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MAPPING OF GRAVEL BIOTOPES AND AN EXAMINATION OF THE FACTORS CONTROLLING THE DISTRIBUTION, TYPE AND DIVERSITY OF THEIR BIOLOGICAL COMMUNITIES

C.J. Brown, A.J. Hewer, W.J. Meadows, D.S. Limpenny, K.M. Cooper,
H.L. Rees and C.M.G. Vivian

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1. EXECUTIVE SUMMARY

Much of the seabed surface around the England and Wales coastline is comprised of coarse material. Where these deposits are present in sufficient quantity, are of the right consistency, and are accessible to commercial dredgers, they may be exploited as a source of aggregate for the construction industry, to supplement land-based sources, or as a source of material for beach nourishment. It is likely that the demand for marine-won aggregate will further increase in the near future (especially to meet coastal defence needs), and construction companies are already prospecting on a much wider geographical scale for new sources of material. In timely anticipation of this increased demand for marine aggregate, this project was established to evaluate the utility of seabed mapping techniques for surveying habitats and also to evaluate the fundamental role of superficial coarse deposits in the coastal marine ecosystem.

The production of high-resolution biotope maps of the seabed will assist in future site-specific environmental assessments of potential aggregate dredging areas, and would be of value during any subsequent environmental monitoring activities. The issue of extraction licences by the Crown Estate is subject to a favourable Government View, with the Department for Environment, Food and Rural Affairs (DEFRA) being an influential contributor, therefore the development and evaluation of the utility of mapping techniques in such applications is appropriate to ensure that the best scientific advice is available to underpin the fisheries and marine environment concerns that are DEFRA's policy remit. This report details work conducted by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) over the course of a three year research programme. The main objectives were to assess the utility of seabed mapping techniques for surveying habitats, and to investigate the factors controlling the distribution, type and diversity of their associated biological communities.

A range of acoustic techniques were evaluated in the first year of the project, and sidescan sonar was selected as the main acoustic mapping system for use in subsequent surveys. In addition, two acoustic ground discrimination systems (AGDS), *RoxAnn* and *QTC-View*, were also chosen for use alongside the sidescan sonar system. Four sites were selected in the eastern English Channel to evaluate the mapping techniques. The main site for study was offshore from Shoreham (28 km x 12 km in area). The site was selected as it offered a range of sediment types which were relatively homogeneous in their distribution, and would therefore offer an environment in which the relationship between acoustic output, physical habitat type and biological assemblage structure could be investigated. The other three sites, at Hastings, the eastern Isle of Wight and Dungeness (all 12km x 4km in area) were chosen to offer a wider range of substrata of varying degrees of spatial complexity (sediment patchiness) over which the techniques developed at Shoreham could be tested.

Each site was intensively surveyed using a digital sidescan sonar system. A mosaic of the sidescan sonar data was produced to provide 100% spatial coverage maps at each location. This was then divided into acoustically distinct regions which, following ground-truthing using underwater video, were found to relate to discrete habitat types. Each region was then sampled using a suite of destructive and non-destructive techniques. The main sampling tools were a 0.1m^2 Hamon grab fitted with a video camera and light (all sites) and a heavy duty 2 m beam trawl (Shoreham and Hastings) which were used to characterise the benthic communities and sediment characteristics within each region. Relationships between acoustic regions, physical habitat characteristics and assemblages were then investigated using a range of univariate and multivariate techniques. Results from these analyses were used to identify discrete biotopes (physical habitats and associated communities) at each site, and to establish which factors were responsible for the distribution, type and diversity of communities within each region.

In most acoustic regions, particularly where there was a high degree of sediment homogeneity within discrete habitat boundaries, statistically distinct assemblages were identified. The situation was less clear where the seabed consisted of a complex arrangement of sediment types, such as to the east of the Isle of Wight. Nonetheless, discrete assemblages were still detected, although it was more difficult to ascertain natural boundaries between neighbouring habitats/assemblages. Sediment properties (granulometry) and seabed morphology appeared to be the main factors controlling the distribution of communities at each site. Hydrographic factors (tidal velocities, suspended loads, water temperatures, etc.) were also considered but, over the relatively small geographical scale of the individual sites, these factors appeared to have little influence on within-site variability in assemblage structure.

At each site, data derived from the analysis of the acoustic, biological, sedimentological and visual data sets were used to identify and define biotopes. Discrete biotopes often existed within the boundaries of acoustically distinct regions. However, this was not always the case and the physical habitat and biological assemblages were sometimes similar over a number of acoustic regions, and were therefore classed as one type of biotope in these situations.

The AGDS data were analysed in collaboration with the SeaMap Group, University of Newcastle upon Tyne. A number of image analysis methods were used to process the data collected at the site off Hastings. Habitat maps from these analyses were produced, and results were compared to the habitat maps derived from the sidescan sonar data. There was general agreement between the two types of system, although this was very dependent on the post-processing methods applied to the AGDS data sets. The swathe coverage of the sidescan sonar system proved, unsurprisingly, more accurate at identifying habitats than the single beam AGDS systems. A detailed account of this work is presented in a separate report (Foster-Smith *et al*., 2001).

2. INTRODUCTION

Efforts to describe and interpret the distribution of benthic communities over large geographical areas date back to the classic studies of Petersen and co-workers in Danish waters (e.g. Petersen, 1918). In the Eastern English Channel the fauna of large sectors of seabed are well documented by Holme (1961, 1966) and, on the French side, by Cabioch and co-workers (Cabioch, 1968). Many of these earlier mapping studies, along with most other benthic surveys, have traditionally used grabs and/or dredges to describe the invertebrate fauna of the sea floor. Such techniques provide single, geographically separated points of data across the area of seabed under investigation. In order to produce spatial distribution maps of sediments and assemblages from such sources of data it is necessary to interpolate between these data points. However, interpolation has the potential to overlook discrete seabed features and/or biological assemblages, which may lie between sampling stations. Recent developments in acoustic technologies may provide a solution to this problem, particularly when attempting to describe the spatial distribution of habitats/assemblages over relatively small areas, and are offering new insights and opportunities to explore and map seabed habitats.

There are many sonar devices currently on the market which can be used to map various seabed properties (e.g. sediment type, topography, surface texture), and these acoustic systems can generally be divided into the following categories: (a) broad-acoustic beam (swathe) systems such as sidescan sonar; (b) single beam acoustic ground discrimination systems (AGDS) such as RoxAnn and QTC-View; (c) multiple beam swathe bathymetric systems; (d) multiple beam (interferometric) sidescan sonar systems (Kenny *et al*., 2000). The development of many of these systems stems from rapid improvements in acoustic electronics in the 1970s and 1980s, which led to major enhancements in data quality. Whilst the use of such systems was originally focused on geological studies of the seabed, it was at this stage that the potential use of acoustic techniques for studying benthic ecosystems was recognised (e.g. Warwick and Davies, 1977; Holme and Wilson, 1985; Davoult and Clabaut, 1988).

Recent improvements in acoustic systems in the 1990s, in particular with swathe and multibeam systems as a result of increased digital processing power offered by modern computers, have led to very high resolution and affordable systems entering the market place. This development is reflected in the number of recent investigations which have used acoustic techniques as a means to infer the biological status of the seabed (e.g. Magorrian *et al*. (1995), Greenstreet *et al*. (1997), Davies *et al*. (1997) using RoxAnn systems; Prager *et al*. (1995), Anderson *et al*. (1998) using QTC systems; Service (1998), Service and Magorrian (1997), Wildish and Fader (1998), Phillips *et al*. (1990), Schwinghamer *et al*. (1996, 1998), Tuck *et al*. (1998) using sidescan sonar; Kostylev *et al*. (2001) using multibeam bathymetry.). Although the outcomes of these studies are, in general, encouraging, the approaches have not yet reached the stage of uncritical, routine application. However, these developments are offering the opportunity for researchers to move away from a process of inference around a matrix of spot samples into the realm of spatially continuous mapping using spot sampling for ground-truthing. For this reason the use of acoustic techniques to assist in mapping the geographical distribution of biotopes (e.g. physical habitats and associated biological communities) can be seen to have many potential advantages, including the prospect of 100% coverage of the seabed as resources allow or priorities dictate.

This report details the development of techniques for mapping seabed habitats/communities using sidescan sonar, used in conjunction with biological sampling and underwater video surveys, on coarse substrata. This work was conducted as part of the DEFRA funded research project AE0908. Results of the work are presented and the implications of the findings for improved evaluation of potential dredging areas and subsequent monitoring of environmental impacts are discussed. In addition to the work presented in this report, further studies using other acoustic techniques (e.g. RoxAnn/QTC-View) were also carried out under project AE0908, the result from which are presented else where (Foster-Smith *et al*., 2001).

3. OBJECTIVES

The main focus of the project was the development of an integrated approach to seabed mapping using a combination of physical, geophysical and visual techniques, and this work is detailed within this report. This was achieved through a series of field surveys and trials, conducted over a period of three years, designed to test the utility of various acoustic techniques for mapping seabed habitats (comprising mainly coarse sediments), and evaluate their usefulness in mapping the spatial extent of seabed communities. Specific objectives were:

- To characterise the seabed in an area of the eastern English Channel using various physical and geophysical techniques.

- To determine the causes of biological variation and of observed patchiness and to devise appropriate sampling strategies to allow for this variation. This work aimed to take particular account of dynamic aspects of the environment within which the benthic communities had developed.

- To establish the utility of seabed mapping techniques for surveying habitats.

- To evaluate the susceptibility of gravel biotope benthic communities to anthropogenic disturbances in contrasting areas, particularly by dredging. This aimed to involve the testing of established and novel methods for describing and quantifying biological status and sensitivity.

- To report on the significance of the findings for the management of aggregate extraction activities.

Other work carried out under AE0908 is presented in the Final Report to DEFRA (Anon, 2001), and in other project reports and publications (Brown *et al*., 2000, 2001; Foster-Smith *et al*., 2001)

4. DEVELOPMENT AND EVALUATION OF SURVEY TECHNIQUES

4.1 Evaluation and selection of acoustic and biological sampling techniques/gear

The first year of the research programme involved evaluation and selection of suitable acoustic survey systems (side-scan sonar, swathe bathymetry). A trial was conducted at sea in May 1998, to compare the images produced from a range of these systems supplied by a number of manufacturers. A digital sidescan system was judged to be the most appropriate sonar for use in biotope mapping studies, as it provided high-resolution, textural information about the seabed with the potential to distinguish areas of different sediment types and their associated benthic communities. The use of sidescan sonar was also a more cost-effective option than the swathe bathymetry systems, which allowed for large-scale surveys to be undertaken.

It was also decided to evaluate two acoustic ground discrimination systems (AGDS) which were available, easy to run and relatively cheap compared to other acoustic systems. This work is presented in a separate report (Foster-Smith *et al*. 2001).

4.2 Selection of survey sites

A pilot survey, using an EG&G analogue sidescan sonar system ground-truthed using a 0.1m^2 Hamon grab, was carried out in August 1998 at a site to the east of the Isle of Wight (Figure 1). Problems in distinguishing discrete habitats and benthic assemblages were encountered due to the high degree of sediment heterogeneity within the area, and consequently it was not possible to establish any strong links between the acoustic and biological data sets. In order to widen the scope of the study, and further develop the biotope mapping methods that were applied in Year 1, three locations exhibiting a wider range of physical and biological gradients were selected for study in Year 2. An area of seabed in the English Channel off Shoreham (12 km x 28 km), with strong biological and physical gradients, displaying a high level of sediment homogeneity within discrete habitat boundaries, was selected as the main site for study. The other two areas (each 12 km x 4 km), one offshore from Hastings and the other to the east of Dungeness, were selected on the grounds that both contained similar sediment types to those encountered off Shoreham, but were widely separated geographically (with the potential to force biological differences between areas) and, in the case of the site at Dungeness, displayed greater small-scale complexity in the arrangement of their sediment types (Figure 1). The survey approach adopted in Year 2 was an improvement on that taken in Year 1 at the pilot survey site and, following analysis of these data sets, it was deemed necessary to revisit the Isle of Wight study area in Year 3 and test these techniques over a very complex area of seabed. The 4 areas shown in Figure 1 represent the sites over which the techniques described in Sections 4.3 and 4.4 were applied.

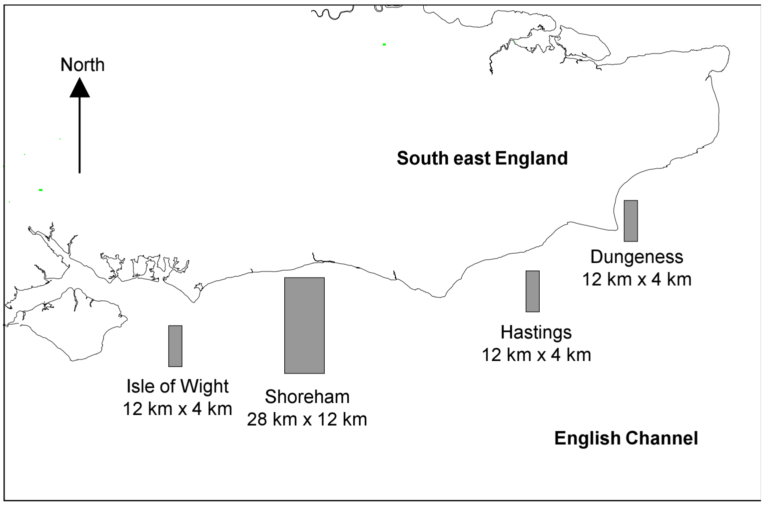


Figure 1. Location of the four survey sites, eastern English Channel

4.3 Methods - Acoustic surveys

4.3.1 Sidescan sonar survey

Intensive surveys of the Shoreham, Hastings and Dungeness sites were carried out in 1999 using a Datasonics SIS1500 digital chirps sidescan sonar with a Triton Isis logging system. Delphmap post-processing software was used to mosaic the imagery and classify texturally different regions. 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 ensonify 100% of the survey area. Vessel position was provided by the Veripos Differential Global Positioning system (DGPS) and towed sensor position calculated by vessel heading, towcable layback and towfish depth, all of which were logged in real time by the Isis system. A drop-camera frame fitted with an under-water video camera and light was deployed at a number of stations across the survey areas in order to provide visual ground-truth data to aid interpretation of the sidescan sonar data set.

The Isle of Wight area was surveyed in a similar manner during the pilot survey conducted in August 1998 using an EG&G DF1000 analogue sidescan sonar system. A repeat survey over a reduced number of survey lines was carried out in July/August 2000 at this site, using the higher resolution Datasonics digital chirps sidescan sonar system, in order to establish the degree of temporal change to the physical seabed habitat so that the area could be re-sampled using the mapping approaches developed in Year 2.

4.3.2 Data interpretation

Seabed features (sand ripples, rough ground, bedrock outcrops etc.) and an indication of the sediment characteristics (soft or hard sediments) could be identified from the sidescan sonar mosaics, and the presence of these features/characteristics was confirmed through the underwater video data collected at the ground-truth stations. Using this approach, each of the 4 sites was divided into acoustically distinct regions which represented distinct physical habitat types. These regions formed the basis for the design of subsequent biological and sedimentological surveys (see Section 4.4.1).

4.4 Methods - Biological surveys and ground-truthing

4.4.1 Survey design and sampling

At each of the four locations, the design of the biological and ground truthing surveys was structured around the acoustically distinct regions identified from the output of the sidescan sonar surveys. The main sampling tool was a 0.1m^2 Hamon grab fitted with a video camera and light. This was the preferred type of sampling gear due to its ability to collect samples on coarse, unconsolidated sediments. The grab was fitted with a video camera in order to record an image of the seabed adjacent to the collection bucket of the grab, thus providing information about the undisturbed surface of the substrate at each sampling station. At each site, sampling stations were randomly positioned within each acoustic region, and the number of stations within each region was linked to the size of the area.

A total of 43 Hamon grab samples were collected from across the study area at Shoreham (August 1999). Similarly, a total of 16 grab samples were collected at both the Dungeness (August 1999) and Hastings (October 1999) study sites, and 25 grab samples at the Isle of Wight study site (July/August 2000). Following estimation of the total volume of each grab sample, a 500 ml sub-sample 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 retained macrofauna were fixed in 4-6% formaldehyde solution (diluted with seawater) for laboratory identification and enumeration.

At the Shoreham and Hastings study sites, beam trawl surveys were also conducted in order to characterise the epifauna (July/August 2000). A modified 2 m beam trawl, with a heavy-duty steel beam, chain mat and a 4 mm knotless mesh liner fitted inside the net (see Jennings *et al.* 1999 for design specifications) was deployed at selected sampling stations within a number of the acoustically distinct regions. The beam trawl was deployed from the stern ramp of the research vessel using a warp length of three times the water depth. Each tow covered a fixed distance of 120 m across the seabed, which was determined using Sextant software linked to the ship's Differential Global Positioning system. The speed of the ship and the deployment time were also recorded. On retrieval of the trawl an estimate of the sample volume was made.

At all four sites a drop-camera frame fitted with a video camera and lights was deployed at a number of stations to obtain additional visual ground-truth data from each of the acoustic regions. The camera system was suspended above the surface of the seabed as the vessel was allowed to drift. Deployments were made at slack water when currents were less than 1 knot in order to achieve good quality video footage.

4.4.2 Sample processing

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, 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.

For each positive identification a representative specimen was retained in order to establish a reference collection.

Each beam trawl sample was washed over a 5 mm square mesh sieve and macrofaunal species were identified and enumerated at sea. Colonial species were recorded as either present or absent. Any specimens which could not be identified at sea were fixed in 4-6% formaldehyde solution and returned to the laboratory for identification.

