the grounds that the BGS seabed sediment chart for the area showed the site has similar substrates (sandy gravels and gravelly sands) to the sites in the eastern Channel. The standard survey methodology was applied, using sidescan sonar to identify acoustically distinct areas and ground-truthing those areas using a 0.1 m² Hamon grab to provide samples for PSA and macrofaunal analyses, which were conducted following the routine procedures detailed earlier in this report.

Data from all four sites were collated and the PSA data examined with a view to filtering out sampling points where the actual sediment type departed from expectation. Such departure was to be anticipated as the Hamon grab sampled

Figure 6.1. Location of the four sampling sites in the English Channel



at a very small spatial scale whereas the 1:250,000 BGS sediment charts give a broad interpretation of sediment distribution over much larger spatial scale, and would not be expected to detail small scale variability or patchiness. A sub-set of samples representing sandy-gravelly sediments was selected, based on the criteria that PSA data showed the samples contained 10-50% gravel. [Sand content lay in the range 44.8 – 88.1%, mud 0.3 – 15.6%].

The structure of a community is defined by two factors, namely the variety of species present and their relative abundance. Species lists for each site were compared to assess macrofaunal specificity; i.e. how many of the taxa were unique to each site and how many were common between sites. The (dis)similarity between the species lists for the four sites was visualised by a graphical representation using MDS ordination on presence/absence data.

Taxa that are present in extremely low abundance were eliminated to identify the 'core' elements of the community. Site-specific variability in abundance was assessed using MDS ordination to visualise the (dis)similarity between sites and samples, and how that (dis)similarity pattern altered under two data modifications:-

- i) as the rarer species were eliminated and
- ii) as the abundance data were aggregated to progressively higher levels of taxonomic identification (Genus, Family, Order, Class, Phylum).

The underlying premise of these analyses was that if the core structure of the community remained more or less constant, despite any biogeographical variability, there would be few implications for predictive mapping. Species that were exclusive to particular sites would obviously have a high leverage in discriminating between sites, but the occurrence of exclusive or rare species does not necessarily constitute a fundamental change in the nature of the community; rather it flags a local variant of a more general habitat or biotope type.

The extent of any linkage between geographical patterns in community composition and the underlying

environmental variables was examined using the BIO-ENV and RELATE routines in PRIMER, considering sediment composition and depth at each of the sampling stations. Sediment grain size was classified on a five point scale (gravel, >2 mm; coarse sand, 2 mm – 500 µm; medium sand, 500 µm – 250 µm; fine sand, 250 µm – 63 µm; mud, <63 µm), with composition expressed as percentage values for each size category, the data being log transformed to reduce skewness. Depth of water was measured in metres, and the PSA and depth data normalised to place both on a dimensionless scale.

6.3 Results

Thirty of the 65 stations sampled across the four sites satisfied the selection criterion of having 10-50% gravel content. Principal component analysis of the percentage gravel, sand and mud in the retained samples showed a fairly even spread of points (Figure 6.2), the absence of site-specific clusters indicating that none of the sites was radically dissimilar in terms of sediment composition. There was some indication that samples from Looe tended to have a higher mud content than those from the eastern Channel sites.

A total of 331 macrofaunal taxa were recorded from the 30 stations. The species composition of macrofaunal communities was considerably different between western and eastern Channel sites (Table 6.1). Not only were there a greater number of taxa at Looe, but 52.6% (102/194) were specific to that site and accounted for just over 20% of the total macrofaunal abundance. Some taxa were specific to each of the eastern Channel sites, despite the fact that they were not as spatially separated from each other as they were from the Looe site. Pooling data for the eastern Channel sites showed that 59.8% (137/229) of the taxa were specific to the eastern area. Many of the taxa were present in low abundance, 36% being represented by a single specimen, and 72% by five or fewer individuals (Figure 6.3).

Figure 6.2. Ordination of principal component analysis for the sediment samples from the 30 sites in the English Channel selected for analysis. PC1 accounted for 66% of the variability and represented different mixtures of sand and gravel (which were inversely related). PC2 accounted for 34% of the variability and represented an increasing mud component.

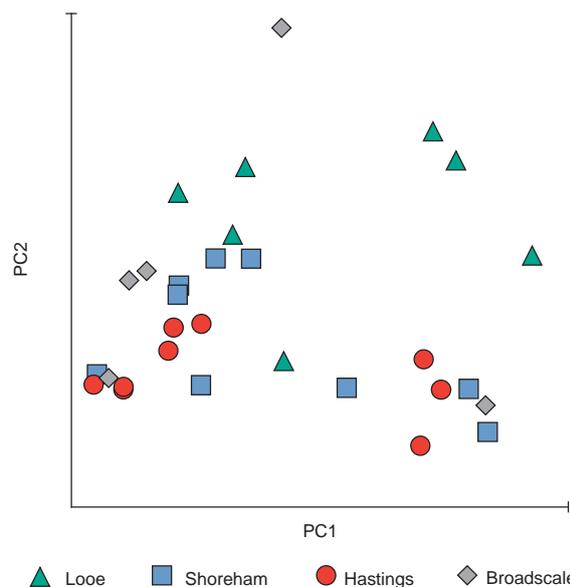


Table 6.1. Summary data relating to the list of macrofaunal taxa (excluding colonial forms) recorded at each of four sites in the English Channel, giving the number of taxa specific to each site and the percentage of the total abundance they accounted for. Also, the same data for all of the eastern Channel sites pooled together (Looe was the only site in the western Channel).

| | Depth range (m) | Number of samples | Number of taxa recorded | Number of taxa specific to site | % Abundance |
|----------------|-----------------|-------------------|-------------------------|---------------------------------|-------------|
| Looe (West) | 50-56 | 7 | 194 | 102 | 20.4 |
| Shoreham (E) | 24-40 | 9 | 138 | 36 | 5.1 |
| Hastings (E) | 16-48 | 9 | 127 | 32 | 3.0 |
| Broadscale (E) | 20-35 | 5 | 121 | 25 | 4.1 |
| East (pooled) | 16-48 | 23 | 229 | 137 | 59.0 |

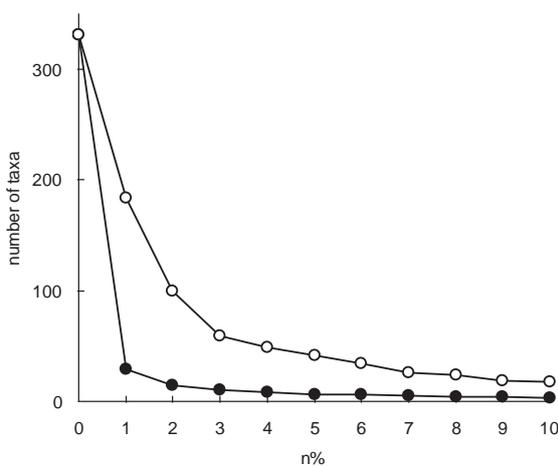
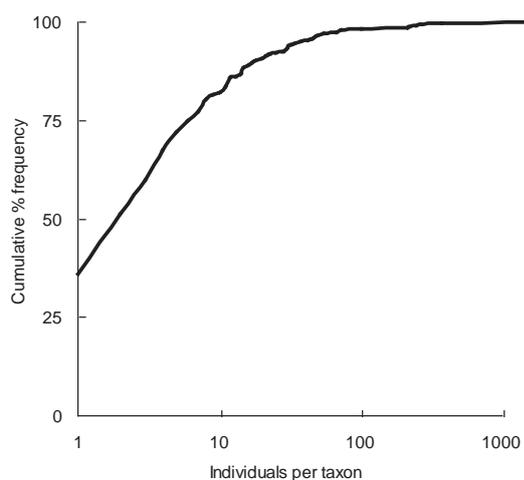
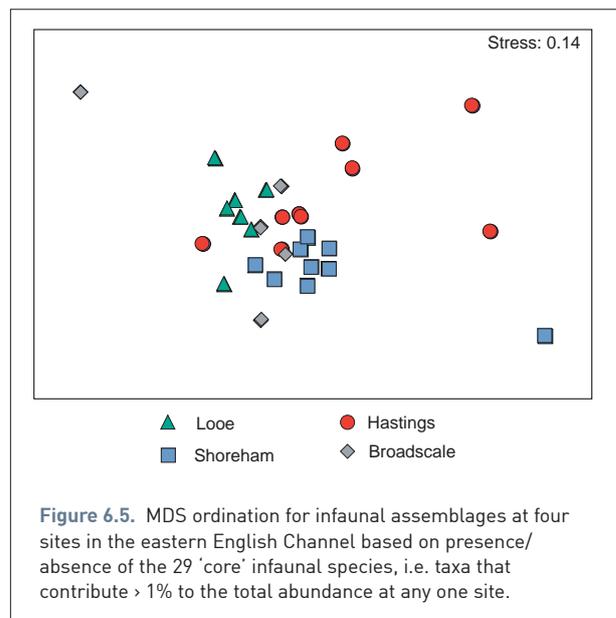
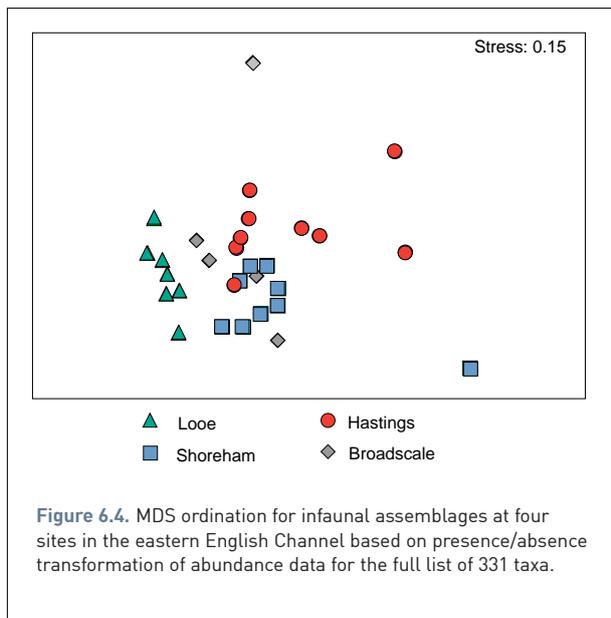


Figure 6.3. Two indications of the high proportion of taxa having low abundance. Cumulative plot (left) showing 36% of the 331 taxa were represented by a single individual (82% by fewer than 10 individuals). Also, the effect on the taxon list of progressively eliminating rarer taxa (right), i.e. retaining only those taxa contributing >n% of the total abundance in any one sample (open circles) or any one site (closed circles).



The relationship between the four sites in terms of the specificity of their taxa was visualised by MDS ordination of the Bray-Curtis similarity matrix calculated for presence/absence data (Figure 6.4). This is essentially a graphical comparison of the species lists for each sample. Samples from Looe formed a distinct cluster somewhat removed from the samples collected in the eastern channel, and some separation is evident between the Shoreham and Hastings samples, even though these sites are only 65 km apart. Four samples appear to be 'outliers' of the main group. Three of these represent samples with very low numbers of species (the outlier from Shoreham having two species, one from Hastings having nine, and that from the Broadscale area having seven). The other outlying Hastings sample contained two species that did not occur in any other sample. However, in general, there is a distinct biogeographic variation in the full species list between the west and eastern sites and a lesser but notable variation among the eastern sites.

The inclusion of poorly represented taxa in macrofaunal data-sets often does not greatly influence the outcome and subsequent multivariate statistical analyses, so in some circumstances it is justified to remove them from data-sets prior to analysis. Retaining only taxa that contributed >1% of the total abundance at any one site had a marked effect on the species list, reducing it from 331 taxa to just 29 (Figure 6.3). When the previous analysis is repeated for these 29 taxa (Figure 6.5) there is a marked reduction in the dissimilarity between the western and eastern sites, indicating a higher degree of consistency (low biogeographical variability) in the species composition of the core community. Table 6.2 lists these 29 core taxa and their occurrence at each of the sites. They comprise 25 Families in 16 Orders, compared to 145 Families in 55 Orders in the full list of 331 taxa. Nineteen of the core taxa were present at all four sites, five were specific to the eastern Channel sites and one to the western Channel.

The effects of data reduction on the analysis of sample similarity are presented in Figure 6.6. These analyses are based on raw abundance data, rather than presence/absence. A further selection has been made, retaining taxa that contributed >1% to the total abundance in any one of the 30 sampling stations (rather than any one of the four sites, as above), which reduced the taxon list from 331 to 184 taxa. Consequently, three levels of elimination of rarer species were considered: none (retain 331 taxa), <1% for 30 stations (retain 184 taxa) and <1% for 4 sites (retain the 29 'core' taxa). Additionally, the effect of aggregating data to higher levels of the taxonomic hierarchy was examined. No transformation was applied to the abundance data when calculating the Bray-Curtis similarity matrix as this would have had the effect of increasing the influence of rarer taxa and counteracting the measures already taken to progressively eliminate them from the data.

The baseline relationship between samples is indicated by upper left MDS plot in Figure 6.6 (no aggregation : 331 taxa) and showed a distinct cluster for the western Channel samples (Looe site) that was slightly removed from the points for the Eastern Channel samples which did not form site-specific clusters. The elimination of rarer taxa and/or the aggregation of taxa to Family level did not have marked effect on this baseline pattern. Significant effects only became apparent when taxa were aggregated to Order or Class level. At the Order level, inclusion of all the taxa tended to mask the differences between the east and west Channel sites, but this was restored as rare taxa were progressively eliminated. At the Class level, there was no evidence for a systematic difference between the biogeographic regions.

BIO-ENV analysis showed a weak correlation between environmental variables (the five sediment grain size classes and depth) and the biotic pattern at the four sampling sites. Abundance data for the full set of 331 taxa

Table 6.2. Presence/absence of taxa representing the 'core' of the macrofaunal community at four similar sites in the English Channel. Of the original list of 331 taxa, only these 29 contribute >1% of the total abundance at any one site. 1=present, 0=absent; W=western channel, E=eastern Channel.

| Taxon | Looe (W) | Shoreham (E) | Hastings (E) | Broadscale (E) | Present at # sites |
|--------------------------------|----------|--------------|--------------|----------------|--------------------|
| <i>Abra alba</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Cerianthus lloydii</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Clymenura</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Echinocyamus pusillus</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Ehlersia cornuta</i> (agg.) | 1 | 1 | 1 | 1 | 4 |
| <i>Glycera lapidum</i> (agg.) | 1 | 1 | 1 | 1 | 4 |
| <i>Lagis koreni</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Lanice conchilega</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Lumbrineris gracilis</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Mediomastus fragilis</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Mysella bidentata</i> | 1 | 1 | 1 | 1 | 4 |
| NEMERTEA | 1 | 1 | 1 | 1 | 4 |
| <i>Notomastus</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Owenia fusiformis</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Poecilochaetus serpens</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Polycirrus</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Praxillella affinis</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Scalibregma inflatum</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Spiophanes bombyx</i> | 1 | 1 | 1 | 1 | 4 |
| <i>Balanus crenatus</i> | 0 | 1 | 1 | 1 | 3 |
| <i>Pomatoceros lamarcki</i> | 0 | 1 | 1 | 1 | 3 |
| <i>Sabellaria spinulosa</i> | 0 | 1 | 1 | 1 | 3 |
| <i>Ophiura</i> | 1 | 0 | 1 | 1 | 3 |
| <i>Photis longicaudata</i> | 1 | 1 | 0 | 1 | 3 |
| <i>Magelona johnstoni</i> | 0 | 0 | 1 | 1 | 2 |
| <i>Ophelia borealis</i> | 0 | 1 | 1 | 0 | 2 |
| MAXILLOPODA | 1 | 1 | 0 | 0 | 2 |
| <i>Polydora caeca</i> (agg.) | 1 | 1 | 0 | 0 | 2 |
| <i>Aponuphis bilineata</i> | 1 | 0 | 0 | 0 | 1 |

was transformed (4th root) to give greater weight to the rarer species as these would, intuitively, be most sensitive to geographical differences in environmental variables. The suite of variables that best explained the biotic structure were depth and the proportions of coarse and fine sand (Spearman's rank correlation coefficient = 0.25), but the

correlation was not significant at the 5% level (RELATE procedure). Although PCA analysis had indicated that sediments at Looe had a higher mud content than at other stations (Figure 6.2), this was clearly not having a marked influence on the biogeographic variability within the selected samples.

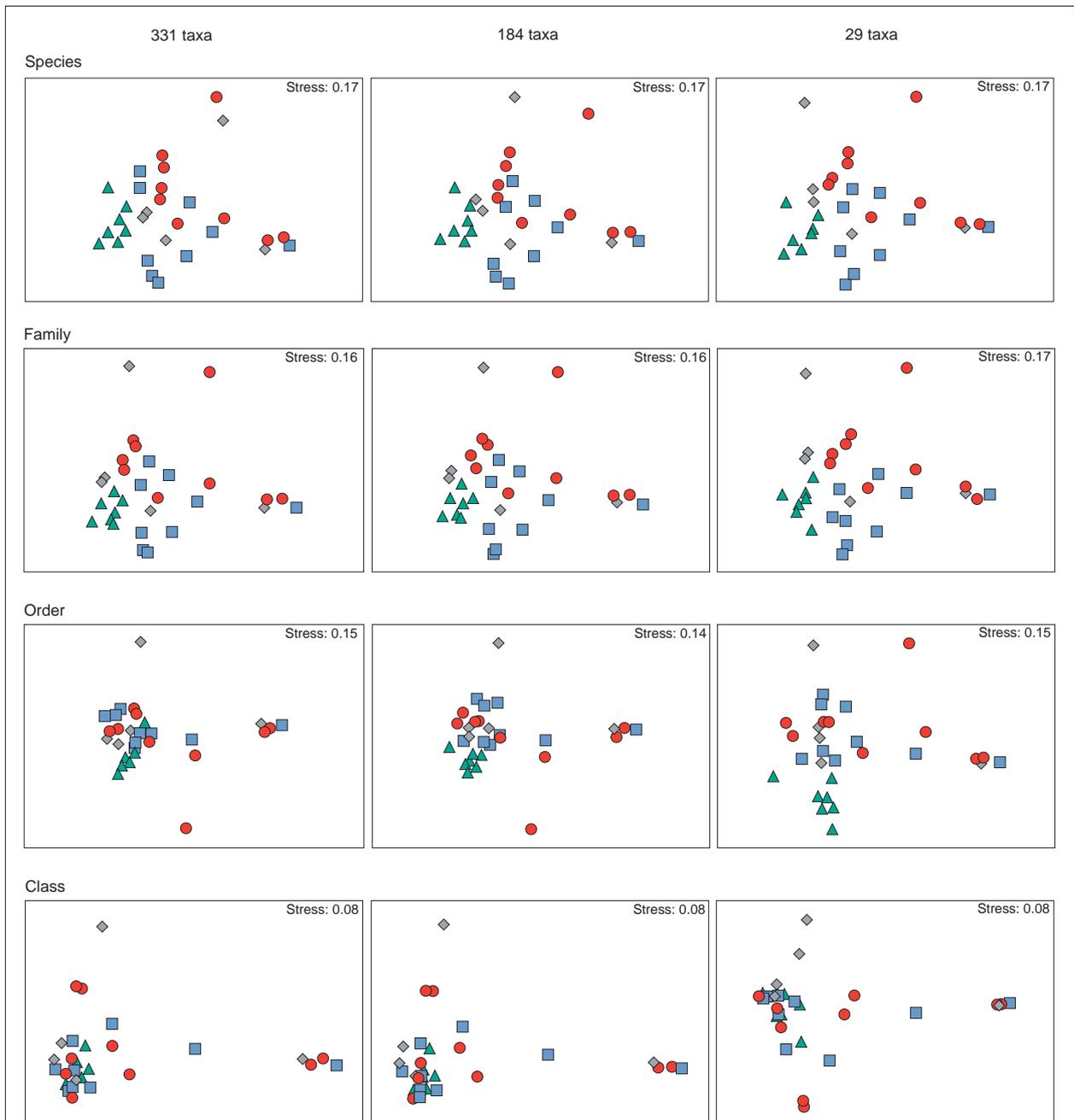


Figure 6.6. Effect of data selectivity and aggregation on MDS ordinations for infaunal samples from four sites in the English Channel. Three columns represent progressive elimination of rarer taxa (from full data set of 331 taxa to 'core' species of 29 taxa). Four rows represent progressive aggregation of abundance data to higher taxonomic levels. All plots based on Bray-Curtis similarity matrix of untransformed abundance data. (Key to stations as in previous diagrams).

6.4 Discussion

The analyses confirm that a biogeographic variation exists between sites of similar substrate in the western and eastern Channel, and indicate that the dissimilarity between sites was due mainly to the presence/absence of less common taxa. Selecting-out these rarer species identified the core component of the community which was less prone to biogeographic variability. This core component would be suitable as a basis for confidently predicting the more common species associated with this habitat type in the English Channel.

Any prediction must be made on the basis of a model (otherwise it is merely a guess) and it follows that the accuracy of the prediction is reliant on the robustness of that model. In the analyses above, we based our model of the core community on information from both western and eastern Channel sites. Had the model been based solely on the eastern Channel sites, our prediction would have been that the points on the MDS plot in Figure 6.6 that relate to the samples from Looe would fall within the scatter of points from our 'model' sites at Shoreham, Hastings and the broadscale area. Clearly, that prediction would have been inaccurate as the points for Looe actually lie slightly outside the scatter of the other points, indicating that our model was not sufficiently robust. Incorporating the Looe samples in the model would effectively 'widen the franchise', conferring greater reliability on the model and greater confidence in its efficacy for prediction within the English Channel.

In any model-based prediction there is a trade-off between accuracy and precision. Had we made a less precise prediction based on the western Channel model, and forecast only the Order or Class of taxa to be found at Looe, then the prediction would have proved accurate as at these taxonomic levels the points for Looe do lie within the spread of points from the three model sites. Accuracy and precision are therefore two factors to consider in terms of the confidence of predictively mapping communities. The implication of biogeographical variability is that the model used to make the prediction must be derived from data and knowledge covering an appropriate spatial area, i.e. precise predictions should not be made outside the geographical bounds of the model, so local models should not be applied on a regional basis. In order to project outside the bounds of the model, a compromise needs to be made in terms of the precision of the prediction if confidence is to be maintained (as community structure becomes progressively invariant at higher taxonomic levels).

Another approach to generalised prediction of communities is to eschew taxonomic identity altogether

and instead to describe the community in terms of its functional structure. This approach has recently gained prominence through a body of work on 'biological traits analysis' (Bremner *et al.*, 2003, 2004), the structure of a community being described by the traits of the component organisms. Using this system, a habitat description might be '*sandy muddy gravel dominated by emergent sessile filter feeders, predatory and scavenging macro-epifauna and shallow burrowing infauna, with cobbles and boulders characterised by encrusting and foliate colonial organisms*'. Such categorisations are generally insensitive or resistant to geo-spatial variability in physical and biological factors and so would enable predictive mapping at near- and far-field scales. A significant limitation of this approach for spatial planning is that there is currently insufficient understanding or appreciation of the value of many of these 'functional communities' to the wider ecosystem, so we are not generally well placed to advise on their conservation value. However, recent moves towards an ecosystem approach to management has given rise to many ecosystem-based studies, such as those into essential fish habitat, and as our understanding of the interrelation between functional community types improves so will the utility of their application in predictive mapping and marine resource management.

The BIO-ENV analysis detailed above revealed only a weak correlation between the available data on environmental variables and the observed biotic pattern over the four Channel sites. It would therefore appear that other environmental variables, such as temperature and/or current speed (near-bed shear stress), will be more prominent agents in causing biogeographic variability. Holme (1961) described a strong temperature gradient in the Channel, with an annual range at the seabed from 9 to 12°C in the west and 6 to 16°C in the east. Tolerance to temperature minima, maxima and rate-of-change are well known determinants of species distribution, both in the horizontal and vertical planes (i.e. Latitude/Longitude and depth), along with other factors that affect the physical and physiological functioning of an organism (e.g. salinity and shear stress). Any model used for predictive habitat mapping would therefore benefit from the inclusion of these, and other, environmental parameters as this would enable the model to be fine-tuned, to include or exclude taxa on the basis of their resistance to or tolerance of variable oceanographic conditions. It would take some considerable effort to experimentally determine limiting values for these variables for the thousands of marine benthic species recorded in the north-east Atlantic, but much can be achieved by correlating the known variability in these parameters with the known distribution of species.

There is, however, a danger in becoming too focused on precise detail and it is important to remain aware of the objectives that underpin the requirement for predictive modelling. It is not intended to be highly specific, but rather to provide a more general indication of habitat type to enable a forecast to be made of the range of biotopes that might exist in an, as yet, un-surveyed area. Biotope descriptions tend to be imprecise, partly as a consequence of biogeographic variability and local heterogeneity, as seen in the extract of the JNCC biotope classification for a circalittoral muddy mixed sediment given in Figure 6.7. This type of classification is less sensitive to geo-spatial variability in physical and biological factors and is more suited to predictive mapping at regional (i.e. western English Channel) or provincial scales (e.g. Channel, Celtic Sea, North Sea). Any predictive mapping must take account of regional and provincial variations in species occurrence, modifying the finer detail within the biotope description according to the known species list for the target area. The existing JNCC biotope classification (Connor *et al.*, 2004) tends to focus on epifaunal and emergent species as they are derived largely by direct observation in near-shore waters, supplemented by some sample analysis. Consequently, they can be difficult to match to benthic ecological data from more distant offshore and shelf waters (> 6 NM from shore) which necessarily employ a different approach to surveying,

focusing primarily on analysis of infaunal grab or core samples, that can only rarely be supplemented by 'direct' camera observation of the sea bed surface. Small trawls can be used to sample epifauna, but this is highly unsatisfactory as there is currently no routine way of ensuring that the trawl selectively samples a single biotope rather than dragging through several adjacent biotopes or habitats. There is consequently an urgent need to further develop habitat and biotope classification for offshore waters with a level of detail or resolution that is fit-for-purpose in predictive mapping.

A further complication is inherent in the 'biotope classification' approach, in that it implies benthic communities are comprised of a patchwork of discrete ecological units (biotopes), a concept that does not fit easily with the more common observation of a continuum of change between adjacent assemblages. Two conceptual approaches that may be useful in addressing this problem are the consideration of biotope 'complexes' (i.e. several closely related biotopes existing in a habitat), and the modelling and prediction of assemblages on the basis of probability theory (e.g. Souissi *et al.*, 2001). This latter approach is described in detail in Chapter 7.

When considering the future predictive capability of geophysical mapping tools it is important to recognise the limitations of these techniques imposed by the laws

Code **SS.SMX.CMx.CIlOmx** = ***Cerianthus lloydii* and other burrowing anemones in circalittoral muddy mixed sediment**

Habitat classification

Salinity: Full (30-35ppt)

Wave exposure: Exposed, Moderately exposed, Sheltered, Very sheltered

Tidal streams: Moderately strong, Weak, Very weak

Substratum: Sandy muddy gravel

Zone: Infralittoral, Circalittoral

Depth band: 5-10 m, 10-20 m, 20-30 m

Biotope description

Circalittoral plains of sandy muddy gravel may be characterised by burrowing anemones such as *Cerianthus lloydii*. Other burrowing anemones such as *Cereus pedunculatus*, *Mesacmaea mitchellii* and *Aureliania heterocera* may be locally abundant. Relatively few conspicuous species are found in any great number in this biotope but typically they include ubiquitous epifauna such as *Asterias rubens*, *Pagurus bernhardus* and *Liocarcinus depurator* with occasional terebellid polychaetes such as *Lanice conchilega* and also the clam *Pecten maximus*. *Ophiura albida* may be frequent in some areas, and where surface shell or stones are present ascidians such as *Ascidella aspersa* may occur in low numbers

Figure 6.7. Extract from the JNCC Marine Biotope Classification for Britain and Ireland (internet version 04.05, accessed March 2005) giving habitat classification and biotope description for one community found in circalittoral muddy mixed sediments.

of physics. Remote sensing technologies rely on the reflective properties of the materials they sense, and those properties differ according to the density of the material and the wavelength of the incident energy. Denser materials are more reflective, while energy is more easily reflected the shorter its wavelength. The density of living organisms is such that they reflect the majority of light energy (shorter wavelength) but are transparent to the majority of sound energy (longer wavelength), so they are strongly detected by optical methods but only weakly detected by acoustics. For many years this weak acoustic reflection has been successfully exploited in the detection of schooling and swarming pelagic and demersal organisms (e.g. scombrid, clupeid and gadoid fish, and 'krill') by fishers and scientists alike, but technical limitations have so far prevented the wide-spread application of acoustic techniques in the detection of benthic organisms, as their weak acoustic signal is considerably overwhelmed by the far stronger reflectance of the (denser) seabed substrates that surround them. Consequently, with the exception of a few significant cases, it is not possible to characterise the acoustic signature of benthic communities, so existing techniques can not generally be used for direct predictive mapping. The exceptions are, however, extremely important.

Dense accumulations of organisms such as biogenic reefs or sea-grass beds can produce an acoustic signal that differentiates them from the surrounding sediments, so they could be amenable to predictive habitat mapping by geophysical remote sampling techniques. Biogenic structures like *Sabellaria* and *Lophelia* reefs, or *Modiolus*, *Posidonia* and maerl beds, are attributed as being of great conservation value on account of their high biodiversity and sensitivity to disturbance. Accordingly they are listed among the primary candidates requiring protection under existing legislature ("Annex I Habitats") and will be a principal consideration in the formulation of marine policy and implementation of marine resource management. Although detectable, the specific acoustic signature of these structures is difficult to determine from standard acoustic techniques and their identification is currently reliant on ground-truth sampling. Nevertheless, recent advances in acoustic technology have provided state of the art techniques with far greater resolving and discriminatory power, and it is now a matter of developing their application and interpretation in order to recognise and catalogue the characteristic 'fingerprint' of these important habitats.

The future is also promising for soft-substrate habitats where acoustic signals penetrate the sediment but are reflected by denser inclusions such as bivalve shells, or density discontinuities like the burrows of the Norway

lobster, *Nephrops norvegicus* (a commercially valuable species). The acoustic signatures of these sediments would differ according to the relative abundance of the population, so it is theoretically possible to characterise areas of high population density. These deep mud habitats are of increasing commercial importance as fishing effort moves away from pressured fin-fish stocks and so also require special consideration.

For the majority of habitats that exist in the coarse and mobile sediments which cover much of the area of the continental shelf, it remains the case that acoustic techniques can not discriminate them on the basis of their community composition. It is also the case that acoustic techniques have difficulty discriminating some sediment types from others, which may be important in a biological context such as the gradation from a sand to a mud. This highlights the critical importance of ground-truthing acoustic surveys by direct sampling and, where possible, direct observation to build up our knowledge of the association between the biological, chemical and physical components of the ecosystem. Where we can demonstrate strong associations, the nature of the sediment can be used as a proxy for the nature of the biotic community, which confers an immense utility on geophysical mapping tools that can survey the seabed at spatial scales many magnitudes higher than that occupied by a single benthic organism. At these spatial scales, biogeographic variability in community composition can be significant. Therefore, predictive mapping must either account for that variability (in the case of specific or precise predictions) or maintain accuracy and confidence by modifying the prediction to a level of precision that is appropriate to the characteristics of the model.

7. Predictive mapping of marine fauna and seabed communities

7.1 Introduction

One of the main impediments to the development of maps showing the distribution of marine seabed fauna, biological assemblages, and the communities they form is the high costs associated with data collection and processing. Remotely operated vehicles and acoustic technologies offer a relatively rapid (and therefore lower cost) means of developing 100% coverage maps of conspicuous epifaunal populations, but only over relatively small spatial scales (Kenny *et al.*, 2003). When mapping over larger areas of seabed, the distribution of marine fauna often needs to be predicted at unknown locations through interpolating biological information from discrete samples. As part of this process, maps of abiotic surrogates can be used to infer biological distributions based on predefined, empirical relationships between marine fauna and their physical environment. Despite concerns over the reliability of abiotic surrogates (Stevens and Connolly, 2004), these methods offer an alternative to ground-truthed acoustic maps of the seabed (see earlier Chapters) for constructing maps of marine species and community distributions.

A large number of spatial prediction methods are available. The more objective of these rely on the use of regression-based techniques to first estimate the relationship between a biological variable, such as measured abundance of a marine species, and one or more physical factors. Digital maps of those same physical factors, typically held in a Geographic Information System (GIS), can then be used to predict the species' distribution and abundance. The merits and pitfalls of the various techniques in this rapidly growing area of numerical ecology are discussed in a number of reviews and dedicated books, such as those of Guisan and Zimmerman (2000), Boyce and McDonald (1999), and Scott *et al.* (2002). In Section 7.2 below we describe one of these modelling techniques, quantile regression, and use it to predict the distribution of adult sole in the eastern English Channel (EEC) from discrete biological samples and associated physical parameters. Quantile regression has over recent years received increasing attention owing to a number of unique properties that set it aside from more commonly used modelling techniques, such as generalised linear and generalised additive modelling (GLM and GAM respectively). In addition to a number of advantageous statistical properties, quantile regression can limit the degree to which the value of a location to a species is underestimated, a desirable outcome from a biological conservation perspective. Quantile regression can achieve this by allowing models to be estimated at the upper bounds of species-habitat distributions. These estimates

can be used to describe how a species' habitat is acting to limit aspects of its population dynamics, such as local abundance and geographic distribution. A more detailed discussion of quantile regression as applied to species prediction modelling is given in Cade and Noon (2003) and Eastwood and Meaden (2004).

Regression-based techniques are generally unsuited to predicting the distribution of biological communities unless they can be reduced to a single metric, such as species diversity. However, in many instances maps are needed that describe the spatial distribution of the various biological assemblages that together comprise the seabed community as a whole. In Section 7.3 below we describe a multivariate technique derived from geology that has recently been applied to mapping marine biological assemblages and communities (Souissi *et al.*, 2001). Our example uses benthic macrofauna data collected from an area of gravels and sands off the south coast of England near to Shoreham. The benthic community in this area has already been described in some detail by Brown *et al.* (2002) as part of a previous Defra funded research programme. To classify and map the biotopes in the Shoreham area Brown *et al.* (2002) used a 'top-down' approach where physically-defined habitat regions were compared on the basis of the level of similarity between the associated biological assemblages. The approach outlined here differs in that assemblages were classified into distinctive groups according to the level of similarity between faunal compositions. A 'bottom-up' approach relying on biological similarity measures has been found to arrive at more precise definitions of species assemblages given that physical habitat descriptors alone often account for only a limited proportion of the variability in the spatial distribution and composition of biological communities associated with gravel and sand seabed environments (Brown *et al.*, 2002; Hewitt *et al.*, 2004; Steven and Connolly, 2004).

More detailed descriptions of the analyses described below are given in Eastwood *et al.* (2003) and Eastwood *et al.* (2004).

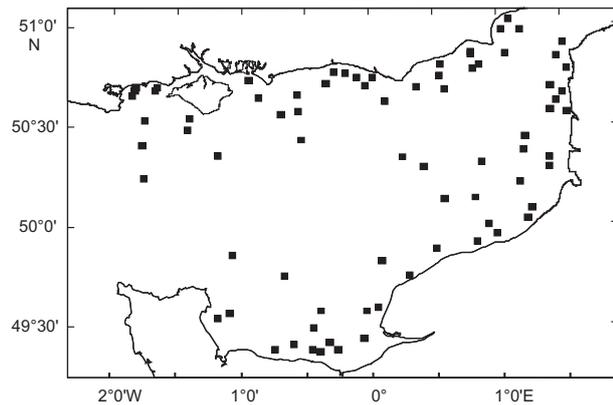
7.2 Predictive mapping of individual marine fauna

7.2.1 Materials and methods

Sole catch data

Catch densities of adult sole from Cefas' annual beam trawl survey of the EEC were used for model development and testing. The survey takes place in August at a series of fixed survey stations (Figure 7.1), and data were available for a 12-year period from 1990 to 2002. Fish samples were

Figure 7.1. Beam trawl station positions.



collected using a 4 m beam trawl along with a number of environmental parameters, namely water column depth, seabed sediments, temperature, salinity, and tide speed. Catches of sole were converted to relative densities based on the area swept by the gear, and expressed as numbers-at-age per 1000 m². Models were developed for two life history stages: mature sole and the transition stage from juveniles to adults. Only the mature sole model is shown here. All other model outputs are presented in Eastwood *et al.* (2003).

To account for potential shifts in the overall spatial distribution of sole with differing levels of population abundance, years were grouped into three categories of differing estimated population size (Figure 7.2). The time-series was also split into two model development groups: data from 1990 to 1998 were used to construct the models, whilst data from 1999 to 2002 were retained for model testing.

Digital environmental maps

Digital maps of the environmental parameters represented in the beam trawl survey dataset were created from various data sources. A map of the bathymetry in the UK sector of the EEC was developed using digital data supplied by the UK Hydrographic Office. A map of tide-

speed was created by interpolating the data collected during the beam trawl survey, whilst the British Geological Survey supplied a digital map of seabed sediments. For ease of model development, sediment categories were combined into two, broad classes: < 30% gravel content and > 30% gravel content. Water column temperature and salinity maps were developed by interpolating point source data from the ICES Oceanographic database. ArcGIS v.9 was used to store and manipulate the digital maps, and for subsequent spatial modelling and mapping.

Regression quantile (RQ) model specification

Cade *et al.* (1999) provide full details of the statistical theory and concepts behind RQ modelling, so only a summary description will be given here. Regression quantiles are the linear model equivalent of one-sample quantiles in that they allow a data distribution to be split into quantile or percentile classes. For example, the 50th quantile for a single data series would return the median. One-sample quantiles are extended to regression by minimising a function of absolute deviations, as opposed to least-squares regression which minimises a function of squared deviations (the sum of squares). The 50th regression quantile is equivalent to a least absolute deviation (LAD) regression where 50% of the observations are less than

Figure 7.2. Time series of mean sole catch densities from the eastern English Channel beam trawl survey, showing the 3 population abundance categories (high, average, and low) and 2 model development groups (development and testing).

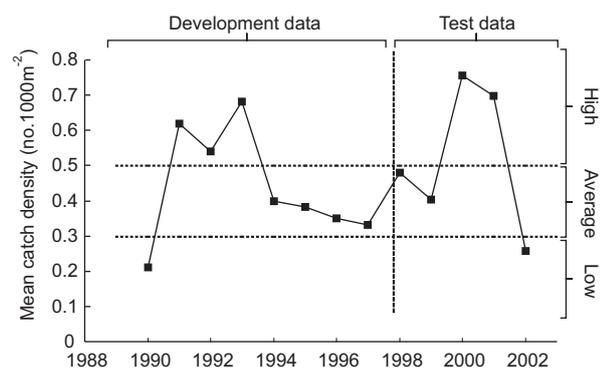
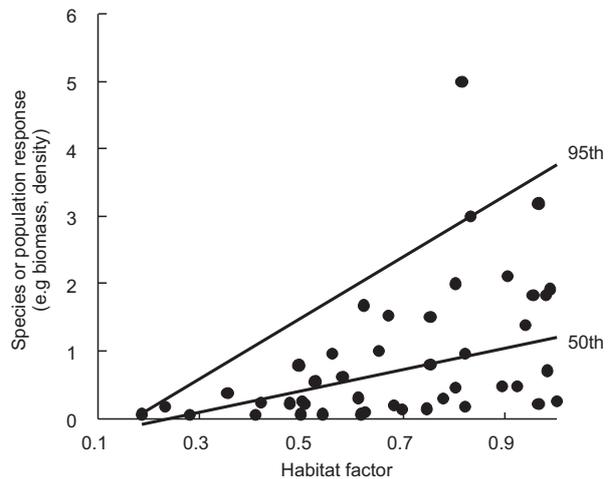


Figure 7.3. Hypothetical data distribution of a species or population-level response to a habitat factor, and fitted 50th and 95th regression quantiles (RQ). The 50th RQ splits the distribution such that 50% of the data points are less than and 50% greater than the fitted line.



and 50% greater than the fitted line (Figure 7.3). LAD regression therefore estimates the conditional median in a linear model. In other words, the LAD regression model represents the median of a data distribution, for example species counts plotted against (conditional on) one or more environmental factors. In contrast, ordinary least-squares regression estimates conditional means.

Environmental parameters recorded at the time of the beam trawl survey were used as predictor variables when constructing the regression quantile models. An additional predictor variable was included to represent the three population size categories. A series of multiple RQ models was estimated for sole catch densities as the dependent variable. Model selection followed a process of backwards elimination of the predictor variables and aimed to arrive at an upper quantile model (nominally considered to be > 75th quantile) that contained only significant ($P < 0.05$) parameters. The BLOSSOM statistical software programme (Cade and Richards, 2000) was used to estimate RQ parameters.

Spatial model construction and testing

Parameter estimates given by the RQ models were used to recode the digital environmental maps to arrive at a series of spatial models (maps) representative of the upper limits to the catch density of 2- and 3+-group sole during periods of differing population abundance. A schematic of this process is given in Figure 7.4. The spatial extent of the final output maps was controlled by the minimum combined extent of the environmental maps. Models were tested by comparing observed catch densities from 1999-2002 with those predicted by the models given the environmental data collected during the test years.

7.2.2 Results

Regression quantile model specification

Table 7.1 lists the parameters and associated coefficients for the final model of mature sole. The 80th RQ was the highest quantile where all previously selected terms remained significant. Sediment type and depth were the only environmental factors retained. The population size coefficients provide estimates of the increase in

Figure 7.4. Schematic showing the process of constructing digital maps of species distributions from regression models.

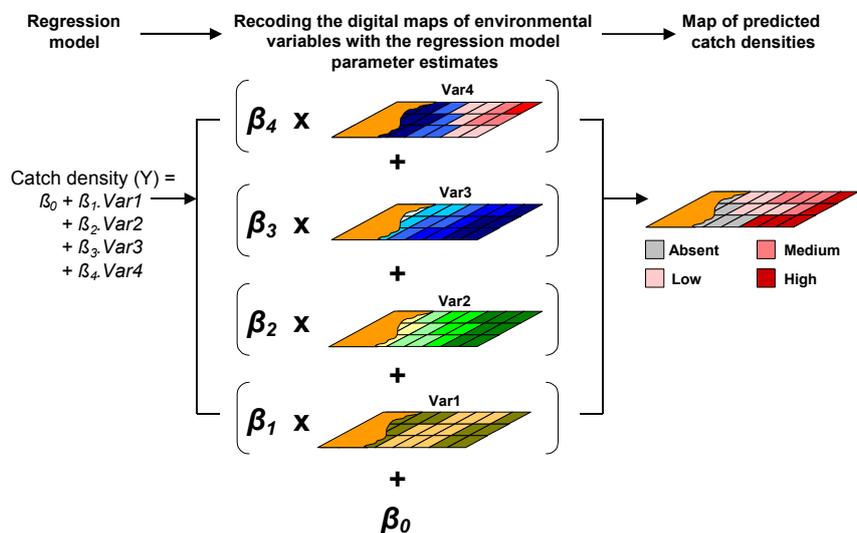


Table 7.1. Parameters and associated coefficients for 80th RQ model for mature sole.

| Variable | Coefficient (β_i) |
|--------------------------|---------------------------|
| Pop. size (low) | 0.2186 |
| Pop. size (ave.) | 0.3035 |
| Pop. size (high) | 0.7670 |
| Age | 0.0816 |
| Sediment | 0.2538 |
| Depth | -0.0043 |
| Pop. size (ave) * Depth | -0.0066 |
| Pop. size (high) * Age | -0.1281 |
| Pop. size (high) * Depth | -0.0129 |

catch density according to depth and sediment type during years when the population abundance is lower than average, average, and higher than average. The age variable represents the difference in catch densities between 2- and 3+-group sole. Significant interactions between model predictors are represented in Table 7.1 by Variable₁ * Variable₂, e.g. Pop. size (ave) * Depth.

