Report Number
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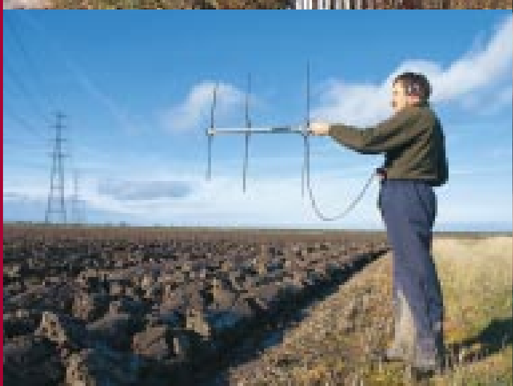
English Nature Research Reports



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Sabellaria spinulosa reef in The Wash and North Norfolk Coast cSAC and its approaches: Part II, fine scale mapping of the spatial and temporal distribution of reefs and the development of techniques for monitoring condition

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Contents

1. Background

As part of the development of the Management Scheme for the Wash and North Norfolk cSAC it is necessary to establish the baselines and condition and compliance monitoring programmes for the interest features in order to determine whether the conservation objectives have been, or are in the process of being achieved. Biogenic sand reefs built by the polychaete *Sabellaria spinulosa* are one of the features of interest as a 'reef' in its own right, having recently been upgraded from being a 'key component of subtidal mixed sediment communities'. The Wash and its approaches are considered particularly important because they are thought to harbour the only known well-developed, stable reefs created by this species in the UK.

The 2001 project is the latest in a series of surveys carried out by SeaMap and the Eastern Sea Fisheries Joint Committee (ESFJC) in this area starting with the Broadscale Mapping Project (BMP) in 1997. The BMP surveys were designed to map the distribution of a wide range of biotopes and *Sabellaria spinulosa* reefs were not specifically targeted. Remote sensing was used to map the full range of biotopes present in the area and the field sampling was designed to be representative of these biotopes (1) for descriptive purposes and (2) to be ground truth data for classification of the remote data. Broad scale map-based surveys (unless they are also exhaustive) can only be indicative about biotope distribution and are accompanied by a variable and often high level of uncertainty.

Nevertheless, the surveys showed that there were clear broad scale trends to the distribution of biotopes. The descriptions based on video and grab sample data also showed that many of the infaunal biotopes were very similar in species composition or had a large area of overlap.

It was not until video evidence of well developed reefs was collected from the northern margins of the sand extraction area 107 (outside of the cSAC) that the existence of these reefs was brought to the attention of English Nature (although personal communication with CEFAS has established that this was known to them at about this time). Although there was no direct observation of reefs within the Wash cSAC itself (due to poor underwater visibility during the surveys), comparison of the infaunal composition of grab samples taken from certain sites within the Wash and the observed reefs in area 107 suggested that reefs might also occur in the cSAC. Certainly, extremely dense populations of *Sabellaria* were found. This survey described the range of biotopes found and it was suggested that *Sabellaria* biotopes ranged from low density populations, through high density communities with poor reef development to well developed reefs. In other words, there was likely to be a continuum between similar biotopes.

SeaMap has since conducted three surveys (1999[1], 2000[2] and 2001[3]) with varying objectives. In 1999 the primary objective was to provide a basis for monitoring changes in the distribution of major habitats and biotopes at selected representative locations within the Wash. The justification for selecting representative sites was to keep survey costs down to an acceptable level and this remained an important consideration in the design of subsequent

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[1] Foster-Smith, R.L. 2000. *Establishing a monitoring baseline for the Wash subtidal sandbanks, the Wash & north Norfolk Coast cSAC.* A report for English Nature.
[2] Foster-Smith R.L. & White, W.H. 2001. Sabellaria spinulosa *in the Wash & North Norfolk Coast cSAC and its approaches: Stage I, Mapping techniques and ecological assessment.* A report for Eastern Sea Fisheries Joint Committee and English Nature.
[3] The subject of this report.

surveys. Again, *Sabellaria* was not specifically targeted, but the results suggested a decrease in *Sabellaria* between 1997 and 1999. No high density populations or reefs were observed.

The 2000 survey was the first to specifically target *Sabellaria* and the aims were (primarily) to investigate ways of detecting reefs through the use of acoustic techniques (acoustic ground discrimination systems – AGDS and sidescan sonar) and direct observation using remote video. Two sites were selected for the survey – one in the cSAC just south of Long Sands and the other was area 107. The survey was partially successful in that the sonar techniques were tested over observable reefs at 107, but did not give a distinctive image using sidescan. They were more readily detected using AGDS, but this system is not high resolution and differences between systems and interpretation of the data result in different boundaries. However, no reefs (or high density *Sabellaria* populations) were found at the Long Sands site and poor weather prevented repeating and confirming results of the acoustic trials over known reefs at 107. This was despite video observations made by ESFJC in the previous year of reefs at the Long Sands site.

A review of all previous grab sample data collected by SeaMap backed up the suggestion that *Sabellaria* reef development might be an extreme form of dense worm population with only a weak indication that reefs might form a distinct population and associated community structure. The records from the 2000 and previous surveys were consistent with the hypothesis that *Sabellaria* is patchily distributed and/or temporally very variable. This remained to be tested but, if worm populations and reefs are dynamic rather than stable structures, this should influence both management objectives for maintaining this interest feature and the design of monitoring surveys for compliance.

Another suggestion emanating from the previous studies is that reefs are well developed and relatively stable offshore and they are more variable further into the Wash. The overall distribution of samples where *Sabellaria* was found at moderate to high densities certainly indicates a gradual reduction in their frequency of occurrence the further these sites are into the Wash.

It is difficult to detect and measure the patchy distribution of benthic biotopes and to determine any broad scale trends and their environmental causes. This is particularly the case if the patches cannot be 'seen' with reasonably fine scale resolution over large areas. The options open for survey are:

1. Sidescan for high resolution images of reefs to measure and map reef patchiness: The problems with this approach are (a) that there is no evidence to support this technology as a tool for obtaining clear and distinctive images of reefs and (b) if reefs are variably developed then it might be difficult to detect the full range of reefs against a background of other habitats.
2. AGDS for sediment discrimination: This could be used to predict distribution, but (as previously stated) not at a very satisfactory resolution or high level of certainty.
3. Video: This is the only technique that can detect reefs with confidence. However, (a) the sample area covered is small, (b) it is dependant on good underwater visibility, and (c) low *Sabellaria* tubes cannot be identified from the video.
4. Grab samples: Analysis of the infauna confirms the presence of *Sabellaria* and also enables measurement of associated species diversity. However, the sample area is very small and subject to 'hit-and-miss' in patchy habitats. To overcome this, high

numbers of samples are required and analysis of these is expensive, unless this is restricted to a visual assessment on-board.

5. Novel acoustic technologies: Acoustic 'cameras' based on scanning sonar might be able to detect reefs. However, this technology has not been tried and the coverage of the sonar is restricted.

With these constraints in mind, the 2001 survey was planned to try to address some of the outstanding issues from the previous surveys, particularly the assessment of patchiness and variable development of reefs and possible broad scale trends.

2. Objectives

The objectives (that apply to the SeaMap collaboration) as set by English Nature are stated as:

1. To identify the distribution of *S. spinulosa*:
    a. To map the maximum likelihood distribution of *S. spinulosa* in selected survey boxes along the transect.
    b. To test techniques by assessing the application of different acoustic survey and ground-truthing methods for identifying and measuring *S. spinulosa* reefs at different stages in development.
2. To asses natural change in *S. spinulosa*:
    a. To gauge the short and long term stability and seasonality of *S. spinulosa* reefs by measuring changes in reef extent over space and time, using repeat surveys.

The latter objective was not directly addressed over the short time frame of the 2001 survey, but the results of the survey will have a bearing on suitable design of future surveys.

3. Methods

3.1 Survey design

The survey design was based on stratified and nested sampling of selected sites based on the broad scale predictive maps from the BMP project and more recent surveys. It is important to note that the purpose of the classification of the remote data was to interpret using supervised classification techniques and not to define the acoustic characteristics of biotope ground. This is perfectly acceptable if the area is stable and repeat sampling can return to target areas. However, if long term stability cannot be assumed, and stratified sampling for target biotopes is required, then it is important to be able to predict the sort of ground where they are likely to be found. In other words, RoxAnn is used as a real-time prospecting tool to identify particular ground types.

Thus, the strategy for the 2001 survey consisted of the following stages:

1. Highlight areas likely to support *Sabellaria spinulosa* identified from previous broadscale surveys. The sites selected for the 2001 survey were to be placed at

intervals along a transect from the inner Wash, along Long Sands/Lynn Deeps to further offshore outside the cSAC boundary (the Scott Patch area and Area 107). This disposition of the sites was designed to detect any broad offshore/onshore trends.

2. Resurvey these areas using RoxAnn in real-time to refine the selection and position of the box sampling areas (or 'super-quadrats').
3. Having stratified the sampling, to randomly sample within the super-quadrats.
4. Use remote sensing techniques to detect spatial structures at a fine scale within the super-quadrats.

The super-quadrats had sides of 1km (original design 250m – see discussion under 'Methods'). Ten grab samples were collected from randomly selected stations (but accurately located to within 50m) within the boxes and these were assessed visually for reef development, sediment granulometry estimation and then the infauna were extracted and preserved for later identification. Each of these grab sample sites were also sampled with a drop down video which not only could assess the physical scale of reef development, but also be used to gauge the patchiness of the biotopes at a broader scale than the grab sample.

Acoustic techniques were also used to try to obtain a broad coverage of the boxes (AGDS and sidescan).

3.2 Field survey

The field work was carried out over two consecutive neap tides in weeks beginning 30 July and 13 August. Poor weather in the first week meant that the sampling of the boxes was undertaken in a piece-meal fashion as opportunity permitted. Nevertheless, the equipment worked well and all survey objectives were accomplished.

3.3 Acoustic survey

The description of the sidescan and AGDS equipment, procedures for data collection and analysis are well documented and not discussed here. The equipment used was the same as for 2000.

The AGDS and sidescan were run together at a track spacing of about 200m and additional AGDS data were collected during sampling. Thus, the AGDS track-point density is not uniform for each box, but always high. The general disposition of the tracks is shown in Figure 1.

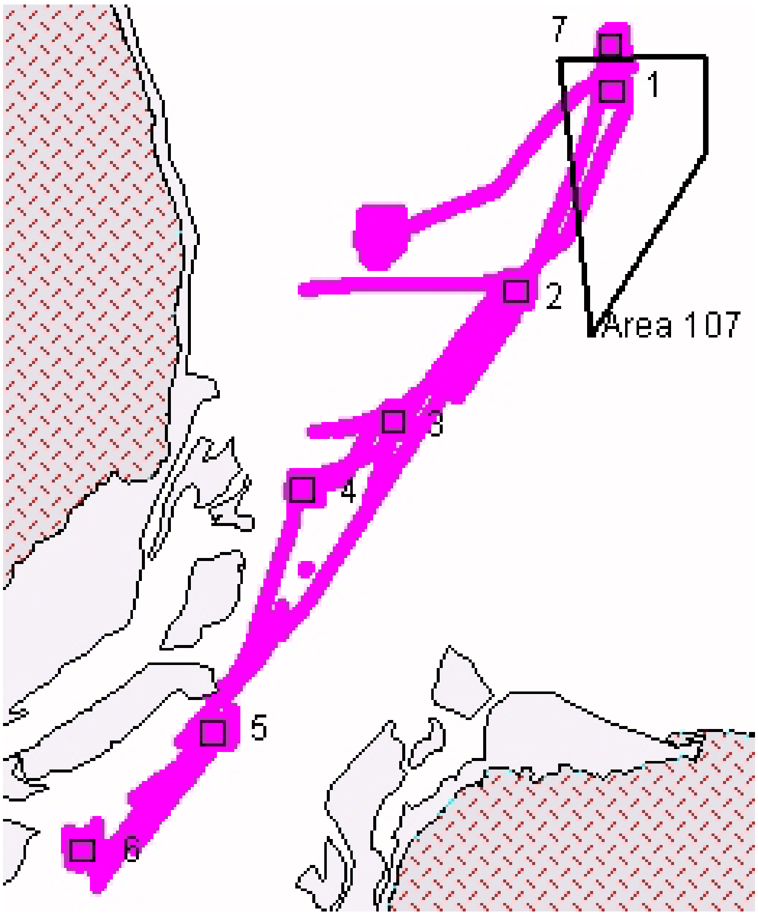

Figure 1. The AGDS track data showing the location of the transect and sample boxes. The sample boxes are in their final positions. Note that sample 7 was chosen later in the survey to investigate the boundary conditions at the edge of area 107. The area tracked to the west of the main transect was surveyed for the ESFJC's on-going mussel survey and did not form part of this survey.