The sediment sub-samples from each grab station were analysed for their particle size distributions. Samples were first wet sieved on a 500 micron stainless steel test sieve, using a sieve shaker. The sediment fraction less than 500 microns, along with water from the wet sieving, was allowed to settle in a bucket for 48 hours. Excess water was then removed using a vacuum pump and the fraction was washed into a sterile petri dish, frozen for 12 hours and freeze dried. The weight of the sediment was also recorded. A sub-sample of the <500 micron freeze dried fraction was then analysed on a laser sizer. The >500 micron fraction was washed from the test sieve into a foil tray and oven dried at ~90^{o}C for 24 hours. It was then dry sieved for 10 minutes on a range of stainless steel test sieves at half phi intervals, down to 1 phi. The sediment on each sieve was weighed to 0.01 g and the results recorded. The results from these analyses were combined to give the full particle size distribution. The mean and sorting values were then calculated.

4.4.3 Data analysis

Univariate analysis

Total number of individuals (excluding colonial species) and total number of species were calculated from both the Hamon grab and beam trawl (Shoreham and Hastings only) surveys as summary measures of benthic assemblages within each acoustic region at each study site. Bartlett's test was used to test for homogeneity of variance. Where the variance was not homogeneous a log transformation of the data was carried out. The significance of differences between acoustic regions was tested using one-way ANOVA. Fisher's least significant difference (LSD) multiple comparisons procedure was used to determine significant differences in the numbers of species and number of individuals between regions. Univariate analyses were performed using the software package STATGRAPHICS Plus, Version 4.

Multivariate analysis

Associations between benthic assemblages and acoustic regions were examined using multivariate statistical methods. At Shoreham and the Isle of Wight, macrofauna data from the Hamon grab survey were divided into categories in order to determine the strength of association between these and acoustically distinct regions. These categories were: 1) all taxa excluding colonial species; 2) burrowing and infaunal species; 3) epifaunal species. At the other study sites the data sets were not divided into faunal categories, and analysis was conducted on the entire data (equivalent to Category 1). Sample and species associations across the survey area for each of the three categories were assessed by non-metric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure on 4th root transformed data (species Categories 1 and 2) or presence/absence data (Category 3) using the software package PRIMER (Clarke and Warwick, 1994). Rare species (i.e. with fewer than three individuals recorded throughout the survey area) were removed from faunal Category 1 in order to reduce the variability caused by these infrequently occurring species. Removing these species was also necessary to conform to certain limitations in the total number of species which can be used during certain tests within the PRIMER software (e.g. SIMPER - see below). The majority of species collected during the beam trawl surveys were epifaunal species. Statistical analysis was therefore conducted on all taxa excluding colonial organisms using identical statistical methods as above on 4th root transformed data.

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.

A correlation-based principal components analysis (PCA) was applied to ordinate results from the sediment particle size analysis. Prior to analysis, environmental variables were converted to approximate normality using a log(1+*N*) transformation. Analysis of similarities (ANOSIM, Clarke, 1993) was performed on particle size data to test the significance of differences in particle size composition between acoustic regions. The relationships between environmental variables and multivariate community structure were assessed using the BIO-ENV procedure within the PRIMER programme. In this procedure rank correlations ($\rho\omega$) 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. The RELATE programme was applied to test for significant relationships between similarity matrices based on relative macrofauna abundances and measured environmental variables, and between categories of macrofauna collected during the grab survey. The Spearman rank correlation (ρ) was computed between corresponding elements of each pair of matrices, and the significance of the correlation determined using a permutation procedure.

4.5 Results

4.5.1 Shoreham

Acoustic data interpretation

Examination of the sidescan sonar data revealed the presence of 8 acoustically distinct regions within the survey area (Figure 2). Underwater video footage established that differences between the acoustic regions were due to changes in substrate type, and that substrates were generally homogeneous in their distribution within each of the regions. Difficulties in identifying boundaries between acoustic regions in the north of the survey area (regions SH, SH/F, and SF) were encountered due to the reduced sidescan sonar image quality caused by the shallow water depths and surface noise. Boundaries between regions across the rest of the survey area were fairly distinct. Examples from the sidescan sonar record of the acoustically distinct regions, along with physical habitat descriptions derived from the underwater video footage, are illustrated in Figure 3.

Sediment characteristics and environmental variables

Examination of the grab samples on deck, and *in-situ* study of the undisturbed seabed surface by the video camera attached to the side of the grab, confirmed that sediment characteristics within each acoustic region were relatively distinct and homogeneous in distribution. Results from the particle size analysis of grab samples, used in conjunction with information derived from the sidescan sonar mosaic and video footage, provided a clear understanding of the physical habitat characteristics within each acoustic region. A range of habitats were identified across the survey area: cobbles with attached algae in shallow inshore waters (depths around 10 m) (Region SH and SH/F); areas of sand expressing different wave amplitudes (Regions SC and SF); mixed coarse substrates (Regions SD and SE); offshore gravelly sand with sand veneers (Region SB); offshore gravel and sand (>60 m) (Region SA).

An ordination by PCA of the particle size distributions from the grab samples is illustrated in Figure 4. There was a large degree of overlap between samples from most acoustic regions, and this was particularly apparent between regions with similar habitat traits (e.g. SA and SB, SD and SE, SH and SH/F), and reflects the subtle changes in sediment properties across the survey area.

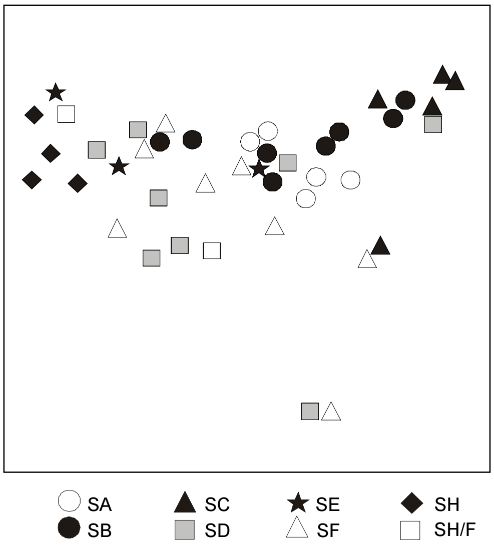


Figure 4. PCA ordinations of particle size distributions

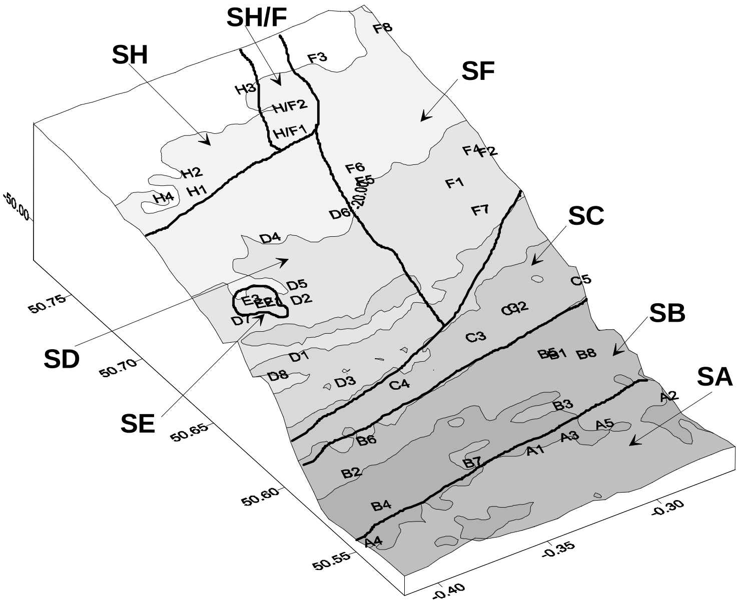


Figure 2. Bathymetric plot of the Shoreham survey area showing the 8 acoustically distinct regions (SA, SB, SC, SD, SE, SF, SH, SH/F) determined from the sidescan sonar data, and locations of the sampling stations. Depth contours have been plotted from QTC-VIEW data collected at the site

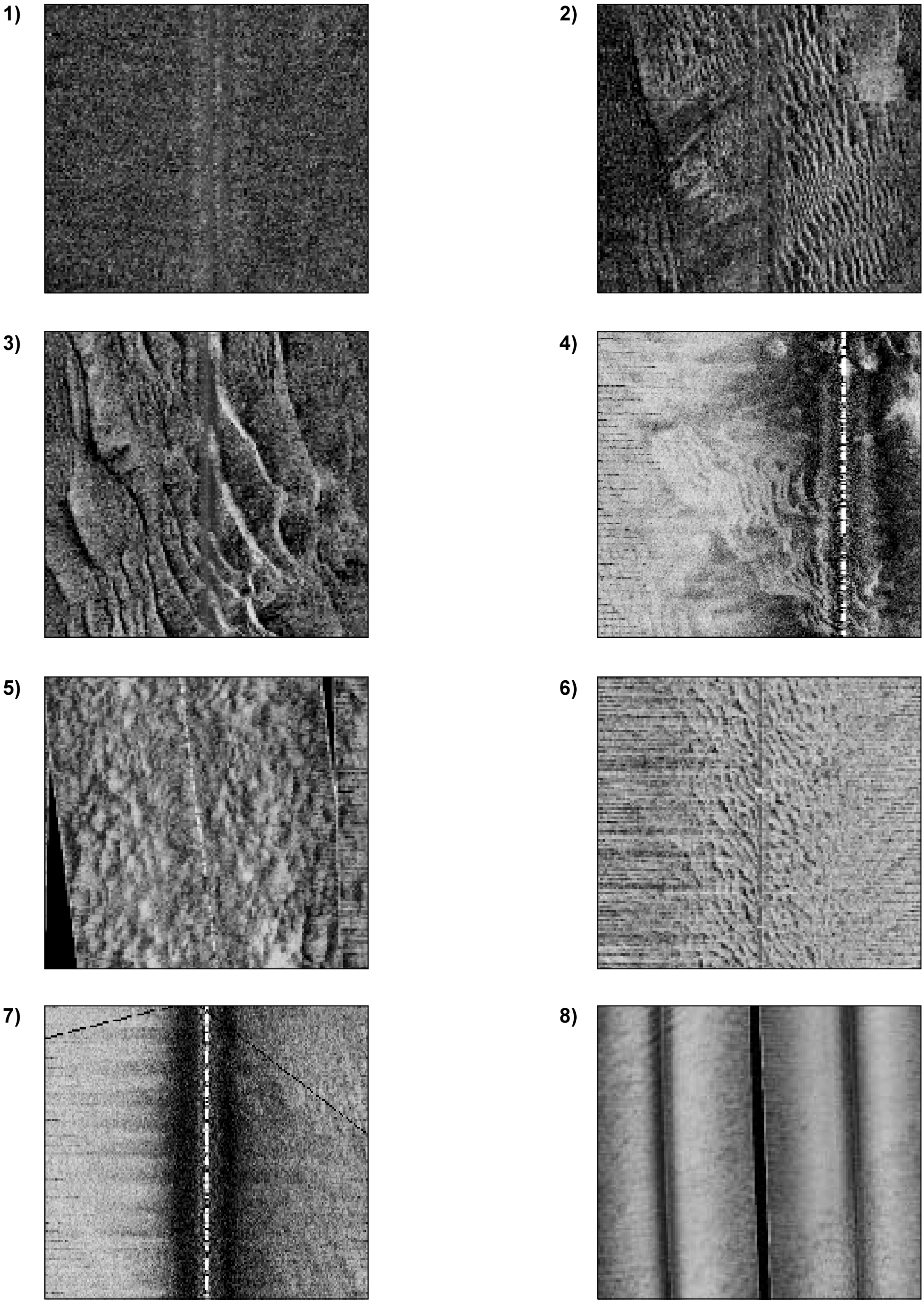


Figure 3. Examples of sidescan sonar images from the acoustically distinct regions:
1) Region SA - Offshore sandy gravel;
2) Region SB - Offshore sandy gravel with sand veneers;
3) Region SC - Large sand waves;
4) Region SD - Mixed heterogeneous sediment;
5) Region SE - Uneven mixed heterogeneous substrates;
6) Region SF - Inshore rippled sand;
7) Region SH - Coarse gravel and cobbles with attached algae;
8) Region SH/F - transition region between SH and SF, mixed substrates of cobbles and sand

However, samples collected from within a number of the acoustic regions (SA, SC and SH) tended to have similar particle size distributions, as depicted by the close proximity of replicate samples from these regions in the ordination (Figure 4). Samples on the left of the ordination (Region SH, SE and SD) tend to consist of coarser sediments (high percentage gravel) and are poorly sorted (high sorting coefficients). These parameters gradually reduce in magnitude across the ordination towards much finer (low percentage gravel), and well sorted (low sorting coefficient) sediments to the right of the ordination (Table 1). Table 2 shows the analysis of similarities results (ANOSIM, Clark 1993) for particle size data between samples. The high degree of overlap between regions and low degree of spatial

Table 2. Analysis of similarity for particle size (mean diameter in mm, sorting coefficient, % gravel, % sand and % silt/clay) distributions between acoustically distinct regions (n.s. Not significant; * significant at p < 0.1; ** significant at p < 0.05). Performed on 4th root transformed data

	SA	SB	SC	SD	SE	SF	SH
SB	n.s.						
SC	**	**					
SD	n.s.	n.s.	**				
SE	*	*	**	n.s.			
SF	n.s.	n.s.	**	n.s.	n.s.		
SH	**	**	**	**	n.s.	**	
SH/F	*	n.s.	**	n.s.	n.s.	n.s.	n.s.

Table 1. Particle size analysis data from Hamon grab samples collected from each acoustic region at the Shoreham study site

Acoustic region	Replicate	% gravel	% sand	% silt/clay	Mean particle size (mm)	Sorting
SA	1	13.77	79.66	6.57	0.546	2.11
	2	39.32	58.14	2.54	1.069	2.27
	3	23.82	70.29	5.89	0.703	2.25
	4	42.03	55.82	2.15	1.377	2.44
	5	25.23	67.19	7.58	0.593	2.44
	mean	**28.83**	**66.22**	**4.94**	**0.86**	**2.30**
SB	1	9.23	90.77	0.00	0.525	1.16
	2	57.42	40.92	1.66	3.121	2.98
	3	23.15	74.06	2.79	0.656	2.05
	4	34.78	60.38	4.85	0.922	2.49
	5	19.27	79.91	0.82	0.713	2.09
	6	51.82	46.81	1.36	2.372	2.79
	7	36.42	60.68	2.91	1.071	2.37
	8	10.40	88.56	1.04	0.498	1.36
	mean	**30.31**	**67.76**	**1.93**	**1.23**	**2.16**
SC	1	1.25	84.39	14.36	0.251	2.13
	2	1.40	96.64	1.96	0.438	1.00
	3	1.96	98.04	0.00	0.609	0.58
	4	16.31	83.69	0.00	0.812	1.30
	5	0.94	98.90	0.16	0.500	0.60
	mean	**4.37**	**92.33**	**3.30**	**0.52**	**1.12**
SD	1	31.84	65.56	2.60	0.926	2.56
	2	54.76	33.78	11.46	1.752	3.85
	3	59.16	39.05	1.79	3.554	3.11
	4	11.51	57.67	30.82	0.173	2.89
	5	48.47	40.82	10.71	1.425	3.64
	6	53.77	40.02	6.21	2.375	3.45
	7	1.10	96.61	2.29	0.309	1.13
	8	61.78	35.13	3.09	4.878	3.51
	mean	**40.30**	**51.08**	**8.62**	**1.92**	**3.02**
SE	1	66.31	28.94	4.76	3.325	3.12
	2	77.45	21.37	1.17	6.753	2.60
	3	39.82	55.91	4.27	0.953	2.21
	mean	**61.19**	**35.41**	**3.40**	**3.68**	**2.64**
SF	1	3.57	80.81	15.62	0.232	2.10
	2	27.01	63.55	9.44	0.591	2.95
	3	59.06	31.87	9.06	2.828	3.84
	4	45.02	49.51	5.47	1.524	3.17
	5	36.56	60.97	2.47	1.258	2.92
	6	56.07	42.60	1.33	3.280	3.02
	7	4.86	63.46	31.68	0.145	2.71
	8	58.28	40.53	1.19	2.770	3.06
	mean	**36.30**	**54.16**	**9.53**	**1.58**	**2.97**
SH/F	1	39.79	48.85	11.36	0.842	3.25
	2	71.46	27.55	0.99	5.591	2.95
	mean	**55.62**	**38.20**	**6.18**	**3.22**	**3.10**
SH	1	74.46	18.25	7.29	6.180	3.62
	2	73.77	21.12	5.12	5.706	3.32
	3	72.79	20.96	6.25	3.912	3.41
	4	84.58	11.75	3.67	6.473	2.60
	mean	**76.40**	**18.02**	**5.58**	**5.57**	**3.24**

clustering within the ordination is reflected in these results. Many of the regions were not statistically distinct in terms of their particle size distribution, and in general there was a high degree of particle size variability between replicate samples. Region SC and SH were the only two regions which tended to be statistically distinct from most of the other regions. However, despite the fact that many of the regions were not statistically discrete in terms of their particle size distributions, the physical habitat characteristics (e.g. seabed morphology, degree of sediment stratification) were still distinct between these regions (Figure 3).

Biological data interpretation

A total of 233 taxa were identified from 43 Hamon grab samples collected from across the survey area. Univariate analysis revealed that Regions SA, SD, SE, and SH had the highest mean number of macrofauna species, and that Regions SE and SH had the highest mean number of individuals, compared to remaining regions (Figure 5). Samples collected by beam trawl comprised 113 taxa. Patterns in the number of species and individuals were similar to those from the Hamon grab survey. Regions SA and SD had the highest mean number of species, and Regions SA and SH the highest mean number of individuals, although values from these regions were not always statistically higher than the other regions due to the high variability of these measures between replicate samples. Region SC had the lowest mean number of species and individuals, and this was true for samples collected during both the beam trawl and grab surveys.