Spatial model construction and testing

Figure 7.5 shows the prediction maps for mature sole. Model outputs are also summarised in Table 7.2. Highest catch densities are consistently located in shallow, inshore waters where sandier sediments predominate, which in turn agrees with the known habitat requirements of sole derived from numerous field observations (Rijnsdorp *et al.*, 1992; Rogers, 1992; Eastwood *et al.*, 2001). As the population abundance increases, the model predicts a consistent increase in population density in the shallow, inshore waters, a feature that is not reflected in the deeper, more offshore waters. Both age groups expand outwards as their overall abundance increases, but not necessarily

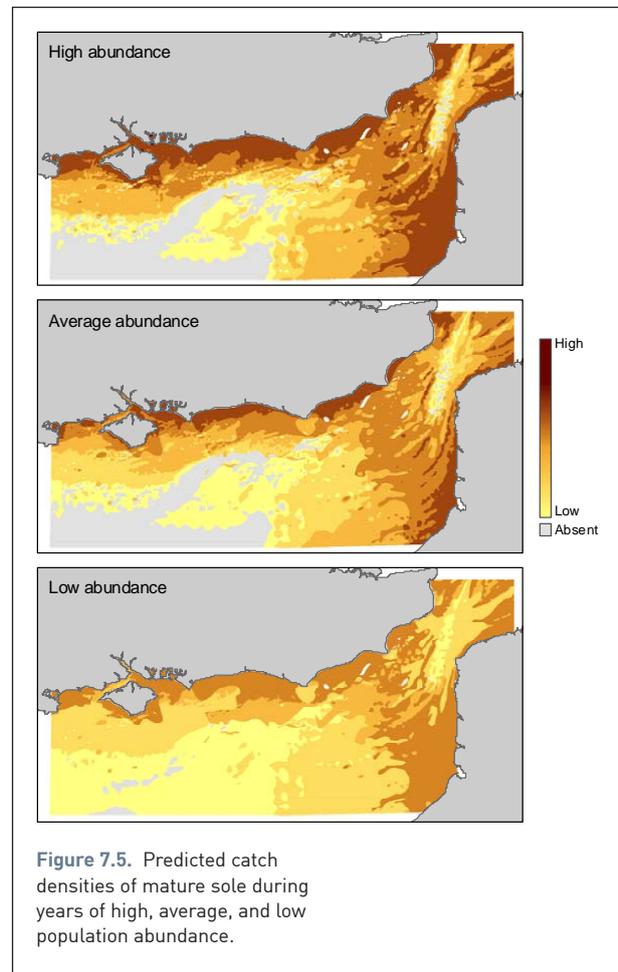


Figure 7.5. Predicted catch densities of mature sole during years of high, average, and low population abundance.

into new, previously unutilised habitats, i.e. sediments containing a higher gravel content. This is reflected in the estimates of the total area where sole are predicted to be present, which remain relatively stable and do not

Table 7.2. Estimates of the maximum area occupied by mature sole during years of high, average and low population abundance.

| Age | Population | Area (km ²) | | | | |
|----------|------------|-------------------------|--------------------------------|-------------------------------|------------------------------|---------|
| | | Absent | >0-1 fish 1000 m ⁻² | 1-2 fish 1000 m ⁻² | >2 fish 1000 m ⁻² | Present |
| 2-group | Low | 6111 | 18834 | 0 | 0 | 18834 |
| | Average | 7464 | 16726 | 756 | 0 | 17482 |
| | High | 3536 | 14876 | 5675 | 858 | 21409 |
| 3+-group | Low | 301 | 24645 | 0 | 0 | 24645 |
| | Average | 4259 | 18245 | 2442 | 0 | 20687 |
| | High | 4584 | 14550 | 5425 | 387 | 20362 |

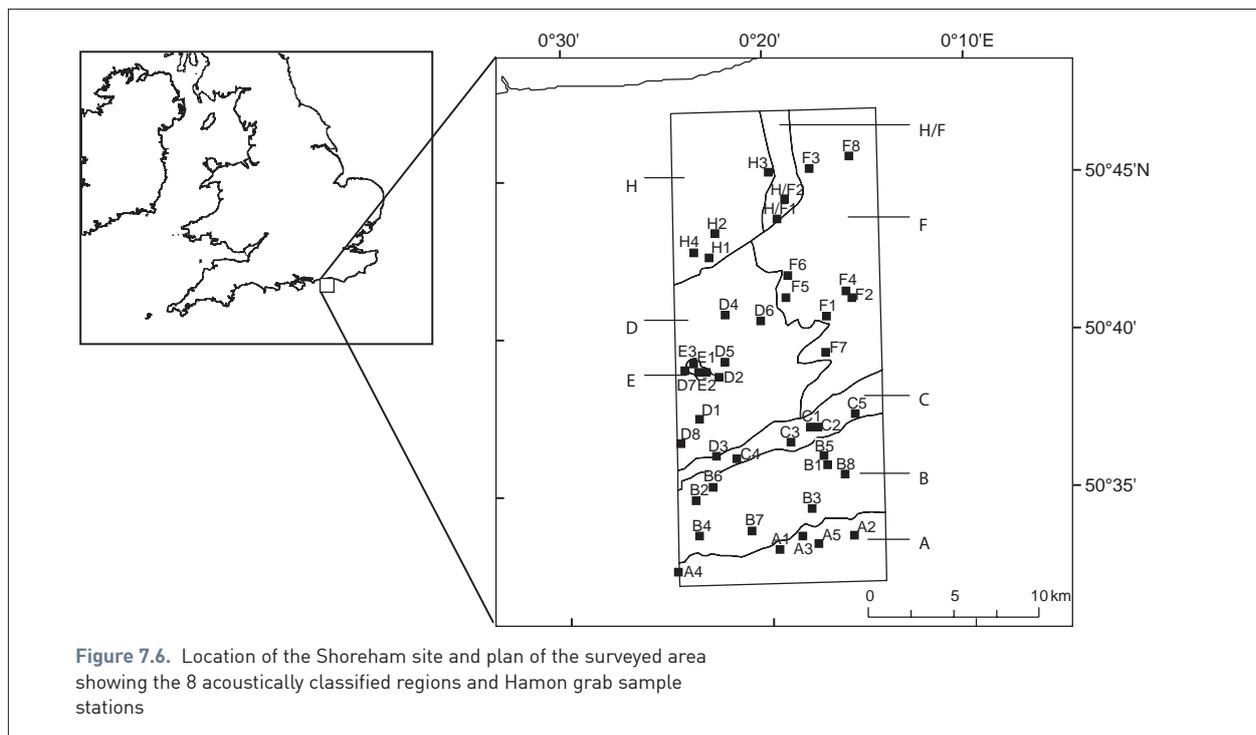


Figure 7.6. Location of the Shoreham site and plan of the surveyed area showing the 8 acoustically classified regions and Hamon grab sample stations

show either a consistent increase or decrease. Instead the model predicts a relatively consistent increase in sole catch densities in the preferred inshore, sandy habitats, with limited expansion into less preferred environments.

The model predictions for times of high population abundance can potentially equate to estimates of the carrying capacity of the habitat. However, given the consistent increase in catch densities in the shallow water sandy habitats, there seems little to suggest that the carrying capacity in these environments was reached during the time period covered by the survey data. In contrast, model predictions for the deeper water, gravelly habitats may provide better estimates of the carrying capacity for these environments.

The model correctly classified 74% of observed catch densities of mature sole, which was significantly lower ($P < 0.05$, one-tailed binomial test) than the expected 80% correct classification rate for an 80th RQ model. This is probably due to the slightly higher catch densities encountered in 2000 relative to 1990 to 1998, and suggests that the model has not been able to estimate an upper limit to catch densities given the overall population sizes recorded in 1999-2002.

7.3 Predictive mapping of seabed communities

7.3.1 Materials and methods

Acoustic and benthic survey

The following description of the sampling methodology is summarised from Brown *et al.* (2002).

An intensive acoustic survey of the Shoreham area (Figure 7.6) was conducted in July 1999 using a Datasonics digital chirps sidescan sonar. The system was operated on a 400 m swathe range, and survey lines were spaced

at 400 m intervals in a north-south orientation in order to encompass 100% of the survey area. The sidescan mosaic was used to divide the survey area into 8 acoustically-distinct regions (labelled A, B, C, D, E, F, H, and H/F).

The design of the macrobenthic grab survey was structured around the 8 acoustically distinct regions identified from the acoustic survey. Sampling stations were randomly positioned within each acoustic region, with the number of stations within each region proportional to the size of the area. The survey was conducted in August 1999. A total of 43 samples were collected from across the survey area using a 0.1 m² Hamon grab. Following estimation of the total sample volume, a 500 ml subsample was removed for laboratory particle size analysis. The remaining sample was washed over 5 mm and 1 mm square mesh sieves to remove excess sediment. The macrofauna retained on both the sieves were fixed in 4-6% formaldehyde solution (diluted with seawater) and returned to the laboratory for identification and enumeration.

In the laboratory Hamon grab samples were first washed with freshwater over a 1 mm square mesh sieve in a fume cupboard to remove the excess formaldehyde solution. Samples were then sorted and the specimens placed in jars or petri-dishes containing a preservative mixture of 70% methanol, 10% glycerol and 20% tap-water. Specimens were identified to species level, or as far as possible, using standard taxonomic keys. The number of each species was recorded, and colonial species were recorded as present or absent.

Characterising and mapping the biological assemblages

The approach used to map the biological assemblages was based on the modified version of the method developed by Souissi *et al.* (2001) as described in Anneville *et al.* (2002).

Only burrowing and infaunal species were used in the analysis. Whilst a number of epifaunal species were also collected by the Hamon grabs, differences in the epifaunal assemblages between acoustically-distinct regions followed a broadly similar pattern to that shown by the infauna (Brown *et al.*, 2002). Burrowing and infaunal species were therefore used to represent changes in the macrobenthic community as a whole. This group consisted of 155 taxa, of which the vast proportion were represented by only a few individuals. The 40 most abundant taxa, which were present in more than 12% of all samples, were retained for further analysis. A principal component analysis (PCA) was then performed on double-root transformed species counts. Data transformation was necessary to ensure multinormality in the data, a necessary requirement before Bayesian probabilities can be computed. PCA scores from the first 25 axes were subject to a hierarchical classification (Euclidean distance, flexible links clustering), to arrive at a set of clusters, representative of biological assemblages, at a selected dendrogram cut-off level. The 25 axes explained over 97% of the total variance in the species data indicating that the ordination gave an appropriate representation of the biological assemblages.

Once an appropriate cut-off level had been decided, Bayesian conditional probabilities were calculated to represent the probability of each station belonging to a cluster (Harff and Davis, 1990). Depending on the PCA scores assigned to each station O_i , the probability that it belongs to a cluster G_j is given by

$$P(O_i \in G_j) = \frac{p_j \left| \sum_j \right|^{-1/2} \exp(-d_j^2(i)/2)}{\sum_{k=1}^g p_k \left| \sum_k \right|^{-1/2} \exp(-d_k^2(i)/2)} \quad (1)$$

Here, p_j is an *a priori* probability that represents the proportion of the number of stations in the cluster G_j to the total number of stations (= 43), and $d_j^2(i)$ is the generalised Mahalanobis distance between G_j and O_i

$$d_j^2(i) = (O_i - m_j^G)' \sum_j^{-1} (O_i - m_j^G) \quad (2)$$

where m_j^G is the centroid of the cluster G_j , i.e. the mean of the scores for the principal axes in the dimension of samples.

Deciding on an appropriate cut-off level for the dendrogram needed careful consideration as a slight shift to a higher or lower degree of similarity could potentially have a marked effect on the final number of assemblages (see final dendrogram in Figure 7.7). First, we took the decision that a partition of stations into more than 8 clusters was unlikely to produce assemblages that were substantially different from each other, given that the study area covered a relatively small geographic region and the seabed consisted of fairly homogenous mobile sands and gravels within each acoustic region (Brown *et al.*, 2002). At each hierarchical level from 2-8, we next computed the maximum conditional probability for each station. Maximum probabilities were most often, but not always, associated with the cluster to which the station had been allocated. At each hierarchical level k the median probability $P_m(k)$ of the returned maximum probabilities was then computed, i.e.

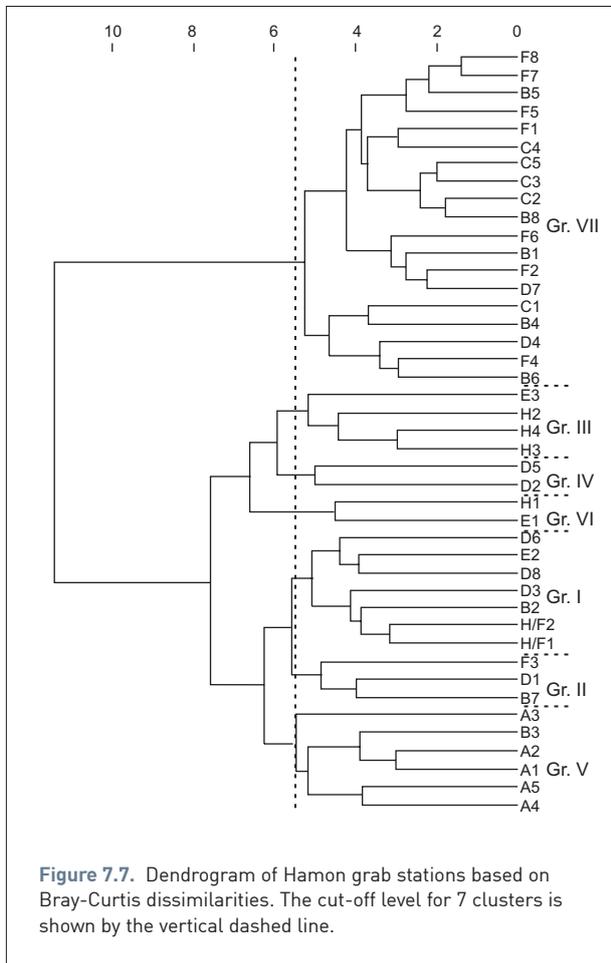
$$P_m(k) = \text{median}(P_{\max}(k)) \quad (3)$$

This provided an average measure of the within-group homogeneity for each hierarchical level and could be used to determine an appropriate dendrogram cut-off level.

Conditional probabilities meet the necessary criteria for the application of geostatistics and kriging interpolators for estimating conditional probabilities at unsampled locations, i.e. between stations (Harff *et al.*, 1993). Once a dendrogram cut-off had been decided and clusters defined, conditional probabilities associated with each assemblage were interpolated onto a regular grid of 10,000 m² resolution using an appropriate kriging interpolator. The final set of maps provided estimates of the probability of a station belonging to a particular assemblage at each grid cell within the study area. A combined map of biological assemblages was produced by returning the assemblage most likely to be found (having the highest probability) at each grid cell. Spatial interpolation and grid cell analysis was performed in ArcGIS v.9.

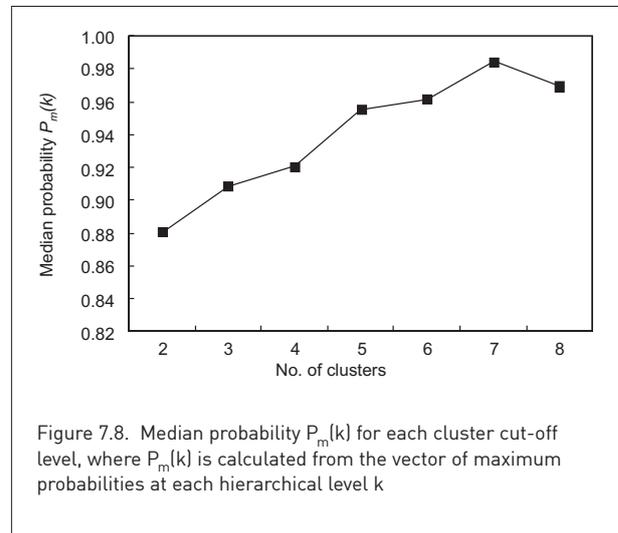
7.3.2 Results

Hierarchical classification of the PCA scores from the first 25 axes resulted in a dendrogram with relatively distinct assemblages (Figure 7.7). The first partition divided the stations into 2 major clusters. Stations in one of the clusters (marked 'Group VII' in the dendrogram) were spatially contiguous and spanned the length of the survey



area in a north-east to south-west orientation. The spatial definition of the other cluster was less clear, indicating that it consisted of a number of discrete but smaller clusters. Group VII remained a distinct cluster until it was finally split into 2 at the 9 cluster dendrogram cut-off.

Conditional probabilities computed at each hierarchical level from 2-8 returned values of $P_m(k)$ that gradually increased in line with the number of clusters, and reached a maximum at 7 clusters (Figure 7.8). A further partition into 8 clusters led to a slight reduction in $P_m(k)$ indicating that the within-cluster association was beginning to weaken. The cut-off at 7 clusters (shown in Figure 7.7) was therefore used to define the biological assemblages.



Interpolating the conditional probabilities for the 7 clusters produced a series of maps describing the estimated likelihood of occurrence of each assemblage over the study area (Figure 7.9). As expected, the Group VII assemblage dominated the site, leaving only three main areas – west-central region, south-east corner, and north-west corner – where the assemblage was unlikely to be present. The spatial distribution of the Group III, IV, and V assemblages largely mirrored the Group VII assemblage and were also associated with a single centre of maximum probability. The Group I, II, and VI assemblages were marked by more than one geographic probability maximum. Of interest is that each assemblage was found to occur throughout much of the study area. So for example, the biological assemblage in the extreme south-west corner will most likely match those typified by Group VII, but to a lesser degree may also match those characterised by the remaining groups.

The final map of combined assemblages contains boundaries that do not generally agree with those associated with the acoustically-distinct regions (Figure 7.10), despite some localised similarities. This is most likely due to the marked differences between the two methods of classification: acoustic classes were defined by way of a subjective assessment of similarity in the acoustic data, whereas the faunal assemblages were defined using an objective measure of similarity in the biological data. Clearly there are differences in the composition and spatial distribution of the infaunal groups that could not be distinguished from a visual interpretation of the acoustic data alone.

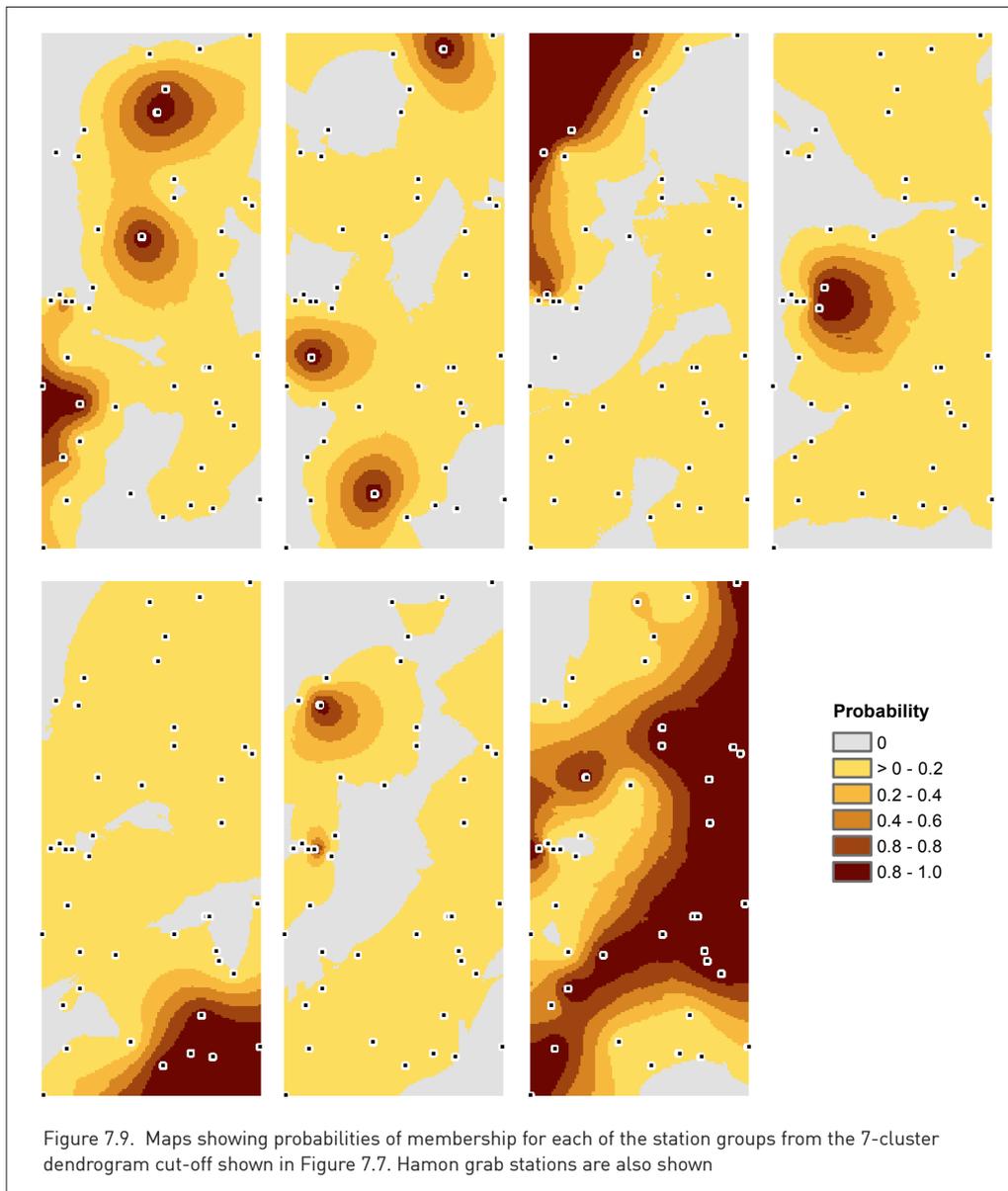


Figure 7.9. Maps showing probabilities of membership for each of the station groups from the 7-cluster dendrogram cut-off shown in Figure 7.7. Hamon grab stations are also shown

7.4 Discussion

The two methods described here have shown how maps can be created for individual marine fauna and seabed communities from point sample data. They form part of a growing number of techniques that have been developed and trialled over recent years, to the point where species distribution modelling has become an area of research in its own right. New techniques will undoubtedly be developed and old ones refined in years to come, with the ultimate aim of reaching consensus on the most appropriate method given the type of species data available and the outcome required.

We have also shown how the distribution of a species can change over time according to differing levels of population size. This component of the population dynamics of many marine fauna needs to be explicitly accounted for in spatial prediction techniques to avoid underestimating the importance of a habitat feature to

a species, for example by developing maps from times of low population size. The method presented in Section 7.2 attempts to develop species distribution maps that account for the expansion and contraction of a population in two ways: first, by directly including a population size component in the modelling procedure, and secondly by using a technique capable of providing estimates of the habitat-imposed limiting effects on a species' response and geographic distribution. Whilst quantile regression is based on well-established statistical theory more experimentation and discussion is needed for it to become more widely adopted by species distribution modellers.

The multivariate classification technique presented in Section 7.3 provides an alternative, bottom-up approach to mapping biological assemblages, in contrast to a top-down imposition of a classification scheme based on physical seabed attributes. The final classification arrived at a set of biological assemblages whose boundaries differed from those given by the acoustic interpretation, but this

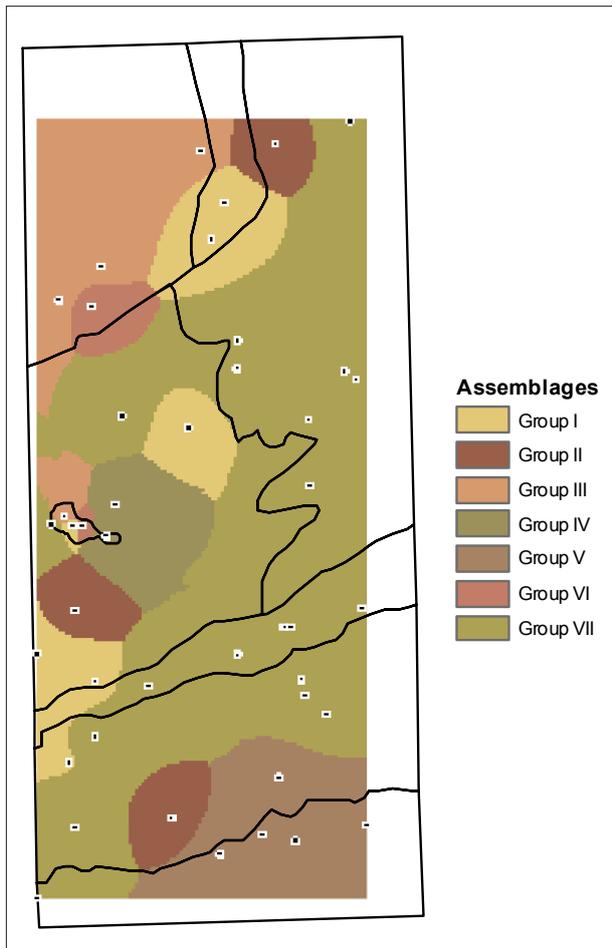


Figure 7.10. Map of combined biological assemblages developed from the 7 clusters shown in Figure 7.9. Hamon grab stations and acoustic classified regions are also shown.

is understandable given the differences between the two classification methods. A bottom-up approach based on measures of biological similarity will inevitably arrive at more precise definitions of biological assemblages as compared to the use of physical surrogates. Even so, boundaries and gradients between physical habitat features cannot be ignored when developing biotope maps owing to their major influence on patterns of species distributions, and ultimately on the assemblages and communities they form. However, if seabed habitat maps are to be used to inform management decisions they need to offer the best possible representation of the underlying biological communities, and this may best be achieved through a bottom-up rather than the more traditional top-down approach to seabed mapping.

8. Utility of mapping techniques for assessing/monitoring features of nature conservation interest

8.1 Introduction

The purpose of this Chapter is to illustrate survey and sampling techniques applied to the detection and monitoring of a particular feature (the *Sabellaria spinulosa* biogenic reef biotope). This biotope is of conservation interest and is potentially vulnerable to the effects of aggregate extraction and construction (Holt *et al.*, 1997). This contrasts with the more general impact surveys of the other bodies of work in this report. This Chapter presents the results of a number of surveys in the Wash and its environs that have taken place between 2000 and 2004, which were emanated from broadscale, baseline studies undertaken previously (1996-9).

Past surveys (Dipper *et al.*, 1989; NRA, 1994; Foster-Smith and Sotheran, 1999; Foster-Smith, 2000; Foster-Smith and White, 2001) and anecdotal records from the Eastern Sea Fisheries Joint Committee (ESFJC) showed that *Sabellaria spinulosa* was present, often in high densities with positive observations of well developed reef structures at some locations. Biogenic sand reefs built by the polychaete *Sabellaria spinulosa* are one of the features of interest as a 'reef' in its own right, having recently been upgraded from being a 'key component of subtidal mixed sediment communities' (English Nature, 1999). As part of the development of the Management Scheme for the Wash and North Norfolk cSAC it is necessary to establish the baselines and condition and compliance monitoring programmes for the interest features in order to determine whether the conservation objectives have been, or are in the process of being achieved.

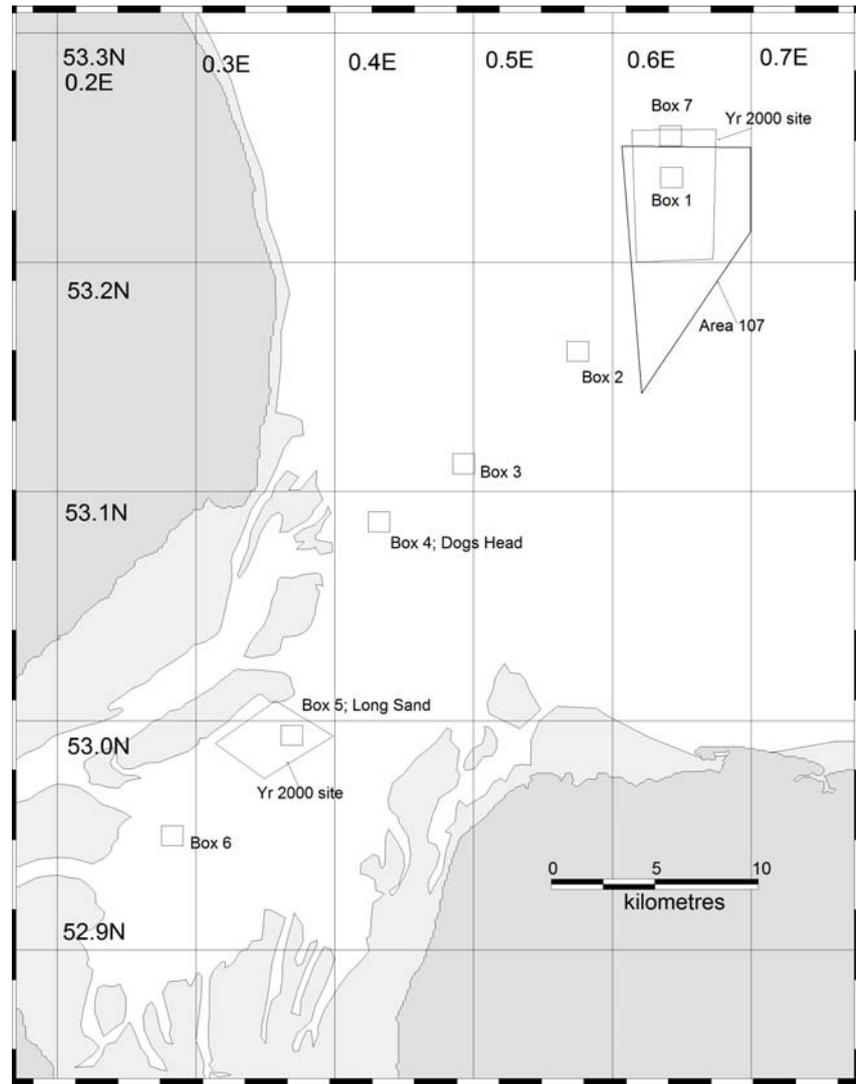
A review of all previous grab sample data collected by SeaMap backed up the suggestion that *Sabellaria* reef development might be an extreme form of dense worm population with only a weak indication that reefs might form a distinct population and associated community structure (Foster-Smith and Hendrick, 2003). This has led to a debate as to what constitutes a *Sabellaria spinulosa* biogenic reef: Is it more realistic to include structures that are not particularly elevated (e.g., simply overgrowing and consolidating underlying sediment)? Again, there are issues regarding the temporal stability of reefs and the position of less well-developed reefs in the cycle of growth and decay of reef structures. If a more inclusive definition of 'reef' is adopted, then this creates problems with detection since less well-developed structures will be harder to pick up acoustically and to observe using video techniques in turbid environments.

It would be highly desirable to detect and map the distribution of reefs remotely (and without the need for

potentially destructive sampling techniques) with a high degree of accuracy and repeatability and with a fine level of discrimination between reef and non-reef. However, it is difficult to detect and measure a patchily distributed feature showing a wide variation in expression of reef characteristics. The acoustic tools available have a wide range of resolution from very coarse (AGDS) to quite fine (high frequency sidescan). Any acoustic image has to be interpreted through ground-truthing and videography would be the method of choice for direct observation: It is less destructive than grab sampling, can see reef formations and can cover an area large enough to assess patchiness. However, underwater visibility has to be adequate to obtain reasonably sharp images – a major limitation in many circumstances. The following tools are discussed:-

1. Sidescan for high resolution images of reefs to measure and map reef patchiness: The problem with this approach is that although there is some evidence to support this technology as a tool for obtaining distinctive images of well-developed reefs, it is less certain that it can detect less well-developed reefs, particularly against a background of other habitats.
2. Multibeam bathymetry can deliver quite high definition three dimensional images of the sea floor from which it should be possible to observe seabed features. Their use for detecting reef structures has not been tested.
3. AGDS for sediment discrimination: AGDS employ a tried and tested system based on a single beam sounder. It can detect (empirically) different sediment types and could be used to predict the distribution of reef sediments. However, spatial resolution is poor and there are concerns about the level of certainty of discrimination and repeatability.
4. Video: This is the only technique that can detect reefs with confidence. However, (a) the sample area covered is small and not very useful for mapping, (b) it is dependant on good underwater visibility, and (c) low *Sabellaria* tubes may not be identified from the video (unless very high definition video is available).
5. Grab samples: Analysis of the infauna confirms the presence of *Sabellaria* and also enables measurement of associated species diversity. However, the sample area is very small and subject to 'hit-and-miss' in patchy habitats. To overcome this, high numbers of samples are required and analysis of these is expensive, unless this is restricted to a visual assessment on-board. There is also a reluctance to use destructive sampling techniques on features of potentially high conservation value.

Figure 8.1. Survey area of the Wash and features referred to in the text.



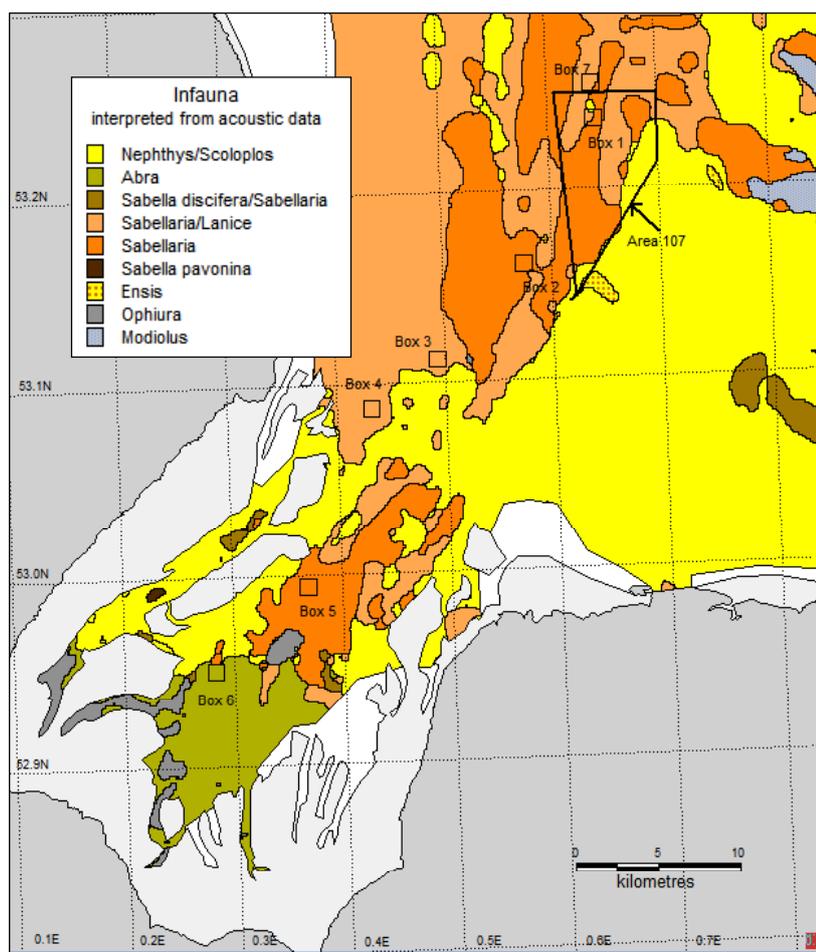
The area of survey and features of the survey design referred to in the text are shown in Figure 8.1. The series of surveys had different objectives that evolved from one year to the next. Thus, the scale of survey, techniques used and strategy also changed. The data are often not as complete as hoped for due to poor weather and underwater visibility. Table 8.1 summarises the survey objectives.

The results are presented under the main objectives rather than a year-by-year basis. These are (1) broadscale mapping; (2) detection; (3) spatial pattern and heterogeneity and, (4) significance of change.

Table 8.1. Summary of Envision/SeaMap surveys in the Wash between 1996 and 2004.

| Year | Acoustic survey | Sampling | Area |
|---------|----------------------------------|--------------------------------------|--|
| 1996-99 | Broadscale mapping: AGDS | Stratified sampling: grab & video | Large area of the Wash and Lincolnshire coast |
| 2000 | Detection: AGDS/Sidescan | Replicate sampling: grab & video | Long Sands & Area 107 |
| 2001 | Spatial patterns: AGDS/Sidescan | Random sampling: grab & video | 7 1 km quadrats along transect from inner Wash to Area 107 |
| 2003 | | Repeat random sampling: grab & video | Quadrats 1 & 4 (above) |
| 2004 | Spatial patterns: AGDS/Multibeam | Repeat random sampling: video | Quadrats 1 & 4 |

Figure 8.2. Map of the distribution of the main types of biota predicted from the interpretation of broadscale AGDS acoustic data and video/ grab ground-truth samples (adapted from Foster-Smith and Sotheran, 1999).



8.2 Techniques

Sidescan: A *Geo Acoustics*TM *SS490* sidescan sonar was used for the survey, which can switch between 100kHz and 500kHz and was linked to an *EOSCAN* digital acquisition system (Polaris Imaging Inc) which provided full geo-referenced data capture and post-processing capability. SeaMap also used an *EOMAP* system (Polaris Imaging Inc) for combining individual sonar lines into a mosaic to create a map of the survey area. Both frequencies were tested, although the lower frequency was used to produce the mosaicked images shown below.

Swath: A *GeoSwath*TM system operating at 200 kHz was available in 2004.

AGDS: The main AGDS system routinely used was a *RoxAnn Groundmaster*TM combined with a *Furuno*TM *600L* echosounder operated at 50 kHz. The data were logged on *Microplot*TM. The point data were saved every 2 seconds. A second RoxAnn system was used on board the Eastern Sea Fisheries Joint Committee vessel *Surveyor* in 2000.

Video: A small towed sledge was equipped with a *Sony*TM 3-chip camera and high intensity discharge lights. The images were recorded on the surface and in the housing on digital tape, giving reasonably high definition.

Grab samples: Grabs were collected with a long-arm van Veen or 0.1m² Day grab. The grabs were at least half full before they were accepted. The samples were allutriated and the washings sieved through a 1 mm mesh. Allutriation was used since *Sabellaria* tubes and associated sediment are too large for sieving directly.

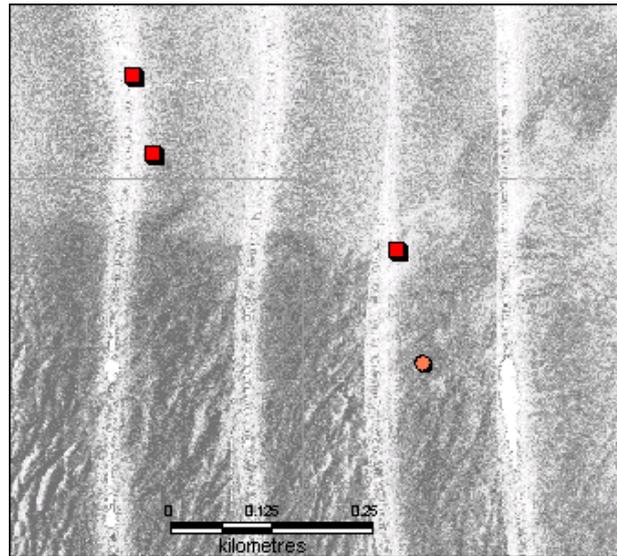
8.3 Summary of survey results

Broadscale mapping of biotopes

The first stage in the survey of an area is often the inventory and mapping of the full range of habitats (biotopes). Since the areas involved may be large (as in this case), it may be adequate to cover the ground at a low resolution (economising on time and cost) as long as the area has been sampled representatively. The surveys between 1996-9 were designed to map the full range of biotopes found in the area at a coarse resolution. The methods and results are described more fully in the survey reports cited above. However, a brief summary is given here to set the scene for the subsequent work on *Sabellaria spinulosa* detection and monitoring.

Figure 8.2 shows the distribution of a few broadly defined assemblages, particularly three *Sabellaria spinulosa* classes (*Sabella discifera/Sabellaria*; *Sabellaria/Lanice*; *Sabellaria spinulosa* reef) and the other major assemblage (*Nephthys/Scoloplos*).

Figure 8.3. Small scale image of the northern border of the licensed sand extraction Area 107. The red squares are locations of observed reef and the orange circle of crusts.



associated with sand extraction (see small scale in Figure 8.3 and the whole area mosaicked in Figure 8.4), there were no clear traces associated with reefs.

However, this result cannot be regarded as definitive since the quality of the image might have been improved by using a higher frequency and towing the sidescan fish closer to the sea floor would have thrown up any small reef features into sharper relief. Images from Cefas from the same area do appear to show a patchy structure on the seafloor.

Nevertheless, the potential criticism remains that discrimination of different levels of reef development might be beyond the capabilities of sidescan.

Figure 8.5 shows the location of samples and AGDS data for the same area of seabed. The area surveyed with sidescan sonar is indicated by the closely spaced *RoxAnn* tracks.

The AGDS were interpolated and the gridded images imported into IDRISI™ for supervised classification (see elsewhere in the report for details and also Wilke and Finn, 1996; Eastman, 1997; Sotheran *et al.*, 1997; Foster-Smith and Sotheran, 2003). The resulting map for Area 107 is shown in Figure 8.6 and indicates that the distribution of *Sabellaria* is concentrated on a strip at the edge of the shallow bank (which lies in the north-western sector of Area 107).

The apparent ability of AGDS to discriminate *Sabellaria* reef must be examined carefully. The ground-truth data are unevenly distributed throughout the area and one large section was not sampled.