3.4 Stratification: selection of Box sites

Six boxes were planned, but in the event 7 were sampled. This was because the absence of well developed reef in the area of Box 1 where it was previously abundant required further investigation of the boundary conditions of the licensed sand extraction area 107.

The original size for the boxes was planned to be 250m. However (on further consideration) this was not considered to be sufficiently large considering the spatial imprecision of the grab sampling. Bear in mind that the samples were to be separated from one another by a known distance, with a margin of error for spatial imprecision. It was estimated that the grab sample could be as much as 50m out from recorded position (mostly due to drift of boat and grab relative to DGPS position as recorded).

The map from the BMP survey was used to select the approximate location of the super-quadrats (Figure 2). The boxes were selected on the basis of maximum probability of the occurrence of *Sabellaria* at high densities.

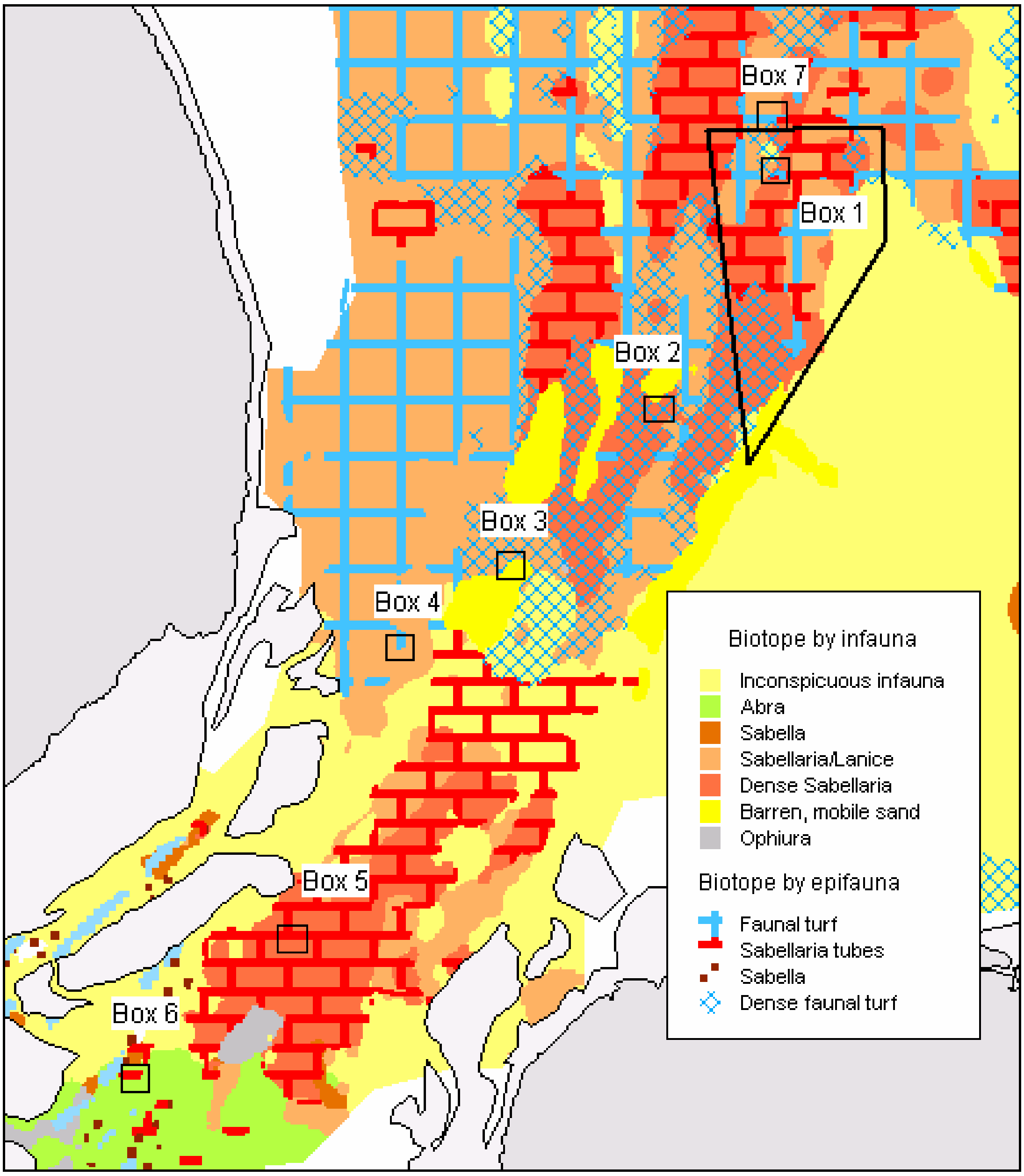

Figure 2. The sampling boxes superimposed on the predicted infaunal and epifaunal biota. The former is shown by the background colour and the latter by the hatch pattern.

It was anticipated that the ground characteristics might have changed in the intervening period and that the AGDS would need to be used as a prospecting tool to refine the selection of sites. Track records and ground truth data from previous surveys were used to define acoustic ground likely to support *Sabellaria*: Acoustic track data were selected using 100m buffers around the ground truth data and then tagged according to the biotope data as supporting (1) dense *Sabellaria* and reefs, (2) moderately dense *Sabellaria* or (3) other biotopes. The track data were then displayed as an E1/E2 scatter plot showing the above categories (Figure 3).

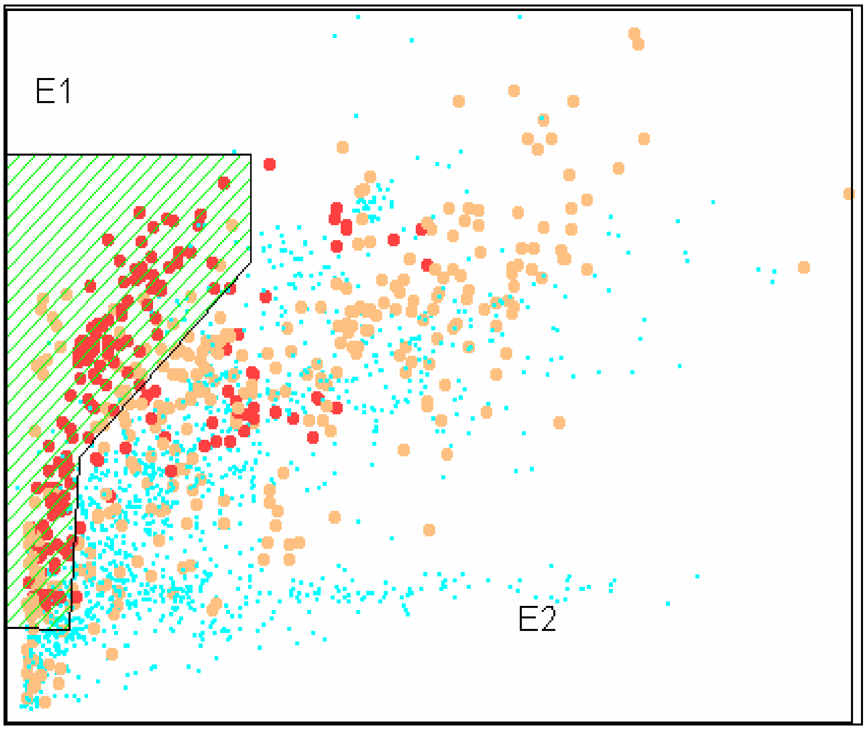

Figure 3. Previous track data (from the BMP survey) selected within 100m buffer zones of the ground truth points and tagged according to dense *Sabellaria* (red), moderate densities (orange) and low densities (blue). The shaded polygon indicates the E1/E2 values where there is the greatest likelihood of finding *Sabellaria*.

The pattern of E1/E2 values was not well defined but, in general, the E2 values (hardness) were lower than the corresponding E1 (roughness) values. The area of the plot most closely associated with *Sabellaria* is shown as the green hatched polygon in Figure 3. This arrangement was transferred to the *Microplot* data logging/display system on *Surveyor* and areas where the track data lay within this box were sought for sampling. A few video drops were carried out to confirm the sea floor characteristics where these were in doubt.

As a result of this real-time prospecting, one box was rejected due to unlikely E1/E2 values (and proved to be uniformly sandy – the AGDS characteristics had changed since the original survey in 1997) and repositioned further to the west in more suitable ground (Box 4). It is interesting to note that this new position had the best developed reefs found on the survey. No *Sabellaria* reef was found in the box in 107 in the first week (in marked contrast to the apparent persistence of this reef from 1997-2000) and it was decided to undertake a 7th box just to the north of the 107 boundary. The inner area sampled (around Box 6) did not show E1/E2 values consistent with the other boxes, but a box was chosen primarily to complete the broad scale transect. However, some moderately high values of *Sabellaria* had been recorded from the locality in previous years.

The positions of the boxes (top left and bottom right) are given in decimal longitudes and latitudes (WGS84) in Table 1.

Table 1. Location of Boxes.

Box	Top left east	north	Bottom right east	north
1	0.632846	53.2418	0.64881	53.2328
2	0.565585	53.1659	0.58151	53.1569
3	0.483509	53.1169	0.4994	53.1079
4	0.42243	53.0915	0.438303	53.0825
5	0.359619	52.9984	0.375441	52.9895
6	0.273633	52.9546	0.289455	52.9456
7	0.632243	53.2599	0.648207	53.2509

3.5 Random sampling

The locations were selected by placing a grid of numbered 25m squares over the super-quadrat and ten were selected using random numbers. Some extra locations were selected in case it proved impossible to grab at one of the ten selected locations (eg, due to static fishing gear) and in such cases a duplicate grid location was selected at random. The final selection of locations is given in Table 2 and shown in Figure 4.

Table 2. Position of the sample locations for grab and video.

Box	**1**		**2**		**3**		**4**	
Sample	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1	53.2407	0.634433	53.1595	0.568633	53.1088	0.485667	53.0905	0.42485
2	53.2413	0.63595	53.165	0.569633	53.1127	0.486467	53.0903	0.43435
3	53.2383	0.638417	53.1581	0.569617	53.1142	0.487117	53.0887	0.430683
4	53.234	0.638417	53.1603	0.570367	53.1131	0.48835	53.0879	0.429767
5	53.2403	0.64045	53.164	0.571367	53.1144	0.492533	53.0878	0.430317
6	53.2369	0.6405	53.161	0.57215	53.11	0.4925	53.0854	0.434117
7	53.2337	0.641967	53.1594	0.573283	53.1161	0.493133	53.0859	0.429633
8	53.2373	0.643417	53.1643	0.576917	53.1107	0.496733	53.0884	0.42625
9	53.2355	0.643533	53.161	0.5786	53.1125	0.497733	53.0836	0.424517
10	53.2394	0.647217	53.1587	0.579617	53.1151	0.498867	53.0869	0.424817
Box	**5**		**6**		**7**			
Sample	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude		
1	52.9959	0.364067	52.9475	0.276883	53.258	0.636967		
2	52.9915	0.364933	52.952	0.2796	53.2521	0.636883		
3	52.9928	0.366233	52.9497	0.280017	53.2548	0.637817		
4	52.9904	0.370717	52.9522	0.282867	53.2546	0.6397		
5	52.994	0.371583	52.9492	0.285517	53.2573	0.641117		
6	52.997	0.372717	52.9485	0.287233	53.2535	0.64175		
7	52.9918	0.372767	52.9519	0.28785	53.2518	0.643667		
8	52.9915	0.374217	52.9467	0.2884	53.258	0.64545		
9	52.9956	0.376583	52.9531	0.290783	53.2563	0.6465		
10	52.9935	0.375917	52.965	0.282067	53.2538	0.64765		