Hamon grab	SA	SB	SC	SD	SE	SF	SH	SH/F
Mean No. Species	34	16	8	30	49	15	39	20
Mean No. Individuals	102	49	13	86	197	34	143	29

2 m Beam trawl	SA	SB	SC	SD	SF	SH
Mean No. Species	35	25	20	31	22	21
Mean No. Individuals	679	186	148	588	203	1384

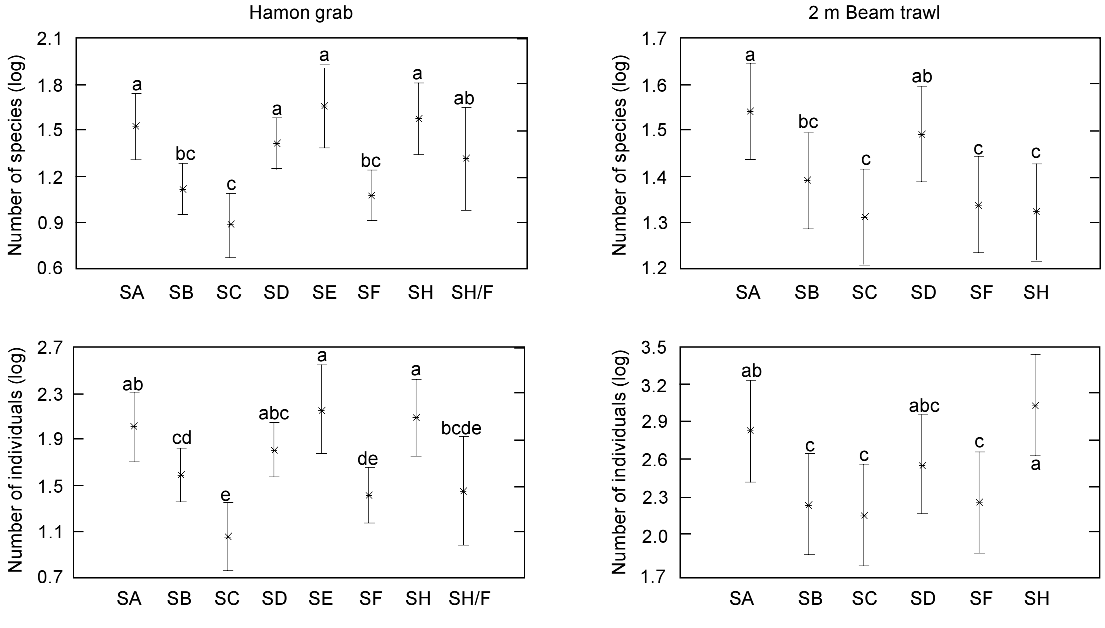


Figure 5. Summary of means and 95% pooled confidence intervals for the numbers of species and numbers of individuals from within each acoustic region. Values labelled with the same letter are not significantly different from one another at p < 0.05, following application of Fisher's LSD multiple comparison procedure

Figure 6 shows the output from non-metric multi-dimensional scaling (MDS) ordinations of data from both the Hamon grab and beam trawl surveys. Ordinations were carried out on the three macrofauna categories identified from the grab samples (following amalgamation of the 1-5 mm and >5 mm fractions) and on all species except colonial organisms from the beam trawl samples. Grouping of replicate samples from within acoustic regions is evident, which, following analysis of similarities (ANOSIM, Clark 1993), illustrates that in most cases there were significant differences in macrofaunal assemblage composition between acoustically distinct regions (Table 3). From the Hamon grab survey, Regions SD and SE, SD and SH/F, and SF and SH/F were the only combinations of regions which did not have statistically distinct assemblages for all three faunal categories. A number of other combinations of regions were not statistically distinct, but these combinations varied depending on which faunal category the ANOSIM test was applied to (Table 3). On the whole dissimilarity values between regions was generally high. High stress values for the ordinations are due to the high-dimensional data set and large number of samples included in the analysis. However, stress values between 0.1 and 0.2 still provide a useful 2-dimensional picture, and the ordinations offer a useful visual method of displaying the results (Clarke and Warwick, 1994).

The dissimilarity values between regions for the beam trawl data were much lower (Table 3). Although replicate samples are not strongly clustered in the ordination (Figure 6), the regions are spatially separated from one another with a low degree of overlap between regions, and these differences are supported by the ANOSIM results (Table 3). Due to the fact that only three replicate samples were collected from within each acoustically distinct region, it was only possible to achieve a significance level of 10% due to limitations in the statistical approach caused by the reduced number of permutations achievable between samples (Clarke, 1993). However, it should be noted that this significance level can be used to infer an ecological difference in community structure between acoustic regions. In most cases assemblage structure was statistically distinct between acoustic regions at this significance level, with the exception of Regions SA and SD, SB and SC, SB and SF, SC and SF and SF and SH.

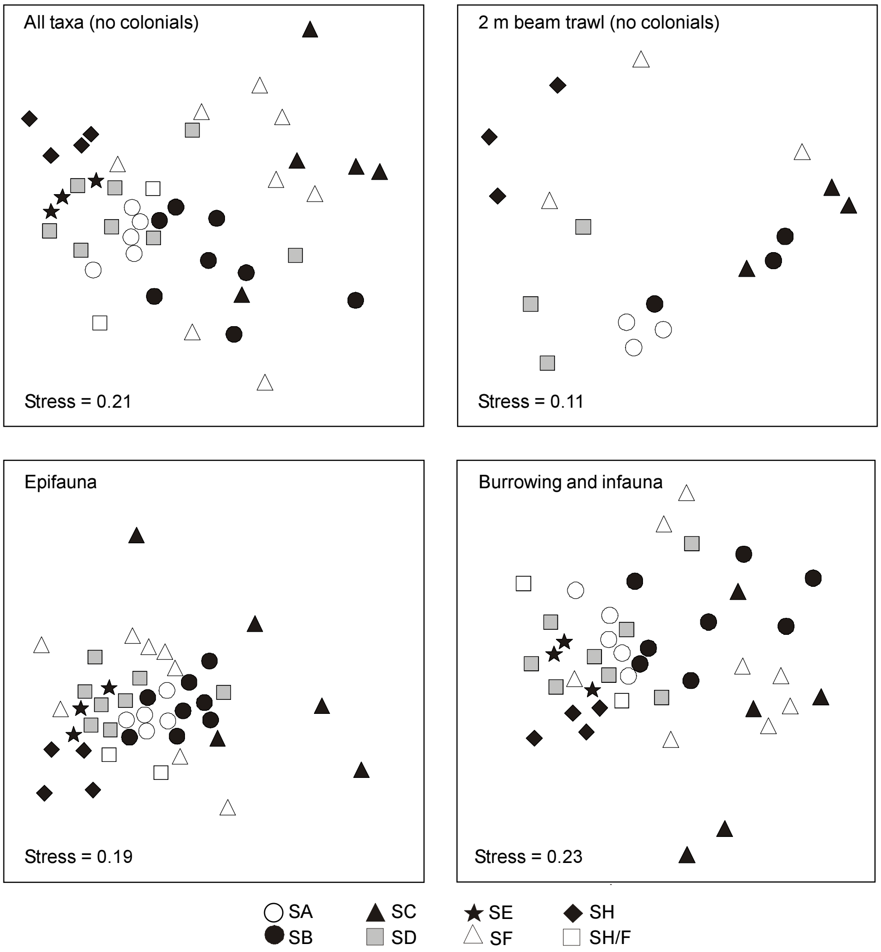


Figure 6. ***MDS plots for macrofaunal assemblages from the Beam trawl and Hamon grab surveys. Beam trawl data - 4th root transformed. Hamon grab faunal Category 1 (all taxa, no colonials) and faunal Category 2 (burrowing and infauna) - 4th root transformed, faunal Category 3 (epifauna) - presence/ absence transformation***

Table 3. Dissimilarities (%) between assemblages from within acoustically distinct regions based on 4th root transformed data (Hamon grab faunal Categories 1 and 2, and 2m beam trawl data) and presence/absence transformed data (Hamon grab faunal Category 3). * denotes significant difference at p < 0.1; ** denotes significant difference at p < 0.05

	SA	SB	SC	SD	SE	SF	SH
Category 1: All taxa - colonial and low abundance species removed (4th root transformed data)							
SB	70						
SC	87**	84**					
SD	67	77**	90**				
SE	66**	80**	92**	67			
SF	83**	81**	83*	82**	85**		
SH	74**	85**	94**	74*	63*	87**	
SH/F	71**	77	89**	72	75*	82	81*
Category 2: Burrowing and infaunal species (4th root transformed data)							
SB	73*						
SC	86**	84**					
SD	67	78**	90**				
SE	66**	80**	91**	69			
SF	82**	80**	83*	82**	84**		
SH	74**	82**	92**	73	66	85**	
SH/F	75**	82*	91**	75	76	84	79*
Category 3: Epifaunal species (presence/absence data)							
SB	59*						
SC	85**	84**					
SD	64**	66**	88**				
SE	63**	70**	91	56			
SF	72*	70**	86**	68*	72		
SH	74**	80**	94**	69**	64**	81**	
SH/F	70**	71**	85	65	68*	69	69*
Beam trawl fauna - colonial species removed (4th root transformed data)							
SB	49*						
SC	61*	48					
SD	50	63*	74*				
SF	67*	62	62	64*			
SH	67*	71*	79*	60*		64	

Results from the RELATE analysis indicate a statistically significant similarity in biotic structure between all combinations of the three categories of benthic fauna from the grab survey (p<0.05). Similarly, there was a statistically significant similarity in the biotic structure between assemblages identified from the 2 m beam trawl survey and Category 1 from the Hamon grab survey (p<0.05) (Table 4). These results indicate that differences in the assemblage structure between acoustic regions were detectable, and that patterns in biotic structure were similar, irrespective of which fraction of the benthic community is sampled, or which sampling technique was used. Correlation between the environmental variables (psa data) and biotic matrices underlying the ordinations in Figures 4 and 6 were highly significant (p<0.01) (Table 4).

Table 4. Spearman rank correlations (ρ) between macrofaunal assemblage structure and environmental variables (particle size data), and between the faunal categories identified from the Hamon grab and 2 m beam trawl surveys

	PSA data	Epifauna	All
Taxa			
Epifauna	0.408		
Burrowing and infauna	0.425	0.486	0.952
All taxa	0.475	0.600	
Beam trawl data	0.276		0.186

BIO-ENV analyses were conducted on (dis)similarity matrices derived from the Hamon grab fauna Categories 1-3 and environmental data to establish which suite of environmental variables best explain the biotic structure. Following analysis of data from all 43 stations (including only the particle size data within the environmental variables) percentage sand and sorting coefficient for faunal Categories 1 and 2, and percentage gravel and sorting coefficient for faunal Category 3, were identified as the best combination of variables. However, in all cases the weighted Spearman rank correlations between assemblage structure and environmental variables were low ($\rho\omega<0.3$). Tests were not carried out on beam trawl data and environmental data due to the fact that the trawl samples were collected over a stretch of seabed, and the environmental data were collected from single point stations.

Biotopes

Further exploration of the community groupings identified in the MDS ordinations, using the similarity percentages program SIMPER, was conducted for benthic data sets collected from the Hamon grab (using faunal Category 1) and beam trawl surveys. Results revealed that the average similarity between replicate samples collected within an acoustic region was relatively low, particularly for the Hamon grab data (Tables 5 and 6). This reflects the remaining large number of low frequency species (after removal of those species with fewer than 3 individuals throughout the survey area) within the data set that contribute to the high dissimilarity between replicates from within an acoustic region.

The output from SIMPER also indicates which taxa contribute the most towards the similarity between replicate samples from within each acoustic region (Table 5 and 6). Characterising species from each acoustic region identified from the Hamon grab survey were unsurprisingly very different from those identified from the beam trawl survey. Characterising species identified from the beam trawl survey were typically larger and more mobile epifaunal species. In contrast, those species identified from the Hamon grab survey tended to represent the smaller epifauna or infaunal members of the benthic assemblages. However, independent of the type of sampling gear used, characterising species from each acoustic region are typical for the substrate types present within the region. Several species were also identified ranging across all the regions, including *Pagurus bernhardus* and *Alcyonidium diaphanum*.

Using results from the SIMPER analysis of both Hamon grab and beam trawl data, along with information derived from the sidescan sonar mosaic and underwater video and photographic material, 6 discrete biotopes (physical habitats and associated biological assemblage) were identified. These are listed in Section 4.5.5.

Table 5. Results from SIMPER analysis of Hamon grab data at the Shoreham site (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from each acoustically distinct region. Average abundance, similarity percentage, and cumulative similarity percentage for each species and the overall average similarity between replicate samples from within each region are listed

Acoustic region		Average Abundance	%	Cumulative %	Average similarity
SA	*Echinocyamus pusillus*	12.6	8.0	8.03	**48.9%**
	Maldanidae	8.2	7.7	15.75	
	Ampelisca sp.	8.8	7.6	23.3	
	Aonides paucibranchiata	6.6	7.3	30.7	
	Lumbrineris gracilis	4.8	7.2	37.9	
SB	*Echinocyamus pusillus*	12.3	20.9	20.9	**28.6%**
	Spisula sp.	4.5	12.5	33.4	
	Glycera sp.	1.5	11.9	45.3	
SC	*Abra prismatica*	1.2	49.5	49.5	**19.6%**
	Glycera sp.	1.2	15.7	65.2	
	Praunus sp.	0.6	10.7	80.0	
SD	*Lumbrineris gracilis*	4.6	15.4	15.4	**28.5%**
	Maldanidae	9.6	15.4	30.8	
	Amphipholis squamata	4.0	6.4	37.3	
	Echinocyamus pusillus	3.0	5.8	43.2	
SE	*Ampelisca sp.*	5.0	7.2	7.2	**36.0%**
	Amphipholis squamata	13.0	7.2	14.4	
	Maldanidae	4.7	7.0	21.4	
	Lumbrineris gracilis	11.0	6.9	28.3	
	Sabellaria spinulosa	5.0	6.4	34.7	
SF	*Ophelia borealis*	1.5	23.2	23.2	**21.9%**
	Bathyporeia sp.	4.4	19.2	42.4	
	Spisula sp.	2.6	10.7	53.2	
SH	*Crepidula fornicata*	43.7	10.3	10.3	**44.2%**
	Scalibregma inflatum	7.2	7.0	17.3	
	Lumbrineris gracilis	4.2	6.8	24.2	
	Harmothoe sp.	3.5	6.7	30.9	

Table 6. Results from SIMPER analysis of beam trawl data at the Shoreham site (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from each acoustically distinct region. Average abundance, similarity percentage, and cumulative similarity percentage for each species and the overall average similarity between replicate samples from within each region are listed

Acoustic region		Average Abundance	%	Cumulative %	Average similarity
SA	*Psammechinus miliaris*	205	7.5	7.5	**79.4%**
	Aequipecten opercularis	102	6.6	14.1	
	Echinocyamus pusillus	62	5.7	19.8	
	Pagurus bernhardus	48	4.9	24.7	
	Ophiura albida	36	4.9	29.6	
SB	*Pagurus bernhardus*	16	10.5	10.5	**52.8%**
	Crangon allmani	40	10.0	20.6	
	Anapagurus laevis	18	10.0	30.6	
	Ophiura albida	19	9.7	40.4	
	Pomatoschistus minutus	10	8.3	48.6	
SC	*Crangon allmani*	19	12.0	12.0	**56.6%**
	Ophiura albida	20	11.1	23.1	
	Anapagurus laevis	17	10.7	33.8	
	Liocarcinus sp.	10	10.2	44.0	
SD	*Anomia sp.*	120	7.9	7.9	**44.6%**
	Ocenebra sp.	14	7.8	15.7	
	Crepidula fornicata	56	7.8	23.5	
	Psammechinus miliaris	18	7.7	31.2	
	Pagurus bernhardus	34	6.7	38.0	
SF	*Pagurus bernhardus*	45	21.7	21.7	**34.5%**
	Pomatoschistus minutus	49	15.6	37.4	
	Macropodia sp.	3	10.7	48.1	
	Hinia sp.	10	9.7	57.8	
SH	*Crepidula fornicata*	1283	23.9	23.9	**60.2%**
	Ascidiella scabra	11	9.1	33.1	
	Pagurus bernhardus	15	8.8	41.9	
	Macropodia sp.	10	8.2	50.1	

4.5.2 Hastings

Acoustic data interpretation

This survey site crossed Hastings Shingle Bank, and the structure of the bank was clearly discernible from the sidescan mosaic. Examination of these data revealed the presence of 4 acoustically distinct regions (labelled HA, HB, HC and HD) within the survey area (Figure 7). The Shingle Bank could be divided into two regions which, following ground-truthing with the underwater video camera, related to areas of coarse gravel (Region HB) and of dense dredge tracks in coarse gravel infilled with sand and silt (Region HC). The regions to the north and south of the Shingle Bank both appeared from the sidescan record to consist of rippled sand. However, ground-truthing revealed that the inshore region consisted of fine-medium sand at water depths of less than 20 m (Region HA), whereas the offshore region was predominantly slightly gravelly rippled sand at water depths greater than 20 m (Region HD). Boundaries between adjacent regions were clearly defined, and the substrata within Regions HA, HB and HD tended to be homogeneous in their distribution. Examples from the sidescan record of each acoustically distinct region are illustrated in Figure 8.