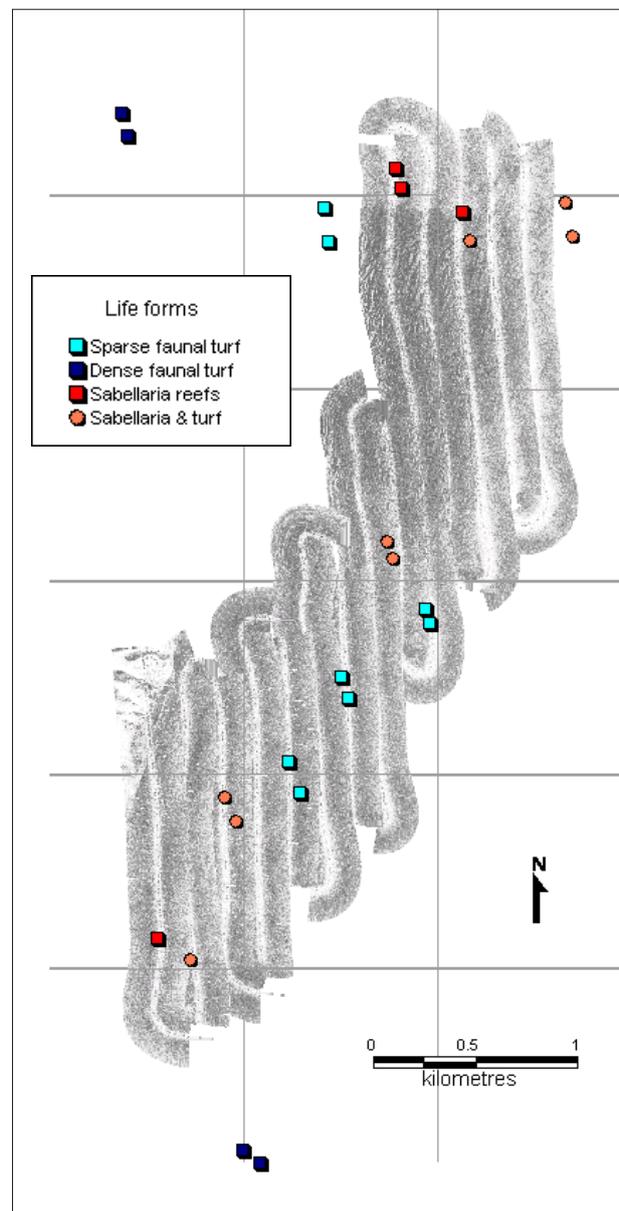


Figure 8.4. The sidescan mosaic over the Area 107 site with biota classes superimposed.

Figure 8.5. RoxAnn tracks over the Area 107 site coloured according to E1 values. Blue stars are the locations of video drops and the green stars the grab stations (from Foster-Smith, 2001).

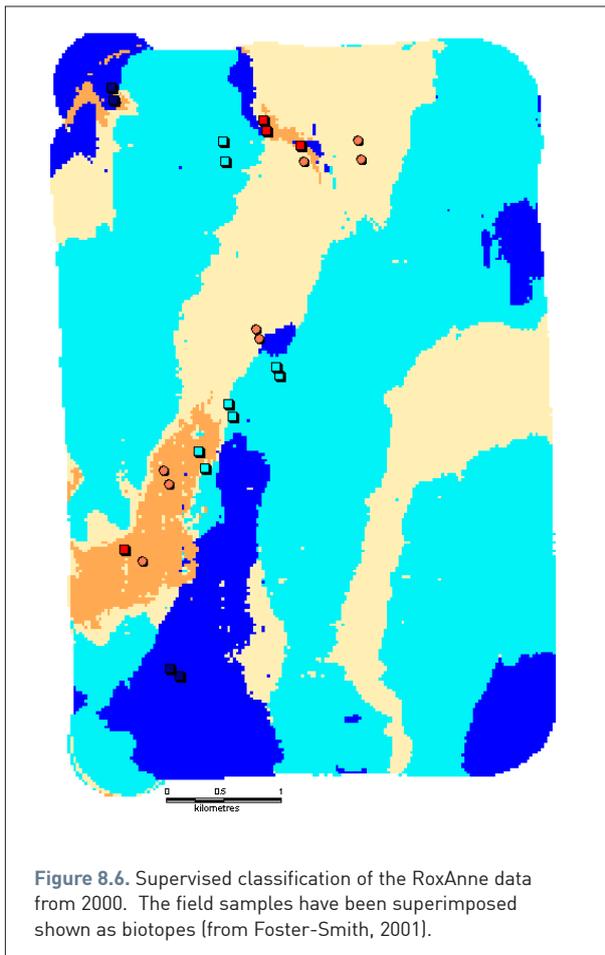
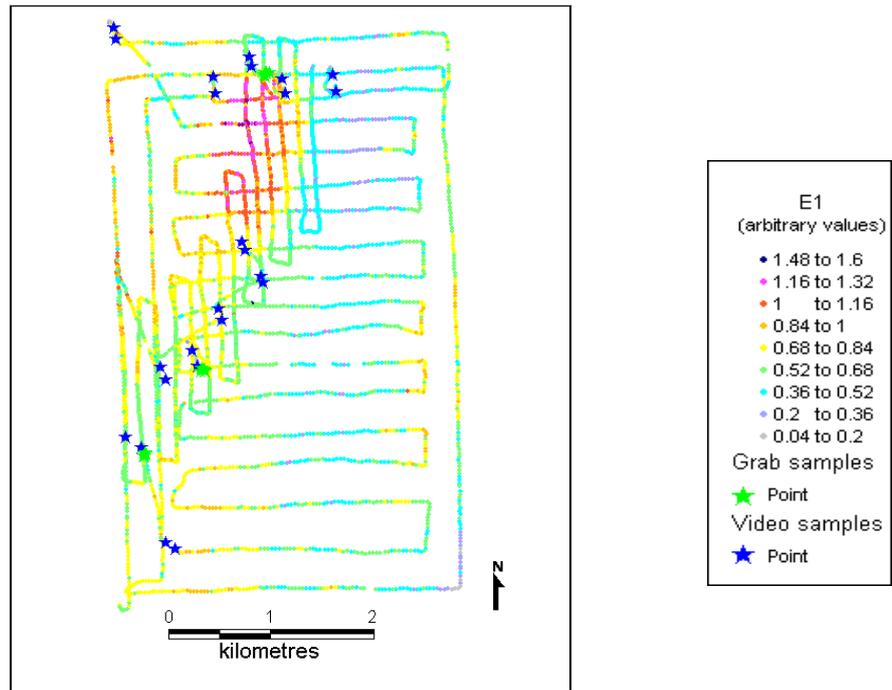


Figure 8.6. Supervised classification of the RoxAnn data from 2000. The field samples have been superimposed shown as biotopes (from Foster-Smith, 2001).

Swath and AGDS

Box 4 (Dogs Head) was adopted as one of two sites for repeated monitoring (the other being Box 1). The Box 4 had waves of coarse sand, sandy gravel and silty sand (with substantial clumps of *Sabellaria*) which have persisted over the years. In 2004 it was possible to use interferometric bathymetric system over the sites with simultaneous recording of *RoxAnn*. The sun illuminated images show seabed features of about 10 – 20 cm in height and have a 'bin size' (resolution) of 3 m or 0.5 m. Smaller irregular hummocks are also apparent over the flat area in Box 4 (Figure 8.7).

It is tempting to attribute these features to reefs, but the three example images (see Figure 8.8) are at about the level of discrimination of the images (these were degraded due to the roll effects at the edges of the swaths – an effect of poor weather).

Interferometric bathymetric systems can also provide sidescan imagery based on backscatter. Although backscatter does give some indication of sediment type, the resolution of the images is not as high as traditional sidescan (Figure 8.9). However, when draped over bathymetry and displayed as a 3-D perspective image, the sand waves are seen as features with strong backscatter and there are long 'tails' of similarly strongly reflective sediment running northeast/southwest from each end of the waves. There are also suggestions that there may be rougher material at the foot of the wave scarps.

RoxAnn data provides some additional guidance for the interpretation of the images from the interferometric bathymetric system. The stronger E2 (hardness) values correspond to the sand waves and their tails, with weaker E2 values between (Figure 8.10).

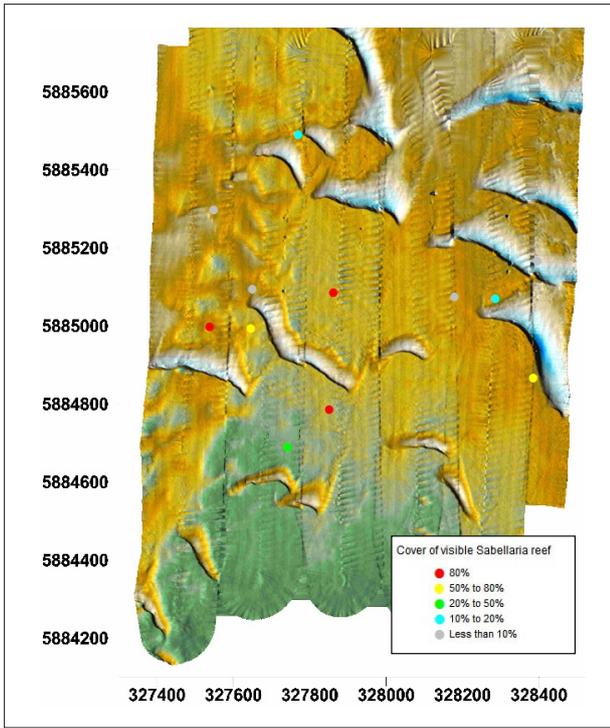
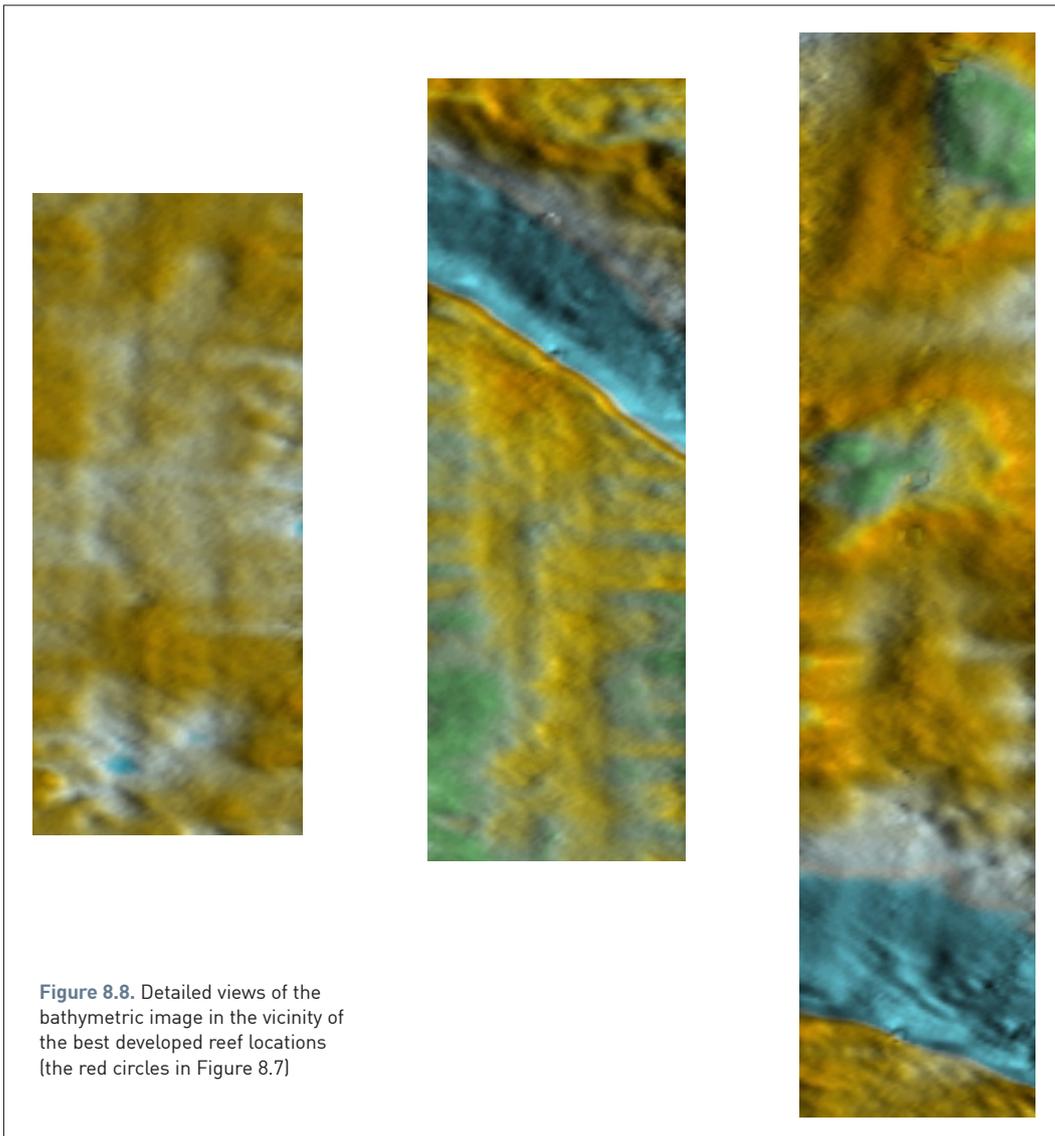


Figure 8.7. Interferometric bathymetry of Box 4. The colours show depth ranging from green (-17m) to blue (-12m). Axes are in metres UTM zone 31.



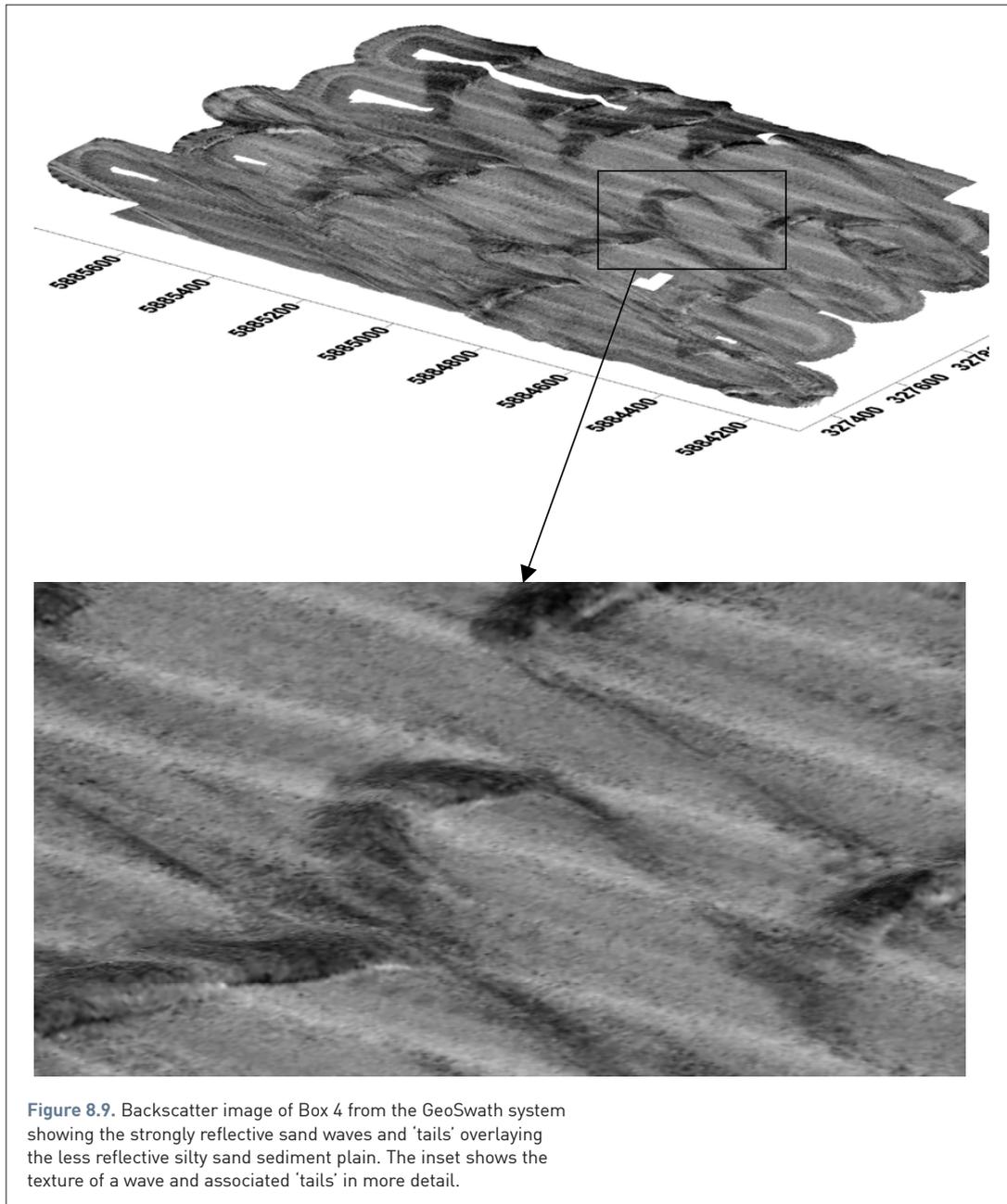


Figure 8.9. Backscatter image of Box 4 from the GeoSwath system showing the strongly reflective sand waves and 'tails' overlaying the less reflective silty sand sediment plain. The inset shows the texture of a wave and associated 'tails' in more detail.

There is a ridge of sand running from the south east corner of the Box to a point midway along the northern boundary of the Box that has waves of harder material, some are irregular and hummocky whilst a few are larger and crescent shaped. The rest of the area is a level patchwork of sand and gravel with some large waves of harder material.

There is no obvious correspondence between *Sabellaria* cover and the AGDS data. Classification using the samples as training sites (not shown) classed into cover categories is unconvincing. It is possible that (1) the ground is so patchy that there can be no direct correspondence between AGDS and video due to combined positional errors and/or (2) *Sabellaria* is found in a wide range of sediments and has no distinct signature.

This poor classification is an apparent contradiction to the results in Area 107 (above). Re-survey of Area 107 in 2001 (the first year of Box sampling) showed a large change in the status of *Sabellaria* from the preceding years in that no substantial reef was observed. Indeed, it has not been observed since 2000, although low 'reef' and crusts have been seen and very high densities sampled. Interferometric images show the dredge marks well, and there is a correspondence between seabed features and AGDS (Figure 8.10).

Unfortunately, it was not possible to sample within Box 1 during the interferometric/AGDS survey in 2004. If the samples from 2001 and 2003 are displayed (i.e., since the apparent collapse of the reef structure in 2000), then once again there is no obvious correlation between *Sabellaria* abundance and the AGDS values.

Figure 8.10. Bathymetric image for Box 4 with RoxAnn AGDS and video sample data overlain. Axes are in metres UTM zone 31.

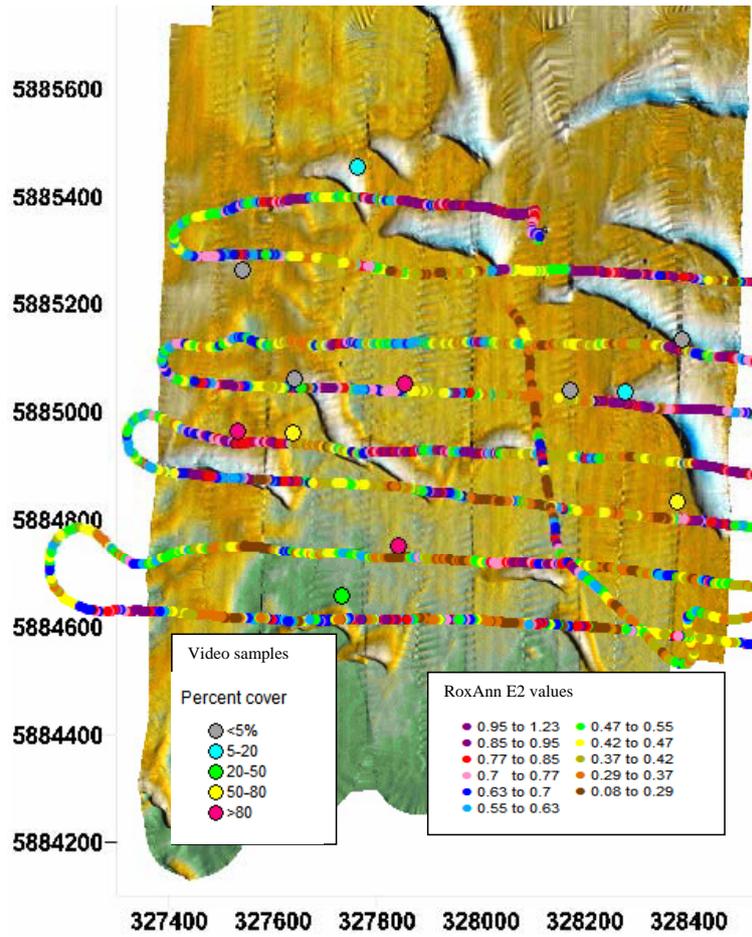
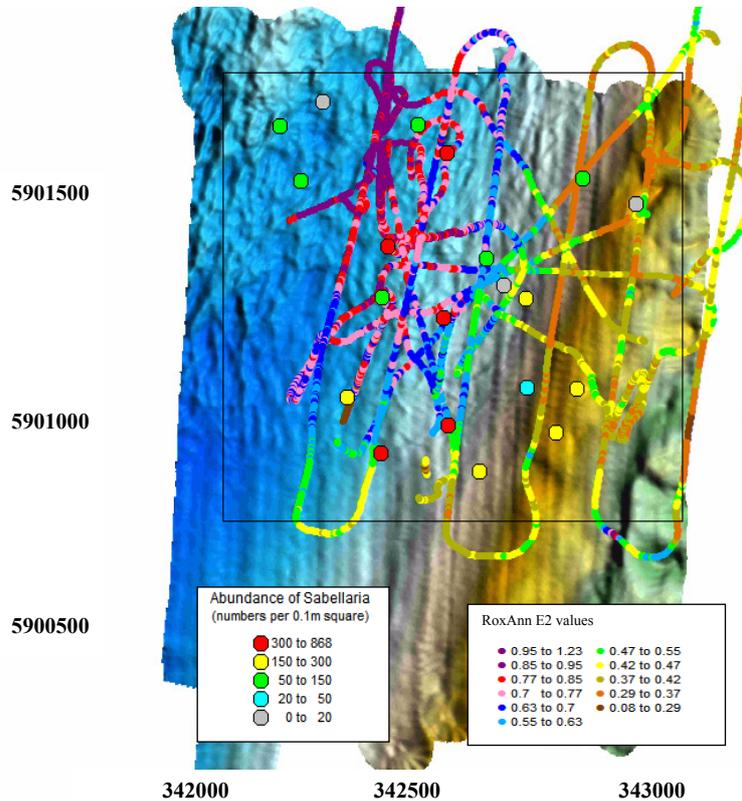


Figure 8.11. Bathymetric image for Box 1 with RoxAnn AGDS and video sample data overlain. Axes are in metres UTM zone 31.



Summary

None of the acoustic remote techniques gave clear images of reefs, let alone crusts and less well-developed structures, or an unambiguous acoustic signature for *Sabellaria*. This cannot be regarded as the definitive statement on the subject since there are many aspects of the surveys that could have improved the performance of the acoustic systems:-

- sidescan operated at higher frequencies;
- sidescan flown closer to the sea floor;
- better roll correction on the interferometric system;
- more accurate positioning to reduce combined AGDS/video

New techniques may also prove useful, such as high definition acoustic imaging and the application of texture/pattern analysis on sidescan and interferometric backscatter data.

However, if reefs are very patchy, temporally changeable and show a wide range of development (within a broad definition of reef), then utilising a strategy based on direct sampling may be the most effective way to assess reef status and monitor change.

Summary of acoustic techniques

Whilst it may be possible to detect large biogenic structures, it is unlikely that acoustic detection of more cryptic benthic communities (such as the range of *Sabellaria* communities that might be considered to be 'reef') will be a direct process: some form of inferential interpretation of the acoustic images is required. The inferential process is integral to the use of AGDS (Sotheran *et al.*, 1997; Foster-Smith and Sotheran, 2003), but interpretation of benthos using high resolution sidescan or interferometric images must still be done indirectly through the interpretation of bedform features. This leaves the mapping process open to error not only from the techniques themselves, but also from the interpretation process. This is particularly important when repeat surveys are to be compared for assessing change. If condition monitoring requires more certainty attached to conclusions regarding change of status of a particular community, then the techniques used for broadscale mapping may not be appropriate.

8.5 Sampling and variability

The distinction between pattern and patchiness depends on the scale of observation used: broadscale survey (low resolution) may render an area as being patchy whilst a fine scale survey (high resolution) may show pattern.

For mapping, this will be determined by the combined errors from the sample area and positional inaccuracies of the acoustic image and the ground-truth observation. Essentially, if two locations in the survey area cannot be spatially distinguished, then the information from the two points must be integrated into a combined description. If the benthos at these two points are different, then the descriptive statistic will need to measure the level of variability. This variability is a measure of patchiness. In other words, patchiness is a measure of the variability of the data at and beyond the limits of spatial resolution of the survey. This inherent variability is termed the 'nugget' in variography.

What is the level of this variability? A standard approach to mitigate against fine scale heterogeneity is to take a small number of replicate grabs (taken at the same location, but allowing for drift and spatial imprecision to space the samples). In 2000 five sites (3 at Area 107 and 2 at Long Sand) were sampled three times and the positions logged as accurately as possible (dGPS close to point of deployment of grab, but with no control over drift of the grab). The number of *Sabellaria* in each grab were used to calculate similarity between pairs of grabs and the similarity have been plotted against lag distance (distance between the pairs) (Figure 8.12).

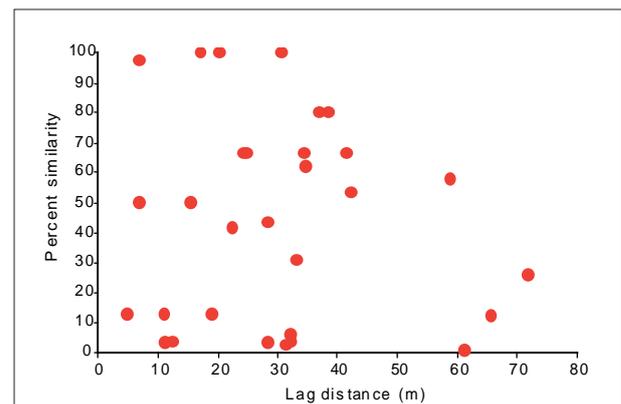


Figure 8.12. Similarity between pairs of samples (based on *Sabellaria* numbers) plotted against the distance between the pairs (lag distance).

The variability between samples that are close together is extremely high and there is no obvious decrease in similarity as lag distance increases.

Thus, over short distances, closely spaced samples are no more similar to each other than more distant samples.

This would indicate that there are no very local patterns within the 80m (\pm the estimated drift error). The local mean value of the samples is the best estimate for any point within the area encompassed by the samples.

This strategy has two main drawbacks: (1) three samples are too few to estimate variability or a mean that can be used as a yardstick for measuring change, and (2) the area encompassed by the samples is small (100 m) and any apparent change measured by repeating the sample might reflect patchiness at a slightly broader scale rather than any real change.

The strategy for the 2001 survey was based on random samples within a large quadrat in an attempt to overcome these problems. The survey strategy was, in outline:-

1. Highlight areas likely to support *Sabellaria spinulosa* identified from previous broadscale surveys.
2. Select 7 1km 'quadrats' placed at intervals along a transect from the inner Wash, along Long Sands/Lynn Deepes to further offshore outside the cSAC boundary (the Scott Patch area and Area 107).
3. Random sample within the 1 km quadrats.
4. Use remote sensing techniques to detect spatial structures at a fine scale within the super-quadrats.
5. Re-survey in 2004 to assess change.

The super-quadrats had sides of 1 km. Ten grab samples were collected from randomly selected stations (but accurately located to within 50 m) within the boxes and these were assessed visually for reef development, sediment granulometry estimation and then the infauna were extracted and preserved for later identification. Each of these grab sample sites was also sampled with a drop down video which not only could assess the physical scale of reef development, but also be used to gauge the patchiness of the biotopes at a broader scale than the grab sample.

The locations of the grabs and video samples were selected by placing a grid of numbered 25 m squares over the super-quadrat and ten were selected using random numbers. Some extra locations were selected in case it proved impossible to grab at one of the ten selected locations (e.g., due to static fishing gear) and in such cases a duplicate grid location was selected at random.

Variance/lag plots

Samples with counts (numbers of *Sabellaria spinulosa*) can be subjected to another graphic demonstration of spatial correlation in which variance between pairs of samples is plotted over increasing lag distance (Burroughs and

McDonnell, 1998). In the following analysis, the variances in the similarity between pairs of samples over lag distances have been calculated for each of the Boxes separately. The pair-wise similarities were placed into bins of increasing lag distances. The exact bin ranges varied between Boxes depending upon the spread of pair-wise lag distances and bins with less than 4 pairs were discarded. Since variance depends on the absolute numbers, the variances for each lag bin have been standardised by dividing by the total variance within each box to enable the plots for the Boxes to be more easily compared. The variance/lag graph for each Box has been plotted separately in Figure 8.13. Also included is the variogram for the data from all pooled, shown as the thick black line. The larger data set has meant that a larger number of lag ranges were possible for this calculation and a meaningful, smooth graph possible.

The variances are themselves very variable between successive lag distances, but few graphs show any clear sign of increasing variance with increasing lag distance (which would be expected if samples close to each other were more similar in numbers of *Sabellaria* than those further apart). However, there may be some indication of spatial correlation in Boxes 1 and 7.

Indices of dispersion

The similarity of the *Sabellaria* numbers in the 10 sample locations within a Box together with their position can be used to measure dispersion using indices such as Moran's I. The basis of such indices is to create two site/site

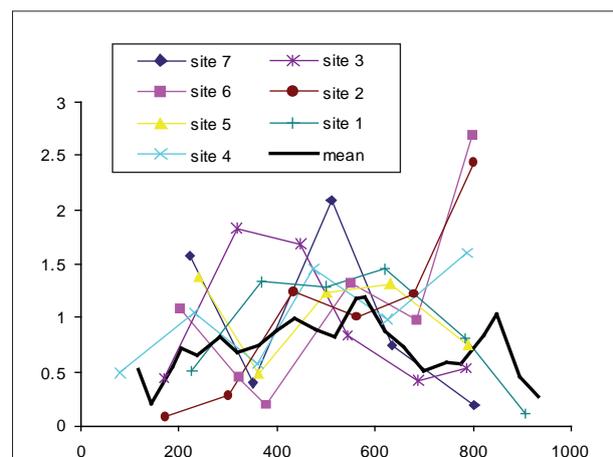


Figure 8.13. Variogram plots for each of the 7 boxes, each made up of variances of pairs of data in 5-6 lag distances ranging from about 100 m to 950 m. The dark line represents the variogram for the data from all Boxes pooled.

matrices of (1) separation (lag) distance and (2) similarity and then calculate the cross-product of corresponding cells in the matrices. The value of the Moran's index approaches -1 when the sites over a given lag distance are more dissimilar than might be expected (negatively correlated) and +1 when are more similar (positively correlated). The indices can be calculated for different lag distances and this gives an indication of the way dispersion/aggregation changes with increasing distance separating the sites. Moran's indices have been calculated for increments in the lag distance of 150 m up to just over 1 km and Figure 8.14 summarises the pattern for all seven Boxes.

Moran's I tends towards a slight negative value at the larger lag distances and at small lags (where the significance of the indices is low because of the smaller number of pairs in the calculation) I is very variable. Two sites (Boxes 2 and 6) show a gradual decrease in I which might indicate some positive correlation at small lags. But the highest values are not large (approximately 0.25) and it is doubtful if the trend is interpretable. If all data are pooled, then there is only a weak trend in spatial association (Figure 8.15).

Summary

There is no general tendency for samples to show spatial correlation over the quadrat and this supports the working model of the quadrat as being uniformly heterogeneous. That is to say, the randomly selected samples are likely to be statistically representative of the quadrat as a whole.

8.6 Change

The Boxes have been sampled since 2001 using a randomised design (i.e., not the same stations as in 2001): in 2003 both boxes were re-sampled and in 2004 only Box 4 was sampled due to adverse weather. The 2001/2003 all stations were grab sampled and the infauna have been counted. There were also video data and from this, and the grab information, an abundance/coverage ranking score has been assigned. In 2004, only the video data has been analysed to date and this has been scored (Table 8.4). This has allowed a preliminary assessment of change to be made not only between 2001/3 but, for Box 4, 2003/4.

A t-test was performed on the quantitative data and a Mann-Whitney test on the ranked scores. Although the mean values declined between 2001/3 in both boxes, there was no significant difference in the mean abundances between 2001/3 for Box 1 ($P = 0.47$), but a very significant

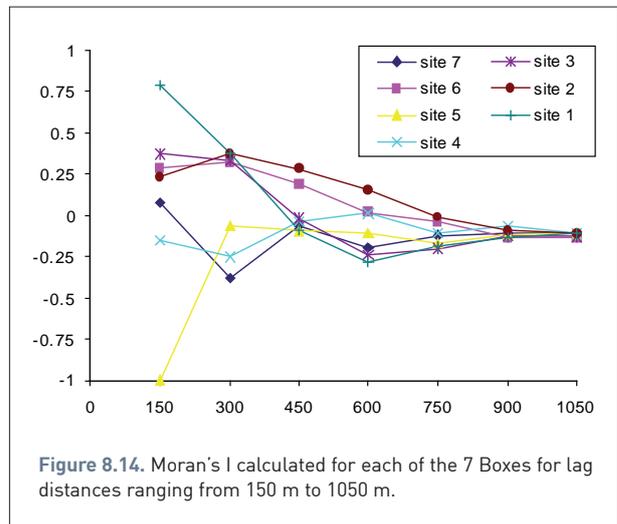


Figure 8.14. Moran's I calculated for each of the 7 Boxes for lag distances ranging from 150 m to 1050 m.

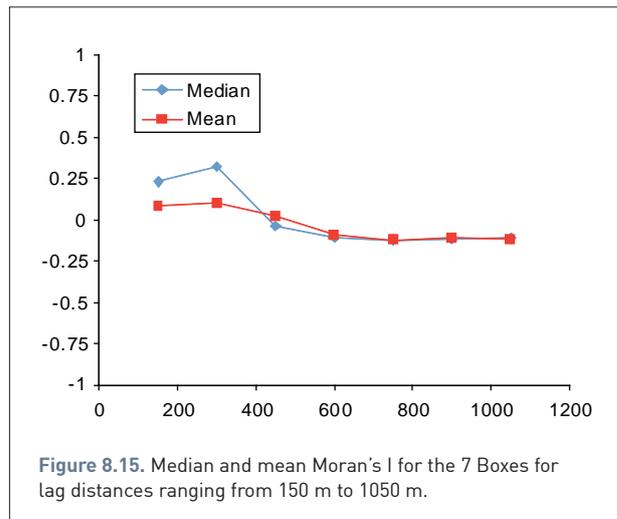


Figure 8.15. Median and mean Moran's I for the 7 Boxes for lag distances ranging from 150 m to 1050 m.

decline in numbers between 2001/3 for Box 4 ($P = 0.0013$). The Mann-Whitney test also suggests that there has been a significant recovery in numbers between 2003/4 (see Table 8.5).

The change in Box 4 in 2003 is very marked whilst the high P value for Box 1 (2001/3) rules out any significant change despite the mean value dropping 30%. The variability is very high for all data (standard deviations of about the same value as the means). However, it is important to ask what magnitude of effect the sampling regime could detect.

Table 8.4. Sample data for Boxes 1 and 4 for the years 2001, 2003 and 2004.

| | Box1 | | | Box4 | | |
|---|-------|-------|------|-------|------|------|
| | 2001 | 2003 | 2004 | 2001 | 2003 | 2004 |
| <i>Sabellaria</i> numbers | | | | | | |
| | 85 | 173 | na | 92 | 3 | na |
| | 9 | 73 | na | 532 | 3 | na |
| | 459 | 113 | na | 401 | 5 | na |
| | 413 | 14 | na | 263 | 18 | na |
| | 578 | 241 | na | 169 | 25 | na |
| | 399 | 77 | na | 196 | 11 | na |
| | 154 | 602 | na | 341 | 1 | na |
| | 157 | 173 | na | 403 | 14 | na |
| | 23 | 93 | na | 74 | 1 | na |
| | 17 | 104 | na | 27 | 2 | na |
| Mean | 229.4 | 166.3 | | 274.6 | 9.0 | |
| <i>Sabellaria</i> score (based on coverage) | | | | | | |
| | 2 | 3 | na | 3 | 1 | 4 |
| | 1 | 2 | na | 4 | 1 | 3 |
| | 4 | 3 | na | 4 | 1 | 4 |
| | 4 | 1 | na | 3 | 1 | 4 |
| | 4 | 3 | na | 3 | 2 | 3 |
| | 4 | 2 | na | 3 | 1 | 3 |
| | 3 | 4 | na | 4 | 1 | 2 |
| | 3 | 3 | na | 4 | 1 | 2 |
| | 2 | 3 | na | 2 | 1 | 1 |
| | 1 | 3 | na | 2 | 1 | 1 |
| Median | 3 | 3 | na | 3 | 1 | 3 |

Table 8.5. Significance of the differences in the means of *Sabellaria* numbers for the 10 samples taken in years 2001 and 2003 (P values).**Box 4**

| | 2001 | 2003 |
|------|--------|--------|
| 2003 | 0.0001 | |
| 2004 | 0.36 | 0.0018 |

Power is determined by sample number, variance in the data, the confidence interval deemed to be significant and the effect size required to be detected (Motulsky, 1995). Usually, a confidence limit of 95% is set for judging significance. This should be interpreted that there is a small risk (5%) of making a claim that there is a difference between populations when there is none – a Type 1 error. However, in environmental studies where populations are highly variable and samples expensive to collect, it is more usual to run the risk of claiming there to be no significant difference when, in reality, there is a difference between the two populations from which the limited samples were drawn (termed a Type 2 error). The chance of this happening is measured through the estimation of the power of the sampling regime and the statistical test used. It is important for environmental studies that sampling strategies have a reasonable prospect of detecting any change, but the significance levels for Type 1 errors are often reduced to avoid Type 2 errors.

The power of the sampling procedures to detect various levels of change have been calculated assuming that it is desirable to maintain a 95% or 90% confidence that a Type 1 statistical error has not been made (i.e., that a difference between two samples is claimed when no difference exists). These calculations (Table 8.6) are based on the measured variances and a sample size of 10.

Table 8.6. Approximate power of 10 random samples from populations based on those encountered in the Wash to detect effects ranging from a 15% change in numbers to 80% change.

| Effect size (% of means) | Confidence interval | |
|-----------------------------|---------------------|------|
| | 90% | 95% |
| 15 | <0.1 | <0.1 |
| 30 | 0.24 | 0.12 |
| 50 | 0.5 | 0.28 |
| 65 | 0.67 | 0.5 |
| 80 | 0.85 | 0.72 |

The power of the sample strategy is low. For example, there is a probability 0.85 (17/20) of detecting a change in *Sabellaria* density of the order of 80% taking 10 random samples and assuming the risk of making a Type I error is acceptable at 90%. Thus, as can be seen from the actual results in Box 4, the strategy is only good at detecting large changes.

Table 8.7. Power to detect changes in proportions of samples with high densities of *Sabellaria* (e.g., scores 3 or 4) for a full range of effect sizes for sample numbers of 10 (left column) and 20 (right column).

Proportion dense *Sabellaria*

| Sample size | 0.1 | | 0.2 | | 0.3 | | 0.4 | | 0.5 | | 0.6 | |
|-------------|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | 10 | 20 | 10 | 20 | 10 | 20 | 10 | 20 | 10 | 20 | 10 | 20 |
| Effect size | Power (% chance of detection) | | | | | | | | | | | |
| 1 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 100 | 99 | 99 |
| 0.9 | 100 | 100 | 100 | 100 | 99 | 100 | 98 | 100 | 83 | 99 | | 90 |
| 0.8 | 100 | 100 | 100 | 100 | 95 | 100 | 78 | 98 | | 82 | | |
| 0.7 | 100 | 100 | 96 | 100 | 79 | 97 | | 80 | | | | |
| 0.6 | 98 | 100 | 84 | 97 | | 81 | | | | | | |
| 0.5 | 91 | 99 | | 87 | | | | | | | | |
| 0.4 | 77 | 93 | | | | | | | | | | |
| 0.3 | | 75 | | | | | | | | | | 80 |
| 0.2 | | | | | | | | | | 82 | 0.8 | 98 |
| 0.1 | | | | | | | | 89 | 83 | 99 | 100 | 100 |
| 0 | | | | | | >80 | >80 | 99 | 99 | 100 | 100 | 100 |

Another possible form of analysis of the data is to class the records as low or high density *Sabellaria* (such as might be obtained through video or an inspection of grab material on board). Table 8.7 illustrates the power (the % chance of detecting a change) with different effect sizes (proportions of dense *Sabellaria* in two samples) accepting a 10% risk of making a Type I error (P set to 0.1) with 10 or 20 samples.

Again, the power of the sampling strategy is low, being restricted to quite large changes in the composition of the quadrat. Increasing the sample size makes the test more powerful, but the frequency would need to change 5 points before there can be any reasonably assured chance of detection.

8.7 Discussion

The exploration of spatial variability in the data is necessary at all spatial scales. Broad-scale maps (e.g., 1:50-100,000), such as a baseline map of the Wash, cannot show the full variability that one might expect to encounter in an area: They present a generalisation (often to the most dominant class, an upper level in a hierarchical structure or some more broadly defined seabed feature). If samples were to be taken within an apparently uniform polygon on the map, then a wide range of other classes may be expected. This range is hard to define statistically since there are often few ground-truth data for statistical analysis and the ground may be very variable.

The problem of variability remains at very fine scales (e.g., 1:1-10,000). Thus, variability between even close samples might be high and thus it may make the detection of local patterns very difficult and uncertain. However, the restricted geographic scale makes replicate sampling more feasible and it may be possible to pin down the mean,

range and variability of the population through sampling such that populations can be compared statistically. It is easy to integrate data over quadrat-scales and work with statistics that summarise the nature of the quadrat.

It is the scales between which are most difficult to address. Patches become large enough to require mapping rather than integration into a summary description and the processes that drive these patterns start to assume more importance and operate at the scale of management. However, whilst quite a high level of inaccuracy might be hidden in broad-scale generalisation, this inadequacy becomes very apparent at the intermediate scale. It no longer suffices for a map to make a statement that *Sabellaria* may be expected to be found in an area: the questions 'how much?' and 'how certain?' become more important.

It has been established that broad-scale mapping can be used to identify areas where *Sabellaria spinulosa* might be expected to occur, but it is likely that the same mapping techniques and strategy cannot be successfully used to map at the intermediate and fine scale heterogeneity, especially in a dynamic environment such as found in the Wash and its environs. Thus, for condition monitoring, a comparison of interpreted maps of *Sabellaria* distribution at intermediate scales would probably be undermined by high uncertainty and variability. If this is a correct assessment of the limits to the power of mapping techniques for this application, then an alternative strategy must be developed. There would appear to be two options: (1) to broadly define uniform areas (encompassing quite a high level of fine scale heterogeneity) and to stratify quantitative sampling or, (2) to adopt high definition imaging and accurate position fixing of samples.