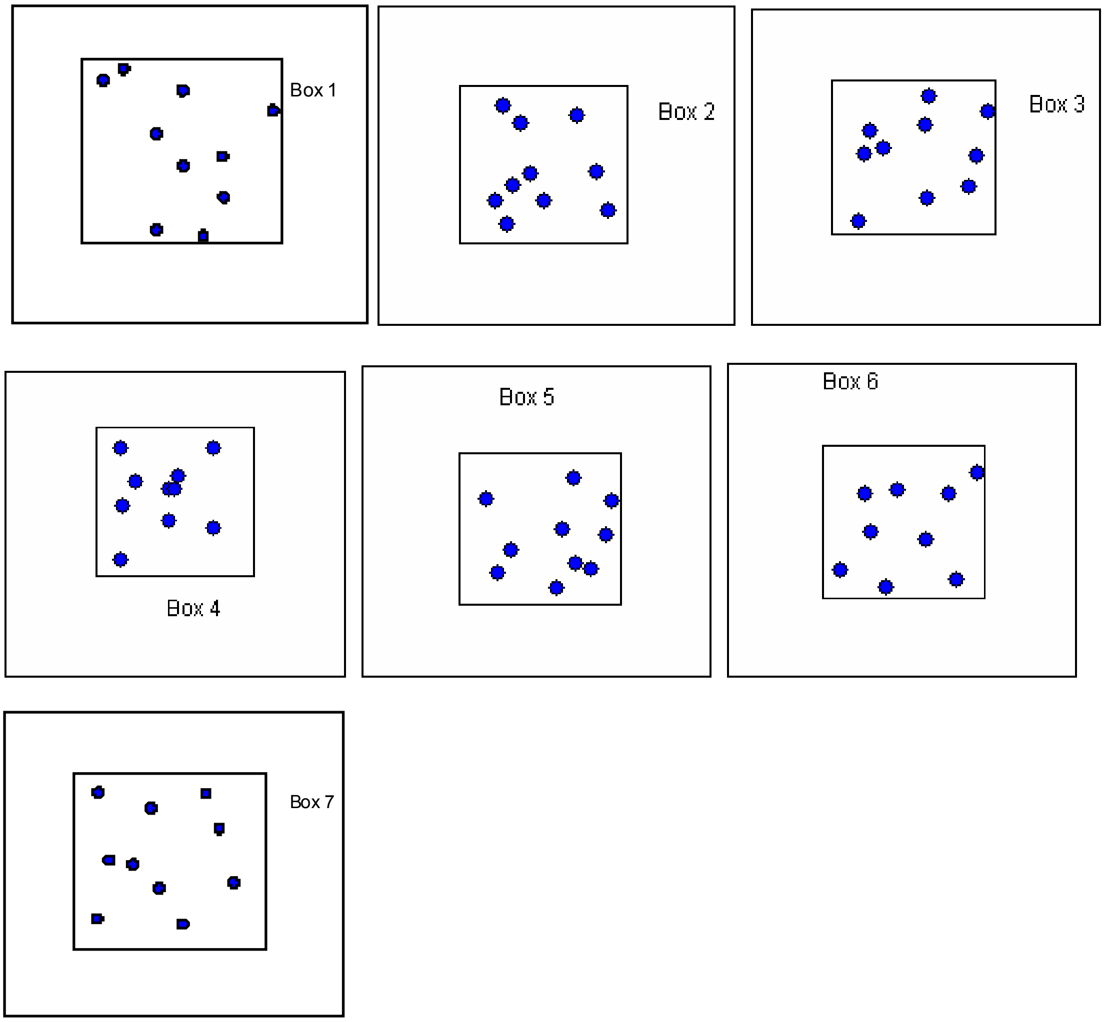

Figure 4. Position of the grab and video samples for each of the boxes.

3.6 Processing the grab samples

The samples were accepted if the day grab was at least half full. If less was collected, then another grab was taken and either added to the previous sample to bulk it up, or to replace the previous sample if the second proved satisfactory on its own. All samples were, therefore, approximately half full.

The sample was photographed and then allutriated (repeatedly washed and the overlying sea water decanted over a 0.1m sieve until there was no evidence of silt in the water). This method was used because the sediments were invariably coarse and did not pass through the mesh. The resulting sediment and fauna retained on the sieve were immediately transferred to storage pots and fixed in 4% formalin. Analysis of the infauna has been subcontracted to Peter Garwood of *Identichaete*.

3.7 Video

The direct observations were made with a digital video system and the tows were also recorded simultaneously on the surface unit in Hi8 format. After the grab samples were collected, the sample stations were re-visited and the video deployed so that the boat would drift (as near as could be anticipated) over the grab station. The tows lasted for no less than 2 minutes and a maximum of 3 minutes. These videos were viewed and assessed for biotope features, reef development and patchiness.

4. Results

4.1 Grab and video samples

Numerous analyses have been carried out on the data and the purpose and procedures of the various stages require some explanation. Table 3 summarises the strategy for the analysis of grab and video sample data.

Table 3. Analyses of the grab and video data. Note that grab sample data from previous surveys have been used in some of the analyses.

Purpose	Data sets	Procedure
Variability of infauna from grab samples		
Variability across range of biotopes	All SeaMap records for all years	Non-spatial site/species similarity matrix & MDS plot
Variability at a very fine scale	2000 data set of replicate samples	Similarity matrix (as above)
Variability within 1km Boxes	2001 data set	Similarity matrix (as above)
Spatial patterns of biota within 1km Boxes		
Patterns in similarity of infauna	2001 infauna	Exploratory geographic plots of similarity to mean for each Box Similarity/lag plots Moran's index of dispersion/lag
Pattern of *Sabellaria* numbers	2001 numbers of *Sabellaria*	Exploratory geographic plots of *Sabellaria* numbers Variance/lag plots Moran's index of dispersion/lag
Spatial patterns video data within 1km Boxes		
Patterns of faunal classes	2001 video records	Exploratory geographic plots of faunal classes
Patterns of sediment classes	2001 video records (supplemented by grab data)	Exploratory geographic plots of sediment classes
Match infauna from grab samples and video faunal classes		
Match video class and (1) *Sabellaria* numbers and (2) grab infaunal classes	2001 video records and grab infaunal samples	Cross tabulation
Match sediment category and (1) infauna and (2) video classes	Summary sediment data (video and grab) and (1) grab infauna and (2) video	Tabulation

4.1.1 Variability of infauna from grab samples

Variability across range of biotopes: Measurement of the variability between grab samples across the whole range of biotopes from the Wash and its environs to act as a reference for assessing the significance of variability within Boxes.

The purpose of stratifying sampling, focusing on the areas likely to support *Sabellaria* biotopes, should have the effect of narrowing the range of variability between samples. For comparative purposes, all grab sample data from previous years were subjected to Multi Dimensional Scaling (MDS) analysis. A reference 'site' was produced from the average faunal composition of the records with the highest densities of *Sabellaria* and each real data point given a percentage similarity value to this reference datum. These similarity values were interpolated within the coordinates of the MDS plot and contoured (Figure 5).

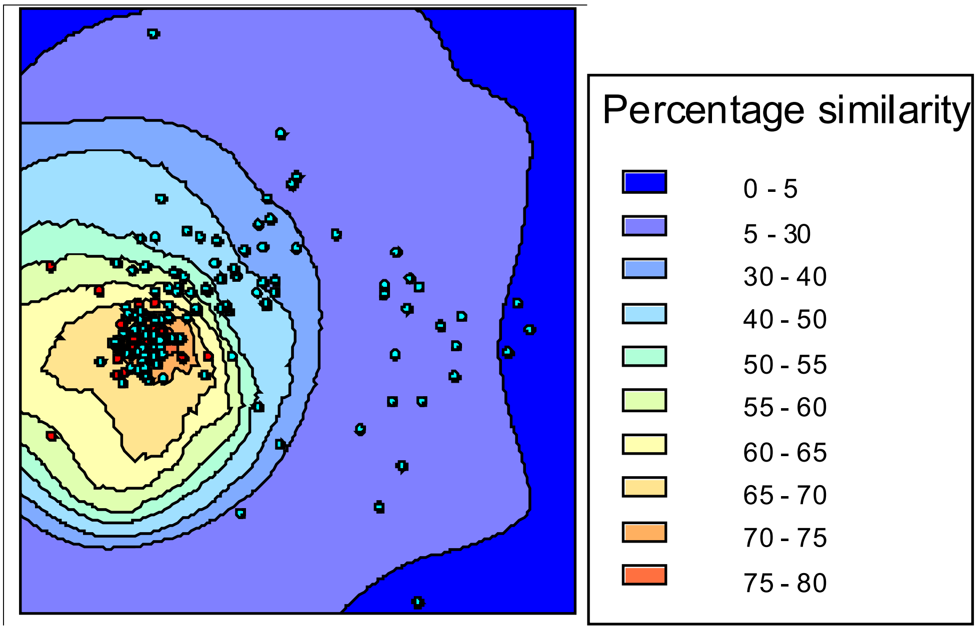

Figure 5. A multivariate plot (MDS) of all grab data with sites with more than 20% *Sabellaria spinulosa* shown in red. The contours show the similarity of the samples to a reference 'site' derived from the average species composition of sites with high densities of *Sabellaria*.

There are a number of important points that are shown in this plot to be considered in subsequent evaluation of survey results: (1) The majority of the *Sabellaria* sites are between 65% and 80% similar to the reference site as compared to the much wider range within the complete data set; (2) many sites with lower densities of *Sabellaria* (the blue circles) are still similar in species composition to the high density *Sabellaria* sites. The latter accords with the description of the infaunal composition of the biotopes within the Wash area that many sites have a similar species composition even through *Sabellaria* (which might be considered a structuring species) may occur in widely varying densities. The overlap between *Sabellaria* and non-*Sabellaria* biotopes might also occur spatially.

This range of 65% and 80% will act as a reference against which to judge any spatial correlation between closely spaced samples. Is this level of similarity also found between sites which are close to each other, or is there greater variability indicating heterogeneous distribution of biotopes? This must be considered when assessing the significance of spatial variability.

4.1.2 Variability at a very fine scale as a further reference for assessing variability within Boxes

Replicate grabs from the 2000 survey were taken from areas where *Sabellaria* was reported/predicted to occur. Five replicates were taken positioning the vessel to approximately the same station and it is estimated that the margin of positional error meant that the grabs were likely to be within 150m of each other. This represents the minimum sampling distance (within-sample variability). Nevertheless, variability was found to be quite high (Table 5) with an average similarity of only 61.8%.

Table 5. Average similarity (between pairs of 5 replicate grab samples taken at 5 stations at 2 sites in 2000).

Station	Site name	Average similarity	Standard deviation
1	Longsands	51.6	10.0
2	Longsands	66.0	5.6
3	107 south	63.0	3.2
4	107middle	68.8	2.0
5	107 north	59.4	3.3

Establishing inherent variability is important since any broader scale patterns within the 1km quadrats must be defined by a higher level of variability than this.

Variability of infauna within 1km Boxes

If the 2001 quadrats are treated as though the 10 samples were randomly chosen replicates, then the average similarity is 59.06% (Table 6), slightly lower than for the inherent, fine scale similarity, but not significantly so.

Table 6. Average similarity between pairs of 10 samples taken within each of the 7 Boxes surveyed in the 2001 survey.

Box number	Average similarity
7	59.38
1	66.80
2	63.57
3	61.31
4	60.98
5	57.72
6	43.63
Average	59.06

4.1.3 Spatial patterns of biota within 1km Boxes

Patterns in similarity of infauna: Exploratory geographic plots

Heterogeneity can be explored visually by plotting the samples spatially within the Boxes coded according to their similarity to the Box average species composition (Figure 6).

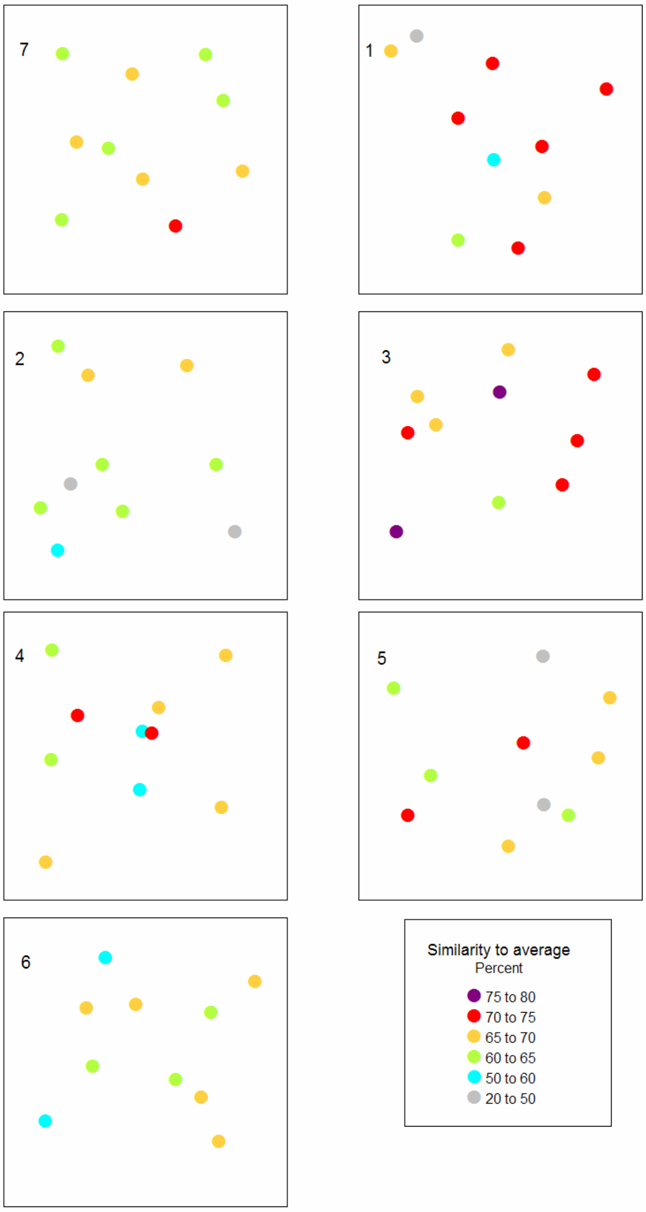

Figure 6. Grab samples plotted within each of the 7 Boxes colour coded to show their similarity to the average faunal composition for each Box.