Sediment characteristics and environmental variables

Examination of the grab samples on deck, and *in-situ* study of the undisturbed seabed surface by the video camera attached to the side of the grab, confirmed the interpretations from the acoustic data. Results from the particle size analysis of grab samples, used in conjunction with information derived from the sidescan sonar mosaic and video footage, provided a clear understanding of the physical habitat characteristics within each acoustic region.

An ordination by PCA of the particle size data from the Hamon grab samples is illustrated in Figure 9. Samples collected from the Shingle Bank (Regions HB and HC) had a much higher percentage of coarse material than samples collected from regions to the north and south of the bank (HA and HD), which consisted mainly of sand (Table 7). This is reflected in the PCA ordination by the separation of HA and HD from HB and HC. The particle size distributions of samples from within Regions HA and HD were also more consistent, as depicted by the tight clustering of samples in the PCA ordination (Figure 9). In contrast there was a much higher degree of particle size variability between replicate samples collected from Regions HB and HC, as depicted by the

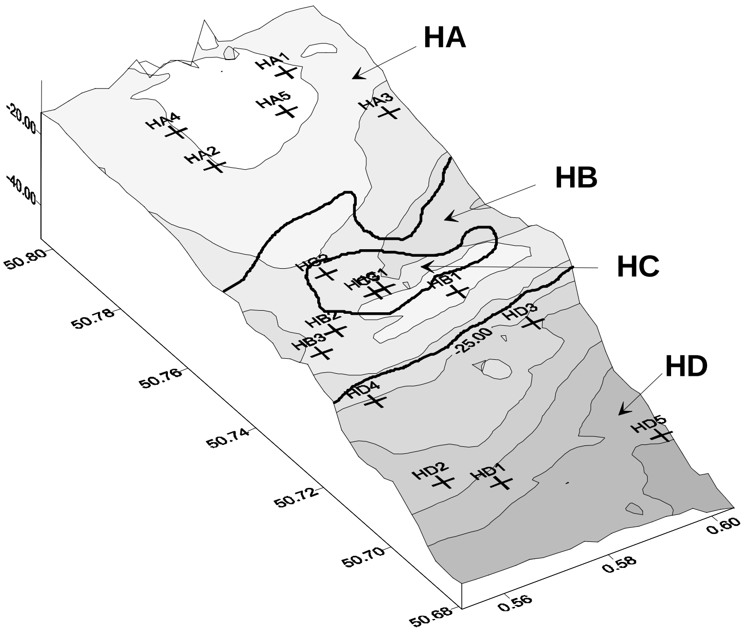


Figure 7. ***Bathymetric plot of the Hastings survey area showing the 4 acoustically distinct regions (HA, HB, HC, HD) determined from the sidescan sonar data, and locations of the sampling stations. Depth contours have been plotted from QTC-VIEW data collected at the site***

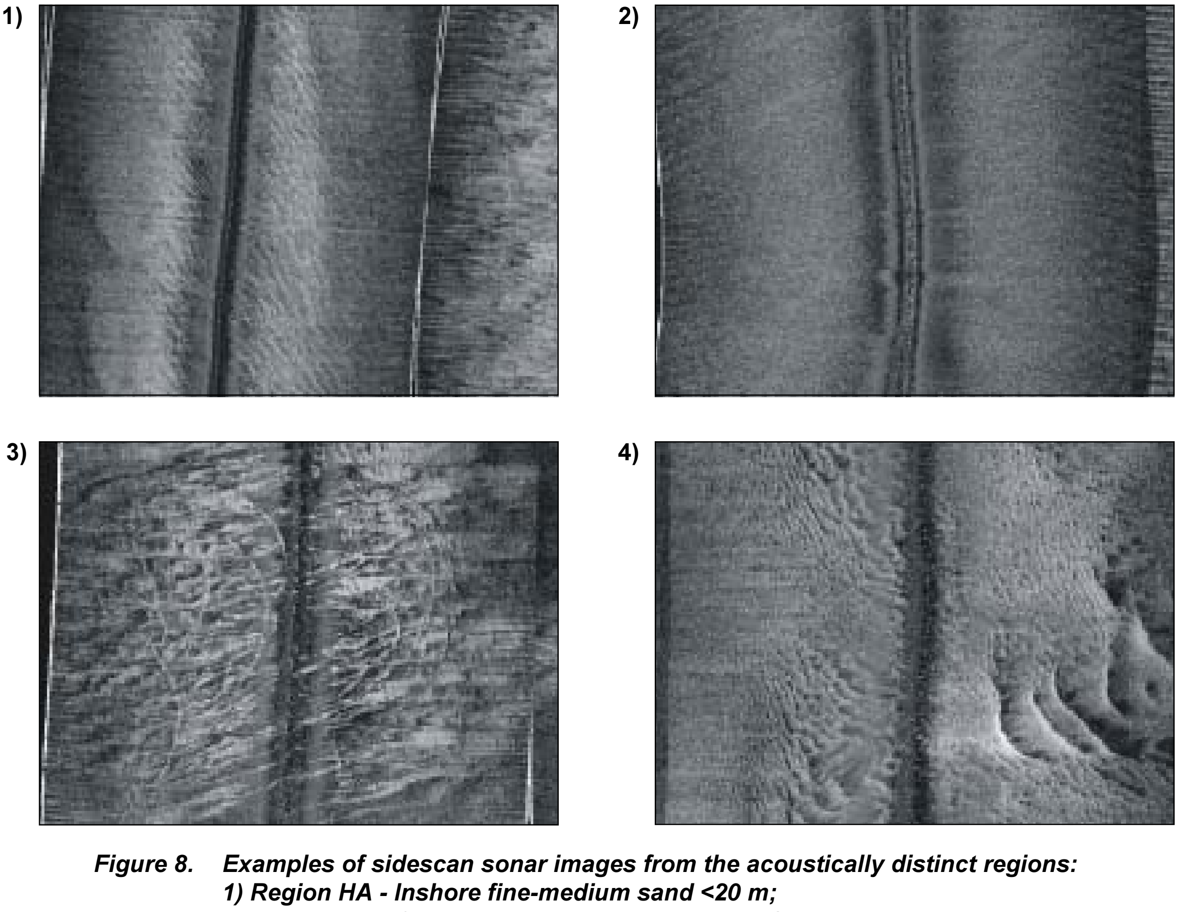


Figure 8. ***Examples of sidescan sonar images from the acoustically distinct regions:***
1) Region HA - Inshore fine-medium sand <20 m;
2) Region HB - Cobbles and gravel - undredged Shingle Bank;
3) Region HC - Disturbed gravel - dredged Shingle Bank;
4) Region HD - Slightly gravelly rippled sand >20 m

much wider spread of samples from these regions in the PCA ordination (Figure 9) and as shown in Table 7. Table 8 shows the analysis of similarities results (ANOSIM, Clark 1993) for particle size data between samples from the four acoustic regions. All regions were statistically distinct from one another, with the exception of Regions HB and HC. However, in terms of seabed morphology, Region HC was visually and acoustically distinct from Region HB, and dense dredge tracks were clearly visible on the side scan sonar record within this region (Figure 8).

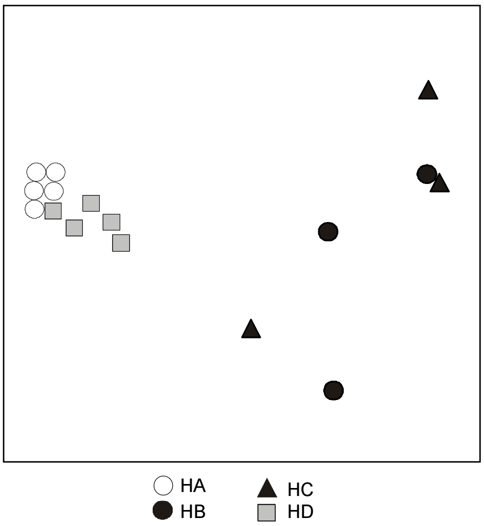


Figure 9. ***PCA ordination of particle size (mean diameter in mm, sorting coefficient, % gravel, % sand and % silt/clay) distributions***

Table 8. Analysis of similarity for particle size (mean diameter in mm, sorting coefficient, % gravel, % sand and % silt/clay) distributions between acoustically distinct regions (n.s. not significant; * Significant at p < 0.1; ** Significant at p < 0.05). Performed on 4th root transformed data

	HA	HB	HC
HB	**		
HC	**	n.s.	
HD	**	**	**

Biological data interpretation

A total of 172 taxa were identified from the 16 Hamon grab samples collected from across the survey area. There was a high degree of variability in the mean number of species between regions, with the undredged Shingle Bank (Region HB) supporting a statistically higher number of species (p<0.05) than the dredged Bank or surrounding sandy regions. Similarly, the undredged Shingle Bank (Region HB) also supported the highest number of individuals, although this value was only significantly greater than the number of individuals from regions HC and HD. A total of 91 taxa were identified from the beam trawl survey. The number of individuals from each region tended to be fairly similar, and there were no significant differences in these values across the whole of the survey site. In contrast, the number of species varied considerably between regions. Region HB supported the highest number of species, which was significantly higher than the number of species from Regions HA and HD (p<0.05). These data are presented in Figure 10.

Table 7. Particle size analysis data from Hamon grab samples collected from each acoustic region at the Hastings study site

Acoustic region	Replicate	% gravel	% sand	% silt/clay	Mean particle size (mm)	Sorting
HA	1	2.03	97.67	0.30	0.31	0.84
	2	0.04	99.96	0.00	0.27	0.38
	3	0.03	99.97	0.00	0.28	0.38
	4	1.32	98.68	0.00	0.32	0.64
	5	0.02	99.98	0.00	0.26	0.37
	mean	**0.69**	**99.25**	**0.06**	**0.29**	**0.52**
HB	1	36.97	55.87	7.16	0.89	2.95
	2	52.52	44.64	2.83	1.97	2.83
	3	65.61	31.18	3.21	4.19	3.13
	mean	**51.70**	**43.90**	**4.40**	**2.35**	**2.97**
HC	1	25.48	70.33	4.18	0.64	2.86
	2	70.93	25.28	3.79	4.01	2.89
	3	84.96	13.11	1.93	4.32	2.13
	mean	**60.46**	**36.24**	**3.30**	**2.99**	**2.63**
HD	1	3.55	95.58	0.87	0.44	1.10
	2	10.57	89.43	0.00	0.53	1.34
	3	1.85	98.15	0.00	0.31	0.68
	4	12.95	85.68	1.37	0.56	1.59
	5	12.22	86.93	0.85	0.59	1.47
	mean	**8.23**	**91.15**	**0.62**	**0.49**	**1.24**

Hamon grab	HA	HB	HC	HD
Mean No. Species	15	50	21	22
Mean No. Individuals	82	132	34	38

2 m Beam trawl	HA	HB	HC	HD
Mean No. Species	21	34	31	26
Mean No. Individuals	183	255	184	268

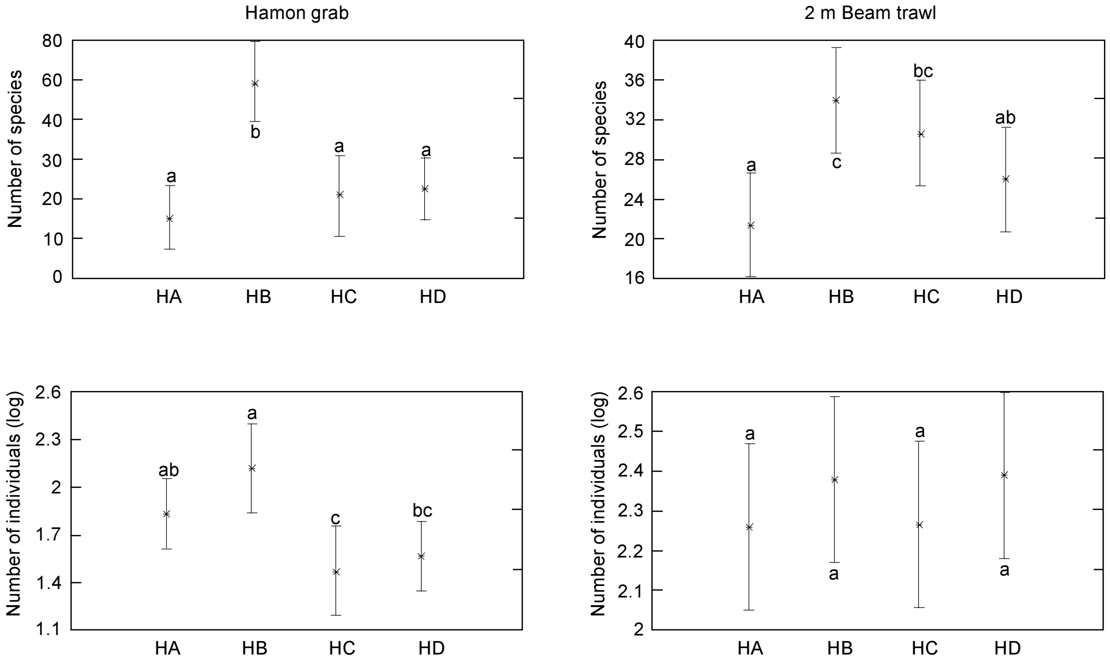


Figure 10. Summary of means and 95% pooled confidence intervals for the numbers of species and numbers of individuals from within each acoustic region. Values labelled with the same letter are not significantly different from one another at $p < 0.05$, following application of Fisher's LSD multiple comparison procedure

Figure 11 shows the output from non-metric multi-dimensional scaling ordination of data from both the Hamon grab and beam trawl surveys. Grouping of replicate samples from each acoustic region is clearly visible and, following analysis of similarities (ANOSIM, Clark 1993), illustrates that there were significant differences in macrofaunal assemblage structure between all acoustic regions, with the exception of Regions HC and HB from the beam trawl data (Table 9).

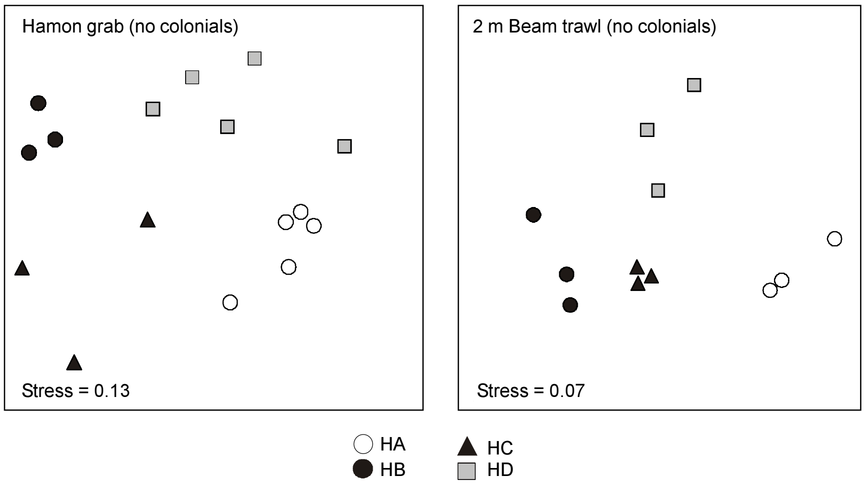


Figure 11. MDS plots for macrofaunal assemblages from the Beam trawl and Hamon grab surveys. All taxa except colonials included; data were 4th root transformed

Table 9. Dissimilarities (%) between assemblages (colonial species removed) from acoustically distinct regions based on 4th root transformed data (* denotes significant difference at $p < 0.1$; ** denotes significant difference at $p < 0.05$)

	HA	HB	HC
Hamon grab: All taxa - colonial species removed			
HB	96**		
HC	91**	84*	
HD	82**	86**	91**
Beam trawl: All taxa - colonials species removed			
HB	71*		
HC	57*	45	
HD	64*	60*	55*

Table 10. Spearman rank correlations (ρ) between macrofaunal assemblage structure and environmental variables (particle size data, Euclidean distance matrix), and between the faunal categories identified from the Hamon grab and 2 m beam trawl surveys. % Significance in brackets

		PSA - 4th root	Hamon Grab
Hamon Grab	No colonials - 4th root	0.534 (0.0%)	-
Beam Trawl	No colonials - 4th root	0.500 (0.1%)	0.461 (0.1%)

Patterns in the biotic structure of communities within each acoustic region were compared between the Hamon grab and beam trawl data sets using the RELATE programme within the PRIMER software, and were found to be statistically similar ($p<0.05$). There were also strong correlations between the biotic matrices underlying the MDS ordinations for both the Hamon grab and beam trawl data sets and the environmental variables (PSA data), which suggests that substrate properties are important in determining species composition (Table 10). BIO-ENV analysis was conducted on the (dis)similarity matrices derived from the Hamon grab data (colonial species removed) to establish which suite of environmental variables best explain the biotic structure. Percentage sand and sediment sorting coefficient were identified as the best combination of variables. Tests were not carried out on beam trawl data and environmental data due to the fact that the trawl samples were collected over a stretch of seabed, and the environmental data were collected from single point stations.