The first option has been explored in this Chapter. Stratified sampling was based on the random sampling

within a quadrat with sides of 1 km. The size of the box (quadrat) is important: too large and the samples will not be from a uniform (or uniformly patchy) area due to broader scale spatial trends, too small and the samples may not be representative of a significant area (i.e., be influenced by patchy habitats and seabed features). Thus, the validity of random sampling as a strategy is based on the assumption that there is no strong spatial trends within the boxes, although there may be heterogeneity of biota and even quite large seabed features (as in Box 4). This may not be true, as even in Box 1 there was evidence of a depth gradient and the northwestern sector appeared to show a greater impact of sand extraction compared with other parts of the box.

One drawback to this strategy is its restricted spatial coverage. The extent to which the results from one quadrat reflect wider trends is doubtful: A severe decline in numbers of *Sabellaria* and subsequent recovery in one quadrat, for example, may simply reflect local changes and not be replicated elsewhere. However, this study has demonstrated that reefs can change significantly at the scale of the quadrat.

The detection of broader spatial trends through replication of the quadrat will have implications for survey cost. An alternative approach might be the use of widespread stratified sampling of habitat types. But scattered samples are susceptible to apparent change through fine scale patchiness and the number of samples required to obtain any degree of certainty in the results might be quite large. Detection of temporal changes over a wide area might not be so sensitive to fine scale patchiness, but extraction of significant trends will still require care.

The second option (high definition and precision) might be possible with scanning sonars and acoustic cameras combined with acoustic position fixing devices. The advantages of acoustic techniques over conventional video is their ability to 'see' in turbid environments. ROVs have been used for transects over reefs in good visibility and mosaicking high definition video may also offer good quality images suitable for critical analysis and spatial coverage.

9. Conclusions and recommendations

The following conclusions and recommendations can be drawn from the results of this study:

- During this study we have developed and demonstrated an approach to mapping the seabed which can be adapted to suit a range of spatial scales and is suitable for environmental management and monitoring purposes. This approach is more cost-effective than traditional approaches since it benefits from informed rather than 'blind' sampling. The approach involves the identification and delineation of seabed facies. Constructing facies maps does not present any major technical difficulties. 100% sidescan sonar mosaics are easily achievable for site specific maps. For broader scale regions, a density of ~50% sidescan cover (1 km track spacing using 400 m total swath width sidescan sonar) was found to be appropriate. Lower acoustic coverage can miss significant facies. The marginal benefit of 100% coverage did not appear to warrant the additional cost over the broadscale area surveyed to meet the aims of this study.
- There is no single 'best' scale to represent benthic habitats: the patterns of spatial and temporal distribution of biota vary widely between organisms and their relationship to underlying physical processes (including anthropogenic disturbance) that structure sediment and bedform features. Surveys must be designed around the scale of patterns and processes most relevant to the survey aims. Spatial patterns range from fine scale (which is often regarded as heterogeneity giving rise to statistical stochastic variation), through medium scale local patterns related to local physical conditions (e.g., sediment and bedform features) to broadscale biogeographic distribution patterns. The way in which these scales are accounted for in survey design is fundamental to the patterns and processes being addressed.
- Ground-truth surveys at Hastings show the maps are accurate in both their description of the sediments and the definition of the facies borders. Results also demonstrated that seabed facies are ecologically significant units and this validates their use in mapping seabed habitats. Grab samples show greater spatial correlation with facies than the more mobile epifauna sampled using trawls. Maps of this type are suitable for underpinning marine spatial plans and their employment should ultimately lead to better decision-making.
- Correlation between benthic communities and sediment type is improved when sediment type is categorised at finer scales (e.g. 5 point scale of Gravel, coarse Sand, medium Sand, fine Sand, Mud rather than 3 point scale of Gravel, Sand, Mud). It is therefore recommended that future work investigates the specificity and fidelity of species to finer sediment categories (possibly to Phi size groups). PSA samples from Hamon grabs appear to omit larger sediment particles (cobbles/boulders) which may be significant in structuring biotopes.
- There are many different remote sensing techniques that can be used in habitat mapping surveys. Although there is some overlap in coverage and resolution between the main techniques, each 'sees' different aspects of the seabed and the techniques are often complementary rather than one technique eclipsing others.
- Remote sensing is a rapidly changing area of technology and, in acknowledging this, generic survey design must be 'future-proof' to some extent. Imaging seabed features is relatively straightforward using swath systems, such as sidescan sonar and multibeam bathymetry, but the relationship between features and biotic assemblage and sediment type is not always clear. This may be partly due to the differences in scale of the sampling technique (grab, video) in relation to the mapped feature scale combined with heterogeneity. It may also be due to weak linkages between biota, sediment and features within the context of disturbed habitats.
- Any techniques that rely on classification of remotely sensed data using point ground-truth samples (such as AGDS with grab samples) may be compromised by heterogeneity of the area and the quality of the ground-truth design. The combination of effects such as positional imprecision and differences in scale of observation can produce uncertainties in the clarification which limits the use of this approach. This is especially true if the survey area is under sampled since classification techniques will only 'find' the range of habitats sampled.
- Results of AGDS classification performance between the Tyne and Shoreham sites appear contradictory. For example, unsupervised classification was not particularly successful in discriminating the Tyne dredged material

disposal ground (TY070), but was moderately successful at the Shoreham aggregate extraction site. Supervised classification using sediment classes indicated a distinct area of sediment in the dredged material disposal site (although the nature of the sediment changed from year to year) but very poor delineation of the aggregate extraction area at Shoreham. There are therefore still some uncertainties on the application and full capabilities of these techniques which will require further testing.

- Sidescan sonar images of the seafloor were a useful source of information to consistently cover large areas, detect differences in the spatial distribution of seabed facies (e.g. dredged material deposits, sand waves and rock outcrops, dredged tracks and presence of pits) and assist the delineation of acoustically distinct areas over time.
- Variations in backscatter strength, as represented on a sidescan sonar record, can be a result of changes in sediment type, bed-slope or a combination of these aspects and it is not always clear which is the causative factor. Multibeam bathymetry can provide valuable information relating to the slope and topography of the seabed and this can help the interpretation and corroboration of sidescan images.
- The integration of novel and established tools provides a robust approach for assessing temporal changes in the nature and intensity of anthropogenic impacts. The combination of small scale (i.e. grab and SPI camera to intermediate scale (video and beam trawls) ground-truthing tools provided a powerful means to characterise seabed habitats. Such techniques and approaches, as described in this report, would be suitable for application as part of routine monitoring programmes carried out at existing and prospective aggregate extraction and dredged material disposal sites.
- Seabed heterogeneity makes it difficult to design a sampling strategy that detects the effects of disturbance on biota as sampled using grabs, vertical photography or other point sample techniques. Variability between adjacent samples may be as high as between samples that are widely separated. These fine scale spatial effects may be expected to mask any temporal trends. A measure of heterogeneity (using geostatistical techniques) is useful in planning a sampling strategy. Sampling heterogeneous areas will need careful planning assisted by an appropriate ground-truthing sequence (e.g. sidescan sonar, SPI camera survey, grab survey), if the results are to carry any statistical significance. However, even with a relatively intensive sampling programme it is likely that effect sizes that might be detected will be quite large and levels of significance may need to be reduced when proving an effect.
- It is important to undertake an appropriate pilot survey to document areas of high heterogeneity. During this project, a number of pilot investigations were carried out in order to aid the delineation of acoustically distinct areas and assist in the formulation of ground-truthing strategies. In attempts to map an area with highly heterogeneous substrata two options present themselves, which bear upon the utility of the outcome in an environmental management context. The first requires generalisation ('lumping') in order to define regions that will in all probability contain variable substrata within some broader basis for division (e.g. depth). The second, which may be viewed as more scientifically credible, requires division ('splitting') into as many regions as are formally necessary or possible in accordance with observed substratum variability. Both of these approaches have drawbacks. A possible effect of 'lumping' is that boundaries may be drawn which are more of a human artefact than a true ecological separation. However 'splitting' may result in regions that cannot be accurately ground-truthed. Another important consideration is the use to which the map is to be put. If it is to be used for the purpose of managing the area, it will be important to consider what scale is relevant to that management.
- In a number of surveys, we sought to generalise and delineate broad acoustic regions, accepting that those regions would be heterogeneous and that our boundaries might not be true ecological separations. Despite these limitations we were, in many cases, able to define acoustically distinct areas of the seabed which contained characteristic faunal assemblages and seabed facies. This was due to the employment of optical and acoustic techniques used in conjunction with physical grab samples and/or trawl samples. This emphasises the importance of an integrated approach, especially in areas of high substrate heterogeneity.
- Results from this project illustrate the challenges of mapping areas of the seabed at sites disturbed by various anthropogenic activities. Whilst the employment of "state of the art" mapping approaches was found to enhance our capacity to interpret the effects of

anthropogenic activities, the intrinsic variability of such sites, in some cases, precluded tight classification other than into very broad categories. While this may be viewed by some as a scientifically unsatisfactory outcome, it is precisely this complexity (in particular at the Tyne and Shoreham cases, reflected in substrate heterogeneity) which often characterises sites exposed to anthropogenic activities. For example, environmental monitoring at dredged material disposal sites is often complicated by the presence of a wide range of substrate types, sometimes ranging from sand through gravel to outcropping bedrock. Such substrate heterogeneity is relatively common along the southern and western UK coastlines (e.g. Nab Tower disposal site in the central English Channel) and at other sites where environmental monitoring is necessary (e.g. aggregate extraction sites in the Eastern English Channel), which can cause significant problems for the generation of effective, quantitative sampling designs. This in turn makes it difficult to draw generalisations concerning the status of the seabed. Acoustic mapping was, however, found to greatly facilitate the effective design of sampling programmes through the provision of information concerning the physical nature of the seabed.

- Analyses showed that biogeographic variability between infaunal communities at sites of similar sediment in the west and eastern English Channel was mostly attributable to those species having very low abundance (typically <1% of total abundance). The core of the communities was characterised by approximately 30 taxa, which exhibited a much reduced geographical variability. It is important that predictive models of faunal assemblages/habitats should take proper account of biogeographic variability. To predict the occurrence of low density species, far greater knowledge is required of 'local' species lists.
- Biogeographic variability leads to a trade-off between accuracy and precision within predictive models. Very precise predictions of infaunal assemblages (e.g. to species level) are likely to have a low degree of accuracy, while less precise predictions (e.g. to Order or Class) will be inherently more accurate. The latter predictions will be of increasing value as more becomes known about the functional role played by different taxa within a community. Predictive mapping also needs to take account of the known distribution of species that have a dominant function in structuring biotopes (e.g. *maerl*, *Modiolus*, *Sabellaria*).
- If the sole aim of a survey is to map species/community distributions, then there may not be a need to conduct 100% coverage acoustic surveys of the seabed. Modelling work for this project has shown how a similar biological classification of the Shoreham area was arrived at whether the acoustic data was used or not. However, without the benefit of the acoustic survey, it is likely that a far greater sampling density will be required to impart high levels of confidence in the resulting map.
- Habitat classifications may alter over time due to environmental variability and population change.
- The analysis of benthic samples obtained from grabs and trawls was conducted separately. It is important to establish a common denominator to allow the assimilation of data derived from both towed and point sampling gears in order to provide holistic faunal maps of the seafloor and to improve our understanding of the relationships/role of benthic assemblages. However, there are inherent problems in this due to the great discrepancy in areas sampled by the two gear types, and the 'ability' of trawls to sample across several different habitats in a single sampling event. Addressing this generic problem would be a valuable area for future work. The choice of gear type will influence the fraction of the seabed assemblage that is sampled and will also determine the capacity to discriminate benthic habitats. Such choices also have a bearing on the nature of the final habitat map and will have implications for any derived habitat classification schemes. Until a single 'unified' sampler can be developed, it is recommended that both point sampling devices (e.g. grabs and/or SPI) and towed gears (e.g. trawls and towed video cameras) are used to ground-truth acoustic maps of the seabed.
- This project clearly benefited from the integration of scientific skills from a range of disciplines (i.e. sedimentologists, geologists, fisheries and benthic ecologists and geophysicists). It is recommended for the benefit of future seabed mapping programmes that this cross-disciplinary approach is adopted.

10. Future work

- A programme of work is directed towards characterising the acoustic signature of different sediments, with a particular view towards differentiating the major grades of coarse sediment which all currently fall under the category of 'gravel' in the Folk scheme of sediment classification. It is inappropriate to retain this single, broad category when dealing with biotic communities as it encompasses a range of habitat types that are more adequately described by the sub-divisions of gravel, pebble, cobble and boulder familiar in the Wentworth scheme of sediment classification. The current perception of a 'gravel' habitat is open to a wide variety of interpretations.
- A programme is initiated to develop a seabed habitat/biotope classification for coastal and offshore shelf waters, focusing primarily on mobile and coarse substrates (gravels and sands). It should complement and enhance the two primary classification systems applied in UK waters, namely the JNCC Marine Biotope Classification for Britain and Ireland and the EUNIS (European Nature Information Service) classification. Attempts should be made through a biotope matching programme to link characteristic benthic infaunal communities with existing JNCC biotope descriptions.
- Existing approaches to ground-truthing seabed habitats rely heavily upon assessments of species richness, abundance, biomass and trophic group composition. These approaches are to a large extent deficient in considerations of ecosystem processes since such processes are, in part, governed by functional characteristics of the organism involved, rather than their taxonomic identity. It is recommended that future habitat mapping studies take account of the functional attributes of species found within mapped areas.
- The capability of acoustic techniques for characterising and mapping dense aggregations of benthic marine organisms, particularly those listed in Annex I of the Habitats Directive, should be further explored with a view to developing their predictive capability for application in marine resource management. This may, in part, be addressed by a recent programme of research funded by English Nature, through Defra's Aggregate Levy Sustainability Fund, led by the JNCC which aims to establish the 'Best methods for identifying and evaluating biogenic and cobbly reef'.
- To address the issue of whether surveys conducted over different spatial scales can be linked, experimental surveys need to be conducted over a range of different spatial extents whilst minimising any temporal disparity between the different surveys. The same sampling gear should also be used, or if different gears are used then species conversion factors are needed.
- A programme of work is directed towards establishing associations between acoustically distinct sediments and their biotic communities to enhance the future application of acoustic surveys in predictive mapping of marine habitats and thereby facilitate the process of policy and decision making in marine resource management and spatial planning. Particular attention should be given to 'end-member modelling', moving away from the traditional focus of mean or modal grain size, and placing greater emphasis on the largest and smallest sediment particles (i.e. cobbles and silt) which seem to have a high degree of leverage in determining community structure.
- Research conducted during this study has established that a combination of seabed mapping tools were effective in mapping biological assemblages at sites disturbed by marine aggregate extraction and dredged material disposal. Further evaluation of these methods at existing windfarm sites and in areas potentially suitable for windfarm construction, coupled with investigation into new physical and geophysical methods would establish the extent to which such an approach could be routinely applied in environmental assessment, monitoring and management programmes. Similarly, the approaches developed during this project may be extended to the evaluation of other areas, particularly in areas of nature conservation importance.
- The need for effective stewardship of the marine environment through a policy of integrated management has been widely recognised. Detailed information on the nature and distribution of habitats, resources, and marine landscapes of archaeological importance do not currently exist for the U.K. continental shelf. Maps of seafloor topography, surficial geology and benthic habitat will help implement ecosystem based resource management in U.K. waters. Despite the recognised benefits of mapping the seabed and the availability of appropriate seabed sampling tools and acoustic technology (e.g. multibeam bathymetry, sidescan sonar), a strategy for co-ordinating mapping activities in the U.K has yet to be formulated. There is therefore an urgent need to develop a strategy to simultaneously address the needs of coastal and offshore stakeholders by mapping prioritised areas of the coastal and offshore seabed each year.

11. Approaches to scoping and designing seabed habitat surveys

11.1 Introduction

The aim of conducting a survey of this type is to produce a habitat map that is fit-for-purpose, whether that purpose is in supporting licence application and EIA, providing the baseline assessment against which future monitoring studies will be compared, or undertaking the monitoring surveys themselves. As well as these site-specific studies, there may also be a desire to produce habitat maps over larger spatial areas to underpin or support Regional Environmental Assessments, placing the individual site specific studies in a broader spatial context and helping to assess the significance of certain habitats (and/or potential impacts on those habitats) at the broader spatial scale.

It is important to recognise that these different types of study have different aims, so the manner in which each survey is conducted should meet the specific objectives of that survey. Frequently, environmental assessments have not fully addressed specific issues because the surveys undertaken have failed (through omission rather than intent) to collect the relevant data. Consequently, this chapter provides a guidance framework for scoping and designing surveys. This is given in the form of two interactive decision trees which can be accessed via prompts in the PDF version of this report which is provided on the CD which accompanies this document. The purpose of the two decision trees is not to provide prescriptive answers for all scenarios, but to guide those involved in planning surveys through a decision making process relevant to their particular needs. The decision trees, and the issues that each stage should address, are reproduced in a non-interactive format below.

We have considered survey planning as a two-stage process. The first addresses the scope of the survey, setting out what it needs to achieve in order to be fit-for-purpose. Here, considerations must be given to the interest of both the applicants and the stakeholders, the risk and significance of any potential impact to specific habitats, and the issues to be resolved in defining the parameters of the survey. The output of this first stage is a clear understanding of what the survey is required to achieve and the issues it needs to address. This knowledge is a pre-requisite for the second stage; that of designing a cost-efficient survey involving directed ground-truthing of interpreted acoustic maps. Considerations here relate to the need and/or adequacy of acoustic survey outputs to draft a physical map of the seabed, the planning of the ground-truth survey using suitable sampling methods and the analysis and interpretation of data to produce the final habitat map.

11.2 Scoping the survey ([access first decision tree](#))

This decision process addresses the need to set the parameters for selecting survey techniques and strategies. The purpose is to identify, describe and prioritise the potential areas of conflict that might exist between an applicant and relevant stakeholders to ensure the survey is designed to competently address those issues in the most effective manner.

11.2.1 Flow chart

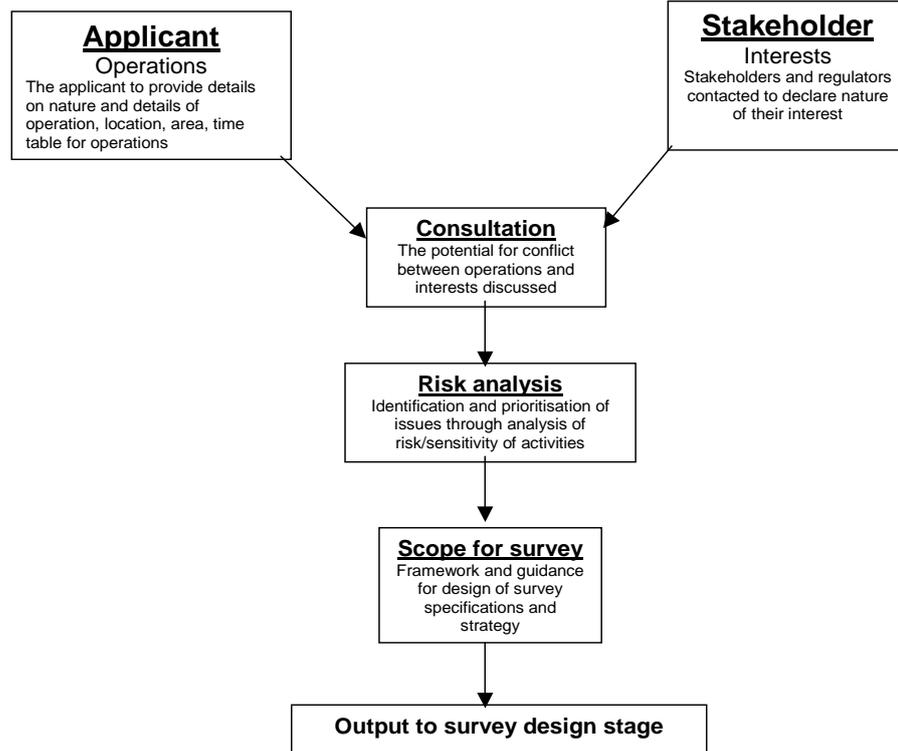
The applicant will be expected to conduct a survey which will detect and map specific features of interest to stakeholders and/or undertake more general surveys of habitats and biota. The effort expended on survey needs to be weighed against the significance of these features, their sensitivity to site specific human activities, their likelihood of occurrence, and the required accuracy and precision of detection and discrimination. Exhaustive, comprehensive and fine detailed survey comes at a price and survey effort needs to be carefully matched to requirements. The process of consultation should establish the survey effort required in order that the applicant can select the most appropriate tools and design a survey which considers all stakeholder needs.

11.2.2 Consultation

The guidance given by regulatory authorities may in some circumstances be prescriptive and well defined. However, guidance is more usually worded in such a way that the applicant is provided with an opportunity to demonstrate that they will consider potential conflicts with other stakeholder interests and can justify the appropriateness of the survey design they plan to implement. The dialogue between applicant and stakeholders/regulators is facilitated through a systematic appraisal of the nature of planned operations and their possible impact on other interests, taking due regard as to the risk, sensitivity and significance of those interests.

There are a number of key factors which will have implications for the level of survey intensity and effort required. The output of the flow chart (see Figure 11.1) should provide answers to the issues raised and provide clear guidance for the selection of suitable survey techniques and strategies.

Figure 11.1. Flow chart for establishing survey parameters.



11.2.3 Information required of the applicant

The applicant will need to make available the relevant information relating to the nature of the operation to enable

other stakeholders to make informed decisions about the potential consequences of the proposed activity. Some of these issues are detailed in Figure 11.2.

| |
|--|
| What is (are) the nature of the operation(s)? |
| Trenching, extraction, construction, disposal |
| Will the operations directly disturb the benthic habitats? Are they likely to affect the deeper sediment, shallow surficial sediments, water column? |
| Abstraction, smothering or alteration of sediment or habitat, adding new structures |
| Will there be indirect or far-field impacts on the seafloor. |
| Creation of sediment plumes and siltation, diffuse pollution, altering hydrodynamic regime |
| What is the extent of each impact? |
| Near-field and/or far-field. |
| What is the duration of each operation? |
| Short duration, long term or permanent |
| What is the intensity of each impact? |
| Low to high level |
| Are there multiple impacts (apart from applicants)? Will there be synergistic effects? |
| Fishing activities, oil/gas, aggregate extraction etc |

Figure 11.2. Some of the issues surrounding the nature of the operation.

| |
|---|
| Nature conservation (EN, SNH, CCW, JNCC, Cefas...) |
| Fine scale (Rare species, conspicuous/inconspicuous). Broadscale (habitats and biotopes). |
| Heritage (EH, National Trust...) |
| Fine scale, specific features (wrecks and structures); broad scale general features, (sediment horizons, peat, fossil forest) |
| Sedimentologists / physical oceanographers (BGS, JNCC, Hydrographic Office, Cefas..) |
| Potential changes to coastal processes, erosion, beach draw-down etc. Navigation hazards during operations. |
| Fisheries (Cefas, Industry representatives.....) |
| Spawning and nursery grounds, important fishing grounds |
| Fishing communities (Sea Fisheries Committees, local interest groups / owners / co-operatives..) |
| Locally important fishing grounds, season |

Figure 11.3. Some of the potential stakeholders.

11.2.4 Stakeholders: who are they and what information is required of them?

Figure 11.3 above lists some of the key stakeholders and consultees, together with examples of features and issues that might concern them.

Stakeholders will also need to specify the nature of the features or issues that they have concerns for with regard to an application. Examples of some of the more specific features or issues that might be relevant are provided below (Figure 11.4).

| |
|--|
| Are there potential fine scale, specific features or issues of interest? |
| Single species, distinct biological communities, specific sediments (peat, clay), structures from seabed (reefs, wrecks), buried/sub-bottom features. Local fisheries. |
| Will an adequate search be made? How much certainty does there need to be in detection? |
| Are the features/issues of more general interest? |
| Baseline mapping of a comprehensive range of biotopes, sediments, bedform features. Important regional fisheries. |
| Are these features known to occur with certainty, likely to occur but not certain, or only a possibility? |
| Known or suspected to occur in vicinity, unknown but favourable conditions, previous records from area, previous detailed survey. |
| How extensive, conspicuous are these features? |
| Extensive, common or very restricted/patchy, rare. Very conspicuous, easily detected or cryptic, small and hard to detect. |
| What level of discrimination between feature classes is required? |
| Broad divisions (upper levels of hierarchy), fine divisions (lower levels of hierarchy) |
| How important is accurate location of features and boundaries? |
| Features/boundaries mapped with high precision and accuracy, only approximate locations required |
| What measurements are required? Estimation of extent/abundance? How important is accurate measurement? |
| Presence/absence of feature classes, abundance scale, counts, densities, weights |
| Is it likely that change will need to be monitored? What levels of change are considered to be significant? What certainty is required of change detection? |
| Coarse changes sufficient or fine changes need to be monitored. |
| What is the sensitivity of the feature to the intended operation/impact. |
| From very sensitive to very robust. |

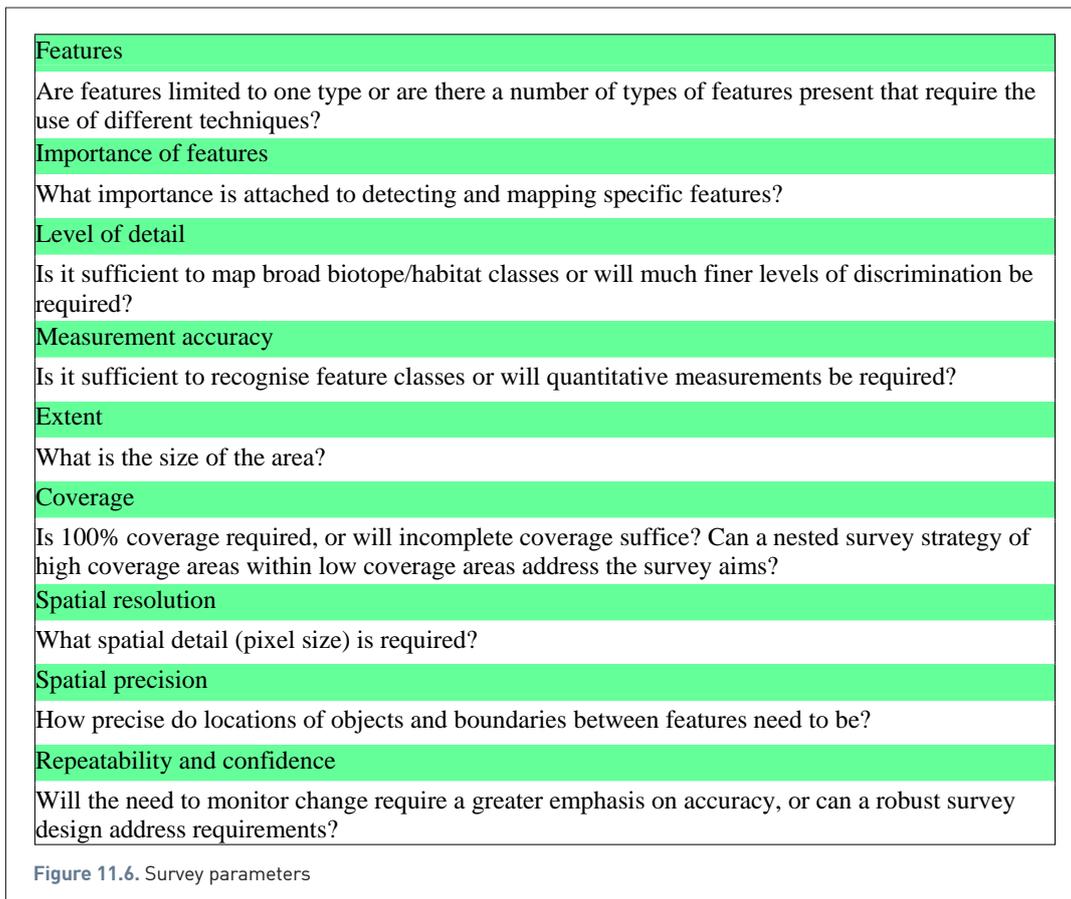
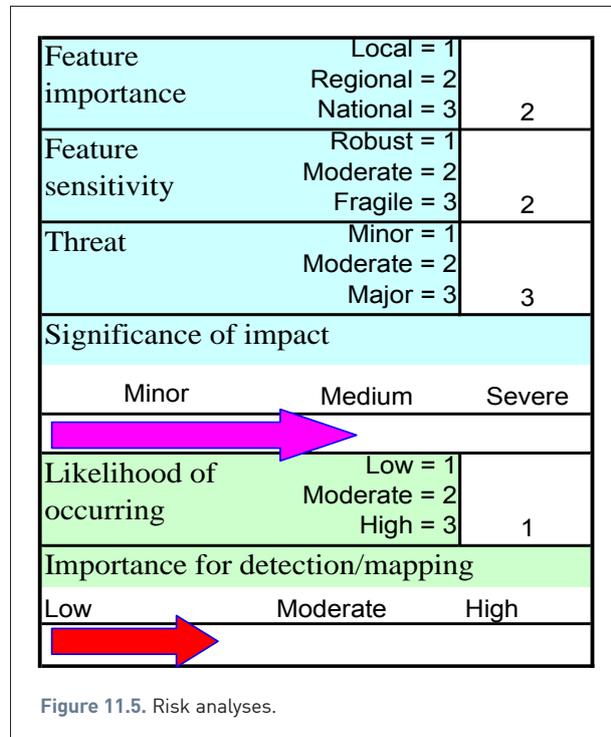
Figure 11.4. Some potential stakeholder issues

11.2.5 Risk analysis

A realistic assessment of the importance of detection and accurate mapping of a feature must combine significance calculations with likelihood of the feature occurring. Figure 11.5 illustrates how the imperative for detailed survey might be estimated for any activity which has a potential for impact. In the interactive version, scores (1-3) entered against importance of the feature, its sensitivity to the particular impact/activity under consideration and the likely threat to that feature are combined to give an indication (length of upper arrow) of the relative significance of the impact. This is further weighted by scoring how likely the feature is to occur in the study area, to provide a final indication (length of lower arrow) of the importance of detecting and/or mapping the feature in question.

11.2.6 Scoping the survey: issues to resolve

Having gathered the information from all stakeholders, the issues which need to be resolved can be discussed to narrow down the survey parameters. Likely themes for discussion are illustrated Figure 11.6. It should be noted at this stage that the various stakeholders will often have differing issues and priorities, and this must be taken into account when the survey is scoped.



11.2.7 Outputs: Survey parameters

The conclusions from the discussions between applicant, stakeholders and regulators will be a checklist, something like the table of survey parameters (Figure 11.7), with indications as to the point along a sliding scale of survey intensity/effort from low to high. This information may be needed for each application and will be used to assist in the survey design decision-making process.

As mentioned earlier in this section, it is likely that different stakeholders will have differing issues and priorities. For example, it may be the case that the issues of one stakeholder could be addressed by a low resolution, broad scale survey approach but that another stakeholder may have issues that could only be addressed by a high resolution survey. It is possible that these differing needs could be addressed by the adoption of a nested survey approach which would satisfy all stakeholders. However, this may not always be the case, and any conflicting needs should be identified as early as possible in the scoping process so that they can be taken forward and accommodated during the survey design stage.

Having fully scoped the survey to understand and accommodate all of the issues that surround an application, the next step is to design the survey that meet those needs. The second decision tree acts as a tool to facilitate this process in a structured way.

11.3 Designing the Survey ([access second decision tree](#))

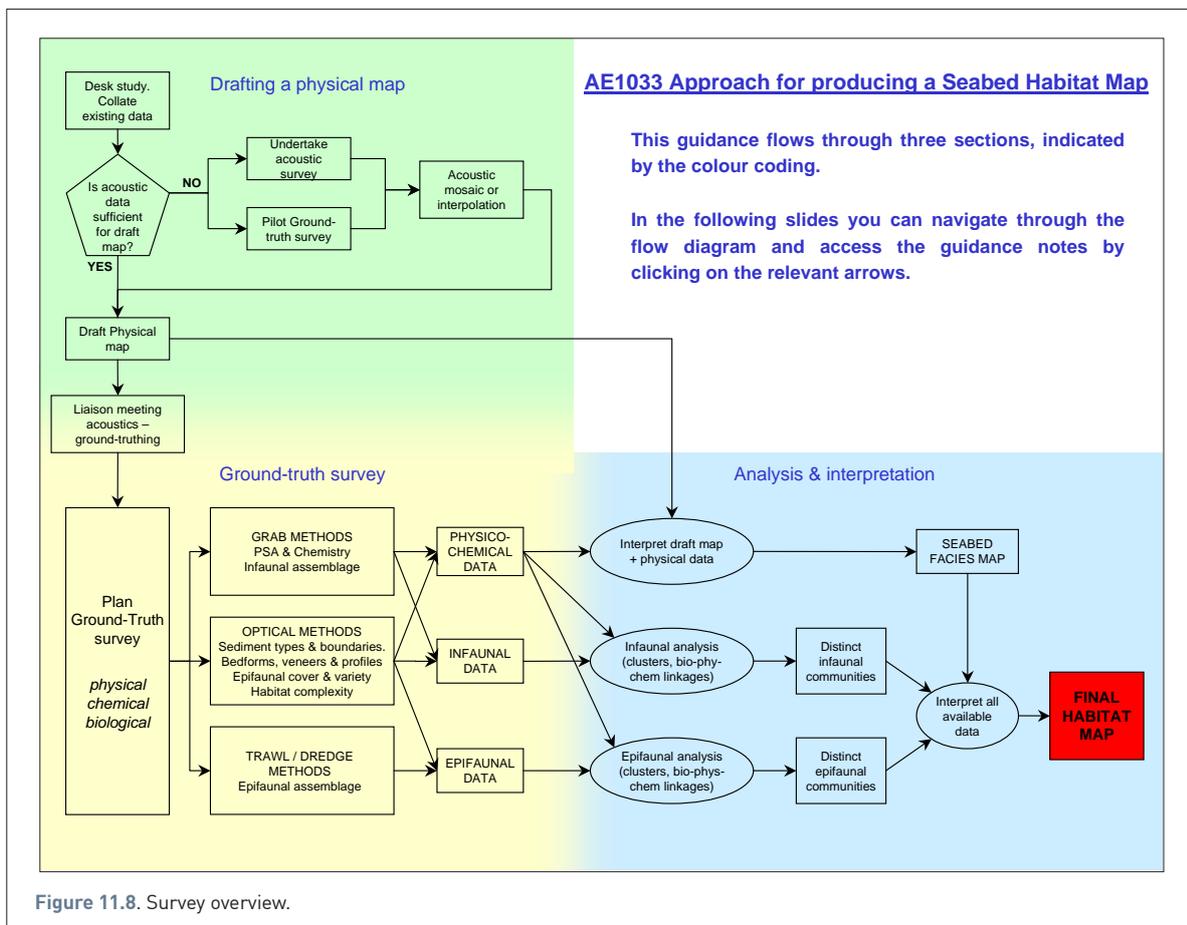
This decision tree addresses the various elements of survey design; that is to select the gear, process the samples and analyse the data in order to produce a seabed habitat map. Again, the intention is not to be prescriptive, as each survey will have to be tailored to meet the specific needs identified in the scoping section above. A range of 'state of the art' methodology has been evaluated during this research through a programme of rigorous field testing in order to establish the most cost effective strategies to meet both site-specific and generic (reconnaissance-type) mapping objectives and guidance on the use and selection of equipment can be drawn from the previous chapters of this report.

This second decision tree is split into three sections, as illustrated by the colour coding in the overview diagram (Figure 11.8).

The following text suggests a stepwise approach for designing a fit-for-purpose habitat mapping survey, and provides the basis for the interactive decision tree which is incorporated within this chapter.

| | | | |
|------------------------------|---------|-------------|---------|
| Sampling/observation | Fine → | -----I----- | ← Broad |
| Measurement accuracy | High → | -----I--- | ← Low |
| Extent | Small → | -----I----- | ← Large |
| Coverage | Low → | -----I----- | ← High |
| Spatial resolution | Low → | -----I----- | ← High |
| Spatial Precision | Low → | -----I----- | ← High |
| Repeatability and confidence | Low → | -----I--- | ← High |

Figure 11.7. Checklist of survey parameters.



1. Desk study – Collate existing data

The desired outcome from the survey work is a spatial map that delineates areas of seabed (polygons) that are distinct in terms of their physical properties and associated biological communities. It is essentially biotope mapping; a biotope being defined as the *habitat* (i.e. the environment's physical and chemical characteristics) together with its recurring associated *community* of species. A structured survey design provides an efficient approach to habitat mapping, and a two-phase approach is recommended. The first phase is to map the physical aspects of the habitat, to delineate areas of different sediment type and bedform, known as seabed facies (e.g. sand wave fields, gravel beds etc). This is best achieved by an acoustic survey of the area. The second phase is to undertake directed ground-truth sampling within these facies to verify the nature of their sediments and determine the composition of their associated infaunal and epifaunal communities.

The starting point is a desk study to find out what data are already available, and what additional data need to be collected by dedicated surveys. Suitable data sources will include public and private research bodies (i.e. government departments and agencies, NGOs, academia, industry) and other 'stake-holders' contacted during the consultation process.

2. Is there sufficient data to produce a draft physical map?

The requirement is for an acoustic map that can be confidently delineated into polygons in order to direct

sampling for the ground-truth survey. Assess both the amount and the quality of existing acoustic data. If they are insufficient, further acoustic surveys will be required.

It is important to appreciate the significance of this step in the production of a seabed habitat map, as the quality of the final map will be determined by the quality of the individual datasets used to produce the map. A single, poor quality dataset can significantly reduce confidence in the final map. Therefore, wherever existing data are used, it should be accompanied by evidence to indicate it is of acceptable quality. This could take the form of a quality assurance statement, and might include survey meta-data (data source, systems used, circumstances of the survey, methods of post-processing and interpretation etc).

3. Undertake acoustic survey

If there is insufficient acoustic data, a new acoustic survey should be undertaken, using individual or multiple techniques appropriate to the task (e.g. sidescan sonar, multibeam bathymetry and/or backscatter, acoustic ground discrimination systems (AGDS)).

The choice of technique(s) should take into account:

- the required resolution: the minimum mapping unit (MMU) should reflect the size of the features and/or disturbance to be detected.
- the scale of the site: while all techniques may be appropriate to small scale sites (those that can be surveyed in a single day), swathe techniques (particularly sidescan sonar) may be the preferred primary survey method for large study areas.

- suitability of the technique for the purpose: is the technique able to resolve certain characteristics of the sediments that may be important at the study site (e.g. areas of soft mud)? A combination of complementary techniques may be desirable (e.g. single beam AGDS with sidescan sonar).
- time and budget available: Does the coverage of the technique match the available time and budget? The footprint of hull mounted systems (multibeam, AGDS) increases with water depth, so shallow sites may take longer to survey than an equivalent spatial area in deeper waters (example for AGDS with 10 degree beam angle: footprint diameter \approx 2, 9 and 18 m at water depths 10, 50 and 100 metres). The coverage of towed swathe systems (sidescan) is dependant on the altitude of the towed body above the seabed, rather than water depth.
- resources available to store and process acoustic data: swath systems can produce very large datasets (thousands of megabytes). Is there sufficient storage capacity available? Are the post-processing systems sufficiently powerful to be able to handle these large data sets?
- operational constraints: is the chosen system suitable for the environment; in areas of high topographic relief (e.g. rocky reefs), hull mounted systems may be preferred to towed systems.

Once the type of equipment has been chosen, further consideration must be given to the specific configuration of each system.

- Sidescan sonar
 - Frequency of the system (determining resolution)
 - Range during survey
 - Analogue versus digital system
- Multibeam
 - True-multibeam or interferometric system
 - Bathymetry and/or backscatter.
 - Calibration requirements
- AGDS
 - System to be used: RoxAnn™, QTC™, EchoPlus™, etc.
 - Operating frequency (dual frequency?)
 - Availability of training sites
 - Single beam or multibeam AGDS (RoxAnn™ vs RoxAnn™ Swath, QTC VIEW™ vs QTC MULTIVIEW™)

Where available, Standard Operation Procedures (SOPs) should be used to acquire and process the acoustic data.

Survey design

Survey design needs to take account of the extent of the area to be surveyed and the acoustic techniques selected for the job. It is always preferable to have full acoustic coverage (100%) of an area in the form of a sidescan or multibeam mosaic, as this is the most accurate basis for delineating seabed facies. While it is practical to expect full coverage for small areas that can easily be surveyed in one day of vessel time (as a guide, \sim 50 sq km), the cost can be prohibitive for much larger areas (say \sim 500 sq km). Full swathe coverage is appropriate for small areas that require a great detail and accuracy, but is less critical for larger areas that don't require such high resolution. Broadscale areas can be accurately mapped using 50% coverage (alternate survey lines) and interpolation between adjacent lines. Where specific areas of interest need to be placed in a broadscale context, a combination of 100% and 50% coverage might be considered. For single beam AGDS, track spacing should take account of along-track variability (the more heterogeneous an area, the closer the track spacing), so the survey design needs to be adaptable. In general, a track spacing of 200 to 500 metres would be expected for surveys intending to use interpolation during analysis (see Foster-Smith *et al.*, 2001).

Survey design must also consider the orientation of survey tracks to ensure linear seabed features are adequately resolved. Features running perpendicular to a sidescan survey track return weaker signals than those running parallel to the track. Several lines running at right angles to the main survey tracks can provide a useful cross-check.

Single versus multiple systems

As different acoustic techniques tend to detect different properties of the seabed, it can be beneficial to use several techniques simultaneously. It is particularly recommended that single beam AGDS is supported by sidescan or multibeam sonar techniques, due to its small spatial coverage and the variability of data quality with weather, tide, suspended load, etc (Davies *et al.*, 2001). The simultaneous acquisition of sidescan sonar and multibeam bathymetry provides a particularly powerful data set, enabling the sidescan mosaic to be draped over the bathymetric map. This helps in the interpretation of the sidescan mosaic, as tonal changes associated with variation in seabed slope, rather than sediment type, can be identified.

Metadata

As acoustic systems are 'tuned' to suit the particular circumstances of a survey and data sets are commonly passed through a number of post-processing stages to arrive at the final 'image', it is important to record and report what has been done at each stage in the acquisition and processing of the data. This 'metadata' should provide information on where and when the survey was undertaken, which equipment was used and the settings applied, the environmental conditions, information on the survey design, data cleansing, post processing etc. All these factors need to be taken into consideration when interpreting the acoustic image and serve to underpin confidence in that interpretation.