Clearly, some Boxes are more variable than others, but there is no pattern to similarity: ie, when compared to the average sample, the ones most similar are not grouped together neither are there any obvious trends across any of the Boxes.

Similarity/lag plots

The similarities between samples have been plotted against the distance separating them (lag distance) in Figure 7. This shows the data from all Boxes and there is very little decrease in similarity over the range of lag distances (50 – 1000m). A small number of samples were very different from the norm for the Box in which it lay (below 40% similarity) and they might be due to poor sampling or the inclusion of very different biotopes within the Box. If these are disregarded then the mean and standard deviation of the remaining samples is 61.5% with a standard deviation of 15.

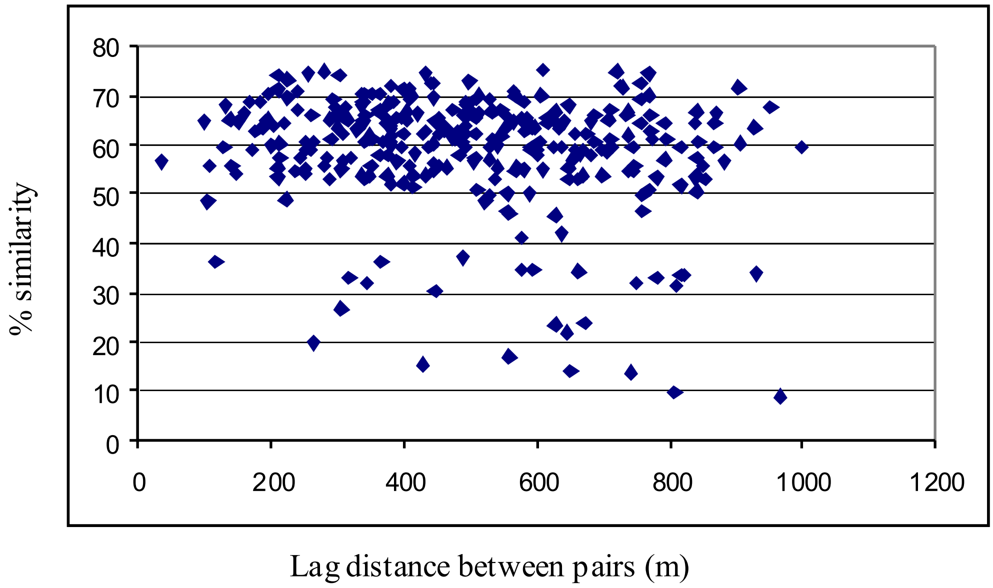

Figure 7. Similarity between pairs of samples plotted against lag distance between the pairs. The points for all Boxes have been summarised on the plot.

It would appear from Figure 7 that there is a spread of similarity values within the range expected from the ground likely to support *Sabellaria* (Table 6) without any clear indication of spatial auto correlation.

Indices of dispersion

The similarity of the faunal composition at the 10 sample locations within a Box together with their position can be used to measure dispersion using indices such as Moran's I. The basis of such indices is to create two site/site matrices of (1) separation (lag) distance and (2) similarity and then calculate the cross-product of corresponding cells in the matrices. The value of the Moran's index approaches -1 when the sites over a given lag distance are more dissimilar than might be expected (negatively correlated) and +1 when are more similar (positively correlated). The indices can be calculated for different lag distances and this gives an indication of the way dispersion/aggregation changes with increasing distance separating the sites. Moran's indices have been calculated for increments in the lag distance of 150 m up to just over 1 km and Figure 8 summarises the pattern for all seven Boxes.

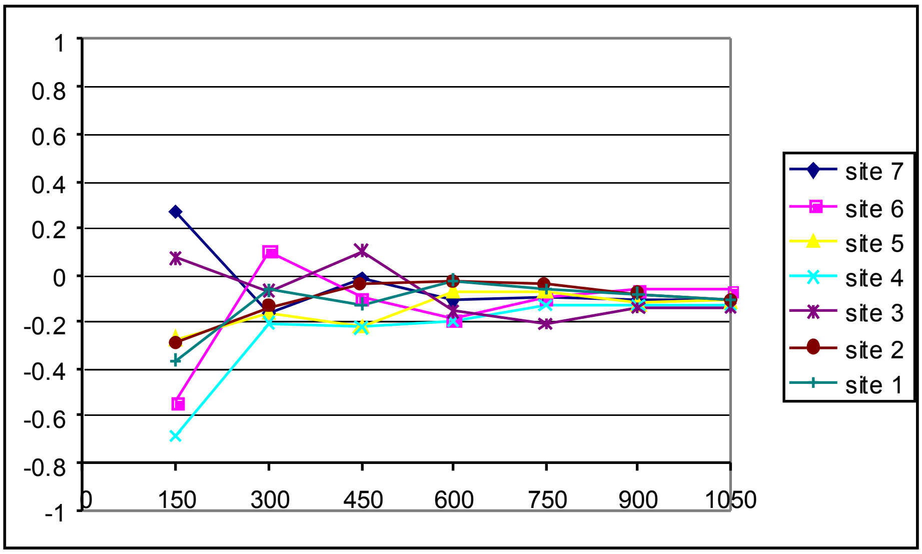

Figure 8. Moran's I calculated for each of the 7 Boxes for lag distances ranging from 150m to 1050m.

All graphs tend towards very slight negative values (the initial variability at small lag distances is due to the low number of pairs of sites that occur with these small separations and are not greatly significant). This indicates that dispersion is much what would be expected by chance. In other words, there is no detectable pattern to the distribution of the infauna at the scale of the sampling and the best description of the Boxes is their mean and variance.

4.1.4 Pattern of *Sabellaria* numbers

Exploratory geographic plots of *Sabellaria* numbers

Any patterns in the distribution of *Sabellaria* can be explored by plotting grabs coded according to numbers found within each grab (Figure 9). No obvious pattern is apparent in most of the Boxes, although there may be an aggregation of *Sabellaria* in Box 1 and a possible north/south trend in Box 7.

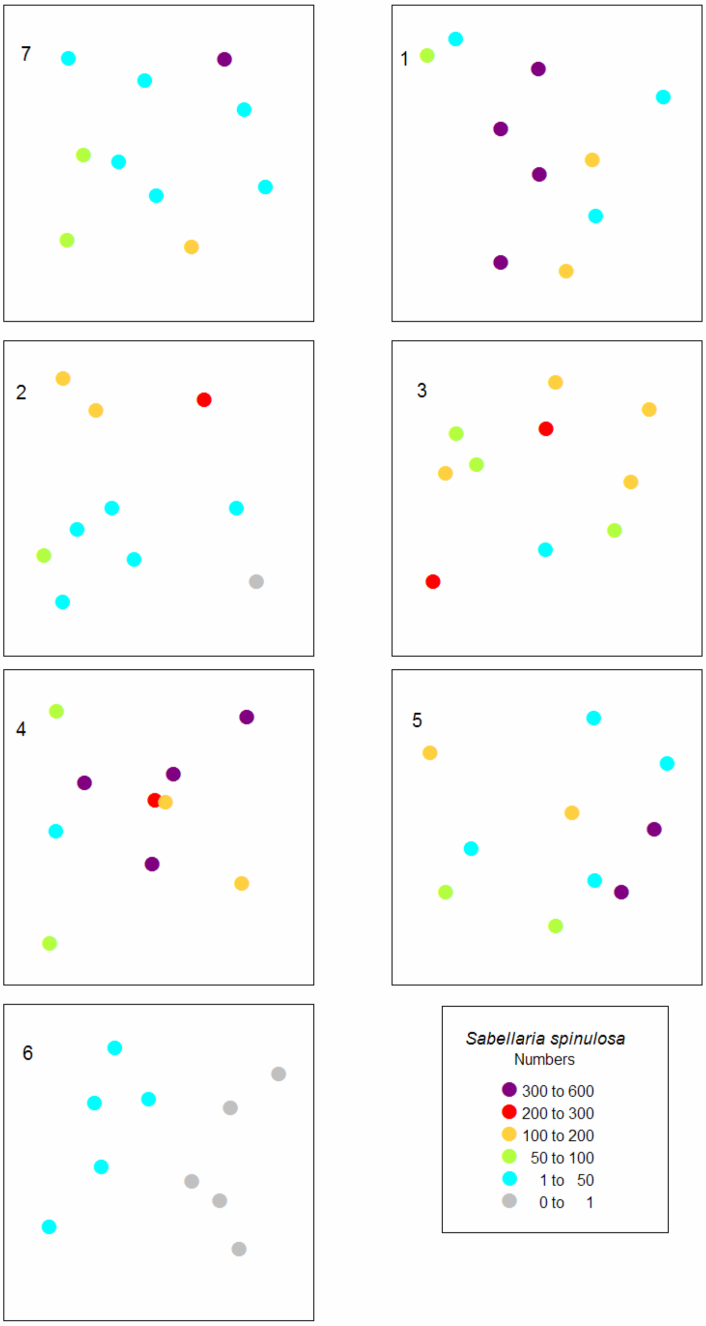

Figure 9. Grab samples plotted within each of the 7 Boxes colour coded to show Sabellaria numbers in each grab.

Variance/lag plots

Samples with counts (numbers of *Sabellaria spinulosa*) can be subjected to another graphic demonstration of spatial correlation in which variance between pairs of samples is plotted over increasing lag distance. In the following analysis, the variances in the similarity between pairs of samples over lag distances have been calculated for each of the Boxes separately. The pair-wise similarities were placed into bins of increasing lag distances. The exact bin ranges varied between Boxes depending upon the spread of pair-wise lag distances and bins with less than 4 pairs were discarded. Since variance depends on the absolute numbers, the variances for each lag bin have been standardised by dividing by the total variance within each box to enable the plots for the Boxes to be more easily compared. The variance/lag graph for each Box has been plotted separately in Figure 10. Also included is the variogram for the data from all pooled, shown as the thick black line. The larger data set has meant that a larger number of lag ranges were possible for this calculation and a meaningful, smooth graph possible.

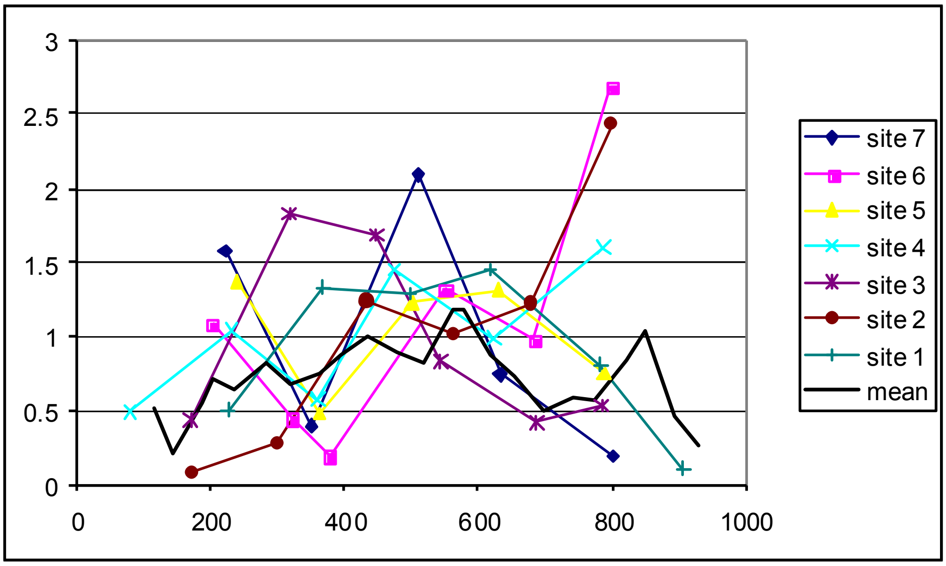

Figure 10. Variogram plots for each of the 7 boxes, each made up of variances of pairs of data in 5-6 lag distances ranging from about 100m to 950m. The dark line represents the variogram for the data from all Boxes pooled.