Biotopes

As for the biological data collected at Shoreham, the community groupings were explored further using the similarity percentages program SIMPER. Results revealed similar findings to those from Shoreham, namely that the average similarity between replicate samples collected within an acoustic region was relatively low, particularly for the Hamon grab data (Table 11 and 12), and that characterising species from each acoustic region identified from the Hamon grab

Table 11. Results from SIMPER analysis of Hamon grab data at the Hastings site (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from each acoustically distinct region. Average abundance, similarity percentage, and cumulative similarity percentage for each species and the overall average similarity between replicate samples from within each region are listed

Acoustic region		Average Abundance	%	Cumulative %	Average similarity
HA	*Spiophanes bombyx*	18.20	25.01	25.01	**42.33%**
	Magelona johnstoni	20.80	23.63	48.63	
	Nephtys cirrosa	2.40	17.65	66.29	
	Bathyporeia gracilis	10.20	15.99	82.28	
HB	*Pomatoceros triqueter*	17.67	10.62	10.62	**43.61%**
	Ascidiacea	11.67	8.49	19.11	
	Echinocyamus pusillus	5.00	7.73	26.85	
	Lumbrineris gracilis	5.00	7.57	34.42	
	Aonides paucibranchiata	2.67	6.55	40.97	
	Caulleriella alata	2.33	6.55	47.51	
	Scalibregma inflatum	2.00	5.85	53.36	
	Glycera lapidum	2.00	5.85	59.22	
	Poecilochaetus serpens	1.67	5.50	64.72	
	Syllis (Type B)	1.00	5.50	70.22	
HC	*Caulleriella alata*	4.33	55.87	55.87	**16.53%**
	Scolelepis squamata	1.33	18.82	74.68	
	Ampelisca spinipes	2.67	13.75	88.44	
HD	*Lumbrineris gracilis*	3.40	22.83	22.83	**27.23%**
	Nephtys cirrosa	2.60	13.41	36.24	
	Spisula elliptica	1.60	11.02	47.26	
	Eurydice pulchra	0.80	10.70	57.96	

Table 12. Results from SIMPER analysis of beam trawl data at the Hastings site (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from each acoustically distinct region. Average abundance, similarity percentage, and cumulative similarity percentage for each species and the overall average similarity between replicate samples from within each region are listed

Acoustic region		Average Abundance	%	Cumulative %	Average similarity
HA	*Pomatoschistus minutus*	54.33	13.31	13.31	
	Pagurus bernhardus	25.67	11.60	24.91	
	Aphrodita aculeata	21.00	11.23	36.14	**66.38%**
	Pontophilus sp.	14.00	10.79	46.93	
	Hinia sp.	15.67	9.36	56.29	
	Buglossidium luteum	11.67	8.50	64.79	
	Callionymus sp.	4.67	7.72	72.51	
	Echiichthys sp.	4.67	7.06	79.57	
HB	*Psammechinus miliaris*	101.00	10.86	10.86	
	Pagurus bernhardus	27.00	10.36	21.22	
	Ophiura albida	19.33	8.76	29.98	
	Buccinum sp.	7.33	7.23	37.21	**56.16%**
	Macropodia sp.	5.67	6.45	43.66	
	Nudibranchia	13.33	6.16	49.82	
	Chlamys sp.	4.33	5.90	55.73	
	Pisidia sp.	6.67	5.86	61.59	
	Pomatoschistus minutus	2.67	5.68	67.27	
	Metridium senile	4.33	5.25	72.52	
HC	*Pagurus bernhardus*	31.33	9.17	9.17	
	Hinia sp.	20.00	8.12	17.28	
	Pomatoschistus minutus	21.00	7.49	24.78	**68.37%**
	Chlamys sp.	8.67	6.88	31.66	
	Macropodia sp.	8.00	6.45	38.11	
	Galathea sp.	7.00	6.39	44.51	
	Liocarcinus sp.	11.67	6.38	50.88	
	Buccinum sp.	6.33	6.22	57.10	
HD	*Pagurus bernhardus*	66.33	16.62	16.62	
	Ophiura albida	85.67	14.44	31.06	
	Liocarcinus sp.	14.00	10.61	41.66	**52.5%**
	Ophiura ophiura	25.33	10.27	51.93	
	Crangon allmanni	14.33	7.87	59.81	
	Pomatoschistus minutus	4.67	7.84	67.65	
	Macropodia sp.	4.67	7.61	75.25	

survey were unsurprisingly very different from those identified from the beam trawl survey. These results, along with information derived from the sidescan sonar mosaic and underwater video and photographic material, were used to derive biotopes, and these are listed under Section 4.5.5.

4.5.3 Isle of Wight

Acoustic data interpretation

In contrast to the sites at Shoreham and Hastings, examination of the sidescan sonar data at the Isle of Wight study site revealed a very complex and heterogeneous seabed. Underwater video footage revealed that there was a very high level of small-scale sediment variability, which made it difficult to establish at what scale distinct habitats should be defined. A pragmatic approach was therefore adopted based on the highest degree of positional accuracy attainable with the ground-truthing methods. Further divisions could not have been accurately ground-truthed. Ultimately, the site was divided into 5 regions (labelled IA, IB, IC, ID and IE) based on gross habitat differences determined from the sidescan mosaic and underwater video footage, whilst realising that there was a high level of substrate variability and patchiness within each acoustic region. These regions and the position of Hamon grab samples are shown in Figure 12. Examples from two of the acoustic regions (Regions ID and IC) are shown in Figure 13.

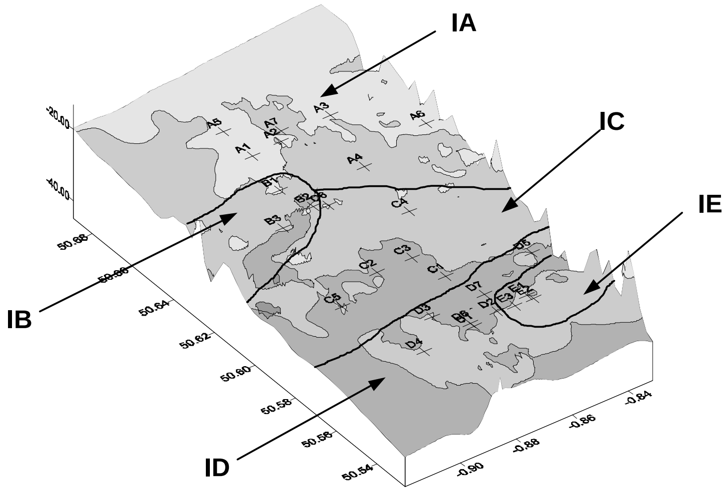


Figure 12. Bathymetric plot of the Isle of Wight survey area showing the 5 acoustically distinct regions (IA, IB, IC, ID, IE) determined from the sidescan sonar data, and locations of the sampling stations. Depth contours have been plotted from QTC-VIEW data collected at the site

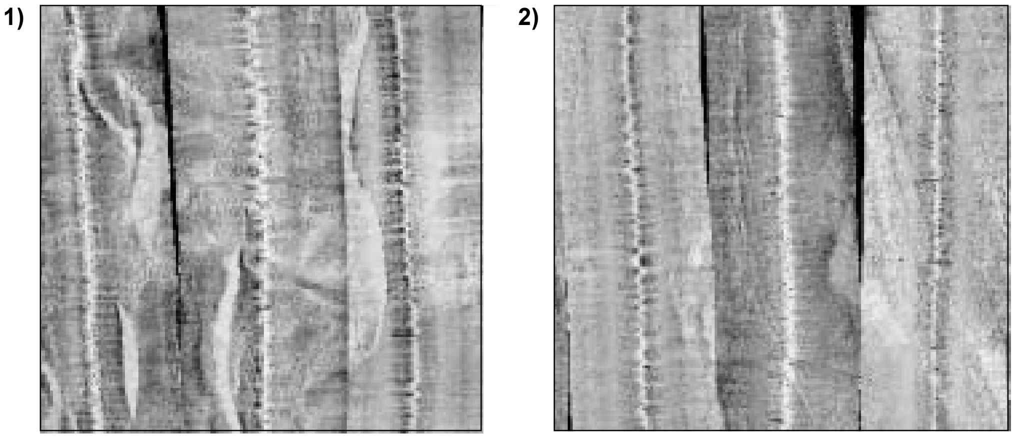


Figure 13. Examples of the sidescan sonar data from: 1) Region ID showing small-scale substrate patchiness (sand, gravel, cobbles and outcrops of bedrock); 2) Region IC showing a silt/sandy veneer over a rock/cobble pavement with patches of surface cobbles and boulders

Sediment characteristics and environmental variables

An ordination by PCA of the particle size distributions from the grab samples is illustrated in Figure 14. There was a large degree of overlap between samples from different acoustic regions, and there was no obvious grouping of replicate samples (with the possible exception of a number of samples from Region ID). Particle size data (Table 13) revealed that there was a high degree of variability in the percentage gravel, sand and silt/clay between replicate samples. This reflects the heterogeneous nature of the substrata within each acoustic region, and makes it very difficult to detect discrete habitats on the basis of these data sets. Results from analysis of similarities tests (ANOSIM, Clark 1993) confirmed that in most cases there was no significant difference in particle size distributions between samples from each acoustic region, with the exception of Regions IA and IB, IA and IE ($p<0.1$) and IA and ID ($p<0.05$) (Table 14).

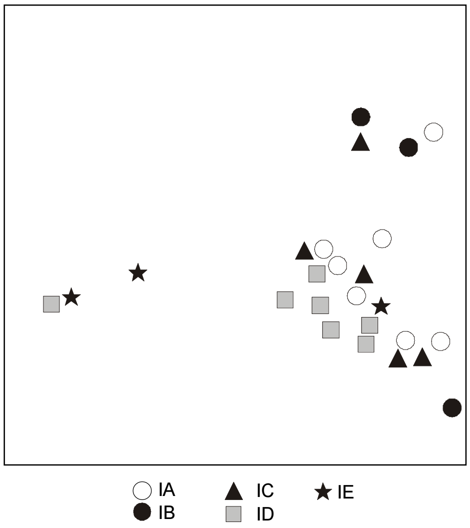


Figure 14. PCA ordination of particle size distributions (mean diameter in mm, sorting coefficient, % gravel, % sand and % silt/clay)

Table 13. Particle size analysis data from Hamon grab samples collected from each acoustic region at the Isle of Wight study site

Acoustic region	Replicate	% gravel	% sand	% silt/clay	Mean particle size (mm)	Sorting Sorting
IA	1	76.62	22.73	0.65	5.74	2.54
	2	57.19	41.00	1.81	2.37	2.92
	3	57.15	39.85	3.01	1.97	2.59
	4	65.44	23.68	10.88	2.51	3.81
	5	60.28	35.78	3.94	3.70	3.44
	6	81.13	16.41	2.46	7.37	2.68
	7	64.92	33.51	1.57	3.41	2.69
	mean	**66.10**	**30.42**	**3.47**	**3.87**	**2.95**
IB	1	86.01	13.27	0.72	10.17	2.24
	2	63.46	26.94	9.60	1.88	3.58
	3	51.26	38.22	10.53	1.10	3.41
	mean	**66.91**	**26.14**	**6.95**	**4.39**	**3.07**
IC	1	69.59	29.86	0.55	7.28	2.71
	2	81.02	17.35	1.63	6.55	2.37
	3	52.85	44.57	2.58	2.05	2.65
	4	52.36	38.11	9.53	1.46	3.35
	5	67.02	29.95	3.02	3.48	2.64
	mean	**64.57**	**31.97**	**3.47**	**4.17**	**2.74**
ID	1	61.01	38.99	0.00	4.21	2.30
	2	71.65	27.81	0.54	4.70	2.32
	3	59.82	39.75	0.43	3.08	2.38
	4	2.46	97.54	0.00	0.63	0.63
	5	57.18	40.99	1.82	2.36	2.54
	6	49.89	50.11	0.00	2.93	2.42
	7	64.20	35.50	0.30	5.58	2.81
	mean	**52.32**	**47.24**	**0.44**	**3.36**	**2.20**
IE	1	3.27	96.73	0.00	0.68	0.68
	2	68.47	29.64	1.90	4.97	2.72
	3	16.06	83.94	0.00	0.80	1.74
	mean	**29.27**	**70.10**	**0.63**	**2.15**	**1.71**

Table 14. Analysis of similarity for particle size (mean diameter in mm, sorting coefficient, % gravel, % sand and % silt/clay) distributions between acoustically distinct regions (n.s. not significant; * Significant at p < 0.1; ** Significant at p < 0.05). Performed on 4th root transformed data

	IA	IB	IC	ID
IB	*			
IC	n.s.	n.s.		
ID	**	n.s.	n.s.	
IE	*	n.s.	n.s.	n.s.

Despite the difficulty in identifying discrete habitats on the basis of the particle size data, there did appear to be acoustic and visual differences in terms of the physical habitat characteristics between the 5 regions, although the variation tended to be more subtle compared to those differences between acoustic regions at the other study sites. Examination of the underwater video footage revealed that Regions IA, IB and IC tended to be slightly muddy/silty in nature, and this elevated percentage of fine material was detected in the particle size data (Table 13 Regions IA, IB and IC). The substratum in Region IB also consisted of high numbers of *Crepidula* shells. In contrast, the two regions in the south of the study site, Regions ID and IE, appeared to comprise coarse material and out-cropping bedrock overlain with areas of sand veneers (Region ID), some of which were fairly thick and extensive (Region IE). Substrates in many of the regions were also consolidated, and there appeared from the video footage to be a considerable epifaunal community.

Biological data interpretation

A total of 338 taxa were identified from the 25 Hamon grab samples collected from across the survey area. The mean number of species and individuals was much higher at this location than at either Shoreham or Hastings (Figure 15), although the high numbers of individuals can be attributed mainly to a small number of taxa which were present in very high numbers at several of the sampling stations (e.g. *Balanus crenatus*, *Sabellaria spinulosa* and *Crepidula fornicata*). It was not possible to conduct beam trawl surveys at this study site due to the rocky and uneven nature of the seabed.

Univariate statistical tests were conducted on the Hamon grab data set. There was a statistically significant difference between the median number of species from each acoustic region, with Regions IA, IB and IC having higher numbers of species than ID and IE (variance was not homogeneous for the mean number of species, therefore the Kruskal-Wallis test was applied to test for a significant difference between regions). Similarly, Regions IA, IB and IC had significantly higher numbers of individuals than Regions ID and IE (Figure 15).

Figure 16 shows the output from non-metric multi-dimensional scaling (MDS) ordinations of data from the Hamon grab survey at the Isle of Wight site. Ordinations were carried out on the three macrofauna categories (following amalgamation of the 1-5 mm and >5 mm fractions). Patterns in community structure were less obvious than at the other study sites for all three faunal categories. Replicate samples from most acoustic regions were not tightly clustered in the ordinations, and there was a high degree of overlap between regions. However analysis of similarities (ANOSIM, Clark 1993) still

Hamon grab	IA	IB	IC	ID	IE
Mean No. Species	61	58	67	26	9
Mean No. Individuals	573	759	287	105	12

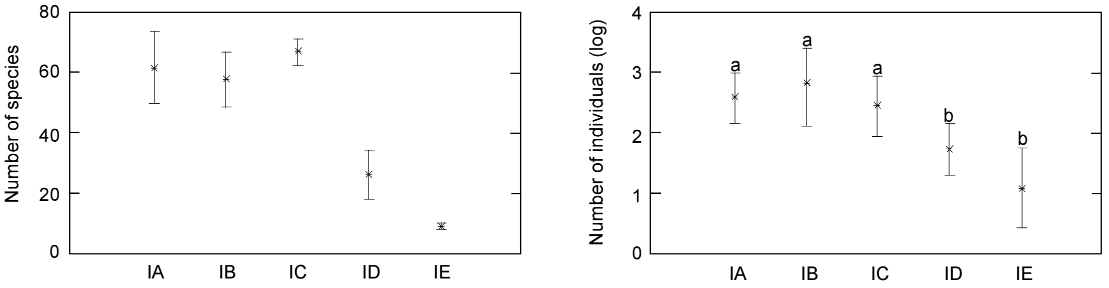


Figure 15. Summary of means with standard deviations (number of species) or 95% pooled confidence intervals (number of individuals) from within each acoustic region at the Isle of Wight site (Hamon grab survey). Values for the number of individuals labelled with the same letter are not significantly different from one another at p<0.05, following application of Fisher's LSD multiple comparison procedure

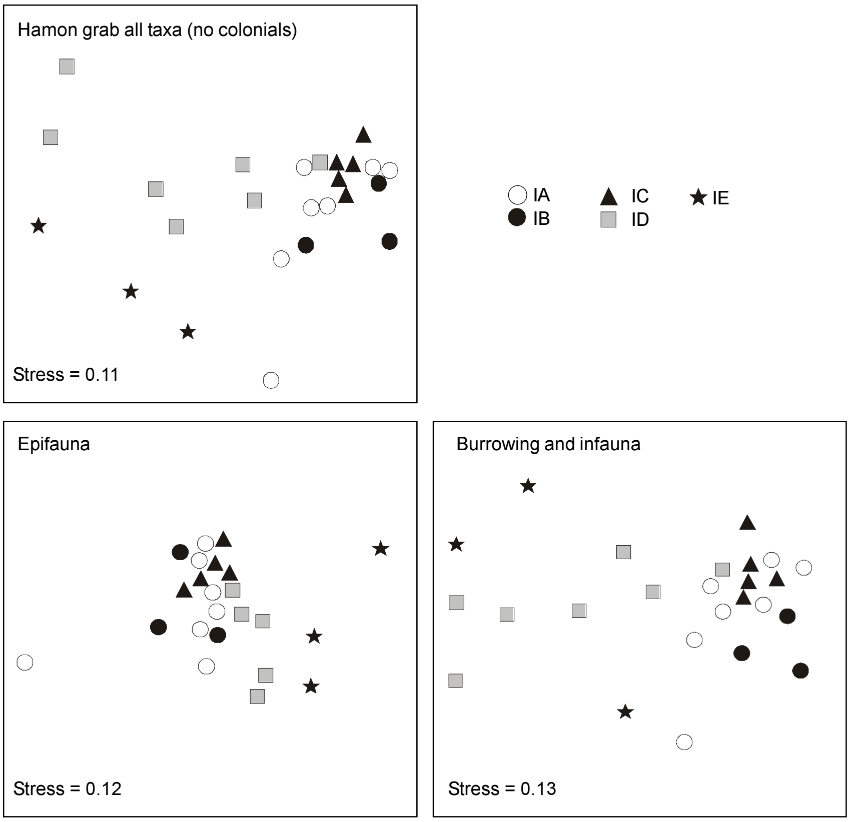


Figure 16. MDS plots for macrofaunal assemblages from the Hamon grab surveys of the Isle of Wight area. Hamon grab faunal Category 1 (all taxa, no colonials) and faunal Category 2 (burrowing and infauna) – 4th root transformed, faunal Category 3 (epifauna) – presence/absence transformed

revealed the presence of statistically distinct assemblages in a number of acoustic regions, but this varied depending on the faunal category to which the statistical tests were applied (Table 15). On the whole, Regions IA, IB and IC had similar assemblage structures, which tended to be statistically distinct from Regions ID and IE which were also similar in terms of assemblage structure. This is reflected in the ordinations; there was a degree of separation between Regions IA, IB and IC and Regions ID and IE in ordinations for faunal Categories 1 (all taxa) and 2 (burrowing and infaunal species), but this separation was not as obvious, but still apparent, in the ordination for faunal Category 3 (epifaunal species).