4. Pilot ground-truth sampling

A limited number of sediment samples should be collected during or immediately after the acoustic survey to ground-truth and validate the initial interpretation of the acoustic data (i.e. to match specific acoustic signatures with specific sediment types). Samples should cover acoustically different areas and are best taken along the survey lines so they relate directly to the acoustic data. A regular sampling grid may be appropriate.

5. Acoustic mosaic

When the survey has been completed, data from the series of survey lines is brought together to produce a mosaic or interpolated image of the entire survey area. For digital data, this is most easily achieved using appropriate computer software, but the same result can be achieved manually with analogue data (e.g. printouts from sidescan sonar). Nowadays, digital data is easier to handle and store than analogue data. It is also more amenable to being re-used in the future and analysed by a variety of software applications.

6. Draft physical map of Acoustically Distinct Regions

An acoustic mosaic or interpolated image is now interpreted to delineate and characterise acoustically distinct regions to produce a draft physical map of the area. Physical characteristics of each region are assigned on the basis of experience of the interpreter and any ground-truth data that may be available (e.g. from the pilot survey). Where multiple acoustic techniques have been used, a combined interpretation can be made by overlaying the separate images. For sidescan sonar and multibeam backscatter it is recommended to follow the standard interpretation of bedform and seabed character (facies) developed by the British Geological Survey as illustrated in the 1990 edition

of their Sea Bed Sediment sheet for Anglesey (Anglesey Sheet, 53°N - 06°W including part of Dublin 53°N - 08°W, British Geological Survey and Geological Survey of Ireland, 1:250,000 Series, Sea Bed Sediments, 1990). For AGDS interpolated images, the characterisation of acoustically distinct areas will be made on the basis of supervised or unsupervised classification of the data clusters, supported by reference to training sites and ground-truth samples. The draft physical map is used to direct and target the physical, chemical and biological sampling to be undertaken in the full ground-truth survey.

7. Briefing meeting: acoustic and ground-truth survey teams

The team that will undertake the ground-truth survey should be fully briefed on the draft physical map so they are aware of its strengths and limitations and can make informed decisions about the design of their survey. If a new acoustic survey has been commissioned, sufficient time should be allowed to interpret and present the results before commencing the ground-truth survey, otherwise sampling can not be directed at acoustically distinct areas and a far more intensive sampling programme will be required to identify and map seabed habitats.

8. Plan the ground-truth survey

The objective of ground-truth sampling is to determine the physical (and chemical) properties of sediments in the acoustically distinct areas and to characterise their associated biotic communities so that the seabed habitats can be described and mapped. Several aspects need to be considered in planning the survey:

- **Sampling design**
Is there sufficient confidence in the draft physical map to enable sampling to be directed at individual seabed facies (stratified sampling). If not, an alternative sampling design should be considered, such as a conventional or radiating systematic grid (see Boyd, 2002 for further guidance on possible survey designs). A combination of sampling designs may be effective, using random sampling points within well defined facies and a conventional grid over ill defined or spatially extensive facies (e.g. large areas of homogeneous sand). A structured sampling design, such as the 'Fibonacci spiral' tested by Cefas (this study – see Chapter 4), is required to systematically assess heterogeneity within facies. If a single facies traverses a number of depth horizons (e.g. 10, 20, 30, 40 metres water depth), each may need to be sampled to account for depth-dependant changes in community structure.

- **Sample frequency and replication**
For marine locations it is very unlikely that a single sample will contain all the species that are to be found in a particular area, so multiple samples will be required to characterise the infaunal and epifaunal assemblages. The law of diminishing returns means that the incremental benefit of one additional sample decreases as more and more samples are collected, so a balance needs to be struck between sampling frequency and the time (and cost) of processing the samples. It is usual to set a minimum number of samples, and to increase this number depending on the size of the area in question and the apparent heterogeneity within the area (more samples for larger or more heterogeneous areas). If sampling is directed within seabed facies, each additional sample can be considered as a replicate. The robustness of any statistical analysis will be related to the number of replicate samples.
- **Monitoring stations**
If an area is to be monitored over time, maybe to assess changes in the impact of a known perturbation (e.g. dredging or disposal activities), then a series of monitoring stations should be established. Adequate sample replication is required at each station to enable valid statistical assessment of any temporal changes.
- **Efficient use of samples and sampling methods**
A single sample can often be used for multiple purposes. For instance, a grab sample can provide sediment for PSA and chemical analyses, and biota for macrofaunal analysis. Consideration should be given to the efficient use of samples, without jeopardising sample integrity. A judicious choice of sampling devices can reduce the number of sampling events required in the ground-truth survey and different sampling techniques can provide complementary information on one particular aspect of the seabed (e.g. grabs, camera surveys and trawls all provide information about benthic communities).

9. Grabs and cores

Grabbing and coring devices allow quantitative sampling of particulate sediments for particle size analysis, chemical analyses and determination of macrofaunal assemblages. A range of grabs and corers is available, though each is designed for slightly different application, so careful consideration should be given when selecting the suite of sampling gears. For further details see Boyd (2002), Davies *et al.* (2001) and Eleftheriou and McIntyre (2005). Mud sediments are typically sampled with corers (e.g. Box core,

Craib core and various multi-coring devices) and sands and gravel with grabs (e.g. Day, Hamon, Van Veen and Shipek grabs). Not all devices provide multi-purpose samples (e.g. Shipek grabs are not appropriate for providing samples of benthic macrofauna).

Suitable criteria should be set for accepting or rejecting samples (e.g. minimum penetration for cores, minimum volumes for grabs) and sample processing should follow recognised standard procedures (see guidelines given by Boyd, 2002 and Davies *et al.*, 2001). Care should be taken to ensure sample processing procedures are compatible between different sampling devices; macrobenthic samples are commonly processed by sieving, but different SOPs recommend different minimum mesh sizes for sieves. If one recommends a 0.5 mm sieve and another a 1.0 mm sieve, then the sieves should be used in tiers and the 1 mm and 0.5 mm sample fractions processed separately so that data can be compared on an equitable basis. For particle size analysis it is recommended to use half-phi size intervals to determine the frequency distribution of grain size; the proportion of gravel, sand and silt/clay can always be derived from the raw data if required.

Accurate and detailed metadata records should be kept for all sampling events, giving information sample acquisitions (date, time, position, water depth, station code, gear type) and sample processing (sample and sub-sample volumes, sieve size, sample labels, photographic records etc). Null and invalid samples should be recorded as such so that confusion does not arise later as to whether or not a sample exists for that station. Null records can also be valuable in indicating areas that may have a hard substrate (boulders, reef and rock outcrops).

Suitable storage and transport should be arranged for hazardous chemicals.

10. Optical methods

Visual observations are a highly effective method of ground-truthing acoustic surveys, providing information on sediment type and bedforms, the distinctness of boundaries between seabed facies, heterogeneity within facies and the existence of sediment veneers. Direct observations of the physical complexity of the seabed and associations between biota and sediments (e.g. boulder fields with dense attached epifauna) are extremely valuable in characterising and describing a habitat, as are semi-quantitative assessments of the relative abundance of identifiable organisms that may not be adequately sampled by other techniques (e.g. anemones and sea-pens). Direct observation becomes increasingly important as sediments become harder and

less amenable to physical sampling, and as a non-destructive methodology it has particular value in assessing habitats of conservation importance (e.g. biogenic reefs). Water turbidity and strong currents are the principal operational constraints that will influence choice of equipment and timing of deployment. Consideration must also be given to logistical constraints such as the suitability of the support vessel and the requirement for technical back-up.

Choice of equipment is dictated largely by the type of survey required:

- **Transect surveys**

Towed video sledges are the most common choice for surveys along pre-defined transect lines, though ROVs with sophisticated navigational capabilities may also be used. As a sledge is towed some distance behind a ship, it is important that its position can be determined accurately so the observations can be properly georeferenced. Traditional methods of estimating the position of any towed device by applying a fixed 'layback' to the ship's position tend not to have the desired accuracy for mapping purposes and it is therefore advisable to use some form of acoustic tracking device, such as a short base-line (SBL) transponder (e.g. Trackpoint II from ORE International or HiPAP (High Precision Acoustic Positioning) from Konsberg Maritime). If there is no requirement to cover a pre-defined track, transect observations can be made using drift dives with a drop-camera system, though it can prove difficult to maintain the optimal altitude of the camera above the seabed.

- **Spot surveys**

Small ROVs are ideal for making 'spot surveys' of a small area (~ 100 m radius) where the purpose is to make an inventory of sediment types and epifauna. They provide greater flexibility than a towed device as they can be piloted to hover and inspect features of interest.

- **Point sampling - surface**

Photographs of the seabed can be taken with a stills camera attached to a sledge, ROV, grab or drop-camera frame, providing information on sediment type and faunal coverage. If the area photographed can be measured (using a scale object or known quadrat) then quantitative assessments can be made. This type of survey is particularly useful on complex hard sediments like boulder areas or reefs that can not be sampled by towed gears or grabs.

- **Point sampling - subsurface**

Sub-surface profiles of the upper layers of sediments can be photographed using a Sediment Profile Imagery (SPI) system, which is essentially an inverted periscope giving a maximum penetration of around 25 cm in soft mud. Over 20 physical, chemical and biological parameters can be quantified from the photographs and used to characterise the benthic habitat and assess its quality (see Solan *et al.*, 2003 for a review).

Adequate metadata records will again be an essential part of surveys using optical methods. Optical records are very data rich but have limited spatial coverage, and it is important that their analysis should not become over-involved leading to highly detailed descriptions of insignificantly small areas that can not be adequately represented on the final habitat map. Several documents provide guidelines on the application of optical techniques see, for example, Davies *et al.*, 2001).

11. Trawl and dredge methods

Trawl and dredge methods are semi-quantitative techniques for sampling epifaunal assemblages. Different designs are effective on different substrates, with gears becoming progressively heavier and more robust as substrates become coarser. Inappropriate choice of gear can lead to significant damage to both samples and gear, and in extreme cases can present an unacceptable safety hazard, so great care must be taken when selecting and operating trawls and dredges. Jennings *et al.* (1999) provide details of a design for a 2-metre beam trawl that we have found suitable on all except very coarse substrates. The Agassiz trawl is another design in common use for scientific sampling of epibenthic macrofauna. If demersal fish are to be considered in the habitat description, they should be sampled separately to the epifauna, using commercial sized beam or otter trawls.

In some areas, the use of trawls and dredges is strictly regulated by law, and operators should make themselves fully aware of any such national or local restrictions through appropriate consultation with regulatory bodies. Local sea-fisheries officers are often well placed to provide advice.

Several matters need to be considered relating to the acquisition and processing of trawl and dredge samples, including:

- i) selecting tow distances with a view to providing small but adequate samples.
- ii) adjusting tow speeds to ensure the trawl is fishing effectively and maintaining contact with the seabed

(can this be monitored by depth-loggers or acoustic tracking devices?).

- iii) determining the start and end positions of tows (acoustic tracking devices).
- iv) establishing criteria for accepting/rejecting samples. Density of epifauna can vary considerably between substrates, so some flexibility may be required in applying strict criteria for minimum sample volumes (e.g. 5 litres on gravels, 2 litres on shallow sands) or adjusting tow distances.
- v) ensuring trawl meshes are thoroughly cleared/cleaned of epifaunal organisms between sampling events to minimise 'wash-down' and cross contamination of samples.
- vi) adequate replication of samples to even out bias caused by chance events (e.g. passing through discrete aggregations of ophiuroid)
- vii) sub-sampling protocols for very large samples. The *entire* catch should be picked through to ensure rare species are accounted for. The abundance of highly numerous species can be estimated by thoroughly sorting known aliquots of the catch. Alternatively, sub-sampling of abundant species is applied after the entire catch has been thoroughly sorted.

As for other sampling methods, adequate and accurate metadata records should be kept (including date, time, positions, tow speed, water depth, station code, gear type, sample and sub-sample volumes, sieve size, sample labels, photographic records etc). The use of a short baseline transponder attached to the trawl or dredge will allow more accurate geo-referencing than calculating position by 'layback' methods.

12. Data

The data resulting from sample analysis should be linked to any associated metadata and Quality Assurance/Quality Control procedures applied. Full data records should be supplied with the final report.

13. Finalise the physical map

The draft physical map is updated to a final version, incorporating any additional data or information gained from the ground-truth survey (grab, core and optical sampling). This may entail making adjustments to delineated regions and providing more complete and detailed descriptions of seabed facies and their physical properties (e.g. assigning sediment classes according to the Folk or Wentworth scales). The review of the draft physical map will result in a quality assured seabed facies map.

14. Infaunal and epifaunal analysis

Analysis of the infaunal and epifaunal data sets should be undertaken separately as they represent different elements of the benthic community and were sampled by different methods. An initial exploration of the data using univariate indices is useful for gaining a general appreciation of the gross community patterns, such as low vs high diversity and/or abundance which might discriminate sites (Warwick, 1993). Following this, non-parametric multivariate analyses are used to determine distinct species assemblages, identify the taxa that typify or discriminate between those assemblages, and determine environmental variables that best explain biotic distributions (Clarke, 1993). This approach to community analysis is detailed by Clarke and Warwick (1994), with appropriate analytical routines provided in the statistical software package PRIMER (Clarke and Gorley, 2001). Results should be reported along with summary description of methodology (i.e. whether biomass or abundance data was used, the data transformations applied etc.) and summary output of the statistical tests (SIMPER, ANOSIM, BIO-ENV, RELATE etc). At the end of the analysis, the infaunal and epifaunal species that typify and/or discriminate the different seabed facies will have been determined and the results can now be applied to the task of defining seabed habitats.

15. Final interpretation of all available information

In the final stage, all the available data is brought together and interpreted to determine the distribution of seabed habitats, that is those areas having distinct physical properties and associated biotic communities. The description (and definition) of the habitat takes account of the relative importance of each of the component elements, with precedence being given to those elements that have greatest influence in structuring the habitat, as illustrated in the examples below:

- i) shallow water fine sand communities dominated by small bivalves (*Abra* spp) and tube dwelling worms (*Lagis koreni*), typically supporting juvenile flatfish species (*Solea*, *Buglossidium*)
- ii) tide-swept circalittoral gravel with dense attached epifauna (hydroids and bryozoans, typically *Flustra* sp.) and diverse communities of errant epifauna typified by spider crabs (Majjiidae) and nut crabs (*Ebalia* spp.). Sandy or muddy sand patches with tube-dwelling worms and burrowing anemones.
- iii) biogenically re-worked soft anoxic mud in deep still waters (typically sea lochs) dominated by burrowing crustacea (*Nephrops*, *Upogebia*, *Callionassa*) with

dense patches of surface dwelling suspension feeding gastropods (*Aporrhais pespelecani* and *Turritella communis*). Sea pens (Pennatulidae and Virgulariidae) are rare but indicative species.

- iv) *Sabellaria* reef in coarse mixed sediment (usually 30-50 m deep). Epifauna characterised by pycnogonids, hermit crabs and amphipods; infauna by polychaetes and bivalves (e.g. *Abra alba* and *Nucula nitidosa*).

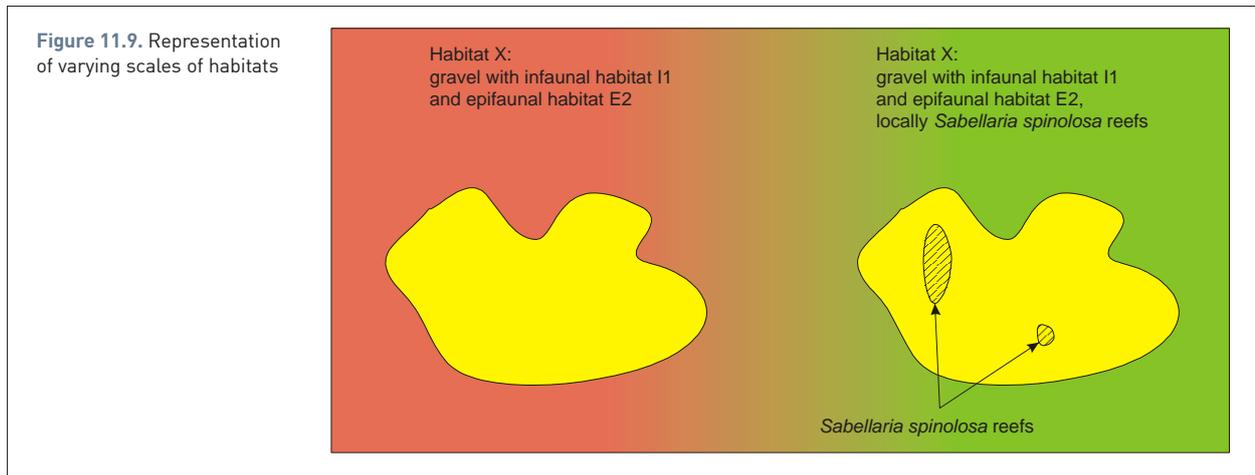
It is important to note that there may be justification to include two or more similar seabed facies in a single habitat, if their sediment structures do not differ to the extent that they support different biotic communities (e.g. short-wavelength megaripple fields and lunate sand wave fields). Conversely, a single facies covering a large spatial area may be separated into different habitats if variable environmental factors (like depth or current speed) cause significantly dissimilar communities to exist on the same substrate type.

In some cases, areas of high conservational interest will need to be delineated separately on the final seabed habitat map. An example would be a well defined biogenic

reef structure occurring in part of a larger seabed facies. If the mapping scale will allow, the feature should be outlined as a polygon, as in the example below (Figure 11.9). If the spatial area of the feature is too small to represent by a polygon, its location should be marked by a symbol, and that symbol included in the key to the map.

11.4 Summary

Whilst the two decision trees presented in this section provide a useful guide to the generation of fit-for-purpose habitat maps, they should not be considered to be definitive in their advice. Site-specific issues may dictate that an approach which is effective at one site may not necessarily be appropriate at another location and it is not possible to incorporate all of those issues within this report. Therefore, it is important that each decision making process is informed by individuals who understand the issues which relate to any specific application. This will ensure that all stakeholders are fully engaged in the process which leads to the production of the most appropriate and cost effective habitat map for any particular location.



12. Publications

The following publications have been produced as a result of research conducted during this study:

BIRCHENOUGH, S.N.R., BOYD, S.E., COGGAN, R.A., FOSTER-SMITH, R., LIMPENNY, D.S., MEADOWS, W.J. AND REES, H., 2004. Ground-truthing acoustic surveys at areas of anthropogenic impact II: Seabed characterisation of an area licensed for dredge material disposal. Presented at: GeoHab Conference, 5-7 May 2004, Galway, Ireland.

BIRCHENOUGH, S.N.R., BOYD, S.E., COGGAN, R.A., FOSTER-SMITH, R., LIMPENNY, D.S., MEADOWS, W.J., REES, H.L., (SUBMITTED). Lights, Camera, Acoustics: Assessing Macrobenthic communities at a Dredged material disposal site off the North East Coast of the UK. Journal of Marine Systems, Spice Conference, 5-9 April Galway, Ireland.

BIRCHENOUGH, S.N.R., BOYD, S.E., COGGAN, R.A., LIMPENNY, D.S., MEADOWS, W.J. AND FOSTER-SMITH, R., 2004. Integration of ground-truthing approaches to characterise an area licensed for dredge material disposal off the Northeast coast of the UK. ICES CM 2004/T:03.

BIRCHENOUGH, S.N.R., 2004. Spi-ing on the seafloor. CEFAS Coast Map News Newsletter, issue 7:33-34.

COGGAN, R., PHILPOTT, S., LIMPENNY, D.S., MEADOWS, W., BIRCHENOUGH, S. AND BOYD, S., 2005. Application of seabed character interpretations to broadscale habitat mapping: a case study from the eastern English Channel. Presented at: GeoHab Conference, 4-7 May 2005, Sidney, Victoria, British Columbia, Canada.

COGGAN, R.A., PHILPOTT, S. LIMPENNY, D.S. AND MEADOWS, W.J., 2004. Developing a strategy for seabed mapping at different spatial scales and resolutions: case study of seabed characterisation in an area of the eastern English Channel. ICES CM 2004/T:04.

COGGAN, R.A., PHILPOTT, S., LIMPENNY, D.S., MEADOWS, W.J., BIRCHENOUGH, S.N.R. AND BOYD, S.E., 2004. Ground-truthing acoustic surveys at areas of anthropogenic impact I: Characterisation of habitats in an area licensed for aggregate extraction. Presented at: GeoHab Conference, 5-7 May 2004, Galway, Ireland.

COGGAN, R.A., 2004. A different way of seeing: sounding things out for marine managers. CEFAS Coast Map News Newsletter, issue 6: 5-7.

EASTWOOD, P.D., SOUISSI, S., ROGERS, S.I., COGGAN, R.A. AND BROWN, C.J., 2004. Mapping sediment biotopes as continuous distributions rather than discrete entities with hard boundaries. ICES CM 2004/T:02.

HEWER, A.J., BROWN, C.J., MEADOWS, W.J., LIMPENNY D.S., COOPER, K.M. AND REES, H.L., 2002. Mapping of gravel biotopes: an integrated approach. ICES CM 2002/K:01.

Limpenny, D.S., Boyd, S.E., Meadows, W.J. and Rees, H.L., 2002. The utility of sidescan sonar techniques in the assessment of anthropogenic disturbance at aggregate extraction sites, ICES CM 2002/K:04.

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ANNEXES

Annex I. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall similarity over time.

| Year | Taxon | Average abundance | % contribution | Cumulative % | Overall average similarity | | |
|-------------------------------|-------------------------------|-------------------------------|----------------|--------------|----------------------------|-------|-------|
| 2001 | <i>Lagis koreni</i> | 4.0 | 20.9 | 20.9 | 32.09 | | |
| | <i>Chamelea striatula</i> | 2.6 | 10.3 | 31.3 | | | |
| | <i>Scoloplos armiger</i> | 1.9 | 8.0 | 39.3 | | | |
| | <i>Nucula nucleus</i> | 2.1 | 8.0 | 47.3 | | | |
| | <i>Dosinia lupinus</i> | 1.9 | 6.5 | 53.8 | | | |
| | NEMERTEA | 0.7 | 4.6 | 58.4 | | | |
| | <i>Goniada maculata</i> | 1.1 | 4.6 | 63.0 | | | |
| | <i>Lumbrineris gracilis</i> | 2.6 | 4.6 | 67.7 | | | |
| | <i>Drilonereis filum</i> | 1.1 | 4.6 | 72.3 | | | |
| 2002 | <i>Lumbrineris gracilis</i> | 4.4 | 13.9 | 13.9 | 41.28 | | |
| | <i>Thyasira flexuosa</i> | 2.6 | 7.9 | 21.7 | | | |
| | <i>Peresiella clymenoides</i> | 1.8 | 5.4 | 27.1 | | | |
| | <i>Prionospio fallax</i> | 1.7 | 4.0 | 31.1 | | | |
| | <i>Scoloplos armiger</i> | 1.5 | 4.0 | 35.1 | | | |
| | <i>Levinsenia gracilis</i> | 1.2 | 3.6 | 38.7 | | | |
| | <i>Amphiura filiformis</i> | 1.7 | 3.3 | 42.0 | | | |
| | NEMERTEA | 1.2 | 3.2 | 45.2 | | | |
| | <i>Chaetoderma nitidulum</i> | 1.2 | 3.1 | 48.3 | | | |
| | <i>Dosinia lupinus</i> | 0.9 | 2.9 | 51.2 | | | |
| | <i>Rhodine gracilior</i> | 1.3 | 2.9 | 54.1 | | | |
| | <i>Chamelea striatula</i> | 1.1 | 2.8 | 56.9 | | | |
| | <i>Glycinde nordmanni</i> | 0.8 | 2.3 | 59.2 | | | |
| | <i>Galathowenia oculata</i> | 0.7 | 2.2 | 61.4 | | | |
| | <i>Abra alba</i> | 1.0 | 2.0 | 63.4 | | | |
| | <i>Lucinoma borealis</i> | 0.9 | 1.9 | 65.3 | | | |
| | <i>Cerebratulus</i> | 0.9 | 1.8 | 67.1 | | | |
| | <i>Mysella bidentata</i> | 1.5 | 1.8 | 68.9 | | | |
| | <i>Nuculoma tenuis</i> | 1.1 | 1.7 | 70.6 | | | |
| | 2003 | <i>Lumbrineris gracilis</i> | 3.5 | 13.2 | | 13.2 | 40.76 |
| <i>Thyasira flexuosa</i> | | 1.7 | 6.8 | 20.1 | | | |
| <i>Nuculoma tenuis</i> | | 1.9 | 6.8 | 26.8 | | | |
| <i>Amphiura filiformis</i> | | 1.4 | 4.6 | 31.4 | | | |
| <i>Spiophanes kroeyeri</i> | | 1.1 | 4.5 | 35.9 | | | |
| <i>Diastylis lucifera</i> | | 1.3 | 4.5 | 40.5 | | | |
| <i>Peresiella clymenoides</i> | | 1.1 | 4.0 | 44.4 | | | |
| <i>Scoloplos armiger</i> | | 1.3 | 4.0 | 48.4 | | | |
| <i>Mysella bidentata</i> | | 1.2 | 3.5 | 51.9 | | | |
| NEMERTEA | | 0.9 | 3.0 | 54.9 | | | |
| <i>Glycera alba</i> | | 0.9 | 2.6 | 57.5 | | | |
| <i>Rhodine gracilior</i> | | 1.0 | 2.2 | 59.7 | | | |
| <i>Nucula nitidosa</i> | | 0.8 | 2.1 | 61.8 | | | |
| <i>Abra alba</i> | | 0.8 | 2.0 | 63.7 | | | |
| <i>Chamelea striatula</i> | | 0.7 | 1.9 | 65.7 | | | |
| <i>Chaetoderma nitidulum</i> | | 0.7 | 1.9 | 67.6 | | | |
| <i>Phaxus pellucidus</i> | | 0.4 | 1.8 | 69.4 | | | |
| <i>Anobothrus gracilis</i> | | 0.5 | 1.7 | 71.1 | | | |
| 2004 | | <i>Lumbrineris gracilis</i> | 3.2 | 18.8 | 18.8 | 37.17 | |
| | | <i>Peresiella clymenoides</i> | 1.9 | 8.4 | 27.1 | | |
| | <i>Thyasira flexuosa</i> | 1.4 | 5.3 | 32.4 | | | |
| | NEMERTEA | 1.2 | 5.2 | 37.6 | | | |
| | <i>Amphiura filiformis</i> | 1.7 | 5.1 | 42.7 | | | |
| | <i>Scoloplos armiger</i> | 1.0 | 4.9 | 47.6 | | | |
| | <i>Campanulariidae</i> | 0.8 | 4.7 | 52.3 | | | |
| | <i>Spiophanes kroeyeri</i> | 1.0 | 3.9 | 56.1 | | | |
| | <i>Nuculoma tenuis</i> | 1.0 | 3.8 | 60.0 | | | |
| | <i>Mysella bidentata</i> | 1.3 | 3.5 | 63.4 | | | |
| | <i>Chaetozone setosa</i> | 0.8 | 3.1 | 66.5 | | | |
| | <i>Ampharete lindstroemi</i> | 0.8 | 2.5 | 69.0 | | | |
| <i>Chaetoderma nitidulum</i> | 0.7 | 2.1 | 71.1 | | | | |

Annex II. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Year | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity | | |
|-----------------------------|-------------------------------|---------------------|-------------------|----------------|--------------|-------------------------------|------|-------|
| 2001v/s 2002 | <i>Lagis koreni</i> | 4 | 0.11 | 7.12 | 7.12 | 72.11 | | |
| | <i>Thyasira flexuosa</i> | 2.8 | 2.64 | 3.39 | 10.51 | | | |
| | <i>Chamelea striatula</i> | 2.6 | 1.08 | 2.74 | 13.25 | | | |
| | <i>Nephtys hombergii</i> | 0.75 | 0.52 | 2.26 | 15.5 | | | |
| | <i>Abra nitida</i> | 1.88 | 0.08 | 2.22 | 17.72 | | | |
| | <i>Dosinia lupinus</i> | 1.88 | 0.87 | 2.12 | 19.84 | | | |
| | <i>Ophiothrix fragilis</i> | 1.53 | 0.38 | 2.07 | 21.91 | | | |
| | <i>Nuculoma tenuis</i> | 2.37 | 1.06 | 1.98 | 23.89 | | | |
| | <i>Ophiura affinis</i> | 1.78 | 0.27 | 1.86 | 25.76 | | | |
| | <i>Poecilochaetus serpens</i> | 0.82 | 0.3 | 1.82 | 27.58 | | | |
| | <i>Prionospio fallax</i> | 1.1 | 1.68 | 1.7 | 29.28 | | | |
| | <i>Diastylis lucifera</i> | 0 | 0.71 | 1.63 | 30.91 | | | |
| | <i>Abra alba</i> | 1.67 | 1.04 | 1.62 | 32.53 | | | |
| | <i>Chaetoderma nitidulum</i> | 0.96 | 1.23 | 1.57 | 34.1 | | | |
| | <i>Aphelochaeta</i> | 0.53 | 0.4 | 1.56 | 35.66 | | | |
| | <i>Lumbrineris gracilis</i> | 2.57 | 4.38 | 1.54 | 37.2 | | | |
| | <i>Lucinoma borealis</i> | 1.44 | 0.86 | 1.48 | 38.68 | | | |
| | <i>Spiophanes bombyx</i> | 0.47 | 0.33 | 1.47 | 40.15 | | | |
| | <i>Nephtys sp.</i> | 0.33 | 0.36 | 1.47 | 41.62 | | | |
| | <i>Arctica islandica</i> | 1.41 | 0.34 | 1.42 | 43.04 | | | |
| | <i>Pisidia longicornis</i> | 0.8 | 0.1 | 1.42 | 44.46 | | | |
| | <i>Rhodine gracilior</i> | 0.82 | 1.3 | 1.41 | 45.88 | | | |
| | <i>Polynoidea</i> | 0.88 | 0.23 | 1.38 | 47.26 | | | |
| | OPHIUROIDEA | 1.53 | 0.33 | 1.36 | 48.62 | | | |
| | NEMERTEA | 0.74 | 1.16 | 1.34 | 49.95 | | | |
| | 2001 v/s 2003 | <i>Lagis koreni</i> | 4 | 0.05 | 6 | | 6 | 65.35 |
| | | <i>Abra nitida</i> | 1.88 | 0.25 | 2.92 | | 8.92 | |
| <i>Nucula nucleus</i> | | 2.14 | 0.05 | 2.75 | 11.67 | | | |
| <i>Lumbrineris gracilis</i> | | 2.57 | 3.45 | 2.58 | 14.24 | | | |
| <i>Dosinia lupinus</i> | | 1.88 | 0.48 | 2.34 | 16.58 | | | |
| <i>Nuculoma tenuis</i> | | 2.37 | 1.88 | 2.14 | 18.72 | | | |
| <i>Chamelea striatula</i> | | 2.6 | 0.65 | 2.08 | 20.8 | | | |
| <i>Ophiura affinis</i> | | 1.78 | 0.23 | 2.07 | 22.86 | | | |
| <i>Abra alba</i> | | 1.67 | 0.82 | 2.01 | 24.87 | | | |
| <i>Arctica islandica</i> | | 1.41 | 0 | 1.83 | 26.7 | | | |
| <i>Nucula nitidosa</i> | | 0.71 | 0.83 | 1.83 | 28.53 | | | |
| <i>Ophiothrix fragilis</i> | | 1.53 | 0.28 | 1.75 | 30.28 | | | |
| <i>Thyasira flexuosa</i> | | 2.8 | 1.74 | 1.74 | 32.02 | | | |
| OPHIUROIDEA | | 1.53 | 0 | 1.66 | 33.68 | | | |
| <i>Drilonereis filum</i> | | 1.07 | 0.31 | 1.51 | 35.19 | | | |
| <i>Pholoe inornata</i> | | 1.33 | 0.35 | 1.35 | 36.54 | | | |
| <i>Lucinoma borealis</i> | | 1.44 | 0.47 | 1.35 | 37.89 | | | |
| <i>Tellimya ferruginosa</i> | | 0.62 | 0.56 | 1.35 | 39.24 | | | |
| <i>Mysella bidentata</i> | | 1.47 | 1.2 | 1.3 | 40.54 | | | |
| <i>Glycera alba</i> | | 0.47 | 0.85 | 1.28 | 41.82 | | | |
| <i>Chaetozone setosa</i> | | 1.14 | 0.11 | 1.27 | 43.09 | | | |
| <i>Nephtys hombergii</i> | | 0.75 | 0.57 | 1.25 | 44.33 | | | |
| <i>Scoloplos armiger</i> | | 1.92 | 1.3 | 1.24 | 45.57 | | | |
| <i>Prionospio fallax</i> | | 1.1 | 0.45 | 1.22 | 46.8 | | | |
| <i>Diastylis lucifera</i> | | 0 | 1.26 | 1.21 | 48.01 | | | |
| <i>Galathowenia oculata</i> | | 0.67 | 0.23 | 1.16 | 49.17 | | | |
| <i>Goniada maculata</i> | | 1.14 | 0.21 | 1.13 | 50.3 | | | |

Annex II. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Year | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity |
|---------------|-------------------------------|-------------------|-------------------|----------------|--------------|-------------------------------|
| 2002 v/s 2003 | <i>Lumbrineris gracilis</i> | 4.38 | 3.45 | 4.59 | 4.59 | 66.01 |
| | <i>Thyasira flexuosa</i> | 2.64 | 1.74 | 2.75 | 7.33 | |
| | <i>Mysella bidentata</i> | 1.46 | 1.2 | 2.34 | 9.68 | |
| | <i>Rhodine gracilior</i> | 1.3 | 0.97 | 2.23 | 11.91 | |
| | <i>Amphiura filiformis</i> | 1.69 | 1.42 | 2.23 | 14.14 | |
| | <i>Prionospio fallax</i> | 1.68 | 0.45 | 2.17 | 16.3 | |
| | <i>Peresiella clymenoides</i> | 1.8 | 1.07 | 1.96 | 18.26 | |
| | <i>Nucula nucleus</i> | 1.16 | 0.05 | 1.76 | 20.02 | |
| | <i>Nuculoma tenuis</i> | 1.06 | 1.88 | 1.76 | 21.77 | |
| | <i>Chaetoderma nitidulum</i> | 1.23 | 0.69 | 1.73 | 23.5 | |
| | <i>Diastylis lucifera</i> | 0.71 | 1.26 | 1.68 | 25.18 | |
| | <i>Scoloplos armiger</i> | 1.45 | 1.3 | 1.64 | 26.82 | |
| | <i>Levinsenia gracilis</i> | 1.22 | 0.46 | 1.61 | 28.43 | |
| | <i>Spiophanes kroeyeri</i> | 0.5 | 1.11 | 1.56 | 29.99 | |
| | <i>Chamelea striatula</i> | 1.08 | 0.65 | 1.54 | 31.54 | |
| | <i>Phoronis muelleri</i> | 0.88 | 0.45 | 1.47 | 33.01 | |
| | <i>Pomatoceros triqueter</i> | 0.14 | 0.5 | 1.45 | 34.46 | |
| | <i>Dosinia lupinus</i> | 0.87 | 0.48 | 1.35 | 35.81 | |
| | <i>Cerebratulus</i> | 0.89 | 0 | 1.33 | 37.14 | |
| | <i>Mediomastus fragilis</i> | 0.87 | 0.13 | 1.27 | 38.42 | |
| | <i>Lucinoma borealis</i> | 0.86 | 0.47 | 1.26 | 39.68 | |
| | <i>Abra alba</i> | 1.04 | 0.82 | 1.25 | 40.93 | |
| | <i>Chaetozone setosa</i> | 0.86 | 0.11 | 1.19 | 42.12 | |
| | <i>Anobothrus gracilis</i> | 0.46 | 0.51 | 1.18 | 43.31 | |
| | <i>Tellimya ferruginosa</i> | 0.28 | 0.56 | 1.15 | 44.46 | |
| | <i>Diplocirrus glaucus</i> | 0.56 | 0.38 | 1.13 | 45.59 | |
| | NEMERTEA | 1.16 | 0.86 | 1.13 | 46.73 | |
| | <i>Galathowenia oculata</i> | 0.73 | 0.23 | 1.13 | 47.85 | |
| | <i>Trichobranchus roseus</i> | 0.65 | 0.51 | 1.11 | 48.96 | |
| | <i>Ophiothrix fragilis</i> | 0.38 | 0.28 | 1.09 | 50.05 | |
| 2001 v/s 2004 | <i>Lagis koreni</i> | 4 | 0.16 | 6.84 | 6.84 | 73.72 |
| | <i>Chamelea striatula</i> | 2.6 | 0.23 | 3.24 | 10.09 | |
| | <i>Abra nitida</i> | 1.88 | 0.29 | 2.78 | 12.87 | |
| | <i>Nucula nucleus</i> | 2.14 | 0.18 | 2.63 | 15.5 | |
| | <i>Abra alba</i> | 1.67 | 0.1 | 2.5 | 17.99 | |
| | <i>Dosinia lupinus</i> | 1.88 | 0.54 | 2.03 | 20.02 | |
| | <i>Thyasira flexuosa</i> | 2.8 | 1.4 | 2.02 | 22.04 | |
| | <i>Mysella bidentata</i> | 1.47 | 1.34 | 1.98 | 24.02 | |
| | <i>Nuculoma tenuis</i> | 2.37 | 0.98 | 1.97 | 26 | |
| | <i>Ophiura affinis</i> | 1.78 | 0 | 1.9 | 27.9 | |
| | <i>Ophiothrix fragilis</i> | 1.53 | 0.08 | 1.88 | 29.78 | |
| | <i>Amphiura filiformis</i> | 0.91 | 1.71 | 1.61 | 31.4 | |
| | <i>Lumbrineris gracilis</i> | 2.57 | 3.24 | 1.57 | 32.97 | |
| | <i>Nucula nitidosa</i> | 0.71 | 0.47 | 1.56 | 34.53 | |
| | OPHIUROIDEA | 1.53 | 0 | 1.56 | 36.08 | |
| | <i>Arctica islandica</i> | 1.41 | 0.27 | 1.51 | 37.59 | |
| | <i>Scoloplos armiger</i> | 1.92 | 1.02 | 1.5 | 39.09 | |
| | <i>Goniada maculata</i> | 1.14 | 0.12 | 1.49 | 40.58 | |
| | <i>Pisidia longicornis</i> | 0.8 | 0 | 1.35 | 41.93 | |
| | <i>Diplocirrus glaucus</i> | 0.67 | 0.63 | 1.31 | 43.24 | |
| | <i>Spiophanes kroeyeri</i> | 0.33 | 1.01 | 1.29 | 44.53 | |
| | NEMERTEA | 0.74 | 1.15 | 1.27 | 45.8 | |
| | <i>Pholoe inornata</i> | 1.33 | 0.06 | 1.27 | 47.08 | |
| | <i>Drilonereis filum</i> | 1.07 | 0.28 | 1.15 | 48.22 | |
| | <i>Campanulariidae</i> | 0 | 0.8 | 1.14 | 49.36 | |
| | <i>Lucinoma borealis</i> | 1.44 | 0.12 | 1.11 | 50.47 | |

Annex II. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Year | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity | | |
|-------------------------------|-------------------------------|-----------------------------|-------------------|----------------|--------------|-------------------------------|-------|-------|
| 2002 v/s 2004 | <i>Lumbrineris gracilis</i> | 4.38 | 3.24 | 4.27 | 4.27 | 67.44 | | |
| | <i>Thyasira flexuosa</i> | 2.64 | 1.4 | 3.37 | 7.64 | | | |
| | <i>Mysella bidentata</i> | 1.46 | 1.34 | 2.51 | 10.15 | | | |
| | <i>Amphiura filiformis</i> | 1.69 | 1.71 | 2.48 | 12.63 | | | |
| | <i>Prionospio fallax</i> | 1.68 | 0.42 | 2.38 | 15.01 | | | |
| | <i>Peresiella clymenoides</i> | 1.8 | 1.88 | 2.24 | 17.25 | | | |
| | <i>Nucula nucleus</i> | 1.16 | 0.18 | 1.96 | 19.22 | | | |
| | <i>Rhodine gracilior</i> | 1.3 | 0.5 | 1.9 | 21.12 | | | |
| | <i>Abra alba</i> | 1.04 | 0.1 | 1.88 | 23 | | | |
| | <i>Chaetoderma nitidulum</i> | 1.23 | 0.66 | 1.86 | 24.86 | | | |
| | <i>Nuculoma tenuis</i> | 1.06 | 0.98 | 1.82 | 26.68 | | | |
| | <i>Scoloplos armiger</i> | 1.45 | 1.02 | 1.7 | 28.38 | | | |
| | <i>Diastylis lucifera</i> | 0.71 | 0.65 | 1.66 | 30.04 | | | |
| | <i>Levinsenia gracilis</i> | 1.22 | 0.59 | 1.58 | 31.62 | | | |
| | <i>Ampharete lindstroemi</i> | 0.39 | 0.79 | 1.53 | 33.15 | | | |
| | <i>Chamelea striatula</i> | 1.08 | 0.23 | 1.51 | 34.66 | | | |
| | <i>Chaetozone setosa</i> | 0.86 | 0.8 | 1.43 | 36.09 | | | |
| | <i>Spiophanes kroeyeri</i> | 0.5 | 1.01 | 1.41 | 37.5 | | | |
| | <i>Phoronis muelleri</i> | 0.88 | 0 | 1.4 | 38.9 | | | |
| | <i>Lucinoma borealis</i> | 0.86 | 0.12 | 1.4 | 40.3 | | | |
| | <i>Dosinia lupinus</i> | 0.87 | 0.54 | 1.39 | 41.69 | | | |
| | NEMERTEA | 1.16 | 1.15 | 1.34 | 43.03 | | | |
| | <i>Diplocirrus glaucus</i> | 0.56 | 0.63 | 1.3 | 44.33 | | | |
| | <i>Mediomastus fragilis</i> | 0.87 | 0.14 | 1.28 | 45.61 | | | |
| | <i>Glycinde nordmanni</i> | 0.81 | 0 | 1.27 | 46.88 | | | |
| | <i>Trichobranchus roseus</i> | 0.65 | 0.29 | 1.26 | 48.15 | | | |
| | <i>Glycera alba</i> | 0.82 | 0 | 1.26 | 49.41 | | | |
| | <i>Cerebratulus</i> | 0.89 | 0 | 1.26 | 50.67 | | | |
| | 2003 v/s 2004 | <i>Lumbrineris gracilis</i> | 3.45 | 3.24 | 4.84 | | 4.84 | 63.77 |
| | | <i>Nuculoma tenuis</i> | 1.88 | 0.98 | 2.92 | | 7.76 | |
| | | <i>Amphiura filiformis</i> | 1.42 | 1.71 | 2.79 | | 10.56 | |
| | | <i>Mysella bidentata</i> | 1.2 | 1.34 | 2.62 | | 13.17 | |
| <i>Peresiella clymenoides</i> | | 1.07 | 1.88 | 2.33 | 15.51 | | | |
| <i>Thyasira flexuosa</i> | | 1.74 | 1.4 | 2.24 | 17.74 | | | |
| <i>Diastylis lucifera</i> | | 1.26 | 0.65 | 2.02 | 19.76 | | | |
| <i>Spiophanes kroeyeri</i> | | 1.11 | 1.01 | 2.01 | 21.77 | | | |
| <i>Scoloplos armiger</i> | | 1.3 | 1.02 | 1.95 | 23.73 | | | |
| <i>Glycera alba</i> | | 0.85 | 0 | 1.88 | 25.61 | | | |
| <i>Nucula nitidosa</i> | | 0.83 | 0.47 | 1.8 | 27.41 | | | |
| <i>Abra alba</i> | | 0.82 | 0.1 | 1.72 | 29.13 | | | |
| <i>Chaetozone setosa</i> | | 0.11 | 0.8 | 1.69 | 30.82 | | | |
| <i>Ampharete lindstroemi</i> | | 0.31 | 0.79 | 1.59 | 32.41 | | | |
| <i>Campanulariidae</i> | | 0.21 | 0.8 | 1.49 | 33.9 | | | |
| <i>Rhodine gracilior</i> | | 0.97 | 0.5 | 1.46 | 35.36 | | | |
| <i>Polycirrus plumosus</i> | | 0.63 | 0 | 1.45 | 36.81 | | | |
| <i>Chamelea striatula</i> | | 0.65 | 0.23 | 1.43 | 38.24 | | | |
| NEMERTEA | | 0.86 | 1.15 | 1.4 | 39.64 | | | |
| <i>Tellimya ferruginosa</i> | | 0.56 | 0.18 | 1.38 | 41.02 | | | |
| <i>Chaetoderma nitidulum</i> | | 0.69 | 0.66 | 1.38 | 42.39 | | | |
| <i>Levinsenia gracilis</i> | | 0.46 | 0.59 | 1.37 | 43.77 | | | |
| <i>Prionospio fallax</i> | | 0.45 | 0.42 | 1.29 | 45.06 | | | |
| <i>Diplocirrus glaucus</i> | | 0.38 | 0.63 | 1.26 | 46.32 | | | |
| <i>Pomatoceros triqueter</i> | | 0.5 | 0.16 | 1.21 | 47.53 | | | |
| <i>Tharyx killariensis</i> | | 0.28 | 0.57 | 1.19 | 48.72 | | | |
| <i>Nephtys</i> | | 0.54 | 0.29 | 1.17 | 49.89 | | | |
| <i>Owenia fusiformis</i> | | 0.54 | 0.17 | 1.17 | 51.05 | | | |