The variances are themselves very variable between successive lag distances, but few graphs show any clear sign of increasing variance with increasing lag distance (which would be expected if samples close to each other were more similar in numbers of *Sabellaria* than those further apart). However, there may be some indication of spatial correlation in Boxes 1 and 7. There is no general tendency for samples to show spatial correlation.

Indices of dispersion of *Sabellaria spinulosa*

Moran's I can be calculated using *Sabellaria* numbers and these have been shown for each Box separately in Figure 11. Once again, I tends towards a slight negative value at the larger lag distances and at small lags (where the significance of the indices is low because of the smaller number of pairs in the calculation) I is very variable. Two sites (Boxes 2 and 6) show a gradual decrease in I which might indicate some positive correlation at small lags. But the highest values are not large (approximately 0.25) and it is doubtful if the trend is interpretable. If all data are pooled, then there is only a weak trend in spatial association (Figure 12).

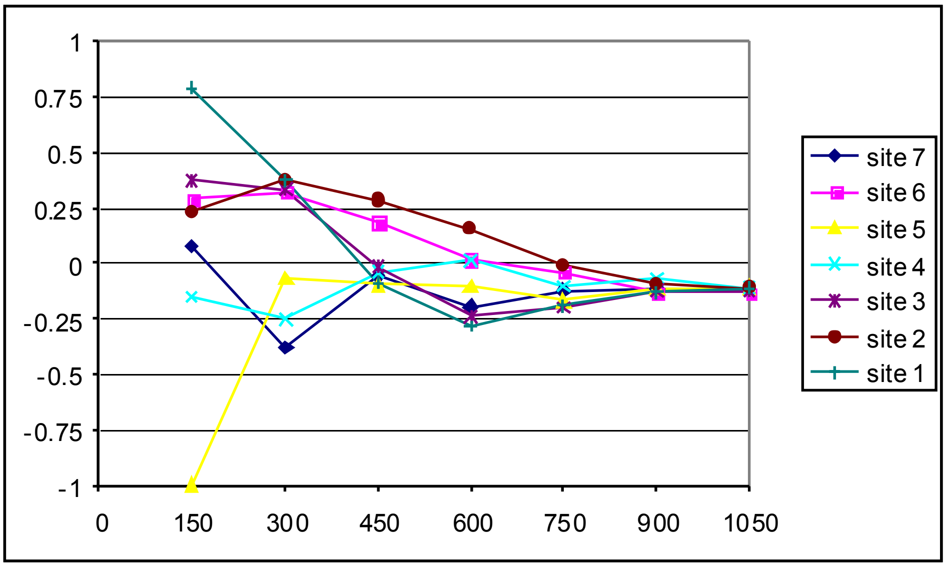

Figure 11. Moran's I calculated for each of the 7 Boxes for lag distances ranging from 150m to 1050m.

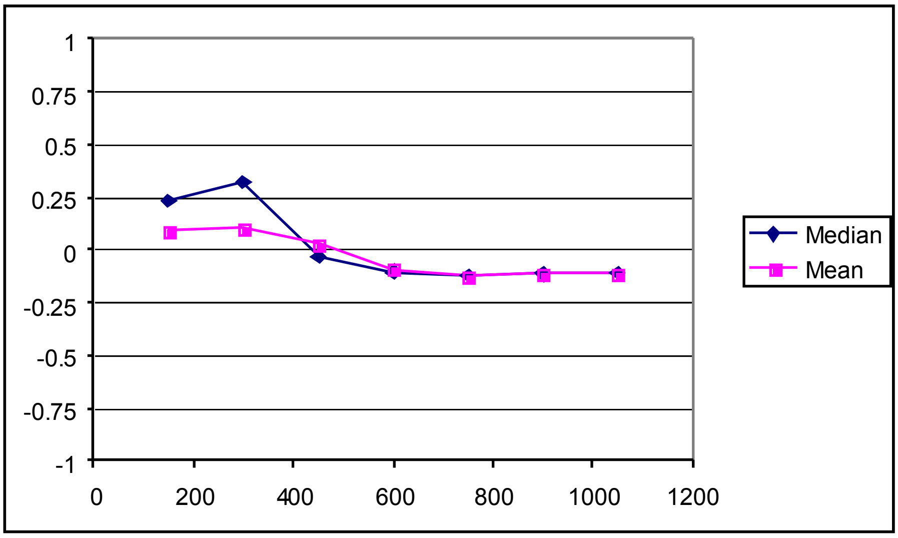

Figure 12. Median and mean Moran's I for the 7 Boxes for lag distances ranging from 150m to 1050m.

4.1.5 Spatial patterns in video data within 1km Boxes

Patterns of faunal classes

The predominant epifaunal communities are shown in Figure 13. The 2-minute recordings covered a very short distance (as measured from the GPS) and although this varied between tows, the average distance was about 50m. In the main there was little variation in the epifauna and sediment type, although some tows did vary. The distribution of epifauna varied considerably between Boxes and some showed trends across the Box. There appeared to be a sharp north/south boundary between barren sand and rich epifauna in Box 7 and a northwest/southeast trend from dense epifauna to sparse *Sabellaria* and epifauna in Box 1.

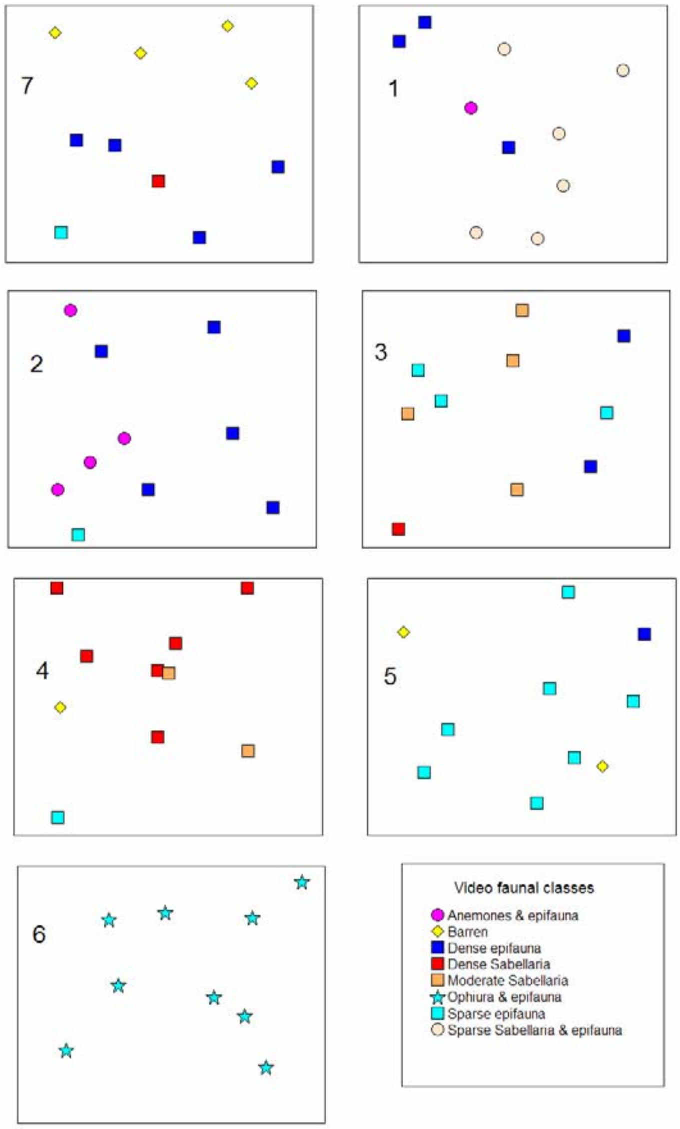

Figure 13. Video samples plotted within each of the 7 Boxes showing the predominant epifaunal community.

Many of the Boxes were very varied, but Box 5 was characterised by sparse epifauna or barren sediment whilst Box 6 was uniformly dominated by *Ophiura* and sparse epifauna. *Sabellaria* reefs were observed in Box 4 and, to a much lesser extent, in Boxes 3 and 7. Of particular note is the lack of well developed reef in either Box 1 or Box 7 where reef was observed in previous years up until and including 2000. Since sampling was intensive in this 2001 survey, it is concluded that this represents a real change in reef status between 2000 and 2001.

The reef in Box 4, although extensive, was very patchy with clumps estimated to be no more than a metre across and the ground to be about 75% covered by gravel and sand. Note that well developed reef seen in area 107 (by way of contrast) consisted of many minutes of camera tow where the area was predominantly reef with a few patches of sand interspersed.

Patterns of sediment classes

The predominant sediment classes for the sample sites are shown in Figure 14. The sediments are diverse for most Boxes, although most are gravely sediments. Only Box 6 has predominantly fine sediment samples.

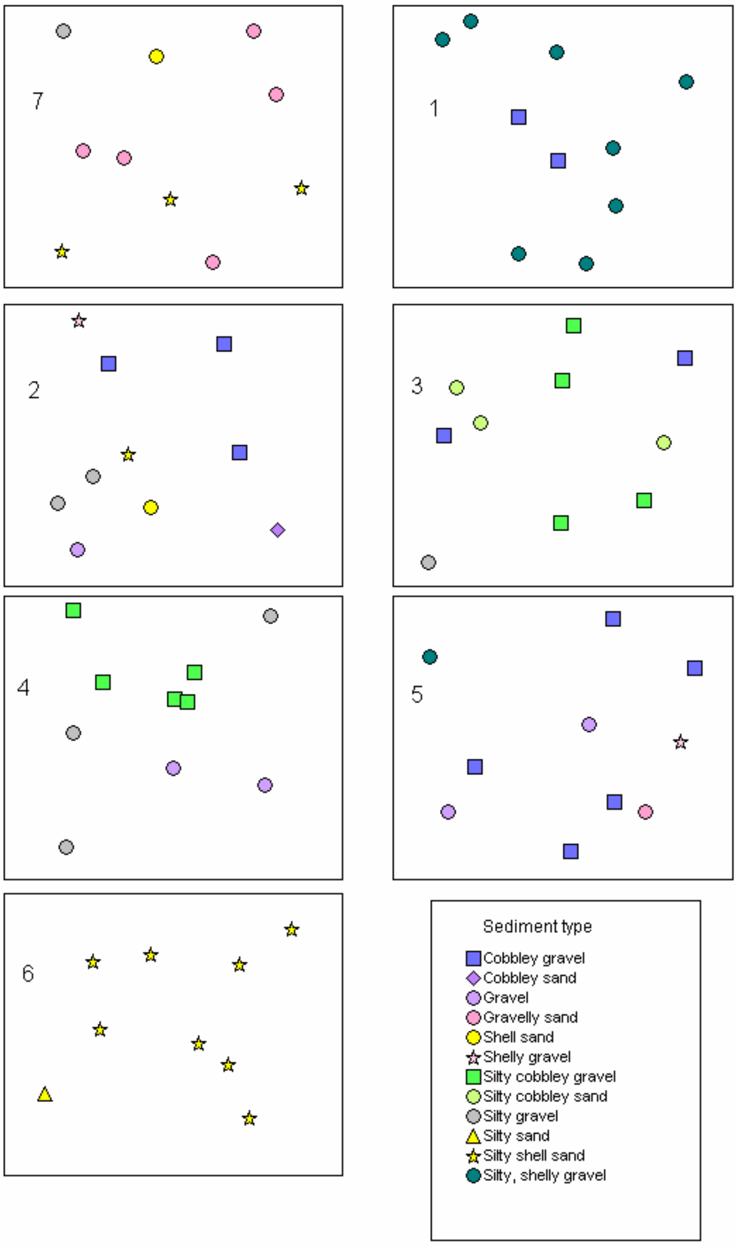

Figure 14. Video samples (supplemented by information from grab samples) plotted within each of the 7 Boxes showing the predominant sediment classes.