Results from the RELATE analysis revealed that there was a strong correlation between the biotic matrices underlying the MDS ordinations for all faunal categories and the environmental variables (PSA data) (Table 16). This suggests that substrate properties are important in determining species composition, despite the fact that particle size distributions from samples collected from across the survey site were very similar. BIO-ENV analyses were conducted on (dis)similarity matrices derived from faunal Categories 1-3 and environmental variables (PSA data) to establish which suite of variables best explain the biotic structure. Following analysis of data from all 25 stations, percentage sand and sediment sorting coefficient were identified as the best combination of variables.

Table 15. Dissimilarities (%) between assemblages from within acoustically distinct regions based on 4th root transformed data (faunal Categories 1 and 2) and presence/absence transformed data (faunal Category 3). * denotes significant difference at p < 0.1; ** denotes significant difference at p < 0.05

	IA	IB	IC	ID
Category 1: All taxa - colonial and low abundance species removed				
IB	63			
IC	58	59**		
ID	77**	80**	76**	
IE	88**	88*	90**	77*
Category 2: Burrowing and infaunal species - low abundance species removed				
IB	65			
IC	58	64**		
ID	78**	82**	76**	
IE	86**	87*	87**	76
Category 3: Epifaunal species				
IB	67			
IC	62	58		
ID	69	69*	67**	
IE	88**	87*	88**	75**

Table 16. Spearman rank correlations (ρ) between macrofaunal assemblage structure and environmental variables (particle size data, Euclidean distance matrix), and between the faunal categories identified from the Hamon grab. % Significance in brackets

	PSA data-4th root	Epifauna-Presence/Absence
No colonials-4th root	0.578 (0.0%)	
Burrowing and Infauna- 4th root	0.567 (0.0%)	0.783 (0.0%)
Epifauna- Presence/Absence	0.402 (0.6%)	

Biotopes

The community groupings were explored further using the similarity percentages program SIMPER, and results revealed characterising species from each of the acoustic regions. Average similarity between replicate samples collected within an acoustic region was relatively low, particularly where the substratum was very patchy (e.g. Regions ID and IE). Similar characterising species were identified from Regions IA, IB and IC, and from Regions ID and IE (Table 17). These results, along with information derived from the sidescan sonar mosaic and underwater video and photographic material, were used to derive biotopes, and these are listed under Section 4.5.5.

Table 17. Results from SIMPER analysis of Hamon grab data at the Isle of Wight site (all taxa excluding colonial and low abundance species, 4th root transformed), listing the main characterising species from each acoustically distinct region. Average abundance, ratio, percentage contribution to similarity, and cumulative percentage contribution to similarity for each species and the overall average similarity between replicate samples from within each region are listed

Acoustic region		Average Abundance	%	Cumulative %	Average similarity
IA	*Ampelisca spinipes*	36.57	5.42	5.42	**38.76%**
	Clymenura sp.	8.71	5.35	10.77	
	Nemertea	5.29	5.26	16.03	
	Lumbrineris gracilis	5.14	4.79	20.82	
	Pomatoceros lamarcki	20.86	3.85	24.66	
	Polycirrus sp.	7.57	3.61	28.27	
	Typosyllis variegata	14.00	3.26	31.53	
	Balanus crenatus	181.29	3.13	34.66	
	Elminus modestus	13.14	3.09	37.75	
	Nematoda	7.57	3.04	40.78	
	Notomastus sp.	4.14	3.04	43.82	
	Sabellaria spinulosa	46.14	3.00	46.82	
	Harmothoe impar	4.14	2.73	49.56	
IB	*Ampelisca spinipes*	19.33	7.73	7.73	**41.83%**
	Crepidula fornicata	21.33	5.63	13.35	
	Amphipholis squamata	10.67	5.28	18.64	
	Nucula nucleus	11.00	4.91	23.55	
	Mediomastus fragilis	5.00	4.70	28.25	
	Lumbrineris gracilis	4.00	4.66	32.91	
	Caulleriella alata	3.00	4.66	37.57	
	Scalibregma celticum	4.33	4.52	42.09	
	Polycirrus sp.	2.67	4.03	46.12	
	Pisidia longicornis	6.00	4.03	50.14	
IC	*Sabellaria spinulosa*	21.00	4.08	4.08	**52.80%**
	Pisidia longicornis	7.40	3.79	7.86	
	Sphenia binghami	12.20	3.67	11.53	
	Typosyllis variegata	6.60	3.61	15.14	
	Nemertea	4.00	3.53	18.67	
	Verruca stroemia	10.60	3.48	22.15	
	Amphipholis squamata	4.80	3.46	25.61	
	Lumbrineris gracilis	3.00	3.25	28.86	
	Clymenura sp.	4.60	3.24	32.09	
	Ampelisca spinipes	3.60	3.06	35.15	
	Anomia (juv)	1.00	2.62	37.78	
	Tricolia pullus	1.00	2.62	40.40	
	Molgula manhattensis	13.60	2.49	42.89	
	Modiolus tumida	5.00	2.38	45.27	
ID	*Notomastus sp.*	2.43	18.33	18.33	**29.45%**
	Eulalia mustela	1.57	18.12	36.46	
	Balanus crenatus	30.57	10.50	46.96	
	Ophelia borealis	3.57	9.78	56.74	
	Nematoda	2.43	3.57	60.31	
	Polycirrus sp.	0.71	3.16	63.48	
	Travisia forbesii	0.43	3.06	66.54	
	Pseudoprotella phasma	2.14	3.03	69.57	
	Crepidula fornicata	1.14	2.64	72.21	
	Nemertea	0.71	2.57	74.78	
IE	Nemertea	1.00	59.97	59.97	**22.27%**
	Ophelia borealis	1.33	21.18	81.15	
	Balanus crenatus	1.33	18.85	100.00	

4.5.4 Dungeness

A wide range of substrate types were present at this study site, ranging from soft mud through to coarse gravel/cobbles. Using the sidescan sonar mosaic and the underwater video footage it was possible to divide the area into five acoustic regions: Region DA - Soft mud; Region DB and DC - Slightly shelly, muddy sand with different amounts of underlying coarse material; Region DD - Coarse substrata (gravel, cobbles and boulders) with areas of muddy sand veneers; Region DE - Thick deposits of coarse sand overlying gravel/cobbles. However, confidence in the acoustic divisions was lower than at the other sites due to most of the regions grading into each other, with no distinct boundaries between regions. The majority of the site (Region DD) appeared to consist of a mixed and fairly heterogeneous seabed and, following the same rationale as for the Isle of Wight site, this area was classed as one type of physical habitat based on the highest degree of positional accuracy attainable using the ground-truthing methods available. Further divisions could not have been accurately ground-truthed.

Due to the poor visibility encountered during the ground-truth surveys in the north of the survey area at this site, and due to rough weather during the AGDS surveys which resulted in the collection of a poor data set, it was decided that this site should be treated as ‘low priority’, and attention should be focused on working up the data from the other three sites. For this reason the biological and AGDS data sets from this site have not been processed.

4.5.5 Derivation of Biotopes

The derivation of biotopes was based on the statistical analysis and interpretation of the biological, video and geophysical data sets at each site, as described above. Where possible, both Hamon grab and beam trawl data were used to obtain a good cross section of the benthic assemblages from each physical habitat. However, it was not always possible to deploy the 2 m beam trawl due to the uneven and rocky nature of the seabed in a number of the acoustic regions. It should, therefore, be noted that the biotopes derived from these regions may be missing important characterising species which are not frequently sampled by grabs (e.g. large or mobile epifaunal species). In some cases, the assemblages identified by one sampling method (e.g. grab) from an acoustic region were statistically distinct, but when sampled by a different method (e.g. trawl) were judged to be similar to assemblages from surrounding regions. Under such situations it was necessary to take account of all available data from the region (underwater video, AGDS) and make a subjective decision as to whether the region should be classed as a distinct biotope or not. Using all the available information it was therefore possible to identify discrete biotopes at each of the survey sites.

In total across the three sites, twelve biotopes were identified as listed below. At the Shoreham site six biotopes were distinguished (SA/B, SC, SD/E, SE, SF and SH). In most cases the spatial extent of these biotopes coincided with the acoustically distinct regions, with the exception of Biotopes SA/B and SD/E each of which covered two acoustic regions (see descriptions below). Similarly, at the Hastings study site, discrete biotopes were identified from each acoustic region (Biotopes HA, HB, HC and HD). However, Biotope HC (the dredged region on the Shingle bank) appeared to be a degraded form of Biotope HB (the undredged Shingle bank) and should possibly be classed as the same biotope. At the Isle of Wight study site acoustically distinct regions did not support discrete communities. Although the site could be divided into 5 acoustic regions there was a high degree of substrate heterogeneity, and as a result there were no clearly definable boundaries between regions. There was also a higher degree of variability in species composition between replicate samples collected from within each acoustic region. Nonetheless, two statistically distinct biotopes were recognised, Biotopes IA/B/C and ID/E. These biotopes spanned a number of acoustic regions which illustrates that acoustically distinct regions do not always support discrete communities.

A comprehensive description along with a visual example of each of the biotopes identified from across the three study sites is listed below:

Biotope SA/B (Shoreham)
Echinoderm dominated (Echinocyamus pusillus and Psammechinus miliaris) gravelly sand with occasional sand veneers.

Regions SA and SB at the Shoreham study site, whilst acoustically different, were very similar in terms of sediment characteristics and the benthic fauna. Particle size analysis revealed that both regions consisted of gravelly sands, with a high proportion of gravel on the seabed surface (determined form the video camera attached to the grab). Region SB differed due to the presence of sand veneers over parts of the area, but the presence of these veneers did not appear to have a major influence on community structure. The two regions could not be statistically separated in terms of community structure (using faunal Category 1 from the Hamon grab data), and were characterised by high numbers of the echinoderms *Echinocyamus pusillus* and *Psammechinus miliaris*.

Biotope SC (Shoreham)
Clean mobile sand with Abra prismatica.

Region SC at the Shoreham study site was characterised by moderately large sand waves. Transport features suggested that the region was mobile and unstable, and this was reflected in the low number of species and densities within the area. The main characterising species identified from the Hamon grab survey was the bivalve *Abra prismatica* and, despite an average abundance of only 1.2 individuals, it accounted for 49.5% of the similarity between samples collected from this region. The shrimp *Crangon allmani*, the brittle star *Ophiura albida* and hermit crab *Anapagurus laevis* were also identified as characterising species from the beam trawl survey.

Biotope SE (Shoreham)
Mussel beds on mixed, heterogeneous sediments.

Although not present across the whole of acoustic Region SE, and not identified as characterising species from the Hamon grab survey, the underwater drop camera revealed that areas of seabed within this region were dominated by *Mytilus edulis**. The Hamon grab survey failed to characterise the fauna and underlying sediments within these areas of dense mussel beds, and as a result they could only be described from the underwater video footage collected through deployment of the drop camera frame. (* tentative identification from the video footage).

Biotope SD/E (Shoreham)
Polychaete dominated mixed, heterogeneous sediments.

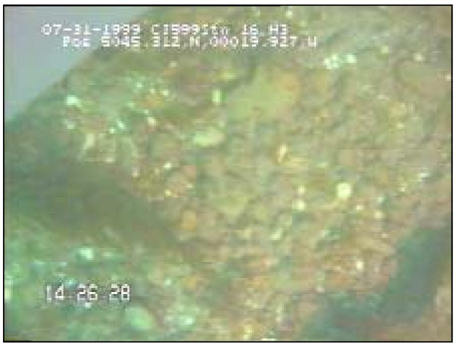
At the Shoreham study site, Region SD and parts of Region SE not covered by mussel beds consisted of very mixed, heterogeneous sediments and, although these regions appeared very different acoustically (Figure 3), they supported similar benthic communities. Both regions contained a large percentage of coarse sediments, and whilst the surface topography appeared very different between regions, particle size distributions were similar. Both regions had very high numbers of species and individuals, and were dominated by polychaetes such as *Lumbrineris gracilis* and Maldanid species, as well as a number of molluscan species (Table 5 and 6). Particle size distributions were similar to those in Regions SA and SB, but with a higher percentage of coarse material, and there were common, characterising species between all four of these regions (e.g. *Echinocyamus pusillus*, *Psammechinus miliaris, Lumbrineris gracilis*). However, differences in habitat and community structure were great enough to distinguish between Biotope SA/B and SD/E.

Biotope SF (Shoreham)
Sand and gravelly sand with Ophelia borealis, Bathyporeia sp. and Pomatoschistus minutus.

The seabed surface within Region SF at Shoreham was predominantly rippled sand, which was clearly identified from the acoustic record and underwater video/ photography. Particle size analysis revealed that the region contained a higher percentage of coarse material than initially expected and, as a result, the particle size distribution of sediments within this region was not statistically distinct from most other regions. However, the surface material appeared to be predominantly sandy, and this was reflected in the characterising fauna, the polychaete worm *Ophelia borealis*, the amphipod *Bathyporeia* sp. and the sand goby *Pomatoschistus minutus*, all of which prefer sandy substrates.

Biotope SH (Shoreham) *Cobbles with algae (unidentified), and Crepidula fornicata.*

Underwater video at the Shoreham site revealed that Region SH was very distinct from other regions. The substrate within the region was very coarse, consisting of a high percentage of cobbles and gravel supporting a large number of epifauna and flora (algal species were abundant within the region but were not identified or quantified). The region supported very high numbers of the slipper limpet *Crepidula fornicata*, which was identified as the main characterising species from both the beam trawl and Hamon grab surveys. Other characterising species included the polychaete worms *Scalibregma inflatum* and *Lumbrineris gracilis*, and the sea squirt *Ascidiella scabra*.



Region SH/F (Shoreham) did not appear to be a distinct region. Problems were encountered identifying the boundaries of the region from the sidescan sonar record, and the region appeared to form a transition between Regions SH and SF. For this reason the area has not been identified as a separate biotope, and has been treated as a zone of transition between the two neighbouring regions.

Biotope HA (Hastings)

Shallow water, polychaete dominated fine sand.

The inshore area of the Hastings study site (Region HA), consisting of fine shelly sand in which polychaete tubes were visible on the underwater video footage, was identified as a discrete biotope. The species composition was characterised by polychaete worms such as *Spiophanes bombyx*, *Magelona johnstoni*, *Nephtys cirrosa* and *Aphrodita aculeata*. Burrowing amphipods of the genus *Bathyporeia* were present as was the sand goby *Pomatoschistus minutus*.

Biotope HB (Hastings)

Coarse gravel with attached epifauna.

Region HB was the undredged region of Hastings Shingle bank. There was an abundance of attached epifauna; the soft coral, Dead Man's Fingers (*Alcyonium digitatum*) in particular distinguished this biotope from the others found at Hastings. Other characterising species included the sea urchin *Psammechinus miliaris*, the sea anemone *Metridium senile*, the hydroid *Sertularia*, the serpulid polychaete *Pomatoceros triqueter* and the encrusting bryozoan *Schizomavella*.

Biotope HC (Hastings)

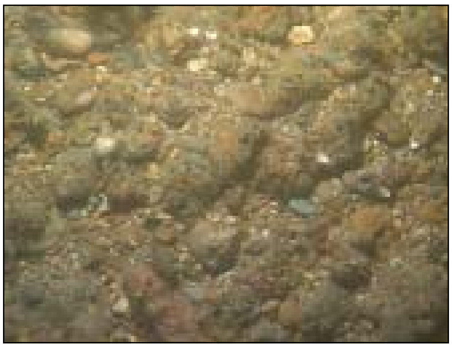
Disturbed (dredged) sandy gravel.

Region HC was the dredged area in the middle of the Shingle bank, surrounded by Region HB. The gravel within this region was sandier and less coarse than that of Region HB, and there were fewer sightings of large epifaunal species on the underwater camera footage from this area. This was confirmed by a marked absence of many of the sessile epifaunal species in the grab and trawl data that were abundant in Biotope HB. Whelks of the genus *Hinia* were a characterising species of HC.

Biotope HD (Hastings)
Deeper water, coarse sand with Ophiura ophiura.

HD was the region furthest offshore at this study site. The sediment was mainly coarse sand with low proportions of gravel in some areas, and the particle size distribution was similar to that of Region HA. However, the biotic component of this region was distinctly different, with fewer polychaete species, although the polychaete worms *Nephtys cirrosa* and *Spiophanes bombyx* were present as they were in Region HA. The brittle stars *Ophiura albida* and *Ophiura ophiura* were identified as characterising species from this habitat.

Biotope IA/B/C (IOW)
Slightly muddy, sandy gravel with epifauna encrusted cobbles.