Annex III. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall similarity over time.

| Areas | Taxon | Average abundance | % contribution | Cumulative % | Overall average similarity |
|------------------------------|-------------------------------|-----------------------------|----------------|--------------|----------------------------|
| A | <i>Lumbrineris gracilis</i> | 3.98 | 12.05 | 12.05 | 39.60 |
| | <i>Peresiella clymenoides</i> | 2.55 | 8.76 | 20.81 | |
| | <i>Amphiura filiformis</i> | 3.27 | 7.57 | 28.37 | |
| | NEMERTEA | 1.6 | 6.66 | 35.04 | |
| | <i>Chaetoderma nitidulum</i> | 1.36 | 4.54 | 39.58 | |
| | <i>Mysella bidentata</i> | 2.3 | 4.12 | 43.69 | |
| | <i>Thyasira flexuosa</i> | 1.45 | 3.78 | 47.47 | |
| | <i>Levinsenia gracilis</i> | 1.13 | 3.76 | 51.24 | |
| | <i>Scoloplos armiger</i> | 1.33 | 3.29 | 54.52 | |
| | <i>Dosinia lupinus</i> | 0.91 | 2.93 | 57.46 | |
| | <i>Spiophanes kroeyeri</i> | 0.75 | 2.57 | 60.02 | |
| | <i>Prionospio fallax</i> | 0.69 | 2.15 | 62.18 | |
| | <i>Nuculoma tenuis</i> | 0.82 | 2.13 | 64.31 | |
| | <i>Glycera alba</i> | 0.63 | 1.96 | 66.26 | |
| | Campanulariidae | 0.42 | 1.81 | 68.07 | |
| | <i>Cerebratulus</i> | 0.46 | 1.79 | 69.86 | |
| | <i>Pholoe inornata</i> | 0.63 | 1.59 | 71.45 | |
| B | <i>Lumbrineris gracilis</i> | 4.07 | 37.27 | 37.27 | 27.31 |
| | <i>Peresiella clymenoides</i> | 0.98 | 7.19 | 44.46 | |
| | NEMERTEA | 1.02 | 6.95 | 51.4 | |
| | Campanulariidae | 0.44 | 4.76 | 56.16 | |
| | <i>Amphiura filiformis</i> | 0.96 | 4.76 | 60.92 | |
| | <i>Prionospio fallax</i> | 1.03 | 4.09 | 65.01 | |
| | <i>Levinsenia gracilis</i> | 0.62 | 3.41 | 68.43 | |
| | <i>Nuculoma tenuis</i> | 0.79 | 2.87 | 71.29 | |
| | C | <i>Lumbrineris gracilis</i> | 2.3 | 15.33 | |
| <i>Thyasira flexuosa</i> | | 1.87 | 7.19 | 22.52 | |
| <i>Nuculoma tenuis</i> | | 1.97 | 6.88 | 29.4 | |
| <i>Scoloplos armiger</i> | | 1.37 | 5.86 | 35.26 | |
| Campanulariidae | | 0.38 | 4.57 | 39.83 | |
| <i>Nucula nitidosa</i> | | 0.76 | 3.94 | 43.77 | |
| <i>Mysella bidentata</i> | | 1.14 | 3.88 | 47.64 | |
| <i>Amphiura filiformis</i> | | 1.04 | 3.85 | 51.5 | |
| <i>Spiophanes kroeyeri</i> | | 0.78 | 3.28 | 54.78 | |
| <i>Nephtys hombergii</i> | | 0.82 | 3.11 | 57.88 | |
| <i>Abra alba</i> | | 1.19 | 2.96 | 60.84 | |
| <i>Nucula nucleus</i> | | 1.05 | 2.55 | 63.39 | |
| NEMERTEA | | 0.65 | 2.44 | 65.83 | |
| <i>Spiophanes bombyx</i> | | 0.6 | 2.42 | 68.25 | |
| <i>Chaetoderma nitidulum</i> | | 0.6 | 2.05 | 70.3 | |
| D | <i>Lumbrineris gracilis</i> | 4.98 | 16.85 | 16.85 | 41.48 |
| | <i>Peresiella clymenoides</i> | 2.71 | 8.66 | 25.51 | |
| | <i>Thyasira flexuosa</i> | 2.06 | 6.22 | 31.73 | |
| | <i>Scoloplos armiger</i> | 1.33 | 4.35 | 36.08 | |
| | NEMERTEA | 1.25 | 3.9 | 39.98 | |
| | <i>Amphiura filiformis</i> | 1.41 | 3.62 | 43.6 | |
| | <i>Rhodine gracilior</i> | 1.68 | 3.3 | 46.9 | |
| | <i>Dosinia lupinus</i> | 1.12 | 3.12 | 50.02 | |
| | <i>Levinsenia gracilis</i> | 0.89 | 2.77 | 52.79 | |
| | <i>Chamelea striatula</i> | 1.01 | 2.66 | 55.44 | |
| | <i>Prionospio fallax</i> | 0.89 | 2.46 | 57.91 | |
| | <i>Glycinde nordmanni</i> | 0.76 | 2.41 | 60.32 | |
| | <i>Galathowenia oculata</i> | 0.66 | 2.25 | 62.56 | |
| | <i>Spiophanes kroeyeri</i> | 1.01 | 2.2 | 64.77 | |
| | <i>Mysella bidentata</i> | 1.12 | 2.16 | 66.93 | |
| | <i>Chaetoderma nitidulum</i> | 0.67 | 1.67 | 68.6 | |
| | <i>Ampharete lindstroemi</i> | 0.81 | 1.56 | 70.16 | |

Annex III. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall similarity over time.

| Areas | Taxon | Average abundance | % contribution | Cumulative % | Overall average similarity |
|-------|------------------------------|-------------------|----------------|--------------|----------------------------|
| E | <i>Thyasira flexuosa</i> | 3.47 | 10.79 | 10.79 | 52.64 |
| | <i>Nuculoma tenuis</i> | 2.68 | 8.83 | 19.62 | |
| | <i>Lumbrineris gracilis</i> | 2.33 | 8.23 | 27.84 | |
| | <i>Diastylis lucifera</i> | 1.57 | 5.63 | 33.47 | |
| | <i>Phaxus pellucidus</i> | 1.35 | 4.4 | 37.87 | |
| | <i>Scoloplos armiger</i> | 1.38 | 4.05 | 41.92 | |
| | <i>Spiophanes kroeyeri</i> | 1.2 | 3.85 | 45.76 | |
| | <i>Chaetozone setosa</i> | 0.8 | 3.56 | 49.32 | |
| | <i>Amphiura filliformis</i> | 1.38 | 3.53 | 52.85 | |
| | <i>Chaetoderma nitidulum</i> | 1.38 | 3.51 | 56.36 | |
| | <i>Aphelochaeta</i> | 1.34 | 3.29 | 59.65 | |
| | <i>Nephtys hombergii</i> | 1.29 | 3.14 | 62.8 | |
| | <i>Mysella bidentata</i> | 1.39 | 2.59 | 65.39 | |
| | <i>Harpinia antennaria</i> | 0.95 | 2.36 | 67.74 | |
| | <i>Nucula nitidosa</i> | 1.01 | 2.21 | 69.95 | |
| | NEMERTEA | 0.7 | 2.16 | 72.11 | |

Annex IV. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Areas | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity |
|------------------------------|-------------------------------|-------------------|-------------------|----------------|--------------|-------------------------------|
| A v/s B | <i>Lumbrineris gracilis</i> | 3.98 | 4.07 | 5.47 | 5.47 | 69.07 |
| | <i>Amphiura filiformis</i> | 3.27 | 0.96 | 5.38 | 10.85 | |
| | <i>Mysella bidentata</i> | 2.3 | 0.85 | 3.93 | 14.78 | |
| | <i>Peresiella clymenoides</i> | 2.55 | 0.98 | 3.81 | 18.59 | |
| | <i>Chaetoderma nitidulum</i> | 1.36 | 0.41 | 2.28 | 20.87 | |
| | <i>Dosinia lupinus</i> | 0.91 | 0.29 | 2.28 | 23.14 | |
| | <i>Thyasira flexuosa</i> | 1.45 | 0.58 | 2.25 | 25.39 | |
| | <i>Scoloplos armiger</i> | 1.33 | 0.76 | 2.1 | 27.49 | |
| | <i>Diastylis lucifera</i> | 0.67 | 0.57 | 2.03 | 29.52 | |
| | <i>Spiophanes kroeyeri</i> | 0.75 | 0.31 | 1.91 | 31.42 | |
| | <i>Nuculoma tenuis</i> | 0.82 | 0.79 | 1.79 | 33.21 | |
| | NEMERTEA | 1.6 | 1.02 | 1.73 | 34.94 | |
| | <i>Diplocirrus glaucus</i> | 0.77 | 0.27 | 1.62 | 36.56 | |
| | <i>Levinsenia gracilis</i> | 1.13 | 0.62 | 1.58 | 38.14 | |
| | <i>Rhodine gracilior</i> | 0.86 | 0 | 1.58 | 39.72 | |
| | <i>Amphictene auricoma</i> | 0.8 | 0.27 | 1.53 | 41.24 | |
| | <i>Harpinia antennaria</i> | 0.72 | 0 | 1.51 | 42.75 | |
| | <i>Nucula nitidosa</i> | 0 | 0.69 | 1.31 | 44.06 | |
| | <i>Edwardsia claparedii</i> | 0.56 | 0.54 | 1.27 | 45.33 | |
| | <i>Chaetozone setosa</i> | 0.58 | 0.35 | 1.23 | 46.57 | |
| <i>Prionospio fallax</i> | 0.69 | 1.03 | 1.23 | 47.8 | | |
| <i>Ampharete lindstroemi</i> | 0.49 | 0.22 | 1.22 | 49.01 | | |
| <i>Tharyx killariensis</i> | 0.55 | 0.16 | 1.22 | 50.23 | | |
| A v/s D | <i>Lumbrineris gracilis</i> | 3.98 | 4.98 | 6.07 | 6.07 | 59.50 |
| | <i>Amphiura filiformis</i> | 3.27 | 1.41 | 4.38 | 10.45 | |
| | <i>Mysella bidentata</i> | 2.3 | 1.12 | 3.54 | 13.98 | |
| | <i>Rhodine gracilior</i> | 0.86 | 1.68 | 2.35 | 16.34 | |
| | <i>Peresiella clymenoides</i> | 2.55 | 2.71 | 2.35 | 18.69 | |
| | <i>Thyasira flexuosa</i> | 1.45 | 2.06 | 2.19 | 20.88 | |
| | <i>Chaetoderma nitidulum</i> | 1.36 | 0.67 | 1.97 | 22.85 | |
| | <i>Scoloplos armiger</i> | 1.33 | 1.33 | 1.85 | 24.7 | |
| | <i>Dosinia lupinus</i> | 0.91 | 1.12 | 1.77 | 26.47 | |
| | <i>Spiophanes kroeyeri</i> | 0.75 | 1.01 | 1.37 | 27.84 | |
| | <i>Diastylis lucifera</i> | 0.67 | 0.72 | 1.37 | 29.21 | |
| | <i>Ampharete lindstroemi</i> | 0.49 | 0.81 | 1.32 | 30.53 | |
| | <i>Trichobranthus roseus</i> | 0.23 | 0.79 | 1.32 | 31.85 | |
| | <i>Chamelea striatula</i> | 0.37 | 1.01 | 1.31 | 33.16 | |
| | <i>Levinsenia gracilis</i> | 1.13 | 0.89 | 1.3 | 34.46 | |
| | <i>Diplocirrus glaucus</i> | 0.77 | 0.6 | 1.28 | 35.75 | |
| | <i>Pholoe inornata</i> | 0.63 | 0.17 | 1.27 | 37.02 | |
| | <i>Sabellaria spinulosa</i> | 0.46 | 0.64 | 1.27 | 38.3 | |
| | <i>Nuculoma tenuis</i> | 0.82 | 0.57 | 1.27 | 39.56 | |
| | <i>Amphictene auricoma</i> | 0.8 | 0.31 | 1.24 | 40.81 | |
| | <i>Anobothrus gracilis</i> | 0.4 | 0.54 | 1.21 | 42.02 | |
| | <i>Tharyx killariensis</i> | 0.55 | 0.58 | 1.19 | 43.2 | |
| | <i>Chaetozone setosa</i> | 0.58 | 0.74 | 1.19 | 44.39 | |
| | NEMERTEA | 1.6 | 1.25 | 1.18 | 45.57 | |
| | <i>Ampelisca tenuicornis</i> | 0.43 | 0.64 | 1.17 | 46.74 | |
| | <i>Harpinia antennaria</i> | 0.72 | 0.05 | 1.13 | 47.87 | |
| | <i>Galathowenia oculata</i> | 0.55 | 0.66 | 1.09 | 48.96 | |
| <i>Thysanocardia procera</i> | 0.43 | 0.42 | 1.09 | 50.05 | | |

Annex IV. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Areas | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity | | |
|------------------------------|-------------------------------|-------------------------------|-------------------|----------------|--------------|-------------------------------|-------|-------|
| B v/s D | <i>Lumbrineris gracilis</i> | 4.07 | 4.98 | 6.07 | 6.07 | 68.33 | | |
| | <i>Peresiella clymenoides</i> | 0.98 | 2.71 | 3.8 | 9.88 | | | |
| | <i>Rhodine gracilior</i> | 0 | 1.68 | 2.8 | 12.68 | | | |
| | <i>Thyasira flexuosa</i> | 0.58 | 2.06 | 2.72 | 15.4 | | | |
| | <i>Mysella bidentata</i> | 0.85 | 1.12 | 2.65 | 18.05 | | | |
| | <i>Amphiura filiformis</i> | 0.96 | 1.41 | 2.34 | 20.39 | | | |
| | <i>Dosinia lupinus</i> | 0.29 | 1.12 | 1.97 | 22.36 | | | |
| | <i>Scoloplos armiger</i> | 0.76 | 1.33 | 1.84 | 24.2 | | | |
| | <i>Ampharete lindstroemi</i> | 0.22 | 0.81 | 1.75 | 25.95 | | | |
| | <i>Diastylis lucifera</i> | 0.57 | 0.72 | 1.74 | 27.69 | | | |
| | <i>Nuculoma tenuis</i> | 0.79 | 0.57 | 1.6 | 29.29 | | | |
| | <i>Spiophanes kroeyeri</i> | 0.31 | 1.01 | 1.58 | 30.87 | | | |
| | <i>Prionospio fallax</i> | 1.03 | 0.89 | 1.56 | 32.43 | | | |
| | NEMERTEA | 1.02 | 1.25 | 1.55 | 33.98 | | | |
| | <i>Chaetozone setosa</i> | 0.35 | 0.74 | 1.49 | 35.47 | | | |
| | <i>Chamelea striatula</i> | 0.36 | 1.01 | 1.47 | 36.94 | | | |
| | <i>Sabellaria spinulosa</i> | 0.22 | 0.64 | 1.44 | 38.38 | | | |
| | <i>Galathowenia oculata</i> | 0.38 | 0.66 | 1.34 | 39.72 | | | |
| | <i>Diplocirrus glaucus</i> | 0.27 | 0.6 | 1.33 | 41.05 | | | |
| | <i>Trichobranchus roseus</i> | 0 | 0.79 | 1.29 | 42.34 | | | |
| | <i>Mediomastus fragilis</i> | 0.63 | 0.42 | 1.26 | 43.59 | | | |
| | <i>Nucula nucleus</i> | 0.51 | 0.46 | 1.24 | 44.83 | | | |
| | <i>Levinsenia gracilis</i> | 0.62 | 0.89 | 1.17 | 46 | | | |
| | <i>Tharyx killariensis</i> | 0.16 | 0.58 | 1.16 | 47.16 | | | |
| | <i>Ampelisca tenuicornis</i> | 0 | 0.64 | 1.13 | 48.29 | | | |
| | <i>Hiatella arctica</i> | 0.41 | 0.28 | 1.11 | 49.4 | | | |
| | <i>Edwardsia claparedii</i> | 0.54 | 0.34 | 1.11 | 50.51 | | | |
| | C v/s A | <i>Amphiura filiformis</i> | 1.04 | 3.27 | 5.04 | | 5.04 | 68.90 |
| | | <i>Peresiella clymenoides</i> | 0.49 | 2.55 | 4.32 | | 9.36 | |
| | | <i>Lumbrineris gracilis</i> | 2.3 | 3.98 | 4.25 | | 13.61 | |
| | | <i>Mysella bidentata</i> | 1.14 | 2.3 | 3.58 | | 17.19 | |
| <i>Nuculoma tenuis</i> | | 1.97 | 0.82 | 2.76 | 19.95 | | | |
| <i>Thyasira flexuosa</i> | | 1.87 | 1.45 | 2.35 | 22.31 | | | |
| NEMERTEA | | 0.65 | 1.6 | 2.16 | 24.47 | | | |
| <i>Scoloplos armiger</i> | | 1.37 | 1.33 | 2.05 | 26.51 | | | |
| <i>Chaetoderma nitidulum</i> | | 0.6 | 1.36 | 1.9 | 28.41 | | | |
| <i>Levinsenia gracilis</i> | | 0.49 | 1.13 | 1.86 | 30.27 | | | |
| <i>Nucula nitidosa</i> | | 0.76 | 0 | 1.63 | 31.89 | | | |
| <i>Rhodine gracilior</i> | | 0.37 | 0.86 | 1.58 | 33.48 | | | |
| <i>Diastylis lucifera</i> | | 0.65 | 0.67 | 1.56 | 35.04 | | | |
| <i>Diplocirrus glaucus</i> | | 0.6 | 0.77 | 1.55 | 36.59 | | | |
| <i>Dosinia lupinus</i> | | 0.35 | 0.91 | 1.55 | 38.14 | | | |
| <i>Spiophanes kroeyeri</i> | | 0.78 | 0.75 | 1.54 | 39.68 | | | |
| <i>Harpinia antennaria</i> | | 0.23 | 0.72 | 1.53 | 41.21 | | | |
| <i>Amphictene auricomma</i> | | 0.21 | 0.8 | 1.52 | 42.73 | | | |
| <i>Nephtys hombergii</i> | | 0.82 | 0.23 | 1.51 | 44.24 | | | |
| <i>Abra alba</i> | | 1.19 | 0.43 | 1.43 | 45.67 | | | |
| <i>Prionospio fallax</i> | 0.88 | 0.69 | 1.39 | 47.06 | | | | |
| <i>Nephtys</i> | 0.74 | 0.25 | 1.25 | 48.31 | | | | |
| <i>Chaetozone setosa</i> | 0.61 | 0.58 | 1.22 | 49.53 | | | | |
| <i>Tharyx killariensis</i> | 0.19 | 0.55 | 1.19 | 50.72 | | | | |

Annex IV. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Areas | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity | | |
|------------------------------|-------------------------------|-------------------------------|-------------------|----------------|--------------|-------------------------------|-------|-------|
| C v/s B | <i>Lumbrineris gracilis</i> | 2.3 | 4.07 | 5.64 | 5.64 | 73.62 | | |
| | <i>Mysella bidentata</i> | 1.14 | 0.85 | 3.29 | 8.94 | | | |
| | <i>Thyasira flexuosa</i> | 1.87 | 0.58 | 3.24 | 12.17 | | | |
| | <i>Diastylis lucifera</i> | 0.65 | 0.57 | 3.09 | 15.26 | | | |
| | <i>Nuculoma tenuis</i> | 1.97 | 0.79 | 3 | 18.27 | | | |
| | <i>Amphiura filiformis</i> | 1.04 | 0.96 | 2.93 | 21.2 | | | |
| | <i>Scoloplos armiger</i> | 1.37 | 0.76 | 2.82 | 24.02 | | | |
| | <i>Peresiella clymenoides</i> | 0.49 | 0.98 | 2.51 | 26.53 | | | |
| | <i>Spiophanes kroeyeri</i> | 0.78 | 0.31 | 2.27 | 28.8 | | | |
| | <i>Nucula nitidosa</i> | 0.76 | 0.69 | 2.22 | 31.02 | | | |
| | NEMERTEA | 0.65 | 1.02 | 2.19 | 33.21 | | | |
| | <i>Dendrodoa grossularia</i> | 0.23 | 0.43 | 1.8 | 35.01 | | | |
| | <i>Nucula nucleus</i> | 1.05 | 0.51 | 1.72 | 36.73 | | | |
| | <i>Nephtys hombergii</i> | 0.82 | 0 | 1.61 | 38.34 | | | |
| | <i>Levinsenia gracilis</i> | 0.49 | 0.62 | 1.59 | 39.93 | | | |
| | <i>Abra alba</i> | 1.19 | 0.11 | 1.58 | 41.52 | | | |
| | <i>Spiophanes bombyx</i> | 0.6 | 0 | 1.58 | 43.09 | | | |
| | <i>Prionospio fallax</i> | 0.88 | 1.03 | 1.5 | 44.6 | | | |
| | <i>Aphelochaeta</i> | 0.45 | 0.41 | 1.46 | 46.06 | | | |
| | <i>Mediomastus fragilis</i> | 0.33 | 0.63 | 1.46 | 47.52 | | | |
| | <i>Ampelisca spinipes</i> | 0.28 | 0.27 | 1.38 | 48.9 | | | |
| | <i>Edwardsia claparedii</i> | 0.19 | 0.54 | 1.33 | 50.24 | | | |
| | C v/s D | <i>Lumbrineris gracilis</i> | 2.3 | 4.98 | 6.17 | | 6.17 | 68.27 |
| | | <i>Peresiella clymenoides</i> | 0.49 | 2.71 | 4.36 | | 10.53 | |
| | | <i>Nuculoma tenuis</i> | 1.97 | 0.57 | 3 | | 13.53 | |
| | | <i>Rhodine gracilior</i> | 0.37 | 1.68 | 2.34 | | 15.87 | |
| <i>Thyasira flexuosa</i> | | 1.87 | 2.06 | 2.33 | 18.2 | | | |
| <i>Mysella bidentata</i> | | 1.14 | 1.12 | 2.11 | 20.31 | | | |
| <i>Amphiura filiformis</i> | | 1.04 | 1.41 | 2.01 | 22.32 | | | |
| NEMERTEA | | 0.65 | 1.25 | 1.81 | 24.13 | | | |
| <i>Spiophanes kroeyeri</i> | | 0.78 | 1.01 | 1.76 | 25.89 | | | |
| <i>Dosinia lupinus</i> | | 0.35 | 1.12 | 1.75 | 27.64 | | | |
| <i>Scoloplos armiger</i> | | 1.37 | 1.33 | 1.69 | 29.33 | | | |
| <i>Abra alba</i> | | 1.19 | 0.53 | 1.62 | 30.95 | | | |
| <i>Levinsenia gracilis</i> | | 0.49 | 0.89 | 1.61 | 32.56 | | | |
| <i>Ampharete lindstroemi</i> | | 0.36 | 0.81 | 1.59 | 34.16 | | | |
| <i>Nephtys hombergii</i> | | 0.82 | 0.17 | 1.51 | 35.66 | | | |
| <i>Chamelea striatula</i> | | 0.75 | 1.01 | 1.49 | 37.15 | | | |
| <i>Sabellaria spinulosa</i> | | 0.13 | 0.64 | 1.44 | 38.6 | | | |
| <i>Nucula nitidosa</i> | | 0.76 | 0.25 | 1.44 | 40.03 | | | |
| <i>Diastylis lucifera</i> | | 0.65 | 0.72 | 1.44 | 41.47 | | | |
| <i>Prionospio fallax</i> | | 0.88 | 0.89 | 1.41 | 42.88 | | | |
| <i>Diplocirrus glaucus</i> | | 0.6 | 0.6 | 1.39 | 44.27 | | | |
| <i>Nephtys</i> | | 0.74 | 0.2 | 1.38 | 45.65 | | | |
| <i>Chaetozone setosa</i> | | 0.61 | 0.74 | 1.35 | 47 | | | |
| <i>Nucula nucleus</i> | | 1.05 | 0.46 | 1.31 | 48.31 | | | |
| <i>Nephtys kersivalensis</i> | | 0.32 | 0.35 | 1.22 | 49.53 | | | |
| <i>Aphelochaeta</i> | | 0.45 | 0.12 | 1.22 | 50.75 | | | |

Annex IV. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Areas | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity |
|----------------------------|-------------------------------|-------------------|-------------------|----------------|--------------|-------------------------------|
| C v/s E | <i>Thyasira flexuosa</i> | 1.87 | 3.47 | 4.74 | 4.74 | 64.97 |
| | <i>Nuculoma tenuis</i> | 1.97 | 2.68 | 3.06 | 7.79 | |
| | <i>Diastylis lucifera</i> | 0.65 | 1.57 | 2.88 | 10.68 | |
| | <i>Mysella bidentata</i> | 1.14 | 1.39 | 2.79 | 13.47 | |
| | <i>Aphelochaeta</i> | 0.45 | 1.34 | 2.75 | 16.22 | |
| | <i>Chaetoderma nitidulum</i> | 0.6 | 1.38 | 2.73 | 18.95 | |
| | <i>Phaxus pellucidus</i> | 0.25 | 1.35 | 2.68 | 21.64 | |
| | <i>Amphiura filiformis</i> | 1.04 | 1.38 | 2.6 | 24.24 | |
| | <i>Lumbrineris gracilis</i> | 2.3 | 2.33 | 2.46 | 26.69 | |
| | <i>Scoloplos armiger</i> | 1.37 | 1.38 | 2.34 | 29.03 | |
| | <i>Harpinia antennaria</i> | 0.23 | 0.95 | 2.28 | 31.31 | |
| | <i>Spiophanes kroeyeri</i> | 0.78 | 1.2 | 2.19 | 33.5 | |
| | <i>Nucula nitidosa</i> | 0.76 | 1.01 | 2.01 | 35.51 | |
| | <i>Nephtys kersivalensis</i> | 0.32 | 0.96 | 1.98 | 37.49 | |
| | <i>Nephtys hombergii</i> | 0.82 | 1.29 | 1.97 | 39.46 | |
| | NEMERTEA | 0.65 | 0.7 | 1.8 | 41.26 | |
| | <i>Chaetozone setosa</i> | 0.61 | 0.8 | 1.63 | 42.89 | |
| | <i>Trichobranchus roseus</i> | 0.25 | 0.88 | 1.57 | 44.46 | |
| | <i>Spiophanes bombyx</i> | 0.6 | 0.63 | 1.55 | 46 | |
| | <i>Prionospio fallax</i> | 0.88 | 0.73 | 1.51 | 47.51 | |
| <i>Rhodine gracilior</i> | 0.37 | 0.98 | 1.46 | 48.97 | | |
| <i>Owenia fusiformis</i> | 0.34 | 0.87 | 1.43 | 50.4 | | |
| E v/s A | <i>Amphiura filiformis</i> | 1.38 | 3.27 | 4.24 | 4.24 | 63.99 |
| | <i>Thyasira flexuosa</i> | 3.47 | 1.45 | 4.05 | 8.29 | |
| | <i>Lumbrineris gracilis</i> | 2.33 | 3.98 | 4.01 | 12.3 | |
| | <i>Peresiella clymenoides</i> | 0.58 | 2.55 | 3.66 | 15.96 | |
| | <i>Mysella bidentata</i> | 1.39 | 2.3 | 3.16 | 19.13 | |
| | <i>Nuculoma tenuis</i> | 2.68 | 0.82 | 3.11 | 22.24 | |
| | <i>Phaxus pellucidus</i> | 1.35 | 0 | 2.33 | 24.57 | |
| | <i>Aphelochaeta</i> | 1.34 | 0.27 | 2.19 | 26.76 | |
| | <i>Diastylis lucifera</i> | 1.57 | 0.67 | 1.88 | 28.64 | |
| | <i>Nephtys hombergii</i> | 1.29 | 0.23 | 1.83 | 30.47 | |
| | <i>Chaetoderma nitidulum</i> | 1.38 | 1.36 | 1.79 | 32.25 | |
| | <i>Scoloplos armiger</i> | 1.38 | 1.33 | 1.77 | 34.02 | |
| | <i>Dosinia lupinus</i> | 0.45 | 0.91 | 1.75 | 35.77 | |
| | <i>Rhodine gracilior</i> | 0.98 | 0.86 | 1.63 | 37.4 | |
| | <i>Nephtys kersivalensis</i> | 0.96 | 0.46 | 1.56 | 38.96 | |
| | <i>Nucula nitidosa</i> | 1.01 | 0 | 1.53 | 40.49 | |
| | <i>Ampelisca tenuicornis</i> | 0.53 | 0.43 | 1.51 | 42 | |
| | <i>Trichobranchus roseus</i> | 0.88 | 0.23 | 1.43 | 43.43 | |
| | <i>Diplocirrus glaucus</i> | 0.31 | 0.77 | 1.4 | 44.82 | |
| | <i>Levinsenia gracilis</i> | 0.61 | 1.13 | 1.39 | 46.22 | |
| <i>Owenia fusiformis</i> | 0.87 | 0.08 | 1.34 | 47.56 | | |
| <i>Amphictene auricoma</i> | 0.09 | 0.8 | 1.3 | 48.86 | | |
| <i>Harpinia antennaria</i> | 0.95 | 0.72 | 1.28 | 50.14 | | |

Annex IV. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas at TY070 dredged material disposal site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Areas | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity |
|-------------------------------|-------------------------------|-----------------------------|-------------------|----------------|--------------|-------------------------------|
| E v/s B | <i>Thyasira flexuosa</i> | 3.47 | 0.58 | 5.76 | 5.76 | 72.80 |
| | <i>Lumbrineris gracilis</i> | 2.33 | 4.07 | 4.52 | 10.28 | |
| | <i>Nuculoma tenuis</i> | 2.68 | 0.79 | 4.02 | 14.3 | |
| | <i>Diastylis lucifera</i> | 1.57 | 0.57 | 3.43 | 17.73 | |
| | <i>Mysella bidentata</i> | 1.39 | 0.85 | 3 | 20.73 | |
| | <i>Chaetoderma nitidulum</i> | 1.38 | 0.41 | 3 | 23.72 | |
| | <i>Phaxus pellucidus</i> | 1.35 | 0 | 2.95 | 26.67 | |
| | <i>Aphelochaeta</i> | 1.34 | 0.41 | 2.52 | 29.19 | |
| | <i>Nephtys hombergii</i> | 1.29 | 0 | 2.52 | 31.7 | |
| | <i>Harpinia antennaria</i> | 0.95 | 0 | 2.38 | 34.08 | |
| | <i>Chaetozone setosa</i> | 0.8 | 0.35 | 2.34 | 36.42 | |
| | <i>Amphiura filiformis</i> | 1.38 | 0.96 | 2.12 | 38.54 | |
| | <i>Spiophanes kroeyeri</i> | 1.2 | 0.31 | 2.05 | 40.58 | |
| | <i>Nephtys kersivalensis</i> | 0.96 | 0 | 2 | 42.59 | |
| | <i>Scoloplos armiger</i> | 1.38 | 0.76 | 1.98 | 44.57 | |
| | <i>Peresiella clymenoides</i> | 0.58 | 0.98 | 1.94 | 46.51 | |
| | <i>Trichobranchus roseus</i> | 0.88 | 0 | 1.58 | 48.09 | |
| | <i>Owenia fusiformis</i> | 0.87 | 0.11 | 1.53 | 49.62 | |
| | <i>Rhodine gracilior</i> | 0.98 | 0 | 1.43 | 51.06 | |
| | E v/s D | <i>Lumbrineris gracilis</i> | 2.33 | 4.98 | 5.41 | |
| <i>Peresiella clymenoides</i> | | 0.58 | 2.71 | 4.51 | 9.93 | |
| <i>Thyasira flexuosa</i> | | 3.47 | 2.06 | 3.61 | 13.54 | |
| <i>Nuculoma tenuis</i> | | 2.68 | 0.57 | 3.57 | 17.11 | |
| <i>Chaetoderma nitidulum</i> | | 1.38 | 0.67 | 2.26 | 19.37 | |
| <i>Aphelochaeta</i> | | 1.34 | 0.12 | 2.22 | 21.59 | |
| <i>Nephtys hombergii</i> | | 1.29 | 0.17 | 2.19 | 23.78 | |
| <i>Phaxus pellucidus</i> | | 1.35 | 0.2 | 2.05 | 25.83 | |
| <i>Rhodine gracilior</i> | | 0.98 | 1.68 | 2.04 | 27.87 | |
| <i>Diastylis lucifera</i> | | 1.57 | 0.72 | 1.98 | 29.85 | |
| <i>Harpinia antennaria</i> | | 0.95 | 0.05 | 1.83 | 31.69 | |
| <i>Sabellaria spinulosa</i> | | 0.09 | 0.64 | 1.8 | 33.49 | |
| <i>Ampharete lindstroemi</i> | | 0.35 | 0.81 | 1.73 | 35.22 | |
| <i>Mysella bidentata</i> | | 1.39 | 1.12 | 1.71 | 36.93 | |
| <i>Amphiura filiformis</i> | | 1.38 | 1.41 | 1.57 | 38.5 | |
| <i>Dosinia lupinus</i> | | 0.45 | 1.12 | 1.53 | 40.03 | |
| <i>Owenia fusiformis</i> | | 0.87 | 0.43 | 1.46 | 41.49 | |
| <i>Spiophanes kroeyeri</i> | | 1.2 | 1.01 | 1.44 | 42.92 | |
| <i>Nucula nitidosa</i> | | 1.01 | 0.25 | 1.4 | 44.33 | |
| <i>Diplocirrus glaucus</i> | | 0.31 | 0.6 | 1.39 | 45.72 | |
| <i>Levinsenia gracilis</i> | 0.61 | 0.89 | 1.38 | 47.1 | | |
| <i>Trichobranchus roseus</i> | 0.88 | 0.79 | 1.35 | 48.45 | | |
| <i>Tellimya ferruginosa</i> | 0.48 | 0.26 | 1.25 | 49.71 | | |
| <i>Prionospio fallax</i> | 0.73 | 0.89 | 1.23 | 50.94 | | |

Annex V. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at Shoreham aggregate extraction site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall similarity over time.

| Year | Taxon | Average abundance | % contribution | Cumulative % | Overall average similarity |
|------|-----------------------------------|-------------------|----------------|--------------|----------------------------|
| 2001 | <i>Scalibregma inflatum</i> | 2.29 | 9.69 | 9.69 | 38.78 |
| | <i>Lanice conchilega</i> | 1.94 | 8.46 | 18.15 | |
| | <i>Lumbrineris gracilis</i> | 2.24 | 8.32 | 26.47 | |
| | <i>Pisidia longicornis</i> | 2.1 | 6.93 | 33.4 | |
| | <i>Amphipholis squamata</i> | 1.45 | 5.71 | 39.11 | |
| | <i>Mediomastus fragilis</i> | 1.81 | 5.55 | 44.66 | |
| | <i>Spiophanes bombyx</i> | 0.86 | 4.61 | 49.28 | |
| | <i>Notomastus latriceus</i> | 1.4 | 4.36 | 53.64 | |
| | <i>Maldanidae</i> | 1.03 | 3.88 | 57.52 | |
| | <i>Caulleriella alata</i> | 1.07 | 3.8 | 61.31 | |
| | <i>Phoronis</i> sp. | 0.8 | 3.77 | 65.09 | |
| | <i>Aonides oxycephala</i> | 0.99 | 2.93 | 68.02 | |
| | NEMERTEA | 0.86 | 2.85 | 70.86 | |
| | <i>Galathea intermedia</i> | 0.71 | 1.98 | 72.84 | |
| 2002 | <i>Balanus crenatus</i> | 6.18 | 9.41 | 9.41 | 51.84 |
| | <i>Sabellaria spinulosa</i> | 4.87 | 7.26 | 16.67 | |
| | <i>Lumbrineris gracilis</i> | 3.06 | 6.2 | 22.87 | |
| | <i>Pisidia longicornis</i> | 2.77 | 4.52 | 27.39 | |
| | <i>Timoclea ovata</i> | 2.21 | 4.32 | 31.7 | |
| | <i>Ampelisca spinipes</i> | 1.98 | 3.7 | 35.41 | |
| | <i>Echinocyamus pusillus</i> | 2.15 | 3.67 | 39.08 | |
| | <i>Pomatoceros lamarcki</i> | 1.95 | 3.62 | 42.7 | |
| | <i>Achelia echinata</i> | 1.68 | 3.1 | 45.8 | |
| | <i>Praxillella affinis</i> | 1.73 | 2.79 | 48.59 | |
| | <i>Crepidula fornicata</i> (juv.) | 1.91 | 2.55 | 51.14 | |
| | <i>Ampharete lindstroemi</i> | 1.37 | 2.39 | 53.54 | |
| | <i>Nematonereis unicornis</i> | 1.16 | 2.12 | 55.65 | |
| | <i>Scalibregma celticum</i> | 1.09 | 2.09 | 57.75 | |
| | <i>Crepidula fornicata</i> | 1.48 | 2.01 | 59.76 | |
| | <i>Leptochiton asellus</i> | 0.87 | 1.74 | 61.5 | |
| | <i>Amphipholis squamata</i> | 1.26 | 1.74 | 63.24 | |
| | <i>Phoronis</i> | 0.98 | 1.73 | 64.98 | |
| | <i>Mediomastus fragilis</i> | 1.22 | 1.59 | 66.56 | |
| | <i>Glycera lapidum</i> | 1 | 1.5 | 68.06 | |
| | <i>Amphicteis midas</i> | 1.04 | 1.47 | 69.53 | |
| | <i>Harmothoe impar</i> | 1.07 | 1.44 | 70.97 | |
| | <i>Lanice conchilega</i> | 0.88 | 1.39 | 72.36 | |
| 2003 | <i>Balanus crenatus</i> | 5.71 | 18.14 | 18.14 | 29.35 |
| | <i>Lumbrineris gracilis</i> | 1.73 | 8.89 | 27.03 | |
| | <i>Amphipholis squamata</i> | 2.06 | 8.34 | 35.37 | |
| | <i>Clymenura</i> | 1.1 | 6.02 | 41.4 | |
| | NEMERTEA | 1.18 | 5.62 | 47.01 | |
| | <i>Scalibregma inflatum</i> | 1.38 | 4.7 | 51.71 | |
| | <i>Sabellaria spinulosa</i> | 2.65 | 4.67 | 56.38 | |
| | <i>Polycirrus</i> | 0.88 | 4.23 | 60.61 | |
| | <i>Ehlersia cornuta</i> | 0.87 | 3.62 | 64.23 | |
| | <i>Praxillella affinis</i> | 0.77 | 3.39 | 67.62 | |
| | <i>Caulleriella zetlandica</i> | 0.88 | 3.23 | 70.85 | |
| | <i>Ophelia borealis</i> | 0.92 | 2.74 | 73.59 | |
| | <i>Lanice conchilega</i> | 0.78 | 2.52 | 76.11 | |
| | <i>Crepidula fornicata</i> | 1.16 | 2.02 | 78.13 | |
| | <i>Aonides paucibranchiata</i> | 0.55 | 1.76 | 79.89 | |

Annex V. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at Shoreham aggregate extraction site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall similarity over time.