4.1.6 Match of infauna from grab samples and video faunal classes

Match of video classes to *Sabellaria* numbers and grab infaunal classes

How do video records match up with the grab samples? Can video detect *Sabellaria* successfully? Table 6 summarises (in a cross tabulation) the performance of video sampling as compared to grab sampling. This indicates that *Sabellaria* is very often missed by the video (the blue cells), especially where there is dense epifauna. Whilst many of the false negatives are for low densities of *Sabellaria*, some high density populations have been missed. It might be expected that the video would not detect low densities of *Sabellaria* amongst epifauna, but the poor detection in 'barren' area is harder to explain.

False positives also occur, but relatively rarely as compared to false negatives. Even well developed *Sabellaria* reefs are characterized by patchiness and one explanation of the false positives is that low density areas amongst the reefs were sampled by the grab by chance.

Table 6. The correlation between video classes of epifauna and (1) *Sabellaria* density from grab samples (mean and median values) and (2) classes of infauna. Blue cells highlight mismatch between infaunal *Sabellaria* and video records. Yellow cells indicate acceptable correspondence.

	Sabellaria density		Infaunal class			
Video	MEAN	MEDIAN	*Sabellaria*	*Ampelisca*	*Ensis*	Others
Dense *Sabellaria*	17.70238	19.7614	6	1	1	0
Sparse *Sabellaria* & epifauna	15.21317	11.82115	3	3	0	0
Moderate *Sabellaria*	11.72838	11.4245	4	0	1	1
Anemones & epifauna	13.64998	10.3145	4	2	0	1
Sparse epifauna	8.672411	8.03907	4	2	4	3
Dense epifauna	10.40803	6.32911	7	5	1	2
Barren	13.84166	3.49854	3	2	2	0
Ophiura & epifauna	0.885727	0.660793	0	0	7	2

Match of sediment category and (1) infauna and (2) video classes

Sabellaria appears to favour silty, cobbley habitats rather than sandy habitats (Table 7). Note that the dense epifauna on the cobbley gravel habitat as observed on the video might have obscured the *Sabellaria* and this could account for the apparent disparity between cobbley gravel habitats supporting 7 records of *Sabellaria* communities as judged by the infaunal composition as opposed to just 1 record as observed from the video (and 10 epifaunal records).

Table 7. Association between *Sabellaria* (1) infaunal class and (2) video class and the sediment type as observed from both the video and the sediment in the grabs.

Habitat	Infaunal class Sabellaria	Others
Cobbley gravel	7	5
Silty cobbley gravel	6	3
Silty, shelly gravel	5	4
Shelly gravel	4	0
Gravel	3	2
Gravelly sand	3	3
Silty gravel	2	6
Silty cobbley sand	1	2
Cobbley sand		1
Shell sand		2
Silty sand		2
Silty shell sand		13

Habitat	Video class Sabellaria	Epifauna	Others
Silty cobbley gravel	8	1	0
Silty, shelly gravel	6	2	1
Gravel	2	3	3
Silty gravel	2	2	6
Cobbley gravel	1	10	5
Silty shell sand	1	2	11
Gravelly sand	0	3	3
Shelly gravel	0	3	2
Cobbley sand	0	1	0
Shell sand	0	1	1
Silty cobbley sand	0	3	3
Silty sand	0	0	2

4.1.7 Summary of variability and spatial patterns as indicated by grab and video samples

The evidence from the grab and video samples suggests:

1. Stratification based on selecting ground likely to support *Sabellaria* decreases the variability between samples considerably;
2. Nevertheless, the variation in (1) the composition of the infauna and (2) *Sabellaria* densities within each Box remains quite high, but no more than might be expected if the samples were designed to be replicates from the same location (within the margin of error of the positioning of the grab);
3. There are no obvious spatial patterns in the Boxes (with perhaps a few exceptions where there is weak evidence for trends across a Box).

The spatial patterns that might be expected to be detected at the scale of resolution of the grab samples would be confined to simple trends across the Boxes and the lack of any clear evidence of such trends does not rule out the possibility of patterns at finer scales. We must turn to remote sensing to pick up finer scale patterns.

4.2 Patterns in acoustic data

Numerous analyses have been carried out on the data and Table 8 summarises the strategy for the analysis of grab and video sample data.

Table 8. Analyses of the remote AGDS and sidescan data. The grab and video data from the 2001 survey have been used to ground truth the remote data in some analyses.

Purpose	Data sets	Procedure
Patterns in AGDS values		
Patterns of acoustic ground types	2001 AGDS data	Geographic track plot of E1 and E2
Association between sediment classes and AGDS data and interpreted sediment distribution patterns	2001 AGDS data and sediment information as ground truth data	E1/E2 plot tagged with sediment. Reclassification of all track data and using the above classification of E1/E2 space
Association between *Sabellaria* numbers and AGDS data and interpreted distribution patterns	2001 AGDS data and *Sabellaria* grab data as ground truth data	E1/E2 plot tagged with *Sabellaria* numbers Reclassification of all track data and using the above classification of E1/E2 space
Pattern in probabilities of *Sabellaria* numbers	Output from the previous analysis	Interpolation and spatial averaging of likelihood values
Patterns in topography using AGDS bathymetric data		
Trends and patterns bathymetry	2001 AGDS depth data	Interpolated grids and contour plots 3-D bathymetric models
Patterns in fine scale sediment features using sidescan		
Fine scale features and association with broader scale patterns	2000/2001 sidescan images	Identify and plot features and superimpose on AGDS data

4.2.1 Patterns of acoustic ground types

The data were firstly adjusted to allow for tidal height by correcting to chart datum at 10-minute intervals. Hunstanton was used as the reference port. The track data were subjected to QA procedures. The first and second week's data sets were slightly different in the range of E1 values and, therefore, the data sets were standardised using the 95th percentile. Dubious depth records were detected using graphical techniques (a plot of depth against time) and about 2% of the records were removed. Likewise, records associated with slow vessel speed were detected and removed. Lastly, the tracks were coloured according to E1 or E2 values and plotted geographically (Figure 15). A visual inspection of the tracks suggested that some tracks were inconsistent with other tracks that they crossed or ran close to. These inconsistencies were apparent because of unusually low E1 values. This phenomenon, although not satisfactorily explained, is not uncommon with AGDS and usually takes the form of a sudden drop in values. These tracks were removed from the data set. About 3% of the data were rejected for this reason.

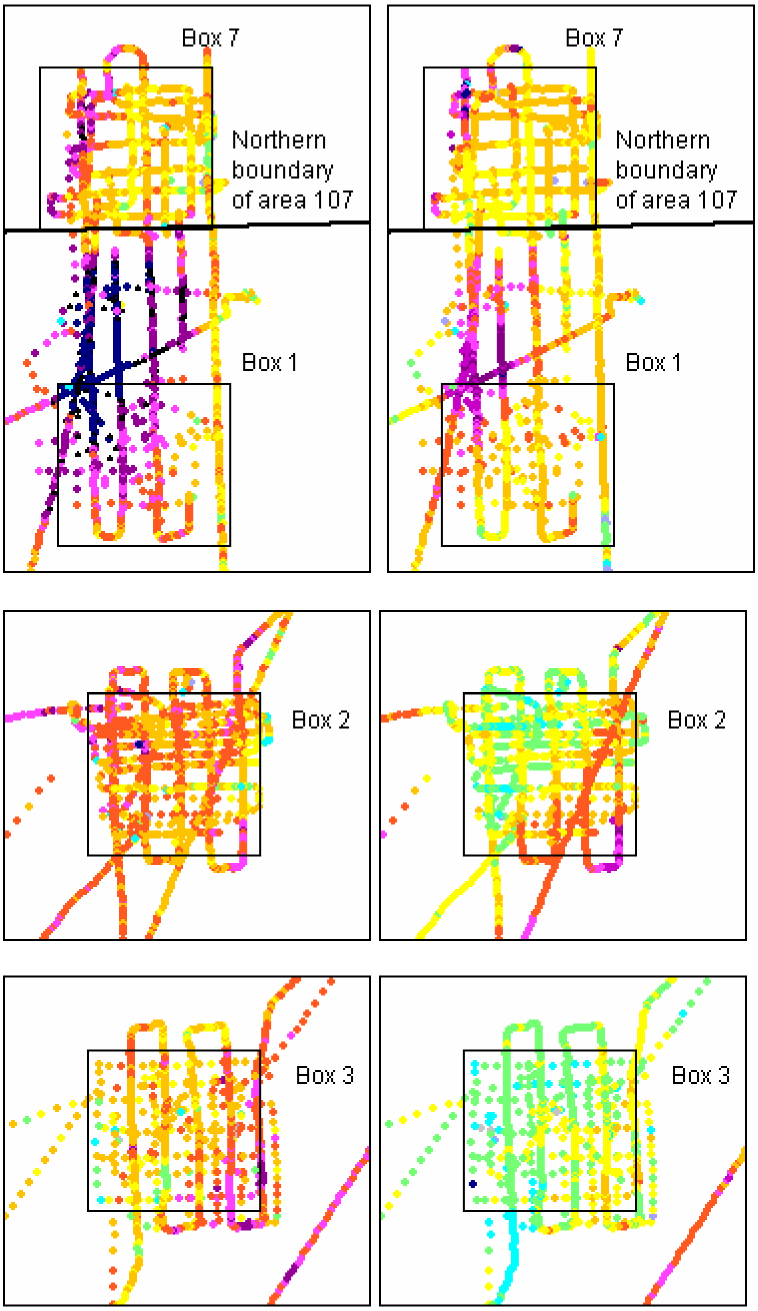

Figure 15. Boxes with AGDS tracks coloured according to E1 (left) and E2 (right). Note that grey and light blue represent low values and red and purple represent high values. The scales are arbitrary and have been adjusted to fit the range of E1 or E2 values for the data set.

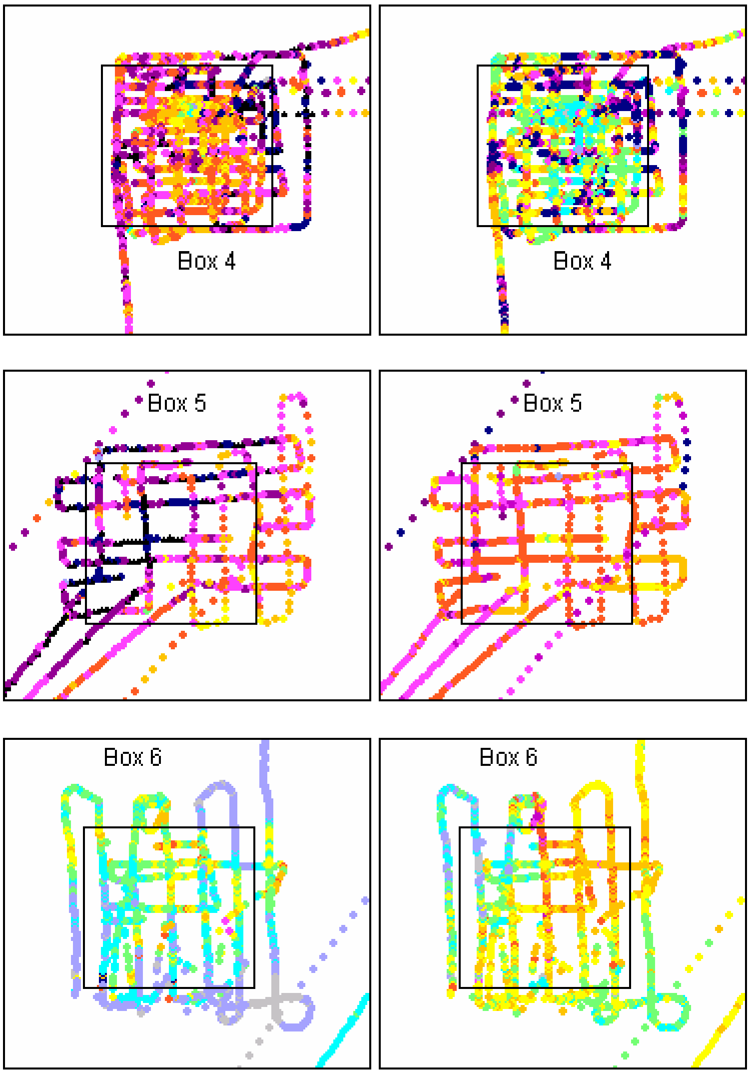

Figure 15 (continued). Boxes with AGDS tracks coloured according to E1 (left) and E2 (right).

There is considerable variation in the overall acoustic values as well as their pattern between Boxes. It is hoped that analysis of these patterns will help the interpretation of the grab and video data.