A common feature of the regions within this biotope was the high content of fine sediments and a variable proportion of cobbles with abundant epifaunal growth, as revealed by the underwater camera. The species composition of Region IA showed strong similarities with both Regions IB and IC; however the species compositions of Regions IB and IC were less similar to each other. This suggests that Region IA may represent an intermediate habitat incorporating elements of both IB and IC. The amphipod *Ampelisca spinipes* and the polychaete worm *Lumbrineris gracilis* were important characterising species of the benthic assemblages for all three regions.

Biotope ID/E (IOW)
Consolidated gravel/rock covered by sand veneers with Ophelia borealis.

Regions ID and IE were very variable in terms of their physical habitat. The underwater camera revealed that Region ID consisted of large areas of sandy gravel. Within Region ID there were also areas of course sand intersected by slight depressions containing gravel and cobbles. Region IE was similar to the latter, being mostly comprised of course sand with a few cobbles. The variability in species composition between replicates within these two regions reflects the physical heterogeneity of the two acoustic regions. The polychaete worm *Ophelia borealis* was, however, an important contributor to similarity in both Regions ID and IE.

Following the site-specific division of each study area into discrete biotopes, cluster analysis was performed on the entire Hamon grab data set from all three sites to establish whether assemblages from different sites inhabiting similar substrata were statistically distinct or not (Figure 17). Overall, samples which had been identified as discrete biotopes at the site-by-site level tended to be grouped together. There was also clustering of samples from each of the three study sites. Results from analysis of similarities tests (ANOSIM, Clark 1993) conducted on these data supported the biotope derivations (Table 18). There was no significant difference between acoustic regions which had been identified as the same biotope (e.g. IA, IB and IC; ID and IE; SA and SB; SD and SE). On two occasions regions which had been identified as discrete biotopes at the site-by-site level were not found to be statistically distinct (SA and SD, and SD and SH/F). These regions did show some degree of similarity in terms of their habitat traits and biological assemblages. However, it was decided that the biotopes derived from the site-by-site analysis of the data should be retained as these derivations were based on all available data (beam-trawl, video, AGDS data), rather than on just the Hamon grab data. The geographical distribution of these biotopes at the Shoreham, Hastings and Isle of Wight sites are shown in Figures 18, 19 and 20.

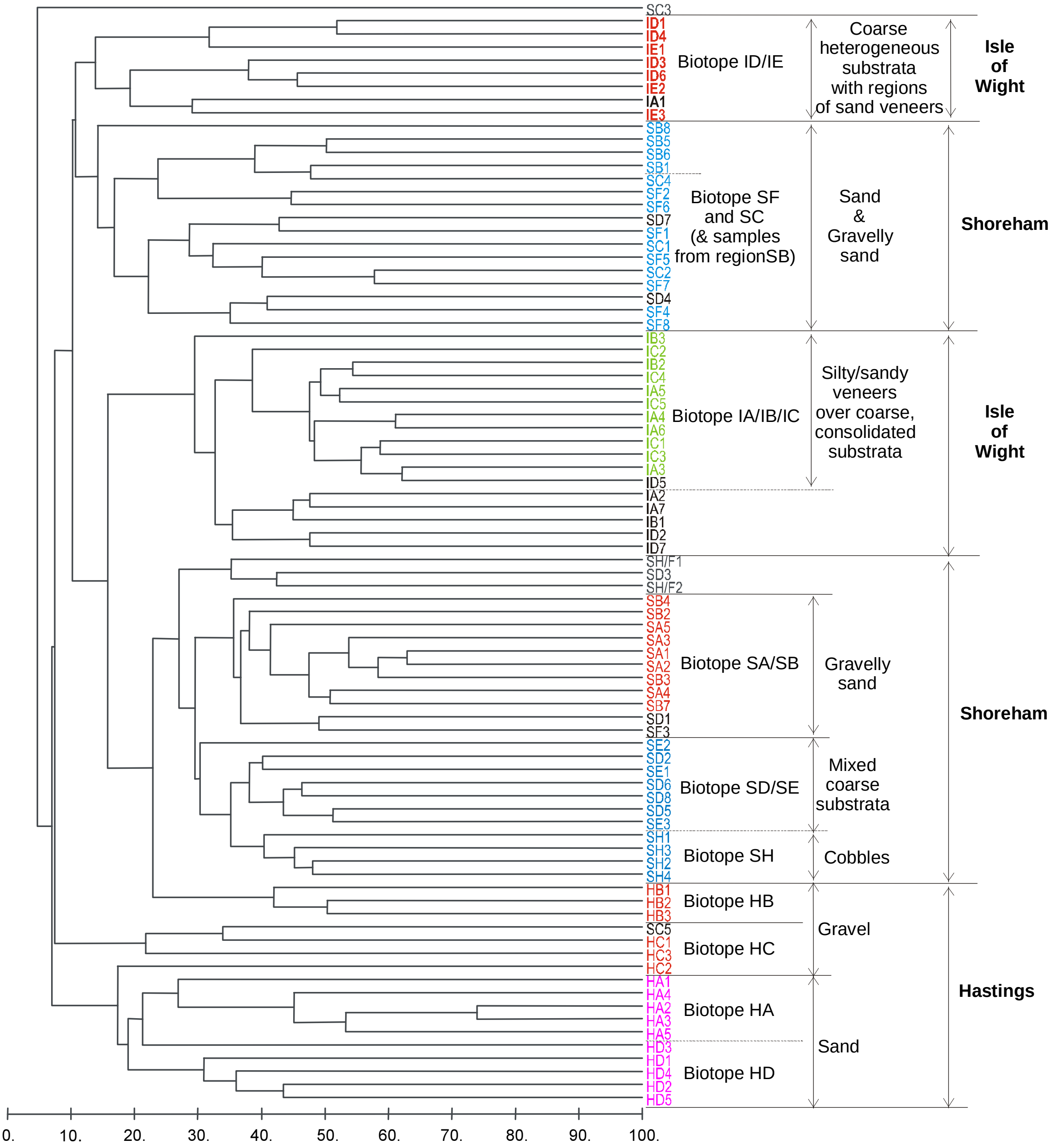


Figure 17. Dendrogram of faunal data from the Hamon grab surveys at the Shoreham, Hastings and Isle of Wight sites. Colonial species have been removed and data were 4th root transformed. Biotopes identified from each of the sites are colour coded and labelled, and stations that do not appear to fit into the biotope classes are coloured in black

*Table 18. Analysis of similarity for Hamon Grab data between acoustically distinct regions from all three study sites (Shoreham, Hastings and the Isle of Wight). Colonial species were removed and analysis was based on 4th root transformed data. (n.s = no significant difference. * = significant difference at p<0.1. Blank = significant difference at p<0.05)*

	IA	IB	IC	ID	IE	SA	SB	SC	SD	SE	SF	SH	SH/F	HA	HB	HC
IB	ns	-														
IC	ns		-													
ID				-												
IE		*		ns	-											
SA						-										
SB						ns	-									
SC								-								
SD						ns			-							
SE		*			*				ns	-						
SF								*			-					
SH									*	*		-				
SH/F		*			*		*		ns	*	*	*	-			
HA														-		
HB		*			*					*			*		-	
HC		*			*					*			*		*	-
HD																

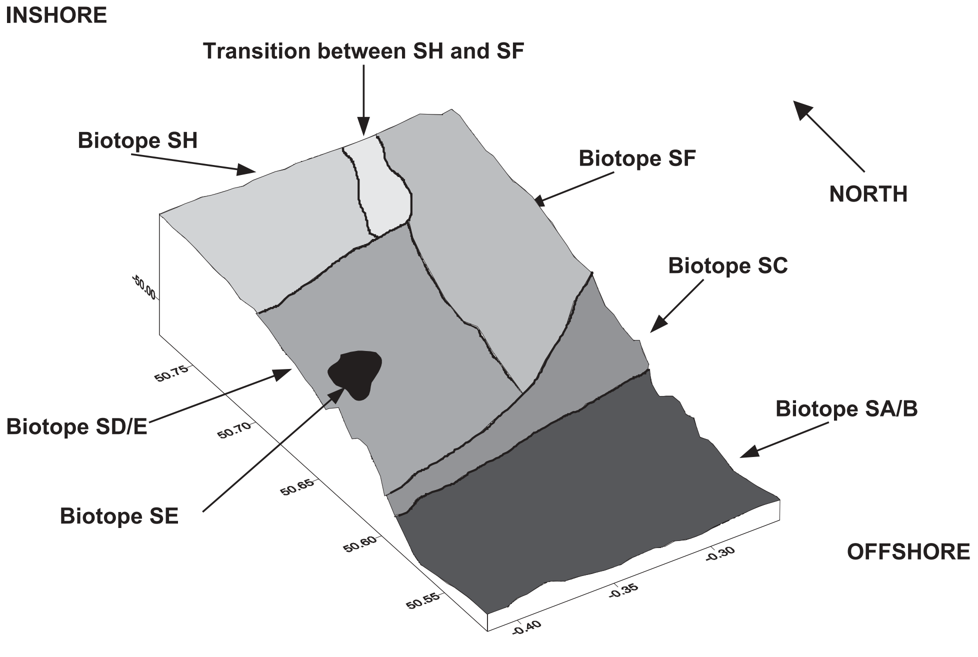


Figure 18. Bathymetric plot of the study site at Shoreham showing the spatial distribution of the 6 biotopes identified (area 28 km x 12 km)

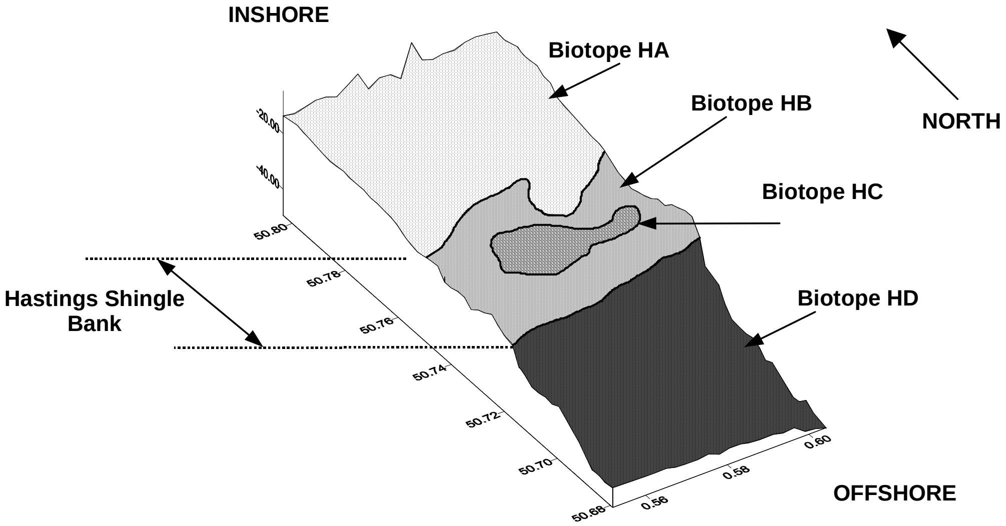


Figure 19. Bathymetric plot of the study site at Hastings showing the spatial distribution of the 4 biotopes and the Shingle bank (area 12 km x 4 km)

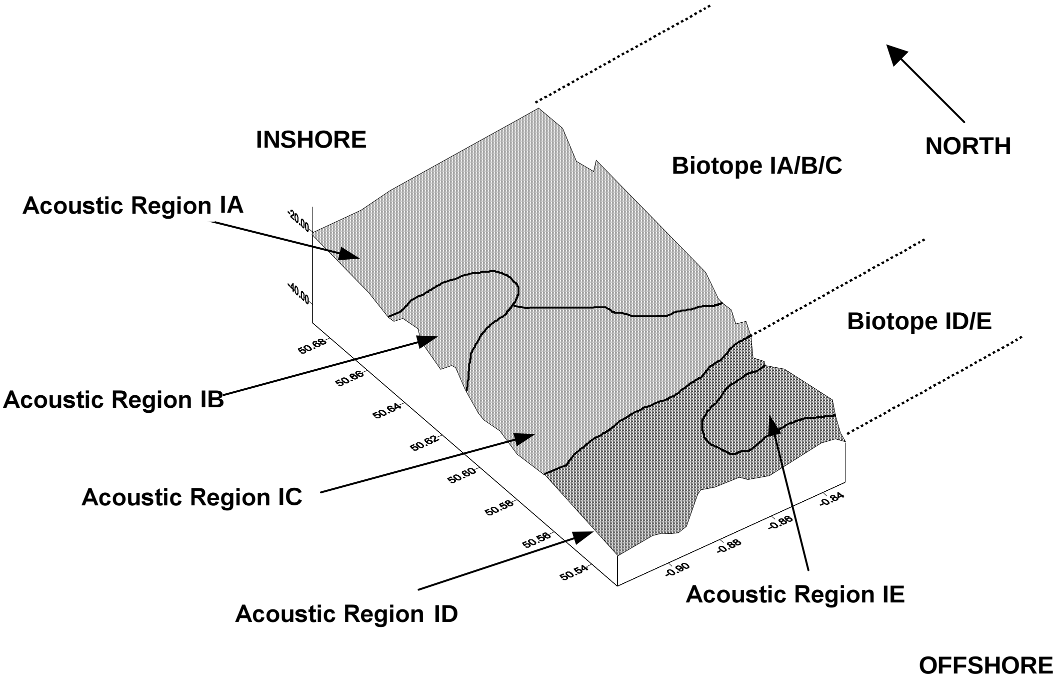


Figure 20. Bathymetric plot of the study site to the east of the Isle of Wight. The spatial distribution of the 5 acoustic regions and 2 biotopes are illustrated (area 12 km x 4 km)

5. DISCUSSION

Objective:
To characterise the seabed in an area of the eastern English Channel using various physical and geophysical techniques.

The methods described above proved successful in characterising seabed habitats in the eastern English Channel. Conventional surveys of the seabed, in a biological (and to some extent geological) context, deploy small samplers at discrete stations, and in order to make inferences concerning the spatial pattern of seabed characteristics (e.g. habitats, sediment distributions or benthic communities) it is necessary to interpolate between these stations. This interpolation process can involve a significant 'leap of faith' concerning the unsampled seabed, and ultimately result in an under-representation of the true variability of the seabed. The work summarised in this report demonstrates the advantages of using acoustic systems, in particular swathe systems such as sidescan sonar, which are capable of exposing patterns or complexities which are hidden to a single-point sampling regime.

The swathe coverage of the sidescan sonar system, coupled with its high resolution imagery of the seabed surface and the ability to mosaic the image to produce 100% spatial coverage maps, allowed relatively large areas of the seabed to be characterised rapidly and accurately. The main benefit of such an approach was the identification of acoustically distinct regions which, following ground-truthing using underwater cameras, were found to relate to discrete physical habitats. By targeting biological sampling it was possible to establish whether statistically discrete communities existed within the boundaries of such regions. This allowed informed interpolation between the biological sampling stations in order to produce biotope maps. In most cases there was a strong correlation between the presence of acoustically distinct regions and discrete assemblages. However, despite the fact that statistically distinct communities did exist within most of the acoustic regions, the variability between replicate samples collected from within an acoustic region, both in terms of species composition and sediment properties, was often very high. This highlights the large degree of natural biological variability and small-scale sediment patchiness that can be encountered in benthic ecosystems, even at locations which appear, superficially, to be relatively homogeneous. It is therefore advisable to collect as many ground-truth samples (biological, sediment and photographic) as resources allow to reduce the chances of misinterpretation. This is particularly important in regions with a high degree of substrate patchiness, such as the eastern Isle of Wight.

The combination of physical and geophysical techniques provided a robust approach to seabed mapping. Confidence in the accuracy of seabed habitat maps produced using either technique in isolation would be much lower than maps produced using an integrated approach utilising a suite of techniques. An example of the benefits of an integrated approach was highlighted through the use of the Hamon grab fitted with an underwater camera. The pilot survey in Year 1 used a 0.1 m^2 Hamon grab without a video camera attached to ground-truth acoustic regions/habitats identified from the sidescan sonar data. There was often disagreement between the predicted substrata from the sidescan sonar record and the type of sediments which were collected by the grab (e.g. the sidescan sonar data revealed a seabed which appeared to consist of rippled sand, and the grab would retrieve a gravel sample from the area). Fitting the Hamon grab with a camera, thereby recording an image of the undisturbed surface of the seabed, revealed that this anomaly between the physical sample and the acoustic data was often due to the presence of a thin sandy veneer at the seabed surface masking the dominant sediment type below. The use of video, grab and acoustics established a clear understanding of the true nature of the seabed habitat, and allowed the spatial distribution of habitats to be mapped with a greater degree of confidence.

The concept of discrete communities versus continua has long been debated. Glémarec (1973), after reviewing the arguments in a number of earlier studies, concluded that there are no sharp distinctions between neighbouring communities but rather gradual changes in the composition of the fauna without discontinuities. However, he recognised that in order to produce maps it is necessary to draw demarcation lines, and as a result communities are defined which relate to the peaks of frequency (or noda) within the continuous gradient of faunal composition. Basford *et al*. (1989, 1990) also reported that 'community types', identified from surveys in the North Sea, were found to grade into one another along continuous environmental gradients, even though discrete assemblages could be identified statistically and characterised by particular species. These studies were conducted at very broad scales, where gradients responsible for the changes in assemblage structure (temperature, salinity and depth), although often gradual, were nevertheless significant over the entirety of the survey area.