| Year | Taxon | Average abundance | % contribution | Cumulative % | Overall average similarity |
|-----------------------------|-----------------------------------|-------------------|----------------|--------------|----------------------------|
| 2004 | <i>Echinocyamus pusillus</i> | 3.37 | 11.63 | 11.63 | 33.71 |
| | <i>Balanus crenatus</i> | 5.01 | 10.89 | 22.53 | |
| | NEMERTEA | 1.84 | 6.78 | 29.31 | |
| | <i>Lumbrineris gracilis</i> | 2.04 | 5.67 | 34.98 | |
| | <i>Glycera lapidum</i> | 1.17 | 4.62 | 39.6 | |
| | <i>Sabellaria spinulosa</i> | 2.82 | 4.38 | 43.98 | |
| | <i>Praxillella affinis</i> | 1.63 | 4.27 | 48.25 | |
| | <i>Clymenura</i> | 1.23 | 3.55 | 51.8 | |
| | <i>Polycirrus</i> | 1.13 | 3.36 | 55.15 | |
| | <i>Cauleriella alata</i> | 1.1 | 3.18 | 58.33 | |
| | <i>Spisula</i> (juv.) | 1.29 | 2.51 | 60.85 | |
| | <i>Aonides paucibranchiata</i> | 0.85 | 2.39 | 63.24 | |
| | <i>Crepidula fornicata</i> (juv.) | 1.43 | 2.29 | 65.53 | |
| | Anomiidae (juv.) | 1.21 | 2.13 | 67.67 | |
| | <i>Timoclea ovata</i> | 0.84 | 2.04 | 69.7 | |
| | <i>Pomatoceros lamarcki</i> | 0.97 | 1.93 | 71.64 | |
| | <i>Nematonereis unicornis</i> | 0.6 | 1.64 | 73.27 | |
| | Amphiuridae (juv.) | 1 | 1.54 | 74.81 | |
| | <i>Poecilochaetus serpens</i> | 0.82 | 1.47 | 76.28 | |
| | <i>Modiolarca tumida</i> | 0.55 | 1.34 | 77.63 | |
| <i>Scalibregma inflatum</i> | 1.16 | 1.31 | 78.94 | | |

Annex VI. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at Shoreham aggregate extraction site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Year | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity | | |
|--------------------------------|-----------------------------------|-----------------------------|-------------------|----------------|--------------|-------------------------------|-------|-------|
| 2001 v/s 2002 | <i>Balanus crenatus</i> | 1.05 | 6.18 | 6.22 | 6.22 | 72.81 | | |
| | <i>Sabellaria spinulosa</i> | 0.27 | 4.87 | 5.21 | 11.44 | | | |
| | <i>Pomatoceros lamarcki</i> | 0.32 | 1.95 | 2.25 | 13.69 | | | |
| | <i>Timoclea ovata</i> | 0.34 | 2.21 | 2.25 | 15.94 | | | |
| | <i>Crepidula fornicata</i> (juv.) | 0 | 1.91 | 2.15 | 18.09 | | | |
| | <i>Echinocyamus pusillus</i> | 0.71 | 2.15 | 2.14 | 20.22 | | | |
| | <i>Praxillella affinis</i> | 0 | 1.73 | 2.12 | 22.34 | | | |
| | <i>Pisidia longicornis</i> | 2.1 | 2.77 | 2.01 | 24.35 | | | |
| | <i>Scalibregma inflatum</i> | 2.29 | 0.97 | 1.98 | 26.33 | | | |
| | <i>Ampelisca spinipes</i> | 0.51 | 1.98 | 1.97 | 28.29 | | | |
| | <i>Achelia echinata</i> | 0 | 1.68 | 1.96 | 30.26 | | | |
| | <i>Lumbrineris gracilis</i> | 2.24 | 3.06 | 1.92 | 32.18 | | | |
| | <i>Crepidula fornicata</i> | 0.72 | 1.48 | 1.85 | 34.02 | | | |
| | <i>Notomastus latriceus</i> | 1.4 | 0 | 1.51 | 35.54 | | | |
| | <i>Amphipholis squamata</i> | 1.45 | 1.26 | 1.51 | 37.05 | | | |
| | <i>Mediomastus fragilis</i> | 1.81 | 1.22 | 1.49 | 38.54 | | | |
| | <i>Lanice conchilega</i> | 1.94 | 0.88 | 1.46 | 39.99 | | | |
| | <i>Ampharete lindstroemi</i> | 0.54 | 1.37 | 1.36 | 41.35 | | | |
| | <i>Harmothoe impar</i> | 0.62 | 1.07 | 1.28 | 42.63 | | | |
| | <i>Maldanidae</i> | 1.03 | 0 | 1.28 | 43.9 | | | |
| | <i>Anomiidae</i> (juv.) | 0 | 1.15 | 1.23 | 45.13 | | | |
| | <i>Nematonereis unicornis</i> | 0.3 | 1.16 | 1.2 | 46.32 | | | |
| | <i>Clymenura</i> | 0 | 0.9 | 1.1 | 47.43 | | | |
| | <i>Amphicteis midas</i> | 0.1 | 1.04 | 1.08 | 48.51 | | | |
| | <i>Upogebia</i> (juv.) | 0 | 0.91 | 1.07 | 49.58 | | | |
| | <i>Glycera lapidum</i> | 0.51 | 1 | 1.06 | 50.64 | | | |
| | 2001 v/s 2003 | <i>Balanus crenatus</i> | 1.05 | 5.71 | 7.84 | | 7.84 | 81.84 |
| | | <i>Sabellaria spinulosa</i> | 0.27 | 2.65 | 3.37 | | 11.21 | |
| | | <i>Amphipholis squamata</i> | 1.45 | 2.06 | 2.79 | | 14 | |
| | | <i>Scalibregma inflatum</i> | 2.29 | 1.38 | 2.52 | | 16.53 | |
| <i>Pisidia longicornis</i> | | 2.1 | 0.35 | 2.51 | 19.04 | | | |
| <i>Lumbrineris gracilis</i> | | 2.24 | 1.73 | 2.38 | 21.41 | | | |
| <i>Mediomastus fragilis</i> | | 1.81 | 0.28 | 2.29 | 23.71 | | | |
| <i>Lanice conchilega</i> | | 1.94 | 0.78 | 2.06 | 25.77 | | | |
| <i>Spiophanes bombyx</i> | | 0.86 | 1.26 | 1.99 | 27.76 | | | |
| <i>Crepidula fornicata</i> | | 0.72 | 1.16 | 1.95 | 29.71 | | | |
| <i>Notomastus latriceus</i> | | 1.4 | 0 | 1.73 | 31.44 | | | |
| <i>Clymenura</i> | | 0 | 1.1 | 1.65 | 33.09 | | | |
| <i>Maldanidae</i> | | 1.03 | 0.08 | 1.61 | 34.71 | | | |
| <i>Phoronis</i> | | 0.8 | 0.12 | 1.6 | 36.3 | | | |
| <i>Caulleriella alata</i> | | 1.07 | 0 | 1.4 | 37.71 | | | |
| <i>Ophelia borealis</i> | | 0.37 | 0.92 | 1.4 | 39.1 | | | |
| <i>Polycirrus</i> | | 0 | 0.88 | 1.38 | 40.49 | | | |
| <i>Pomatoceros lamarcki</i> | | 0.32 | 0.91 | 1.35 | 41.84 | | | |
| <i>Ehlersia cornuta</i> | | 0 | 0.87 | 1.3 | 43.14 | | | |
| <i>Aonides oxycephala</i> | | 0.99 | 0.38 | 1.24 | 44.38 | | | |
| <i>Caulleriella zetlandica</i> | | 0.52 | 0.88 | 1.19 | 45.57 | | | |
| NEMERTEA | | 0.86 | 1.18 | 1.18 | 46.76 | | | |
| <i>Echinocyamus pusillus</i> | | 0.71 | 0.08 | 1.12 | 47.88 | | | |
| <i>Praxillella affinis</i> | | 0 | 0.77 | 1.09 | 48.97 | | | |
| <i>Harmothoe impar</i> | | 0.62 | 0.33 | 1.02 | 49.99 | | | |
| <i>Liocarcinus</i> (juv.) | | 0.71 | 0.08 | 1 | 50.99 | | | |

Annex VI. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at Shoreham aggregate extraction site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Year | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity | | |
|-----------------------------------|-----------------------------------|------------------------------|-------------------|----------------|--------------|-------------------------------|-------|-------|
| 2002 v/s 2003 | <i>Balanus crenatus</i> | 6.18 | 5.71 | 7.41 | 7.41 | 70.9 | | |
| | <i>Sabellaria spinulosa</i> | 4.87 | 2.65 | 4.45 | 11.85 | | | |
| | <i>Echinocyamus pusillus</i> | 2.15 | 0.08 | 2.69 | 14.54 | | | |
| | <i>Pisidia longicornis</i> | 2.77 | 0.35 | 2.68 | 17.22 | | | |
| | <i>Ampelisca spinipes</i> | 1.98 | 0 | 2.33 | 19.55 | | | |
| | <i>Timoclea ovata</i> | 2.21 | 0.39 | 2.23 | 21.78 | | | |
| | <i>Crepidula fornicata</i> (juv.) | 1.91 | 0.25 | 1.98 | 23.75 | | | |
| | <i>Achelia echinata</i> | 1.68 | 0.08 | 1.86 | 25.62 | | | |
| | <i>Lumbrineris gracilis</i> | 3.06 | 1.73 | 1.78 | 27.4 | | | |
| | <i>Amphipholis squamata</i> | 1.26 | 2.06 | 1.64 | 29.04 | | | |
| | <i>Pomatoceros lamarcki</i> | 1.95 | 0.91 | 1.62 | 30.66 | | | |
| | <i>Crepidula fornicata</i> | 1.48 | 1.16 | 1.61 | 32.26 | | | |
| | <i>Praxillella affinis</i> | 1.73 | 0.77 | 1.59 | 33.85 | | | |
| | <i>Ampharete lindstroemi</i> | 1.37 | 0.17 | 1.54 | 35.39 | | | |
| | <i>Spiophanes bombyx</i> | 0.2 | 1.26 | 1.34 | 36.73 | | | |
| | <i>Mediomastus fragilis</i> | 1.22 | 0.28 | 1.31 | 38.04 | | | |
| | <i>Scalibregma inflatum</i> | 0.97 | 1.38 | 1.28 | 39.32 | | | |
| | <i>Phoronis</i> | 0.98 | 0.12 | 1.23 | 40.55 | | | |
| | <i>Scalibregma celticum</i> | 1.09 | 0 | 1.17 | 41.73 | | | |
| | <i>Anomiidae</i> (juv.) | 1.15 | 0.49 | 1.14 | 42.86 | | | |
| | <i>Ophelia borealis</i> | 0.08 | 0.92 | 1.11 | 43.98 | | | |
| | <i>Nematonereis unicornis</i> | 1.16 | 0.37 | 1.1 | 45.08 | | | |
| | <i>Amphicteis midas</i> | 1.04 | 0.08 | 1.1 | 46.18 | | | |
| | <i>Glycera lapidum</i> | 1 | 0.31 | 1.06 | 47.24 | | | |
| | <i>Harmothoe impar</i> | 1.07 | 0.33 | 1.05 | 48.29 | | | |
| | <i>Caulleriella zetlandica</i> | 0 | 0.88 | 1.04 | 49.33 | | | |
| | <i>Terebellides stroemi</i> | 0.97 | 0.08 | 1.04 | 50.37 | | | |
| | 2001 v/s 2004 | <i>Balanus crenatus</i> | 1.05 | 5.01 | 5.57 | | 5.57 | 81.34 |
| | | <i>Echinocyamus pusillus</i> | 0.71 | 3.37 | 3.64 | | 9.22 | |
| | | <i>Sabellaria spinulosa</i> | 0.27 | 2.82 | 2.95 | | 12.17 | |
| <i>Scalibregma inflatum</i> | | 2.29 | 1.16 | 2.64 | 14.82 | | | |
| <i>Lanice conchilega</i> | | 1.94 | 0 | 2.54 | 17.36 | | | |
| <i>Pisidia longicornis</i> | | 2.1 | 0.48 | 2.51 | 19.87 | | | |
| <i>Lumbrineris gracilis</i> | | 2.24 | 2.04 | 2.47 | 22.33 | | | |
| <i>Mediomastus fragilis</i> | | 1.81 | 1.18 | 2.46 | 24.79 | | | |
| <i>Spisula</i> (juv.) | | 0 | 1.29 | 2.07 | 26.86 | | | |
| <i>Praxillella affinis</i> | | 0 | 1.63 | 1.96 | 28.82 | | | |
| <i>Amphipholis squamata</i> | | 1.45 | 0.35 | 1.83 | 30.65 | | | |
| <i>Notomastus latriceus</i> | | 1.4 | 0 | 1.73 | 32.37 | | | |
| <i>Clymenura</i> | | 0 | 1.23 | 1.69 | 34.06 | | | |
| <i>Crepidula fornicata</i> (juv.) | | 0 | 1.43 | 1.62 | 35.68 | | | |
| NEMERTEA | | 0.86 | 1.84 | 1.59 | 37.27 | | | |
| <i>Maldanidae</i> | | 1.03 | 0 | 1.47 | 38.74 | | | |
| <i>Polycirrus</i> sp. | | 0 | 1.13 | 1.4 | 40.14 | | | |
| <i>Phoronis</i> sp. | | 0.8 | 0 | 1.38 | 41.52 | | | |
| <i>Glycera lapidum</i> | | 0.51 | 1.17 | 1.37 | 42.89 | | | |
| <i>Spiophanes bombyx</i> | | 0.86 | 0.2 | 1.35 | 44.24 | | | |
| <i>Anomiidae</i> (juv.) | | 0 | 1.21 | 1.33 | 45.57 | | | |
| <i>Crepidula fornicata</i> | | 0.72 | 0.63 | 1.22 | 46.79 | | | |
| <i>Aonides oxycephala</i> | | 0.99 | 0.44 | 1.2 | 47.99 | | | |
| <i>Caulleriella alata</i> | | 1.07 | 1.1 | 1.19 | 49.18 | | | |
| <i>Pomatoceros lamarcki</i> | | 0.32 | 0.97 | 1.16 | 50.34 | | | |

Annex VI. continued. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over time at Shoreham aggregate extraction site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time.

| Year | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity | | |
|-----------------------------------|-----------------------------------|------------------------------|-------------------|----------------|--------------|-------------------------------|-------|-------|
| 2002 v/s 2004 | <i>Balanus crenatus</i> | 6.18 | 5.01 | 5.6 | 5.6 | 65.01 | | |
| | <i>Sabellaria spinulosa</i> | 4.87 | 2.82 | 4.37 | 9.97 | | | |
| | <i>Pisidia longicornis</i> | 2.77 | 0.48 | 2.83 | 12.8 | | | |
| | <i>Echinocyamus pusillus</i> | 2.15 | 3.37 | 2.39 | 15.19 | | | |
| | <i>Ampelisca spinipes</i> | 1.98 | 0.45 | 2.12 | 17.31 | | | |
| | <i>Crepidula fornicata</i> (juv.) | 1.91 | 1.43 | 2.05 | 19.35 | | | |
| | <i>Timoclea ovata</i> | 2.21 | 0.84 | 1.99 | 21.34 | | | |
| | <i>Lumbrineris gracilis</i> | 3.06 | 2.04 | 1.97 | 23.31 | | | |
| | <i>Pomatoceros lamarcki</i> | 1.95 | 0.97 | 1.83 | 25.14 | | | |
| | <i>Achelia echinata</i> | 1.68 | 0.31 | 1.81 | 26.95 | | | |
| | <i>Spisula</i> (juv.) | 0 | 1.29 | 1.78 | 28.73 | | | |
| | <i>Mediomastus fragilis</i> | 1.22 | 1.18 | 1.77 | 30.5 | | | |
| | <i>Praxillella affinis</i> | 1.73 | 1.63 | 1.68 | 32.18 | | | |
| | <i>Crepidula fornicata</i> | 1.48 | 0.63 | 1.65 | 33.83 | | | |
| | <i>Ampharete lindstroemi</i> | 1.37 | 0.08 | 1.65 | 35.48 | | | |
| | <i>Anomiidae</i> (juv.) | 1.15 | 1.21 | 1.64 | 37.12 | | | |
| | <i>Scalibregma inflatum</i> | 0.97 | 1.16 | 1.44 | 38.56 | | | |
| | NEMERTEA | 0.83 | 1.84 | 1.42 | 39.98 | | | |
| | <i>Amphipholis squamata</i> | 1.26 | 0.35 | 1.37 | 41.35 | | | |
| | <i>Phoronis</i> sp. | 0.98 | 0 | 1.29 | 42.65 | | | |
| | <i>Amphiuridae</i> (juv.) | 0.77 | 1 | 1.23 | 43.87 | | | |
| | <i>Autolytus</i> sp. | 0.86 | 0.57 | 1.22 | 45.1 | | | |
| | <i>Amphicteis midas</i> | 1.04 | 0.2 | 1.2 | 46.3 | | | |
| | <i>Scalibregma celticum</i> | 1.09 | 0.42 | 1.16 | 47.46 | | | |
| | <i>Poecilochaetus serpens</i> | 0.72 | 0.82 | 1.16 | 48.61 | | | |
| | <i>Harmothoe impar</i> | 1.07 | 0.74 | 1.15 | 49.76 | | | |
| | <i>Aonides oxycephala</i> | 0.95 | 0.44 | 1.12 | 50.88 | | | |
| | 2003 v/s 2004 | <i>Balanus crenatus</i> | 5.71 | 5.01 | 9.24 | | 9.24 | 73.57 |
| | | <i>Echinocyamus pusillus</i> | 0.08 | 3.37 | 4.62 | | 13.86 | |
| | | <i>Sabellaria spinulosa</i> | 2.65 | 2.82 | 4.21 | | 18.06 | |
| | | <i>Amphipholis squamata</i> | 2.06 | 0.35 | 2.56 | | 20.63 | |
| | | <i>Spisula</i> (juv.) | 0.14 | 1.29 | 2.23 | | 22.86 | |
| <i>Scalibregma inflatum</i> | | 1.38 | 1.16 | 1.88 | 24.73 | | | |
| <i>Crepidula fornicata</i> | | 1.16 | 0.63 | 1.79 | 26.52 | | | |
| <i>Anomiidae</i> (juv.) | | 0.49 | 1.21 | 1.77 | 28.29 | | | |
| <i>Lumbrineris gracilis</i> | | 1.73 | 2.04 | 1.75 | 30.05 | | | |
| <i>Crepidula fornicata</i> (juv.) | | 0.25 | 1.43 | 1.72 | 31.77 | | | |
| <i>Pomatoceros lamarcki</i> | | 0.91 | 0.97 | 1.58 | 33.35 | | | |
| <i>Spiophanes bombyx</i> | | 1.26 | 0.2 | 1.58 | 34.93 | | | |
| <i>Praxillella affinis</i> | | 0.77 | 1.63 | 1.49 | 36.42 | | | |
| <i>Caulleriella alata</i> | | 0 | 1.1 | 1.48 | 37.9 | | | |
| <i>Glycera lapidum</i> | | 0.31 | 1.17 | 1.48 | 39.38 | | | |
| <i>Mediomastus fragilis</i> | | 0.28 | 1.18 | 1.42 | 40.8 | | | |
| NEMERTEA | | 1.18 | 1.84 | 1.41 | 42.21 | | | |
| <i>Ophelia borealis</i> | | 0.92 | 0.14 | 1.33 | 43.54 | | | |
| <i>Clymenura</i> | | 1.1 | 1.23 | 1.23 | 44.77 | | | |
| <i>Caulleriella zetlandica</i> | | 0.88 | 0.17 | 1.22 | 46 | | | |
| <i>Ehlersia cornuta</i> | | 0.87 | 0.73 | 1.21 | 47.21 | | | |
| <i>Amphiuridae</i> (juv.) | | 0.08 | 1 | 1.15 | 48.36 | | | |
| <i>Jasmineira elegans</i> | | 0.23 | 0.92 | 1.12 | 49.49 | | | |
| <i>Lanice conchilega</i> | | 0.78 | 0 | 1.04 | 50.52 | | | |

Annex VII. Results of SIMPER analysis for infaunal samples indicating the most characterizing taxa over acoustically distinct areas (dredged area and surrounding area) at Shoreham aggregate extraction site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall similarity over time.

| Areas | Taxon | Average abundance | % contribution | Cumulative % | Overall average similarity |
|------------------------------|-----------------------------------|-------------------------|----------------|--------------|----------------------------|
| Dredged Area | <i>Balanus crenatus</i> | 5.71 | 14.19 | 14.19 | 39.15 |
| | <i>Lumbrineris gracilis</i> | 2.36 | 8.09 | 22.29 | |
| | <i>Pisidia longicornis</i> | 2.27 | 6.33 | 28.61 | |
| | <i>Sabellaria spinulosa</i> | 2.75 | 5.76 | 34.37 | |
| | <i>Scalibregma inflatum</i> | 1.74 | 5.05 | 39.42 | |
| | <i>Amphipholis squamata</i> | 1.14 | 3.45 | 42.87 | |
| | <i>Mediomastus fragilis</i> | 1.34 | 3.38 | 46.25 | |
| | <i>Lanice conchilega</i> | 0.94 | 3.34 | 49.59 | |
| | <i>Crepidula fornicata</i> (juv.) | 1.2 | 2.95 | 52.53 | |
| | NEMERTEA | 0.95 | 2.54 | 55.07 | |
| | <i>Pomatoceros lamarcki</i> | 0.97 | 2.38 | 57.45 | |
| | <i>Scalibregma celticum</i> | 0.74 | 2.26 | 59.71 | |
| | Surrounding Area | <i>Balanus crenatus</i> | 3.73 | 0.8 | |
| <i>Echinocyamus pusillus</i> | | 2.23 | 0.89 | 6.35 | |
| <i>Lumbrineris gracilis</i> | | 2.19 | 1.64 | 6.28 | |
| NEMERTEA | | 1.4 | 1.32 | 4.51 | |
| <i>Clymenura</i> sp. | | 1.2 | 1.01 | 4.28 | |
| <i>Praxillella affinis</i> | | 1.56 | 1.05 | 4.21 | |
| <i>Sabellaria spinulosa</i> | | 2.76 | 0.65 | 3.95 | |
| <i>Amphipholis squamata</i> | | 1.39 | 0.76 | 3.48 | |
| <i>Polycirrus</i> sp. | | 1.06 | 0.98 | 3.3 | |
| <i>Timoclea ovata</i> | | 1.15 | 0.89 | 2.73 | |
| <i>Scalibregma inflatum</i> | | 1.14 | 0.81 | 2.44 | |
| <i>Glycera lapidum</i> | | 0.86 | 0.91 | 2.36 | |
| <i>Phoronis</i> sp. | | 0.81 | 0.38 | 2.23 | |
| <i>Lanice conchilega</i> | | 0.78 | 0.61 | 2.04 | |
| <i>Pomatoceros lamarcki</i> | | 1.15 | 0.79 | 1.95 | |
| <i>Caulleriella alata</i> | | 0.8 | 0.79 | 1.91 | |

Annex VII. Results of SIMPER analysis for infaunal samples indicating the most differentiate taxa over acoustically distinct areas (dredged area and surrounding area) at Shoreham aggregate extraction site. Results indicate average abundance and contribution (as % and cumulative percentage) to the overall dissimilarity over time

| Year | Taxon | Average abundance | Average abundance | % contribution | Cumulative % | Overall average dissimilarity |
|------------------|-----------------------------------|-------------------|-------------------|----------------|--------------|-------------------------------|
| Dredged v/s | <i>Balanus crenatus</i> | 5.71 | 3.73 | 7.8 | 7.8 | 68.35 |
| Surrounding Area | <i>Sabellaria spinulosa</i> | 2.75 | 2.76 | 3.45 | 11.25 | |
| | <i>Pisidia longicornis</i> | 2.27 | 0.67 | 2.42 | 13.67 | |
| | <i>Scalibregma inflatum</i> | 1.74 | 1.14 | 2.34 | 16 | |
| | <i>Echinocyamus pusillus</i> | 0.88 | 2.23 | 2.2 | 18.2 | |
| | <i>Lumbrineris gracilis</i> | 2.36 | 2.19 | 2.09 | 20.29 | |
| | <i>Amphipholis squamata</i> | 1.14 | 1.39 | 1.97 | 22.25 | |
| | <i>Praxillella affinis</i> | 0.51 | 1.56 | 1.82 | 24.07 | |
| | <i>Mediomastus fragilis</i> | 1.34 | 0.88 | 1.77 | 25.84 | |
| | <i>Crepidula fornicata</i> | 0.98 | 1.03 | 1.7 | 27.54 | |
| | <i>Clymenura</i> sp. | 0.43 | 1.2 | 1.57 | 29.11 | |
| | <i>Spiophanes bombyx</i> | 0.4 | 0.81 | 1.43 | 30.54 | |
| | <i>Crepidula fornicata</i> (juv.) | 1.2 | 0.72 | 1.41 | 31.94 | |
| | <i>Pomatoceros lamarcki</i> | 0.97 | 1.15 | 1.35 | 33.3 | |
| | <i>Anomiidae</i> (juv.) | 0.86 | 0.65 | 1.32 | 34.62 | |
| | NEMERTEA | 0.95 | 1.4 | 1.31 | 35.93 | |
| | <i>Polycirrus</i> sp. | 0.27 | 1.06 | 1.29 | 37.22 | |
| | <i>Phoronis</i> sp. | 0.05 | 0.81 | 1.2 | 38.42 | |
| | <i>Ophelia borealis</i> | 0.05 | 0.66 | 1.17 | 39.59 | |
| | <i>Aonides oxycephala</i> | 1.01 | 0.39 | 1.16 | 40.76 | |
| | <i>Harmothoe impar</i> | 0.62 | 0.75 | 1.08 | 41.83 | |
| | <i>Timoclea ovata</i> | 0.76 | 1.15 | 1.05 | 42.88 | |
| | <i>Glycera lapidum</i> | 0.64 | 0.86 | 1.01 | 43.89 | |
| | <i>Lanice conchilega</i> | 0.94 | 0.78 | 1 | 44.89 | |
| | <i>Schistomeringos rudolphi</i> | 0.33 | 0.74 | 0.99 | 45.88 | |
| | <i>Poecilochaetus serpens</i> | 0.5 | 0.54 | 0.98 | 46.86 | |
| | <i>Leptochiton asellus</i> | 0.07 | 0.82 | 0.97 | 47.83 | |
| | <i>Ehlersia cornuta</i> | 0.18 | 0.7 | 0.96 | 48.8 | |
| | <i>Polydora caeca</i> | 0.51 | 0.52 | 0.94 | 49.73 | |
| | <i>Nematonereis unicornis</i> | 0.44 | 0.78 | 0.91 | 50.64 | |



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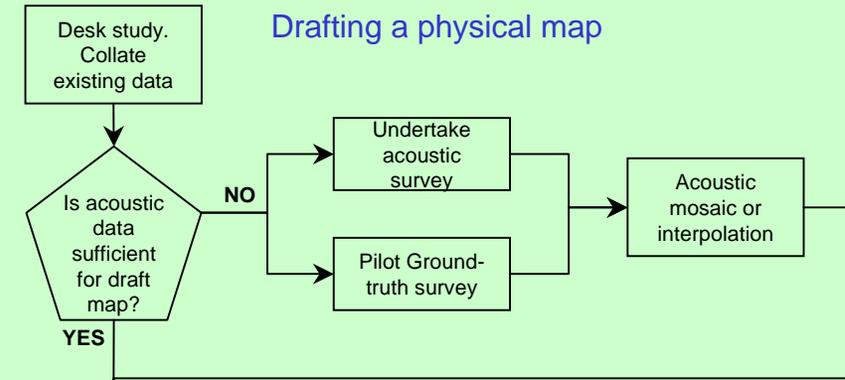
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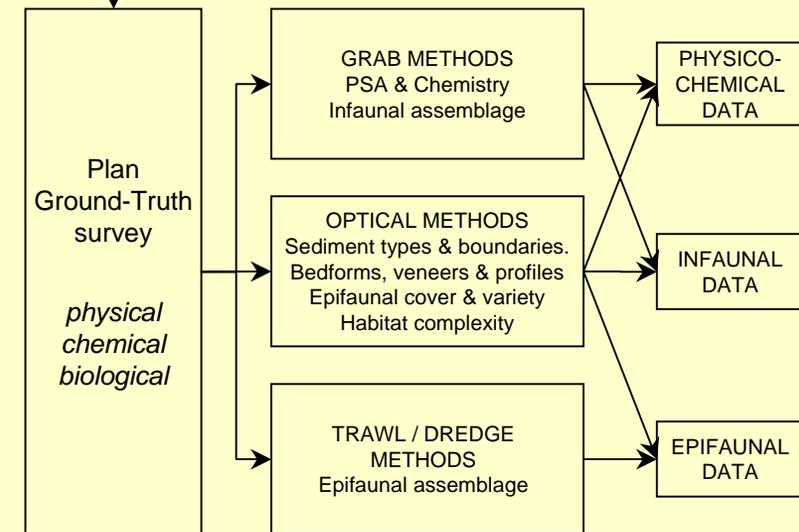
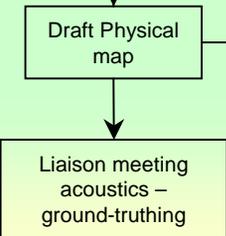
This guidance flows through three sections, indicated by the colour coding.

In the following slides you can navigate through the flow diagram and access the guidance notes by clicking on the relevant arrows.

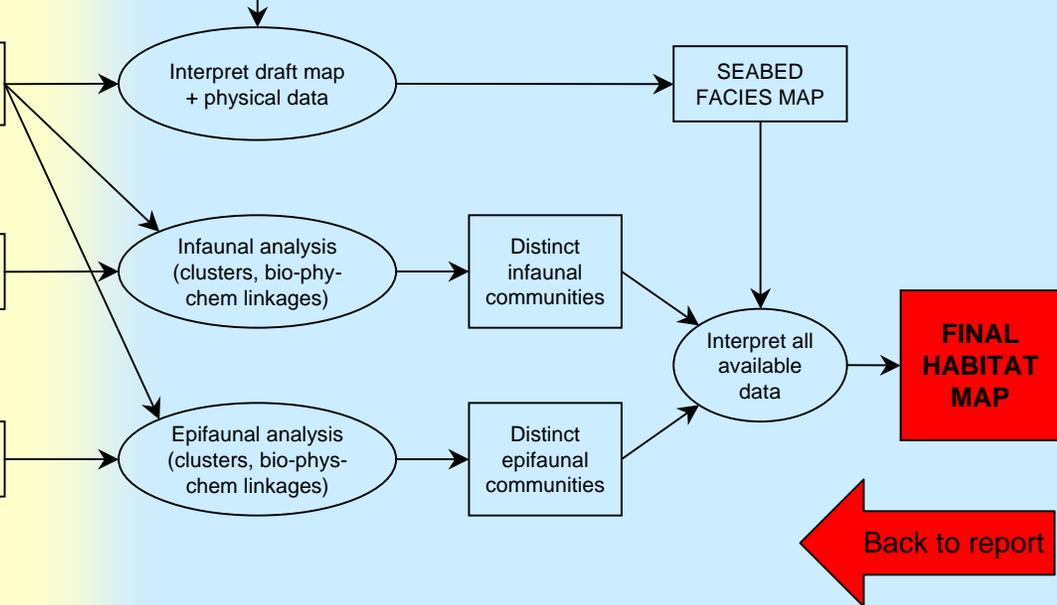
Drafting a physical map



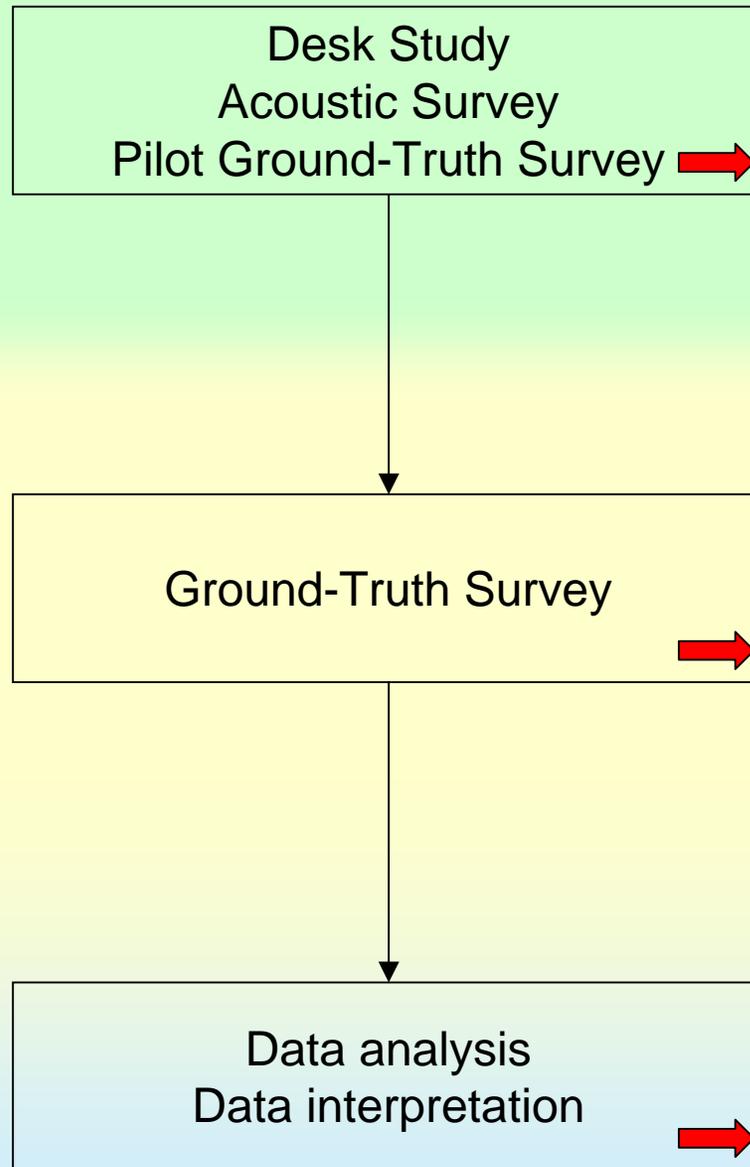
Ground-truth survey



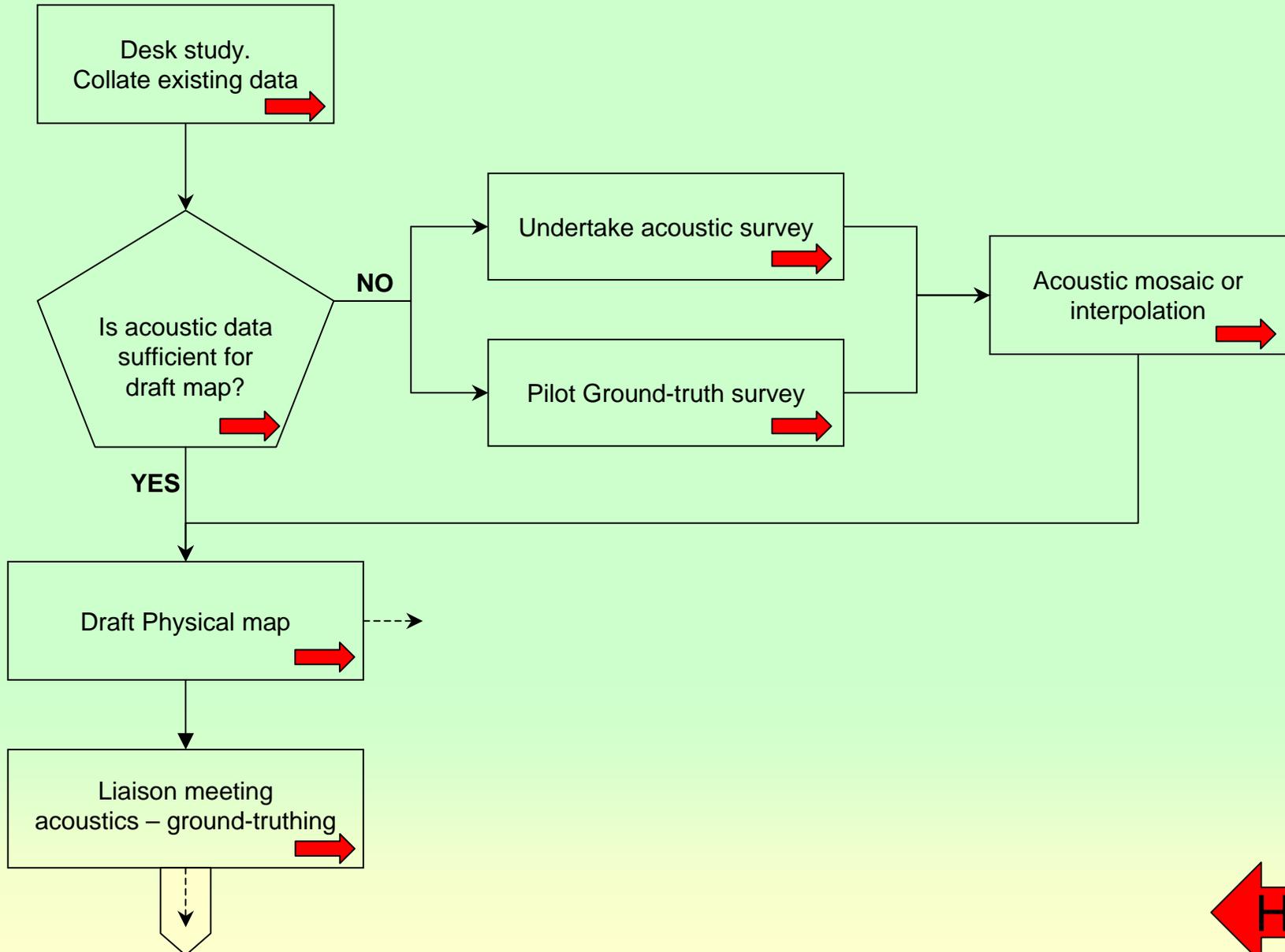
Analysis & interpretation



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Desk study – Collate existing data

The desired outcome from the survey work is a spatial map that delineates areas of seabed (polygons) that are distinct in terms of their physical properties and associated biological communities. It is essentially *biotope* mapping; a biotope being defined as the *habitat* (i.e. the environment's physical and chemical characteristics) together with its recurring associated *community* of species.

A structured survey design provides an efficient approach to habitat mapping, and a two-phase approach is recommended. The first phase is to map the physical aspects of the habitat, to delineate areas of different sediment type and bedform, known as seabed facies (e.g. sand wave fields, gravel beds etc). This is best achieved by an acoustic survey of the area. The second phase is to undertake directed ground-truth sampling within these facies to verify the nature of their sediments and determine the composition of their associated infaunal and epifaunal communities.

The **starting point** is a desk study to find out what data are already available, and what additional data need to be collected by dedicated surveys. Suitable data sources will include public and private research bodies (i.e. government departments & agencies, NGOs, academia, industry) and other 'stake-holders' contacted during the consultation process.



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Is there sufficient data to produce a draft physical map?

The requirement is for an acoustic map that can be confidently delineated into polygons in order to direct sampling for the ground-truth survey. Assess both the amount and the quality of existing acoustic data. If they are insufficient, further acoustic surveys will be required.

It is important to appreciate the significance of this step in the production of a seabed habitat map, as the quality of the final map will be determined by the quality of the individual datasets used to produce the map. A single, poor quality dataset can significantly reduce confidence in the final map. Therefore, wherever existing data are used, it should be accompanied by evidence to indicate it is of acceptable quality. This could take the form of a quality assurance statement, and might include survey meta-data (data source, systems used, circumstances of the survey, methods of post-processing and interpretation etc).



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Undertake acoustic survey (1 of 4)

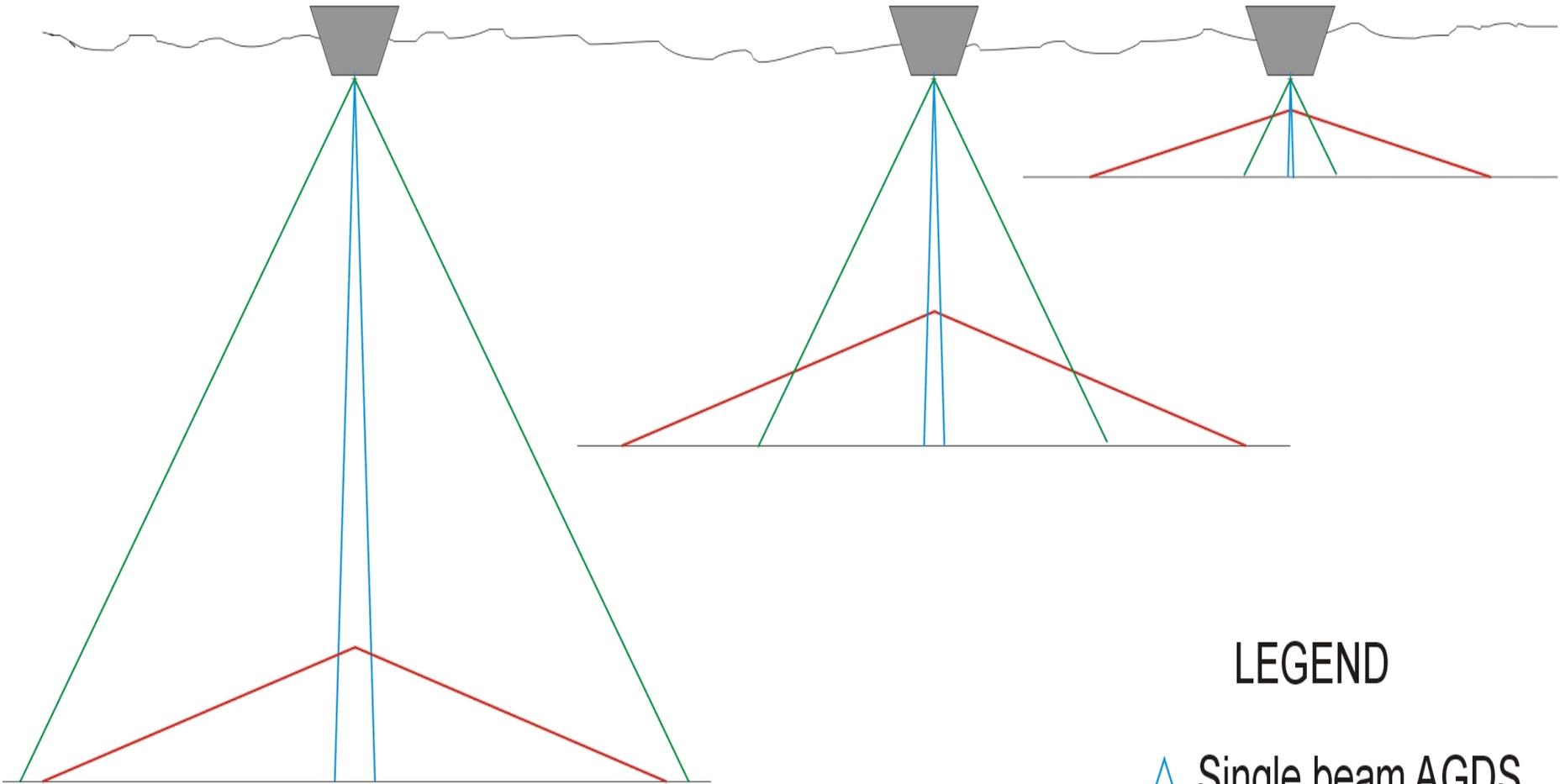
If there is insufficient acoustic data, a new acoustic survey should be undertaken, using individual or multiple techniques appropriate to the task (e.g. sidescan sonar, multibeam bathymetry &/or backscatter, acoustic ground discrimination systems (AGDS)) The choice of technique(s) should take into account:

- *the required resolution*: the minimum mapping unit (MMU) should reflect the size of the features and/or disturbance to be detected
- *the scale of the site*: while all techniques may be appropriate to small scale sites (those that can be surveyed in a single day), swathe techniques (particularly sidescan sonar) may be the preferred primary survey method for large study areas.
- *suitability of the technique for the purpose*: is the technique able to resolve certain characteristics of the sediments that may be important at the study site (e.g. areas of soft mud). A combination of complementary techniques may be desirable (e.g. single beam AGDS with sidescan sonar)
- *time and budget available*: Does the coverage of the technique match the available time & budget? The footprint of hull mounted systems (multibeam, AGDS) changes with water depth, so it may take longer to survey a given area in shallow water than it does in deeper water (example for AGDS with 10 degree beam angle: footprint diameter \approx 2, 9 and 18 m at water depths 10, 50 and 100 metres). The coverage of towed swathe systems (sidescan) is dependant on the altitude of the towed body above the seabed, rather than water depth. [Click here for figure](#)
- *resources available to store and process acoustic data*: swath systems can produce very large datasets (thousands of megabytes). Is there sufficient storage capacity available? Are the post-processing systems sufficiently powerful to be able to handle these large data sets?
- *operational constraints*: is the chosen system suitable for the environment; in areas of high topographic relief (e.g. rocky reefs), hull mounted systems may be preferred to towed systems.