4.2.2 Association between sediment classes and AGDS data and interpreted sediment distribution patterns

RoxAnn detects hardness/roughness features that are more associated with sediment characteristics than biotic characteristics and for this reason the analysis of the relationship between AGDS values and sediment is presented before biota.

Analysis of the AGDS track data was similar to that previously described for prospecting for *Sabellaria* (see section on 'Stratification'). Acoustic track data were selected using 25m buffers around the ground truth data and then tagged according to sediment category. The track data were then displayed as an E1/E2 scatter plot and frequency plots calculated for each category. The E1/E2 space was then divided up to form a template showing the relationship between the AGDS values and the most frequent (likely) sediment category. This gave a confused association since there is considerable overlap between similar categories. The first and second most frequent categories were combined to result in a smaller number of categories to simplify the relationship:

- silty sand;
- silty shelly sand;
- silty cobble & gravel;
- silty gravel & sand;
- cobble & gravely sand;
- cobble & gravel.

The complete AGDS data set was then overlain on this template in E1/E2 space and the track data tagged with the most likely sediment category. The data were then plotted geographically and colour coded to show sediment category (Figure 16).

The tracks show some quite strong spatial patterning within the Boxes and in many cases these patterns are in the form of northwest/southeast trends (ie, running across the main line of the transect. Thus, Boxes 7 and 1 show a trend of cobble and gravel to silty cobble, gravel and sand whilst the trend is reversed in Box 2 and possibly Box 3. Box 4 shows more complex but distinct patterns of cobble and gravel and silty cobble, gavel and sand. Boxes 5 and 6 appear much more uniform with 5 being mainly cobble and gravel and 6 being of finer sediments.

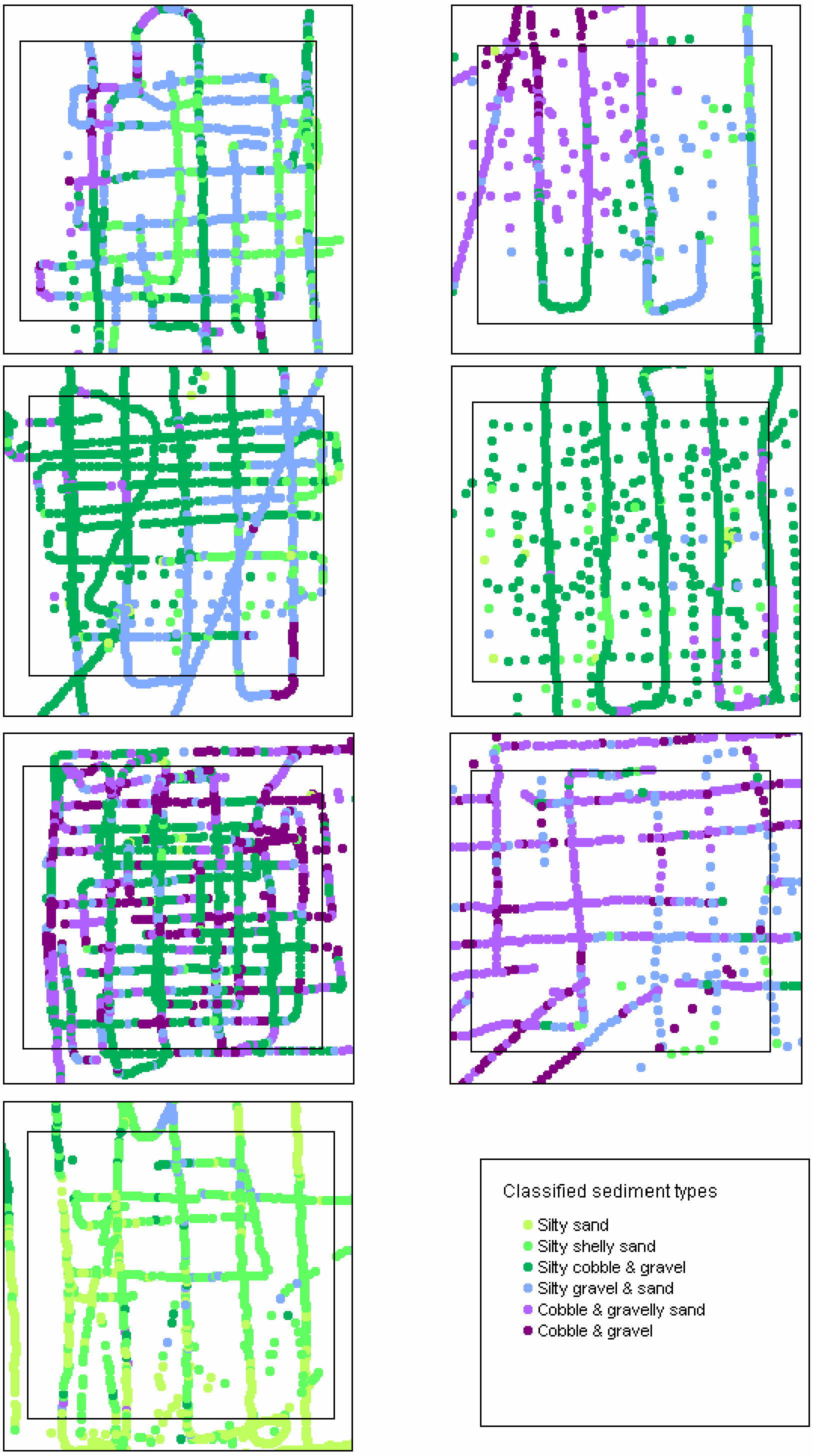

Figure 16. Tracks classified to show sediment types.

4.2.3 Association between *Sabellaria* numbers and AGDS data and interpreted distribution patterns

A similar analysis was undertaken to establish the relationship between *Sabellaria* density and E1/E2. In this case, however, instead of frequencies of categories, contour plots of *Sabellaria* density were calculated from the point data (Figure 17). The relationship is less clear between *Sabellaria* and E1/E2 than for the sediment categories. This is to be expected since *Sabellaria* appears to be able to colonise a range of sediment types which, in turn, can support other communities. However, the general pattern is similar to that found when analysing the previous data before prospecting for *Sabellaria* ground.

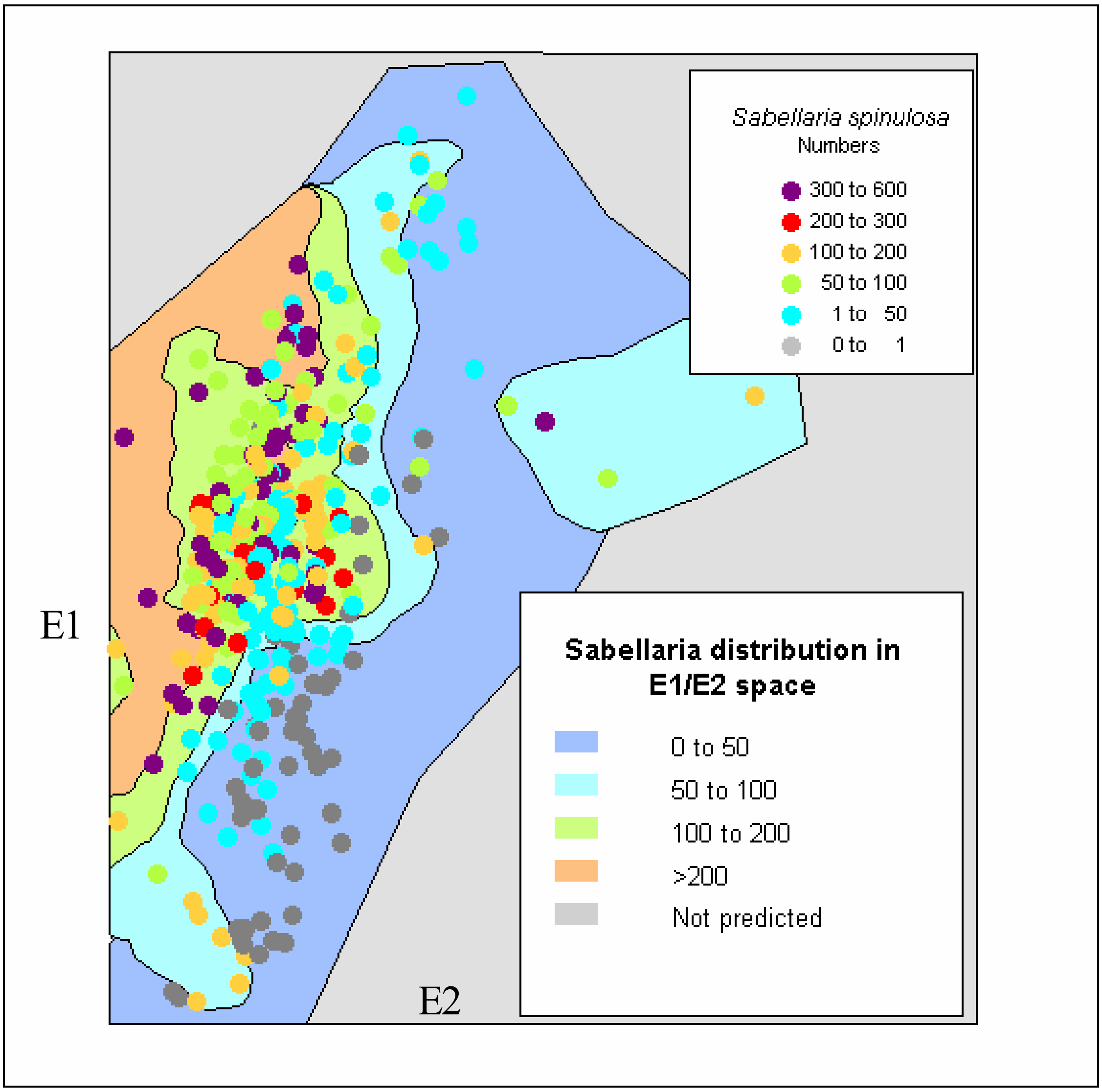

Figure 17. Track points within sample buffer zones displayed in E1/E2 space and coded to show increasing densities of Sabellaria. These point data were interpolated to produce a contoured plot of density.

The contour plot was then used as a template for the whole AGDS data set and the data plotted geographically (Figure 18). The interpreted track data accord fairly well with the ground truth records in that Boxes with high densities of *Sabellaria* have more track points with high expected associated *Sabellaria* densities. However, the tracks are very variable and few Boxes show such clear spatial patterns as were found for the sediment categories. Boxes 1 and 4 appear to have central regions of high *Sabellaria* density.

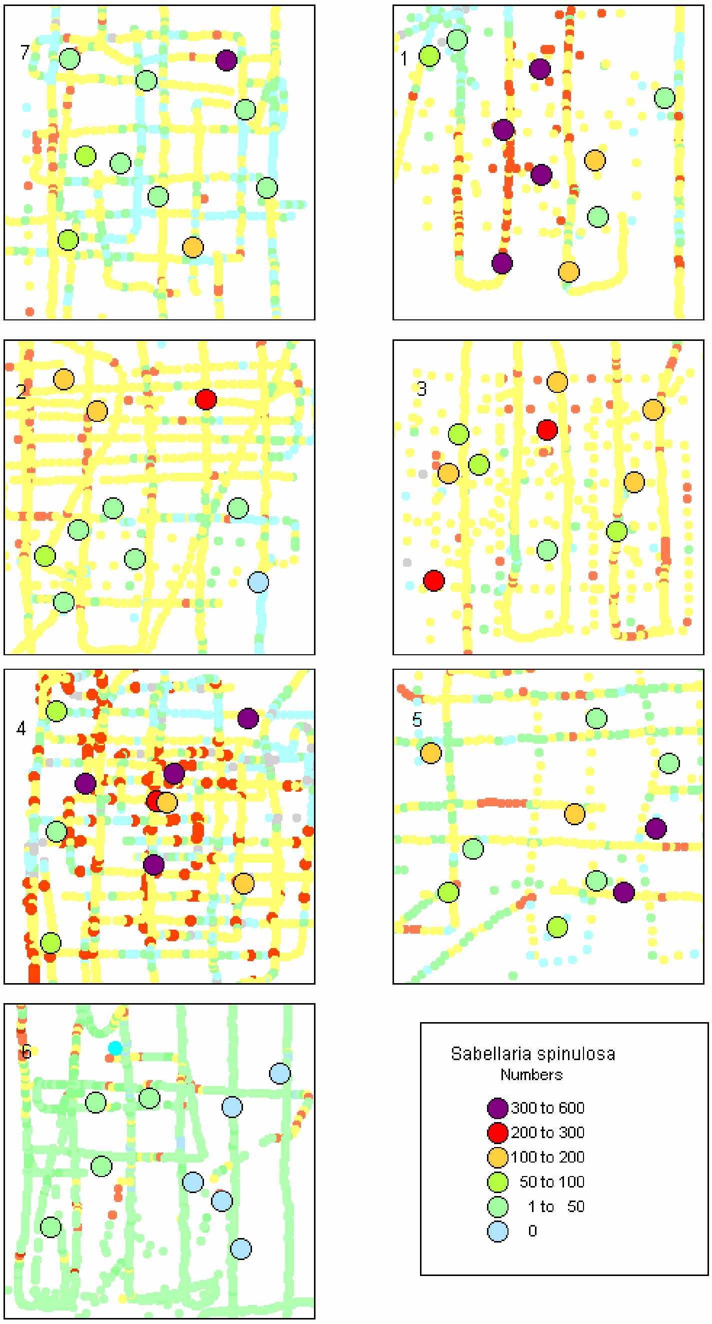

Figure 18. Track data classified to show likely associated Sabellaria densities.