Other factors, such as sediment characteristics, are thought to have a greater influence on assemblage structure at more localised scales (Holme, 1961, 1966; Glémarec, 1973; Eleftheriou and Basford, 1989; Seiderer and Newell, 1999). Substratum types can often show discontinuities across a region which may give rise to distinct boundaries between neighbouring assemblages. The use of sidescan sonar in the current study enabled such boundaries to be identified and mapped. Designing subsequent biological surveys around the acoustically distinct regions determined from the sidescan sonar data made it possible to test whether discrete assemblages existed within these boundaries. In some cases, discrete physical boundaries could be identified between two neighbouring regions which did not support discrete assemblages (e.g. Shoreham Regions SA and SB; SD and SE). In these cases differences between the adjacent regions were too subtle to have a significant effect on the composition of the benthic community. However, discrete benthic assemblages did appear to be contained within the boundaries of most other regions (Region SC, SF and SH), suggesting that at this scale faunistic boundaries can exist, but may only be recognised using appropriate techniques (e.g. high resolution sidescan sonar).

Even though faunistic boundaries were identified within parts of the survey areas, there was also evidence of spatial gradation of habitats and communities from one area to the next. This was particularly apparent in the north of the Shoreham survey area between Regions SH, SH/F and SF. It is possible that boundaries between these regions did exist, but that the poor sidescan sonar record from this area caused by the shallow water depth prevented them from being identified. However, evidence from the underwater video footage did suggest the presence of an east-west sediment gradient from sandy substrates in the east to coarse gravel and cobbles in the west. This gradual east-west sediment transition was also reflected in the biological data; Regions SH and SF were characterised by statistically different benthic communities, with Region SH/F comprising common species from both these regions, thus forming a non-statistically distinct transition region. Such transition regions between distinct habitats/assemblages, sometimes referred to as ecotones, have been described in the past (Dewarumez *et al*., 1992), and it is arguable whether or not they should be treated as entities. The evidence from the current study suggests that the presence of either discrete habitat/faunistic boundaries, or of sediment/faunistic gradients between statistically distinct, adjacent regions is a site-specific phenomenon. However, the lack of clearly definable boundaries between adjacent habitats can cause major problems when attempting to produce high-resolution seabed maps due to difficulties in determining where demarcation lines should be drawn.

Objective:
To determine the causes of biological variation and of observed patchiness and to devise appropriate sampling strategies to allow for this variation. This work aimed to take particular account of dynamic aspects of the environment within which the benthic communities had developed.

In the English Channel, a number of studies have attempted to identify and explain distribution trends in benthic species, assemblages and habitats (Holme, 1961, 1966; Cabioch, 1968; Davoult *et al*., 1988; Sanvicente-Anorve *et al*., 1996). Community types identified in these studies, along with those identified from other regions (e.g. North Sea: Dyer *et al*., 1983; Basford *et al*., 1989, 1990; Eleftheriou and Basford, 1989; Kunitzer *et al*., 1992; Rees *et al*., 1999) show some parallels with the biotopes identified under Section 4 of this report. However, most of these earlier studies were conducted over large areas (i.e. whole sea areas) where differences in the biogeographical ranges of species might be expected to contribute to changes in community structure. At each of the present study sites, biotopes were identified over a relatively small area of seabed, at a much higher resolution, where biogeographical constraints on distributions of species would clearly have no influence on community structure. Instead, more localised variables were responsible for changes in species distributions, such as sediment granulometry. It should therefore be recognised that the biotopes identified in the current study may represent sub-sets within the community types proposed in the past, due to the differences in scale and sampling intensity between the current and past studies.

Sediment type appeared to be the major variable influencing community composition. There was correlation between particle size distribution and assemblage structure at all three study sites, and acoustically distinct regions, which were determined primarily on the basis of changes in surficial sediments across the sites, tended to support statistically distinct communities. However, particle size distributions alone may not always be the best guide to predicting community types. On numerous occasions the particle size distributions of sediments from a number of acoustically distinct regions were similar, despite the regions supporting very different assemblages. In such situations seabed morphology, determined from the sidescan sonar record and underwater video footage, appeared to have a greater influence on assemblage structure. For example, at Shoreham there was no statistical difference between the particle size distributions of sediment samples collected from acoustic Regions SA and SF, but the regions supported statistically distinct communities. This difference can be attributed to seabed morphology and sediment stratification; the seabed surface in Region SF consisted predominantly of the sand fraction of the sediment whereas Region SA consisted of the gravel fraction, even though the overall particle size distributions between the two regions were very similar. This difference in sediment stratification was sufficient to cause a difference in community composition between these two regions. This highlights the importance not only of sediment granulometry to community structure, but also of seabed morphology.

Sediment heterogeneity also had an influence on community structure and the ability to recognise and map discrete assemblages. In certain regions at the Isle of Wight study site (e.g. Region ID) there was a very high degree of small-scale sediment heterogeneity, with regions consisting of a complex arrangement of relatively small patches of sand, gravel and bedrock/boulders occurring in close proximity. Whilst each 'patch' of substrata probably supported a discrete benthic assemblage, it was beyond the positional accuracy of the sampling devices to sample at such a fine scale, and hence impossible to create such detailed biotope maps. This problem was overcome by producing 'coarser resolution' maps which classified the heterogeneous regions as one biotope. The geographical scale of the acoustic regions identified at the Isle of Wight study site was comparable to the scale at which the other study sites at Shoreham and Hastings were divided into acoustic regions. This pragmatic approach still allowed statistically distinct communities to be identified (e.g. Biotope ID/E) whilst recognising that similarity in terms of species composition between replicate samples would be lower in such heterogeneous regions.

Comparison of biotopes between the sites (Shoreham, Hastings and the Isle of Wight) revealed that there were a number of similarities in terms of characterising species and habitat characteristics, even though biotopes between sites were always statistically discrete. There were a large number of species which were common to similar substrates at each site, and at the geographical scale of the study (i.e. Eastern English Channel) there appeared to be few changes in species composition which could be explained by biogeographical factors. Similar findings are presented by Holme (1961, 1966) who reports similar species distribution across this region of the English Channel. There were also similarities between the sites in terms of water depth and hydrodynamic regime. Under such circumstances, it would be expected that similar habitats would support similar communities. However, it is important to emphasise that this may not always be the case, and in other areas factors other than sediment granulometry and seabed morphology may have significant influences on community structure. Further work is needed, testing these techniques over a wider range of biogeographical sites and hydrodynamic conditions, to fully address this issue.

Objective:
To establish the utility of seabed mapping techniques for surveying habitats.

The results from this study revealed that the approach adopted and the methods developed were successful in identifying and mapping the spatial distribution of seabed habitats and biological communities. One of the greatest strengths of this approach was the integrated use of a wide range of physical, acoustic and visual techniques. This allowed a comprehensive picture of the seabed to be built up. The variable nature of the seabed environment, in terms of both the physical and biological properties, makes prediction of these traits based solely on acoustic data almost impossible. Sampling from within each acoustic region at all of the study sites revealed that there was a high degree of sediment and species variability between replicate samples. Whilst differences between regions were sufficient to allow the identification of discrete biotopes, this high level of variability highlights the necessity to collect sufficient numbers of samples from within each region to eliminate the chances of misinterpretation through under-sampling. It should therefore be emphasised that acoustic methods should NOT be used in isolation as a tool for the prediction of seabed traits (biological and physical) and that ground-truthing methods should ALWAYS be used to confirm interpretations.

Comparing acoustic systems revealed that for accurate, continuous spatial mapping swathe systems, such as sidescan sonar, out-performed single beam acoustic systems such as AGDS. Whilst AGDS can provide useful information concerning the nature of the substrata, the main drawback is the need to interpolate between survey lines to obtain continuous coverage maps. The interpolation process has the potential to overlook discrete habitats/assemblages which may lie in the un-surveyed region between the survey lines, and this can lead to under-representation of the true variability of the seabed. However, the data provided by such systems is relatively cheap to collect, provides a useful additional layer of information concerning the seabed, and can often be collected at the same time as the swathe acoustic data (depending on the frequency of the systems). The use of such systems in seabed mapping work should therefore not be overlooked, especially considering recent developments aimed at developing swathe AGDS systems, and sidescan sonar and AGDS should therefore be considered as complementary systems when undertaking high-resolution mapping studies. These issues concerning the usefulness of AGDS systems in habitat mapping are discussed further in a separate report prepared in collaboration with the SeaMap Group, University of Newcastle upon Tyne (Foster-Smith *et al.*, 2001).

In the first year of the study, trials compared multibeam bathymetric systems with sidescan sonar systems as tools for mapping habitats/assemblages on coarse substrata. Whilst both systems were judged to provide useful information concerning the nature of the seabed, and both systems covered a swathe of seabed in one pass, the decision to use sidescan sonar as the main acoustic technique was based on the properties of the output: sidescan sonar provided a textural image of the seabed from which seabed morphology and sediment characteristics could be derived. It was felt that this textural information would be of more use when establishing links between the physical seabed habitats and benthic assemblages than would detailed information concerning depth, as would be provided by swathe bathymetric systems. At the time swathe bathymetric systems were also relatively expensive compared to sidescan systems, and this factor also contributed to the decision to use side scan sonar. Since commencement of this study there have been significant developments in swathe bathymetric technology. Information concerning the nature of the seabed sediments (e.g. hardness, substrate type) can now be determined from the acoustic backscatter data, and developments in this area of acoustic technology are advancing rapidly. It is therefore important to realise that the methodology developed in this study should be reviewed regularly, and augmented with the incorporation of improved techniques.

The derivation of biotopes relied on the use of all available data from the study areas (Sidescan sonar, AGDS, biological and sediment data from grabs and trawls, underwater video footage). Wherever possible statistics were used to aid the identification of discrete assemblages. However, the process was not always straight-forward, and it was often difficult to identify whether two areas should be classed as the same or separate biotopes. The combined use of sidescan sonar and underwater video/photographic techniques proved to be a useful approach in order to provide information concerning the physical characteristics of an area of seabed. However, when characterising the seabed assemblages of an area the type of sampling gear used has a profound effect on how the community is described. In the current study a 0.1 m^2 Hamon grab and a 2 m beam trawl were used to characterise the benthos within the acoustic regions. It was evident from the characterising species identified from each region that the use of either of these techniques in isolation would result in the derivation of different biotope descriptions. This is due to differences in the nature of the sampling gear which results in the collection of a different fraction of the benthic community. Therefore the type of sampling gear has a considerable bearing not only on the identification of characterising species, but also on the power to discriminate between habitat types on the basis of biological traits. The relevance of the characterising species for the management of activities within a mapped region is another important practical consideration which bears upon the biological sampling techniques employed. For this reason the deployment of a combination of sampling techniques would provide a more realistic means of describing the benthic ecosystem, accepting that the capacity to discriminate between habitat types on biological grounds may often be method dependent (Holme, 1961; Rees *et al*., 1999).

Objective:
To evaluate the susceptibility of gravel biotope benthic communities to anthropogenic disturbances in contrasting areas, particularly by dredging. This aimed to involve the testing of established and novel methods for describing and quantifying biological status and sensitivity.

The mapping techniques described in this report allowed detailed biotope maps of the seabed to be produced. Once discrete assemblages had been identified using this approach, their geographical distribution mapped, and their association with the physical habitat established, then the biological status of each biotope could be determined. Established methods for describing the biological status of assemblages, such as total abundance and number of species, were calculated for each biotope. In a similar manner other measures such as Shannon-Wiener diversity index, species richness and species evenness, along with novel measures such as taxonomic diversity and taxonomic distinctness (Clarke and Warwick, 1998, 2001; Warwick and Clarke, 1995, 1998), could also have been calculated for each biotope from the available data. In such a way these measures could be determined across geographical regions, and not just for point data as would normally be the case in conventional benthic surveys using only grabs or trawls to sample the benthic ecosystem. This has the benefit that the relative spatial abundance and status of a particular habitat/assemblage type can be measured. Such information would be useful in a management context, as it provides information on the rarity of a particular habitat which can aid decisions regarding whether or not measures need to be taken to reduce or prevent impacts from anthropogenic activities, such as dredging, in such areas.

Species sensitivity has previously been defined as ‘the intolerance of a habitat, community or individual (or individual colony of a species) to damage, or death, from an external factor’ (Hiscock, 1996). Whilst it is often possible to infer the sensitivity of an individual species through known information on its life history (e.g. life style, life-cycle strategy (‘K’ or ‘r’ strategists), recruitment, longevity etc.), it is often very difficult to quantify such information. This issue becomes more complicated when attempting to quantify or determine the sensitivity of a biotope, which consists of many different species all with different life history traits and sensitivities to perturbation. A number of studies have attempted to develop sensitivity indices for benthic species and communities subjected to different types of disturbance (Rees and Dare, 1993; Cooke and McMath, 1998). However, the results of such studies are some way from routine application in benthic surveys, and further work addressing the development of sensitivity measures is required. Nonetheless, an indication of how sensitive a biotope is to disturbance can be determined from known information concerning the life history traits of individual species within that biotope, and of the nature of the physical habitat in which the species reside.

The mapping approach adopted in the current study allowed judgements to be made about the sensitivity of each biotope to anthropogenic disturbances such as dredging. The stability of each habitat could be inferred from the sidescan sonar data, and this gave an indication as to how sensitive that habitat would be to physical perturbations. In general, the more unstable the physical habitat, the less sensitive and more robust the biotope would be to disturbance. For example, Biotope SC at the Shoreham study site consisted of a region of mobile sand waves with only a low number of ‘r’ selected species. In contrast, Biotope SD/E consisted of a stable physical habitat of consolidated coarse sediments and boulders with a high species diversity, with several ‘K’ strategists. From such information it can be inferred that

Biotope SC would be less sensitive and more resilient to the impacts of dredging than Biotope SD/E. In addition to this, the relative abundance of each biotope is also known and has been accurately mapped. This allows an assessment to be made of how rare each biotope is in terms of its geographical coverage. This may have management implications regarding whether or not dredging should take place in a particular area. For example, a biotope may be deemed sensitive to the impacts of dredging, but may cover a large geographical area. In such a situation removal of sand and gravel may be allowed within a restricted area of the biotope. However, such decisions would not be possible without detailed biotope maps of a region, and therefore the methods described in this report (Section 4) can be seen to hold many advantages for the management and regulation of anthropogenic activities such as dredging.

6. CONCLUSIONS AND RECOMMENDATIONS

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

- An integrated approach, using a combination of remote desctructive (Hamon grab and 2 m beam trawl), acoustic (sidescan sonar, AGDS) and visual (underwater and stills photography) techniques provided a robust approach to seabed mapping. Such an approach allows seabed habitat/biotope maps to be produced to a relatively high level of accuracy and with confidence. ***It is recommended that a <u>combination</u> of the survey techniques listed above are used when producing high-resolution biotope maps of an area.***

- ***The techniques and approaches described in this report would be suitable for use in mapping gravel biotopes at potential aggregate extraction sites.***

- ***Acoustic methods should NOT be used in isolation as a tool for the prediction of seabed traits (biological and physical) and ground-truthing methods should ALWAYS be used to confirm interpretations.***

- ***Swathe acoustic systems***, such as sidescan sonar, ***out-performed single beam acoustic systems*** such as AGDS. The main benefit of swathe systems was the ability to ensonify 100% of the survey area, thus producing full spatial coverage seabed maps. With any single beam system interpolation was required to produce similar coverage maps, and this process has the potential to overlook discrete assemblages or habitats which may lie in the un-surveyed region between survey lines. However, single beam systems tend to be much cheaper than swathe systems and do provide useful information concerning the seabed surface traits (e.g. surface and near sub-surface sediment types) which can be complementary to swathe acoustic data. Their usefulness should therefore not be overlooked.

- Acoustic technology is constantly changing and improving. New acoustic systems and techniques regularly enter the market place. Therefore, ***it is important that the mapping methodology is reviewed regularly, and augmented with the incorporation of improved acoustic techniques where appropriate and where costs permit.***

- ***It is recommended that as many components of the benthic community are sampled as possible (i.e. both macro-infauna and epifauna), through the use of a combination of sampling techniques, in order to provide a more realistic means of describing the benthic ecosystem, accepting that the capacity to discriminate between habitat types on biological grounds may often be method dependent.*** The type of biological sampling gear has a considerable bearing on the identification of characterising species from a particular habitat. Different types of gear sample different fractions of the seabed assemblage, and the type of gear used can therefore have an effect on the power to discriminate between habitat types on the basis of biological traits. The relevance of the characterising species for the management of activities within a mapped region is an important practical consideration which bears upon the biological sampling techniques employed.

- ***Sediment type and seabed morphology appeared to be the major variables influencing community composition in the areas studied during this investigation.*** However, it should be noted that conditions at each of the study sites were comparable, and the extent to which other factors (e.g. hydrographic variables) influence assemblage structure is still unclear from the results of this study. Further work is required to compare habitats from different biogeographical regions, across a wider range of substrata and with different hydrographic regimes.

7. FUTURE WORK

The techniques developed during this project may usefully be extended to site-specific studies of areas of gravel extraction. They may be extended to the evaluation of other seabed substrata and related human impacts, especially dredged material disposal and the effects of fishing activities. They may also be applied to investigate more general benthic ecology issues, such as factors influencing scale-dependant variations in benthic communities. Recent advances in post-processing techniques, particularly in the area of pattern recognition of sidescan sonar data, should facilitate the objective identification of acoustically distinct seabed types at a range of scales. These techniques may be applicable to biotope mapping methodology, and could be linked in to biological investigations into scale dependant variations.

Recent and rapid developments in affordable, high quality, swathe bathymetric systems, have led to these systems becoming popular as tools for use in habitat mapping activities in other countries (Canada, USA, Republic of Ireland). There may be scope to develop habitat mapping procedures using these techniques, in conjunction with biological sampling methods, to map seabed biotopes over relatively large areas.

Many of the issues identified above for further research are included in a DEFRA funded research and development project AE1033 - Role of seabed mapping techniques in environmental monitoring and management (April 2001-March 2005).

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