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Variability of acoustic footprint with changing water depth

LEGEND

▲ Single beam AGDS

▲ Multibeam

▲ Sidescan sonar



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Undertake acoustic survey (2)

Once the type of equipment has been chosen, further consideration must be given to the specific configuration of each system.

- Sidescan sonar
 - Frequency of the system (determining resolution)
 - Range during survey
 - Analogue versus digital system
- Multibeam
 - True-multibeam or interferometric system
 - Bathymetry and/or backscatter
 - Calibration requirements
- AGDS
 - System to be used: RoxAnn™, QTC™, EchoPlus™, etc.
 - Operating frequency (dual frequency?)
 - Availability of training sites
 - Single beam or multibeam AGDS
(RoxAnn™ vs RoxAnn™Swath, QTC VIEW™ vs QTC MULTIVIEW™)

Where available, Standard Operation Procedures (SOP's) should be used to acquire and process the acoustic data.



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Undertake acoustic survey (3)

Survey design

Survey design needs to take account of the extent of the area to be surveyed and the acoustic techniques selected for the job. It is always preferable to have full acoustic coverage (100%) of an area in the form of a sidescan or multibeam mosaic, as this is the most accurate basis for delineating seabed facies. While it is practical to expect full coverage for small areas that can easily be surveyed in one day of vessel time (as a guide, ~ 50 sq km), the cost can be prohibitive for much larger areas (say ~500 sq km).

Full swathe coverage is appropriate for small areas that require a great detail and accuracy, but is less critical for larger areas that don't require such high resolution. Broad scale areas can be accurately mapped using 50% coverage (alternate survey lines) and interpolation between adjacent lines. Where specific areas of interest need to be placed in a broad scale context, a combination of 100% and 50% coverage might be considered.

For single beam AGDS, track spacing should take account of along-track variability (the more heterogeneous an area, the closer the track spacing), so the survey design needs to be adaptable. In general, a track spacing of 200 to 500 metres would be expected for surveys intending to use interpolation during analysis (see Foster-Smith et al., 2001).

Survey design must also consider the orientation of survey tracks to ensure linear seabed features are adequately resolved. Features running perpendicular to a sidescan survey track return weaker signals than those running parallel to the track. Several lines running at right angles to the main survey tracks can provide a useful cross-check.

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Undertake acoustic survey (4)

Single versus multiple systems

As different acoustic techniques tend to detect different properties of the seabed, it can be beneficial to use several techniques simultaneously. It is particularly recommended that single beam AGDS is supported by sidescan or multibeam sonar techniques, due to its small spatial coverage and the variability of data quality with weather, tide, suspended load, etc (Davies et al., 2001).

The simultaneous acquisition of sidescan sonar and multibeam bathymetry provides a particularly powerful data set, enabling the sidescan mosaic to be draped over the bathymetric map. This helps in the interpretation of the sidescan mosaic, as tonal changes associated with variation in seabed slope, rather than sediment type, can be identified.

Metadata

As acoustic systems are 'tuned' to suit the particular circumstances of a survey and data sets are commonly passed through a number of post-processing stages to arrive at the final 'image', it is important to record and report what has been done at each stage in the acquisition and processing of the data.

This 'metadata' should provide information on where and when the survey was undertaken, which equipment was used and the settings applied, the environmental conditions, information on the survey design, data cleansing, post processing etc. All these factors need to be taken into consideration when interpreting the acoustic image and serve to underpin confidence in that interpretation.



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Pilot ground-truth sampling

A limited number of sediment samples should be collected during or immediately after the acoustic survey to ground-truth and validate the initial interpretation of the acoustic data (i.e. to match specific acoustic signatures with specific sediment types).

Samples should cover acoustically different areas and are best taken along the survey lines so they relate directly to the acoustic data. A regular sampling grid may be appropriate.



AE1033 Approach for producing a Seabed Habitat Map

Acoustic mosaic

When the survey has been completed, data from the series of survey lines is brought together to produce a mosaic or interpolated image of the entire survey area. For digital data, this is most easily achieved using appropriate computer software, but the same result can be achieved manually with analogue data (e.g. printouts from sidescan sonar).

Nowadays, digital data is easier to handle and store than analogue data. It is also more amenable to being re-used in the future and analysed by a variety of software applications.



AE1033 Approach for producing a Seabed Habitat Map

Draft physical map

An acoustic mosaic or interpolated image is now interpreted to delineate and characterise acoustically distinct regions, producing a draft physical map of the area.

Physical characteristics of each region are assigned on the basis of experience of the interpreter and any ground-truth data that may be available (e.g. from the pilot survey). Where multiple acoustic techniques have been used, a combined interpretation can be made by overlaying the separate images.

For sidescan sonar and multibeam backscatter it is recommended to follow the standard interpretation of bedform and seabed character (facies) developed by the British Geological Survey as illustrated in the 1990 edition of their Sea Bed Sediment sheet for Anglesey (Anglesey Sheet, 53°N - 06°W including part of Dublin 53°N - 08°W, British Geological Survey and Geological Survey of Ireland, 1:250,000 Series, Sea Bed Sediments, 1990).

For interpolated AGDS images, the characterisation of acoustically distinct areas will be made on the basis of supervised or unsupervised classification of the data clusters, supported by reference to training sites and ground-truth samples.

The draft physical map is used to direct and target the physical, chemical and biological sampling to be undertaken in the full ground-truth survey.



AE1033 Approach for producing a Seabed Habitat Map

Briefing meeting:

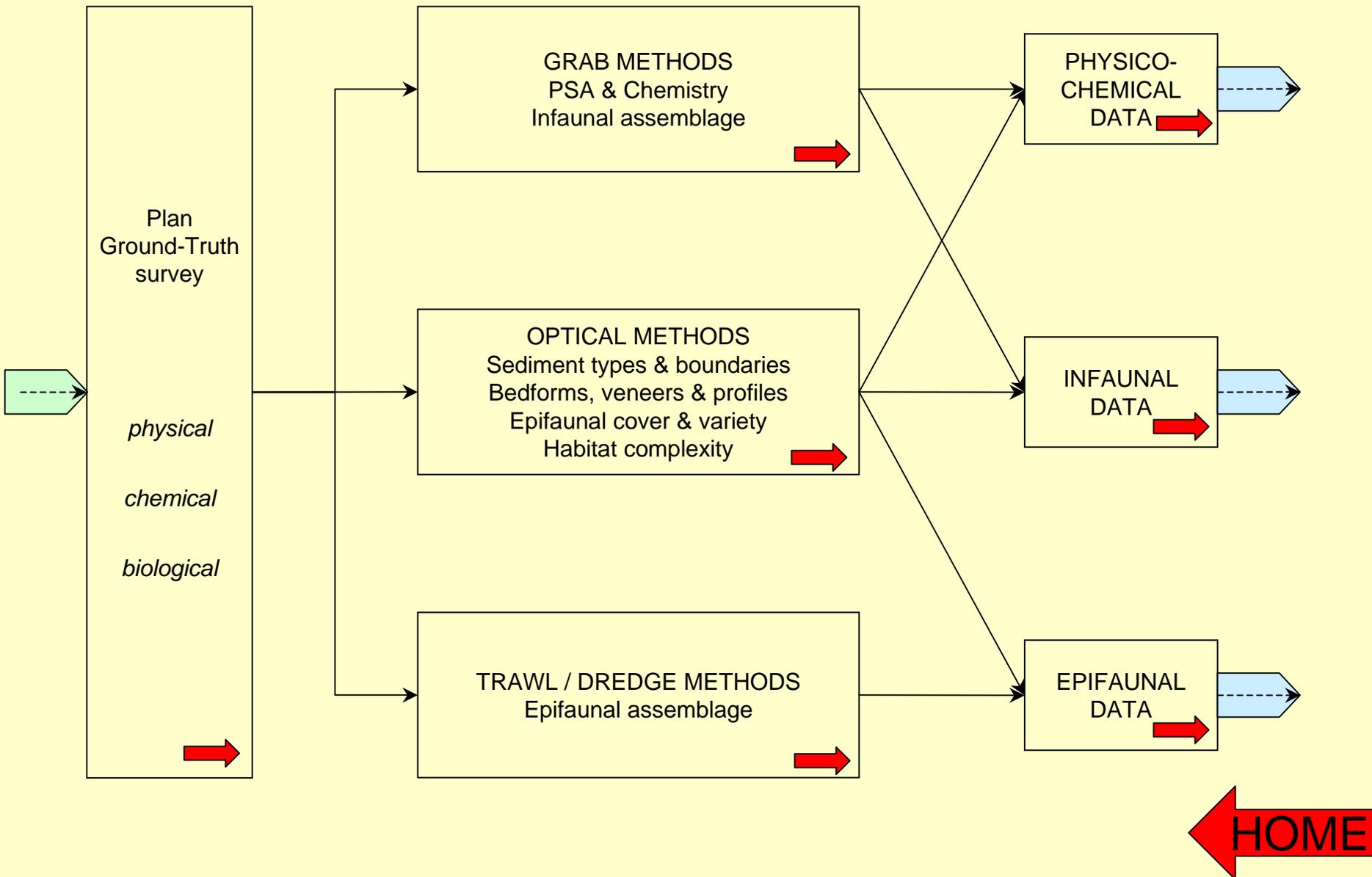
acoustic and ground-truth survey teams

The team that will undertake the ground-truth survey should be fully briefed on the draft physical map so they are aware of its strengths and limitations and can make informed decisions about the design of their survey.

If a new acoustic survey has been commissioned, sufficient time should be allowed to interpret and present the results before commencing the ground-truth survey, otherwise sampling can not be directed at acoustically distinct areas and a far more intensive sampling programme will be required to identify and map seabed habitats.



AE1033 Approach for producing a Seabed Habitat Map



AE1033 Approach for producing a Seabed Habitat Map

Plan the ground-truth survey (1 of 3)

The objective of ground-truth sampling is to determine the physical (and chemical) properties of sediments in the acoustically distinct areas and to characterise their associated biotic communities so that the seabed habitats can be described and mapped. Several aspects need to be considered in planning the survey:

- Sampling design

Is there sufficient confidence in the draft physical map to enable sampling to be directed at individual seabed facies (stratified sampling)? If not, an alternative sampling design should be considered, such as a conventional or radiating systematic grid (see Boyd, 2002 for further guidance on possible survey designs).

A combination of sampling designs may be effective, using random sampling points within well defined facies and a conventional grid over ill defined or spatially extensive facies (e.g. large areas of homogeneous sand). A structured sampling design, such as the 'Fibonacci spiral' tested by CEFAS (this study – Section 4.3.1 & Figure 4.6), is required to systematically assess heterogeneity within facies. If a single facies traverses a number of depth horizons (e.g. 10, 20, 30, 40 metres water depth), each may need to be sampled to account for depth-dependant changes in community structure.



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AE1033 Approach for producing a Seabed Habitat Map

Plan the ground-truth survey (2)

- Sample frequency and replication

For marine locations it is very unlikely that a single sample will contain all the species that are to be found in a particular area, so multiple samples will be required to characterise the infaunal and epifaunal assemblages. The law of diminishing returns means that the incremental benefit of one additional sample decreases as more and more samples are collected, so a balance needs to be struck between sampling frequency and the time (and cost) of processing the samples.

It is usual to set a minimum number of samples, and to increase this number depending on the size of the area in question and the apparent heterogeneity within the area (more samples for larger or more heterogeneous areas).

If sampling is directed within seabed facies, each additional sample can be considered as a replicate. The robustness of any statistical analysis will be related to the number of replicate samples.

- Monitoring stations

If an area is to be monitored over time, maybe to assess changes in the impact of a known perturbation (e.g. dredging or disposal activities), then a series of monitoring stations should be established. Adequate sample replication is required at each station to enable valid statistical assessment of any temporal changes.



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AE1033 Approach for producing a Seabed Habitat Map

Plan the ground-truth survey (3)

- Efficient use of samples and sampling methods

A single sample can often be used for multiple purposes. For instance, a grab sample can provide sediment for PSA and chemical analyses, and biota for macrofaunal analysis. Consideration should be given to the efficient use of samples, without jeopardising sample integrity.

A judicious choice of sampling devices can reduce the number of sampling events required in the ground-truth survey. Different sampling techniques can provide complementary information on one particular aspect of the seabed (e.g. grabs, camera surveys and trawls all provide information about benthic communities).



AE1033 Approach for producing a Seabed Habitat Map

Grabs and cores (1 of 2)

Grabbing and coring devices allow quantitative sampling of particulate sediments for particle size analysis, chemical analyses and determination of macrofaunal assemblages. A range of grabs and corers is available, though each is designed for slightly different application, so careful consideration should be given when selecting the suite of sampling gears. For further details see Boyd (2002), Davies *et al.* (2001) and Eleftheriou and McIntyre (2005).

Mud sediments are typically sampled with corers (e.g. Box core, Craib core and various multi-coring devices). Sands and gravel sediments are sampled with grabs (e.g. Day, Hamon, Van Veen and Shipek grabs). Not all devices provide multi-purpose samples (e.g. Shipek grabs are not appropriate for providing samples of benthic macrofauna).

Suitable criteria should be set for accepting or rejecting samples (e.g. minimum penetration for cores, minimum volumes for grabs).

Sample processing should follow recognised standard procedures (see guidelines given by Boyd, 2002 and Davies *et al.*, 2001). Care should be taken to ensure procedures are compatible between different sampling devices; macrobenthic samples are commonly processed by sieving, but beware that different SOPs recommend different minimum mesh sizes for sieves.

If one SOP recommends a 0.5 mm sieve and another a 1.0 mm sieve, then the sieves should be used in tiers and the 1 mm and 0.5 mm sample fractions processed separately so that data can be compared on an equitable basis.

For particle size analysis it is recommended to use half-phi size intervals to determine the frequency distribution of grain size; the proportion of gravel, sand and silt/clay can always be derived from the raw data if required.



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AE1033 Approach for producing a Seabed Habitat Map

Grabs and cores (2)

Accurate and detailed **metadata** records should be kept for all sampling events, giving information about sample acquisitions (date, time, position, water depth, station code, gear type) and sample processing (sample and sub-sample volumes, sieve size, sample labels, photographic records etc).

Null and invalid samples should be recorded as such so that confusion does not arise later as to whether or not a sample exists for that station. Null records can also be valuable in indicating areas that may have a hard substrate (boulders, reef and rock outcrops).

Suitable storage and transport should be arranged for hazardous chemicals.



AE1033 Approach for producing a Seabed Habitat Map

Optical methods (1 of 3)

Visual observations are a highly effective method of ground-truthing acoustic surveys, providing information on sediment type and bedforms, the distinctness of boundaries between seabed facies, heterogeneity within facies and the existence of sediment veneers.

Direct observations of the physical complexity of the seabed and associations between biota and sediments (e.g. boulder fields with dense attached epifauna) are extremely valuable in characterising and describing a habitat, as are semi-quantitative assessments of the relative abundance of identifiable organisms that may not be adequately sampled by other techniques (e.g. anemones and sea-pens).

Direct observation becomes increasingly important as sediments become harder and less amenable to physical sampling, and as a non-destructive methodology it has particular value in assessing habitats of conservation importance (e.g. biogenic reefs).

Water turbidity and strong currents are the principal operational constraints that will influence choice of equipment and timing of deployment.

Consideration must also be given to logistical constraints such as the suitability of the support vessel and the requirement for technical back-up.

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AE1033 Approach for producing a Seabed Habitat Map

Optical methods (2)

Choice of equipment is dictated largely by the type of survey required:

- Transect surveys

Towed video sledges are the most common choice for surveys along pre-defined transect lines, though ROVs with sophisticated navigational capabilities may also be used.

As a sledge is towed some distance behind a ship, it is important that its position can be determined accurately so the observations can be properly georeferenced. Traditional methods of estimating the position of any towed device by applying a fixed 'layback' to the ship's position tend not to have the desired accuracy for mapping purposes and it is therefore advisable to use some form of acoustic tracking device, such as a short base-line (SBL) transponder (e.g. Trackpoint II from ORE International or HiPAP (High Precision Acoustic Positioning) from Kongsberg Maritime).

If there is no requirement to cover a pre-defined track, transect observations can be made using drift dives with a drop-camera system, though it can prove difficult to maintain the optimal altitude of the camera above the seabed.

- Spots surveys

Small ROVs are ideal for making 'spot surveys' of a small area (~ 100 m radius) where the purpose is to make an inventory of sediment types and epifauna. They provide greater flexibility than a towed device as they can be piloted to hover and inspect features of interest.



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AE1033 Approach for producing a Seabed Habitat Map

Optical methods (3)

- Point sampling - surface

Photographs of the seabed can be taken with a stills camera attached to a sledge, ROV, grab or drop-camera frame, providing information on sediment type and faunal coverage. If the area photographed can be measured (using a scale object or known quadrat) then quantitative assessments can be made. This type of survey is particularly useful on complex hard sediments like boulder areas or reefs that can not be sampled by towed gears or grabs.

- Point sampling - subsurface

Sub-surface profiles of the upper layers of sediments can be photographed using a Sediment Profile Imagery (SPI) system, which is essentially an inverted periscope giving a maximum penetration of around 25 cm in soft mud. Over 20 physical, chemical and biological parameters can be quantified from the photographs and used to characterise the benthic habitat and assess its quality (see Solan *et al.*, 2003 for a review).

Adequate **metadata** records will again be an essential part of surveys using optical methods.

Optical records are very data rich but have limited spatial coverage, and it is important that their analysis should not become over-involved leading to highly detailed descriptions of insignificantly small areas that can not be adequately represented on the final habitat map.

Several documents provide guidelines on the application of optical techniques are listed in the bibliography (especially Davies *et al.*, 2001).



AE1033 Approach for producing a Seabed Habitat Map

Trawl and dredge methods (1 of 2)

Trawl and dredge methods are semi-quantitative techniques for sampling epifaunal assemblages.

Different gear designs are effective on different substrates, becoming progressively heavier and more robust as substrates become coarser. Inappropriate choice of gear can lead to significant damage to both samples and gear, and in extreme cases can present an unacceptable safety hazard, so great care must be taken when selecting and operating trawls and dredges.

Jennings *et al.* (1999) provide details of a design for a 2-metre beam trawl that we have found suitable on all except very coarse substrates. The Agassiz trawl is another design in common use for scientific sampling of epibenthic macrofauna.

If demersal fish are to be considered in the habitat description, they should be sampled separately to the epifauna, using commercial sized beam or otter trawls.

Trawling and dredging are destructive sampling methods and should not be undertaken in areas of high conservational interest (e.g. biogenic reefs, sea-grass beds etc).

In some areas, the use of trawls and dredges is strictly regulated by law, and operators should make themselves fully aware of any such national or local restrictions through appropriate consultation with regulatory bodies. Local sea-fisheries officers are often well placed to provide advice.



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AE1033 Approach for producing a Seabed Habitat Map

Trawl and dredge methods (2)

Several matters need to be considered relating to the acquisition and processing of trawl and dredge samples, including:

1. selecting tow distances with a view to providing small but adequate samples.
2. adjusting tow speeds to ensure the trawl is fishing effectively and maintaining contact with the seabed (can this be monitored by depth-loggers or acoustic tracking devices?).
3. determining the start and end positions of tows (acoustic tracking devices).
4. establishing criteria for accepting/rejecting samples. Density of epifauna can vary considerably between substrates, so some flexibility may be required in applying strict criteria for minimum sample volumes (e.g. 5 litres on gravels, 2 litres on shallow sands) or adjusting tow distances.
5. ensuring trawl meshes are thoroughly cleared of epifaunal organisms between sampling events to minimise cross contamination of samples.
5. adequate replication of samples to even out bias caused by chance events (e.g. passing through discrete aggregations of ophiuroids)
6. sub-sampling protocols for very large samples. The *entire* catch should be picked through to ensure rare species are accounted for. The abundance of highly numerous species can be estimated by thoroughly sorting known aliquots of the catch. Alternatively, sub-sampling of abundant species is applied after the entire catch has been thoroughly sorted.

As for other sampling methods, adequate and accurate **metadata** records should be kept (including date, time, positions, tow speed, water depth, station code, gear type, sample and sub-sample volumes, sieve size, sample labels, photographic records etc).

The use of a short baseline transponder attached to the trawl or dredge will allow more accurate geo-referencing than calculating position by 'layback' methods.



AE1033 Approach for producing a Seabed Habitat Map

Data

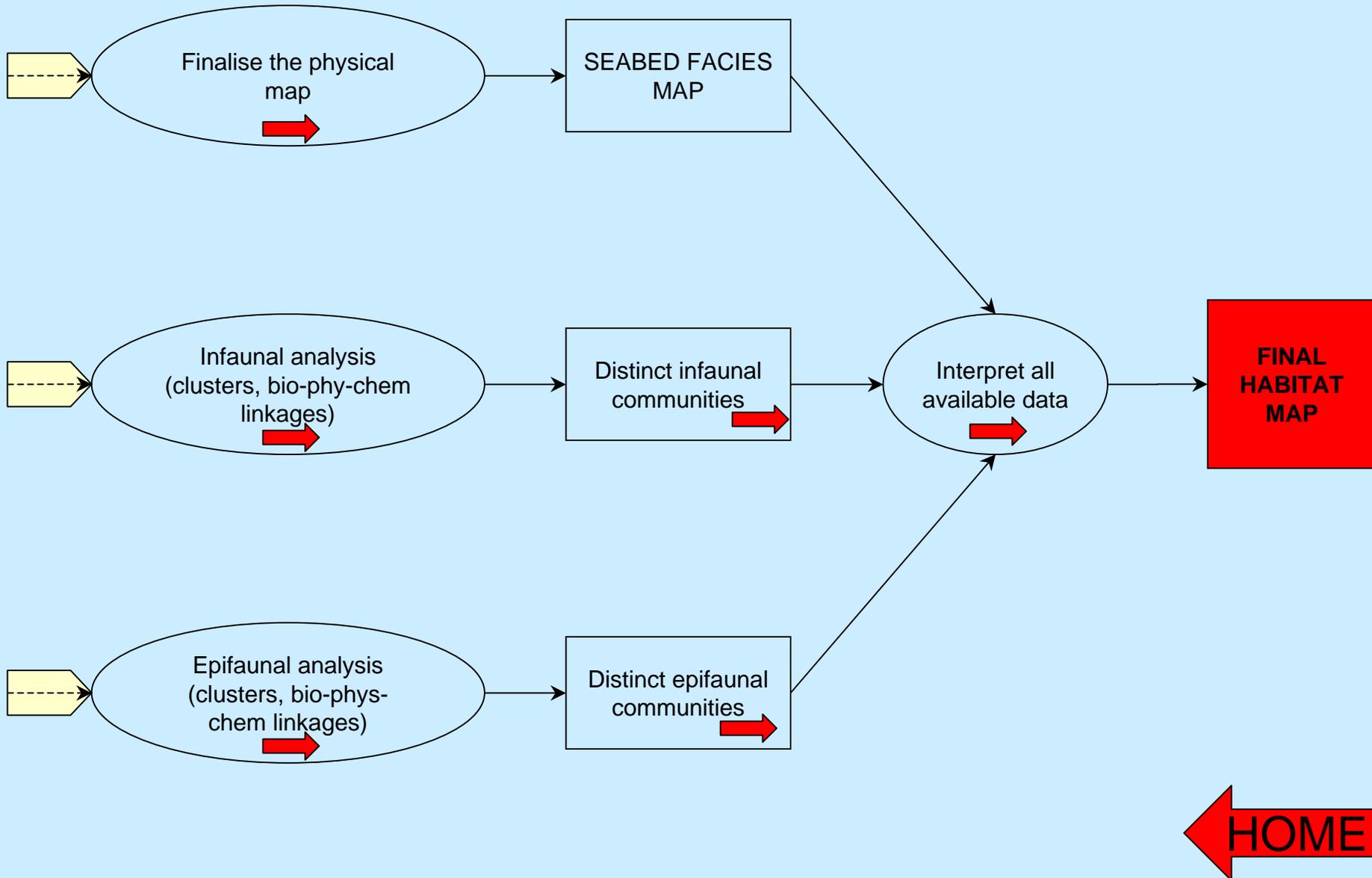
All data must pass through adequate Quality Assurance / Quality Control procedures.

The data resulting from sample analysis should be linked to the associated metadata.

Full data records should be supplied with the final report.



AE1033 Approach for producing a Seabed Habitat Map



AE1033 Approach for producing a Seabed Habitat Map

Finalise the physical map

The draft physical map is updated to a final version, incorporating any additional data or information gained from the ground-truth survey (grab, core and optical sampling).

This may entail making adjustments to the regions delineated in the draft physical map, and providing more complete and detailed descriptions of the seabed facies and their physical properties (e.g. assigning sediment classes according to the Folk or Wentworth scales).

The review of the draft physical map will result in a quality assured seabed facies map.



AE1033 Approach for producing a Seabed Habitat Map

Infaunal and epifaunal analysis

Analysis of the infaunal and epifaunal data sets should be undertaken separately as they represent different elements of the benthic community and were sampled by different methods.

An initial exploration of the data using univariate indices is useful for gaining a general appreciation of the gross community patterns, such as low vs high diversity and/or abundance which might discriminate sites (Warwick, 1993).

Following this, non-parametric multivariate analyses are used to determine distinct species assemblages, identify the taxa that typify or discriminate between those assemblages, and determine environmental variables that best explain biotic distributions (Clarke, 1993).

This approach to community analysis is detailed by Clarke & Warwick (1994), with appropriate analytical routines are provided in the statistical software package PRIMER (Clarke & Gorley, 2001).

Results should be reported along with summary description of methodology (i.e. whether biomass or abundance data was used, the data transformations applied etc.) and summary output of the statistical tests (SIMPER, ANOSIM, BIO-ENV, RELATE etc).

At the end of the analysis, the infaunal and epifaunal species that typify and/or discriminate the different seabed facies will have been determined and the results can now be applied to the task of defining seabed habitats.



AE1033 Approach for producing a Seabed Habitat Map

Final interpretation (1 of 2)

In the final stage, all the available data is brought together and interpreted to determine the distribution of seabed habitats; that is those areas having distinct physical properties and associated biotic communities.

The description (and definition) of the habitat takes account of the relative importance of each of the component elements, with precedence being given to those elements that have greatest influence in structuring the habitat, as illustrated in the following examples:

- shallow water fine sand communities dominated by small bivalves (*Abra* spp) and tube dwelling worms (*Lagis koreni*), typically supporting juvenile flatfish species (*Solea*, *Buglossidium*)
- tide-swept circalittoral gravel with dense attached epifauna (hydriods & bryozoans, typically *Flustra* sp.) and diverse communities of errant epifauna typified by spider crabs (Majidae) and nut crabs (*Ebalia* spp.). Sandy or muddy sand patches with tube-dwelling worms and burrowing anemonies.
- biogenically re-worked soft anoxic mud in deep still waters (typically sea lochs) dominated by burrowing crustacea (*Nephrops*, *Upogebia*, *Callionassa*) with dense patches of surface dwelling suspension feeding gastropods (*Aporrhais pespelicani* & *Turritella communis*). Sea pens (Pennatulidae & Virgulariidae) are rare but indicative species.
- Sabellaria reef in coarse mixed sediment (usually 30-50 m deep). Epifauna characterised by pycnogonids, hermit crabs and amphipods; infauna by polychaetes and bivalves (e.g. *Abra alba* & *Nucula nitidosa*)



Continue



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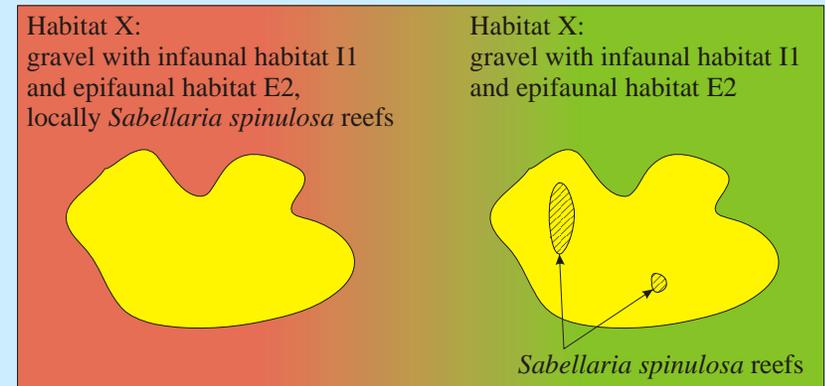
AE1033 Approach for producing a Seabed Habitat Map

Final interpretation (2)

It is important to note that it may be justified to include two or more similar seabed facies in a single habitat, if their sediment structures do not differ to the extent that they support different biotic communities (e.g. short-wavelength megaripple fields and lunate sand wave fields).

Conversely, a single facies covering a large spatial area may be separated into different habitats if variable environmental factors (like depth or current speed) cause significantly dissimilar communities to exist on the same substrate type.

In some cases, areas of high conservational interest will need to be delineated separately on the final seabed habitat map. An example would be a well defined biogenic reef structure occurring in part of a larger seabed facies. If the mapping scale will allow, the feature should be outlined as a polygon, as in the example below. If the spatial area of the feature is too small to represent by a polygon, it's location should be marked by a symbol, and that symbol included in the key to the map.



AE1033 Approach for producing a Seabed Habitat Map

Boyd, S.E. (compiler), 2002. Guidelines for the conduct of benthic studies at aggregates dredging sites. U.K. Department for Transport, Local Government and the Regions (DTLR), London and CEFAS, Lowestoft. 117pp.

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Clarke, K.R. and Warwick, R.M., 1994. *Change in marine communities: an approach to statistical analysis and interpretation*. Plymouth: Plymouth Marine laboratory, 144pp.

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C. & Vincent, M., 2001. *Marine Monitoring Handbook – March 2001*. Joint Nature Conservation Committee (JNCC), Peterborough. 405pp.

Foster-Smith, R.L., Brown, C.J., Meadows, W.J. & Rees, I., 2001. Procedural Guideline 1-3: Seabed mapping using acoustic ground discrimination interpreted with ground truthing. In, *Marine Monitoring Handbook* (ed. Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C. & Vincent, M.) Peterborough, U.K.: Joint Nature Conservation Committee.

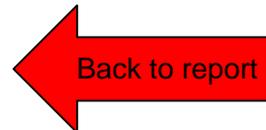
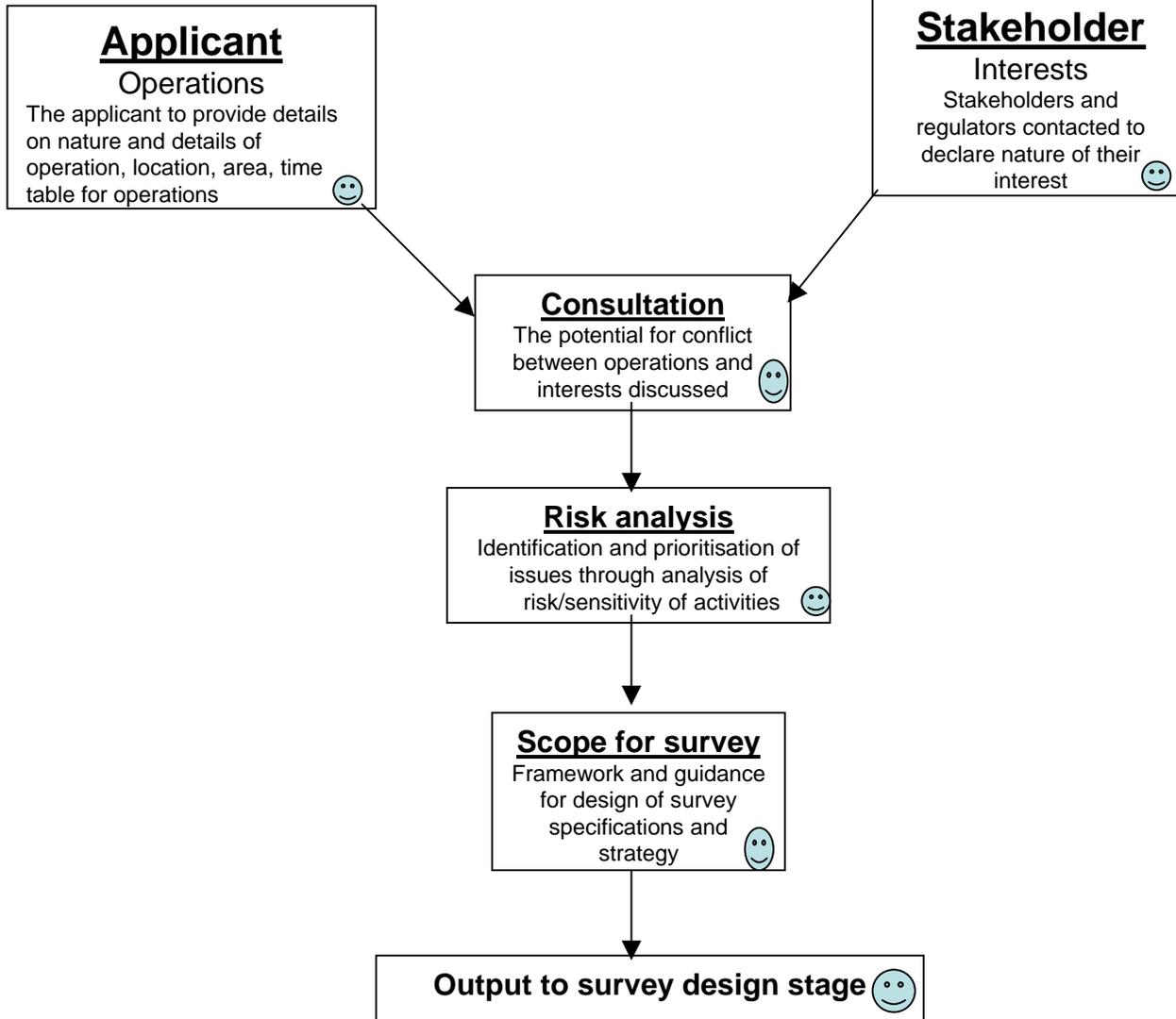
Jennings, S., Lancaster, J., Woolmer, A. & Cotter, J, 1999. Distribution, diversity and abundance of epibenthic fauna in the North Sea. *Journal of the Marine Biological Association of the United Kingdom* 79: 385 - 396.

Solan, M., Germano, J.D., Rhoads, D.C., Smith, C., Michaud, E., Parry, D., Wenzhoefer, F., Kennedy, B., Henriques, C., Battle, E., Carey, D., Iocco, L., Valente, R., Watson, J., Rosenberg, R., 2003. Towards a greater understanding of pattern, scale and process in marine benthic systems: a picture is worth a thousand worms. *Journal of Experimental Marine Biology and Ecology*: 285-286, 313-338.

Warwick, R.M., 1993. Environmental impact studies on marine communities: pragmatic considerations. *Australian Journal of Ecology*, 18: 63-80.

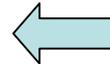


Purpose: to identify, describe and prioritise the potential areas of conflict between applicant and stakeholders to be addressed by benthic survey 😊



The applicant will be asked to survey to detect and map specific features of interest to stakeholders and/or undertake more general surveys of habitats and biota. The effort expended on survey needs to be weighed against the significance of these features, their sensitivity to activities and likelihood of occurrence as well as the required accuracy and precision of detection and discrimination in measurement. Exhaustive, comprehensive and fine detailed survey comes at a price and survey effort needs to be carefully matched to requirements. The process of consultation should establish the effort required so that the applicant can select the most appropriate tools and design a satisfactory survey.

There are a number of key factors that have implications for survey intensity and effort. The output of the flow chart will be answers to the questions posed.



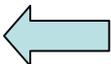
Consultation

The guidance given by regulatory authorities may be prescriptive and well defined, but more usually is worded such that the applicant should show they have considered potential conflicts with other interests and stakeholders and can justify the survey design they plan to implement. The dialogue between applicant and stakeholders/regulators is facilitated through a systematic appraisal of the nature of planned operations and their possible impact on other interests, taking due regard as to the risk, sensitivity and significance of those interest to activities.



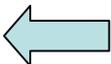
Survey issues to resolve

| |
|--|
| Features |
| Are features limited to one type or are there a number of types of features present that require the use of different techniques? |
| Importance of features |
| What is the assessment of the importance to detect and map feature? |
| Level of detail |
| Is it sufficient to map broad biotope/habitat classes or will much finer levels of discrimination be required? |
| Measurement accuracy |
| Is it sufficient to recognise feature classes or will quantitative measurements be required? |
| Extent |
| What is the size of the area? |
| Coverage |
| Is 100% coverage required, or will incomplete coverage suffice? Can a nested survey strategy of high coverage areas within low coverage areas address survey aims? |
| Spatial resolution |
| What spatial detail (pixel size) is required? |
| Spatial precision |
| How precise do locations of objects and boundaries between features need to be? |
| Repeatability and confidence |
| Will the need to monitor change require a greater emphasis on accuracy, or can a robust survey design address requirements? |



Information required of the applicant

| |
|--|
| What is (are) the nature of the operation(s)? |
| Trenching, extraction, construction, disposal |
| Will the operations directly disturb the benthic habitats? Are they likely to affect the deeper sediment, shallow superficial sediments, water column? |
| Abstraction, smothering or alteration of sediment or habitat, adding new structures |
| Will there be indirect or far-field impacts on the seafloor. |
| Creation of sediment plumes and siltation, diffuse pollution, altering hydrodynamic regime |
| What is the extent of each impact? |
| Near and/or far-field. |
| What is the duration of each operation? |
| Short duration, long term or permanent |
| What is the intensity of each impact? |
| Low to high level |
| Are there multiple impacts (apart from applicants)? Will there be synergistic effects? |
| Fishing activities, oil/gas, aggregate extraction etc |



Stakeholders and areas of interest

Nature conservation (EN, SNH, CCW, JNCC, Cefas...)

Fine scale (Rare species, conspicuous/inconspicuous). Broadscale (habitats and biotopes).

Heritage (EH, National Trust...)

Fine scale, specific features (wrecks and structures); broad scale general features, (sediment horizons, peat, fossil forest)

Sedimentologists / physical oceanographers (BGS, JNCC, Hydrographic Office, Cefas..)

Potential changes to coastal processes, erosion, beach draw-down etc. Navigation hazards during operations.

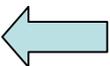
Fisheries (Cefas, Industry representatives.....)

Spawning and nursery grounds, important fishing grounds

Fishing communities (Sea Fisheries Committees, local interest groups / owners / co-operatives..)

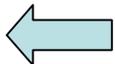
Locally important fishing grounds, season

Stakeholders need to specify the nature of the features they are interested in 😊



Information required of stakeholders

| |
|---|
| Are there potential fine scale, specific features or issues of interest? |
| Single species, distinct biological communities, specific sediments (peat, clay), structures from seabed (reefs, wrecks), buried/sub-bottom features. Local fisheries. Will an adequate search be made? How much certainty does there need to be in detection? |
| Are the features/issues of more general interest? |
| Baseline mapping of a comprehensive range of biotopes, sediments, bedform features. Important regional fisheries. |
| Are these features known to occur with certainty, likely to occur but not certain or only a possibility? |
| Known or suspected to occur in vicinity, unknown but favourable conditions, previous records from area, previous detailed survey. |
| How extensive, conspicuous are these features? |
| Extensive, common or very restricted/patchy, rare. Very conspicuous, easily detected or cryptic, small and hard to detect. |
| What level of discrimination between feature classes is required? |
| Broad divisions (upper levels of hierarchy), fine divisions (lower levels of hierarchy) |
| How important is accurate location of features and boundaries? |
| Features/boundaries mapped with high precision and accuracy, only approximate locations required |
| What measurements are required? Estimation of extent/abundance? How important is accurate measurement? |
| Presence/absence of feature classes, abundance scale, counts, densities, weights |
| Is it likely that change will need to be monitored? What levels of change are considered to be significant? What certainty is required of change detection? |
| Coarse changes sufficient or fine changes need to be monitored. |
| What is the sensitivity of the feature to the intended operation/impact? |
| From very sensitive to very robust. |



A realistic assessment of the importance of detection and accurate mapping of a feature must combine significance calculations with likelihood of the feature occurring. [Click button to go to interactive table](#)

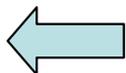


| | | |
|----------------------------------|---|----------|
| Feature importance | Local = 1 Regional = 2 National = 3 | 2 |
| Feature sensitivity | Robust = 1 Moderate = 2 Fragile = 3 | 2 |
| Threat | Minor = 1 Moderate = 2 Major = 3 | 3 |
| Significance of impact | | |
| | Minor | Medium |
| | Severe | |
| | | |
| Likelihood of occurring | Low = 1 Moderate = 2 High = 3 | 1 |
| Importance for detection/mapping | | |
| | Low | Moderate |
| | High | |
| | | |

Enter numbers on a scale of 1-3

The extent of the bar indicates significance

And importance



Survey parameter Table

| | | | |
|------------------------------|---------|-------------|---------|
| Sampling/observation | Fine → | -----I----- | ← Broad |
| | | | |
| Measurement accuracy | High → | -----I--- | ← Low |
| | | | |
| Extent | Small → | -----I----- | ← Large |
| | | | |
| Coverage | Low → | -----I----- | ← High |
| | | | |
| Spatial resolution | Low → | -----I----- | ← High |
| | | | |
| Spatial Precision | Low → | -----I----- | ← High |
| | | | |
| Repeatability and confidence | Low → | -----I--- | ← High |
| | | | |