4.2.4 Patterns in topography using AGDS bathymetric data

The AGDS based on single beam echosounders with moderately wide beam angle of about 15^o has a relatively poor resolution, no greater than about 25m, and cannot be used to detect fine features of the seabed. But the depth data can be used to detect broad scale topographic features and trends in slope. The depths corrected to chart datum have been interpolated to create a continuous surface which has been contoured (Figure 19) and used to create a 3 dimensional model (Figure 20). Since the depths varied from one Box to another, each has been treated separately.

The topography of most Boxes is relatively simple. Only in Box 4 are there any complex topographic features. There are no clear associations between *Sabellaria* and slope, although this might be the case in Boxes 1 and 5.

4.2.5 Patterns in fine scale sediment features using sidescan

Sidescan images can be of high resolution and have the potential to detect fine scale features. The separate track images were mosaiced and boundaries digitised around discernible fine scale features (Figure 21). Many of the Boxes were featureless, consisting of an even 'graininess' typical of gravel and sand or cobble and gravel. Dredge marks were characteristic of the northeast section of Box 4 with a clear cut-off coincident with the boundary of the 107 licensed aggregate extraction area (as noted and illustrated in the report for the year 2000). Boxes 7 and 2 showed no obvious features. Boxes 3, 4, 5 and 6 all had features ranging from small ribbons to small waves aligned northeast/southwest along the line of the transect (and Lynn Deeps). The video recorded waves of gravel alternating with cobble/gravel troughs. Box 4 contained some large gravel waves aligned northwest/southeast and these were clearly visible on the video. These waves appear to be encroaching on level cobble and gravel that supported *Sabellaria* reefs.

4.2.6 Summary of acoustic patterns

There is a distinction between patterns that are directly detected by remote sensing and those that are interpreted from the AGDS data using samples as ground truth data. AGDS detected trends in acoustic values across many of the Boxes, finer scale and more complex patterns in some (notably Box 4) and a moderate degree of patchiness spanning a few track data points in most Boxes. This has been interpreted as reflecting patterns in the limited range of sediment categories (cobble and gravel at the 'hard and rough' end of the E1/E2 spectrum and silty sand at the 'soft smooth' end). Thus, the AGDS data would appear to pick up trends and patterns not detected by the ground truth data alone.

Bathymetric data can detect broad sediment features (large waves) and general trends in slope, but not the fine scale features detected by sidescan. The contribution of sidescan to the detection of environmental patterns of significance to the biota is hard to assess. On one hand some fine scale features (gravel ribbons) were detected (although the importance of the ribbons to *Sabellaria* is not clear) and it detected dredge marks (which are of potential importance to management of the conservation interest). On the other hand sidescan does not discriminate between the various sediment categories.

Sabellaria has not been specifically and uniquely detected by AGDS and the interpretation of the acoustic data in terms of *Sabellaria* is equivocal. Areas likely to support *Sabellaria* can be highlighted, but other communities may be present instead. This is not surprising since *Sabellaria* can colonise a variety of sediments and show considerable overlap with other biota, especially epifaunal communities. Nevertheless, predicted probabilities of finding *Sabellaria* do seem to fit the ground truth data.

Thus, although acoustic remote sensing has added to our knowledge of environmental pattern within the Boxes, it is unlikely that this knowledge can readily be used to explain why *Sabellaria* was found at some sites within some of the Boxes and not others. In other words, the Boxes show a level of heterogeneity from scales ranging from the effective resolution of the sidescan (sand ribbons) to AGDS (trends) and the grab samples that cannot be easily mapped and taken into account when explaining differences in *Sabellaria* densities. There are some notable exceptions, such as the sand waves and reefs in Box 4 and the central concentration of *Sabellaria* in Box 1.

The samples can effectively be regarded as randomly chosen from a uniformly heterogeneous area.

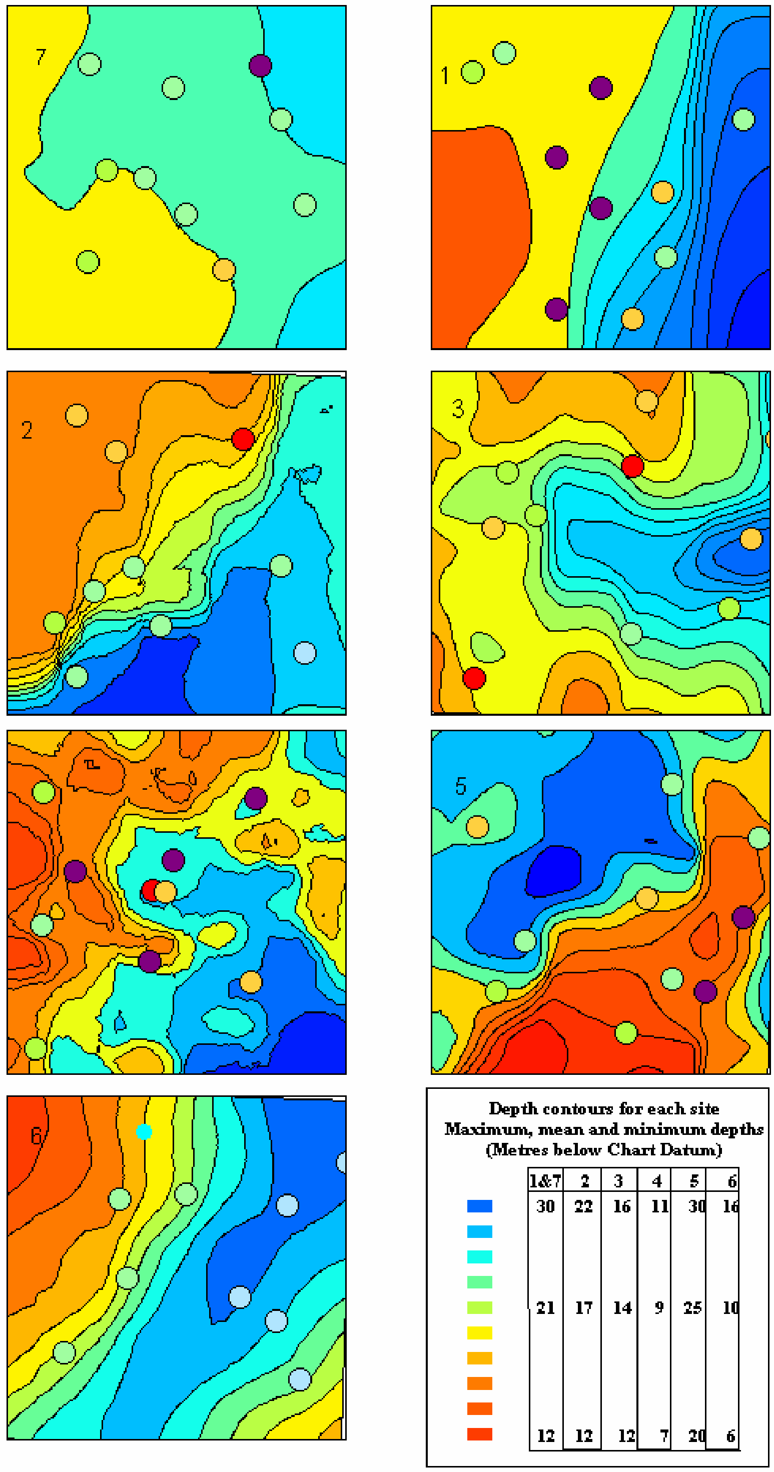

Figure 19. Bathymetry of the Boxes. Note that the scales differ between Boxes to highlight variations in topography within each Box.

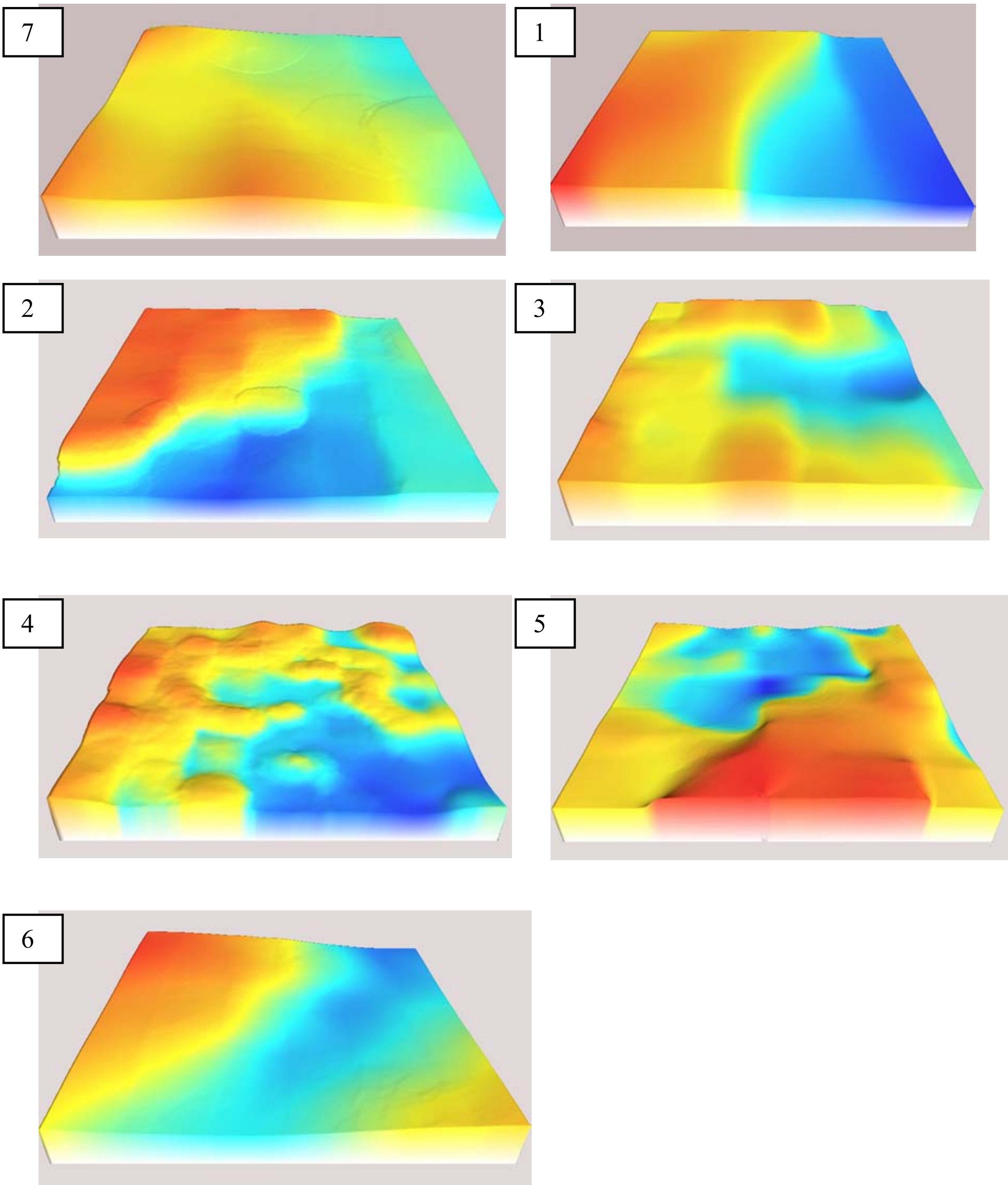

Figure 20. Topography of Boxes (no vertical exaggeration used) to show general trends in bathymetry and finer scale topographic features.

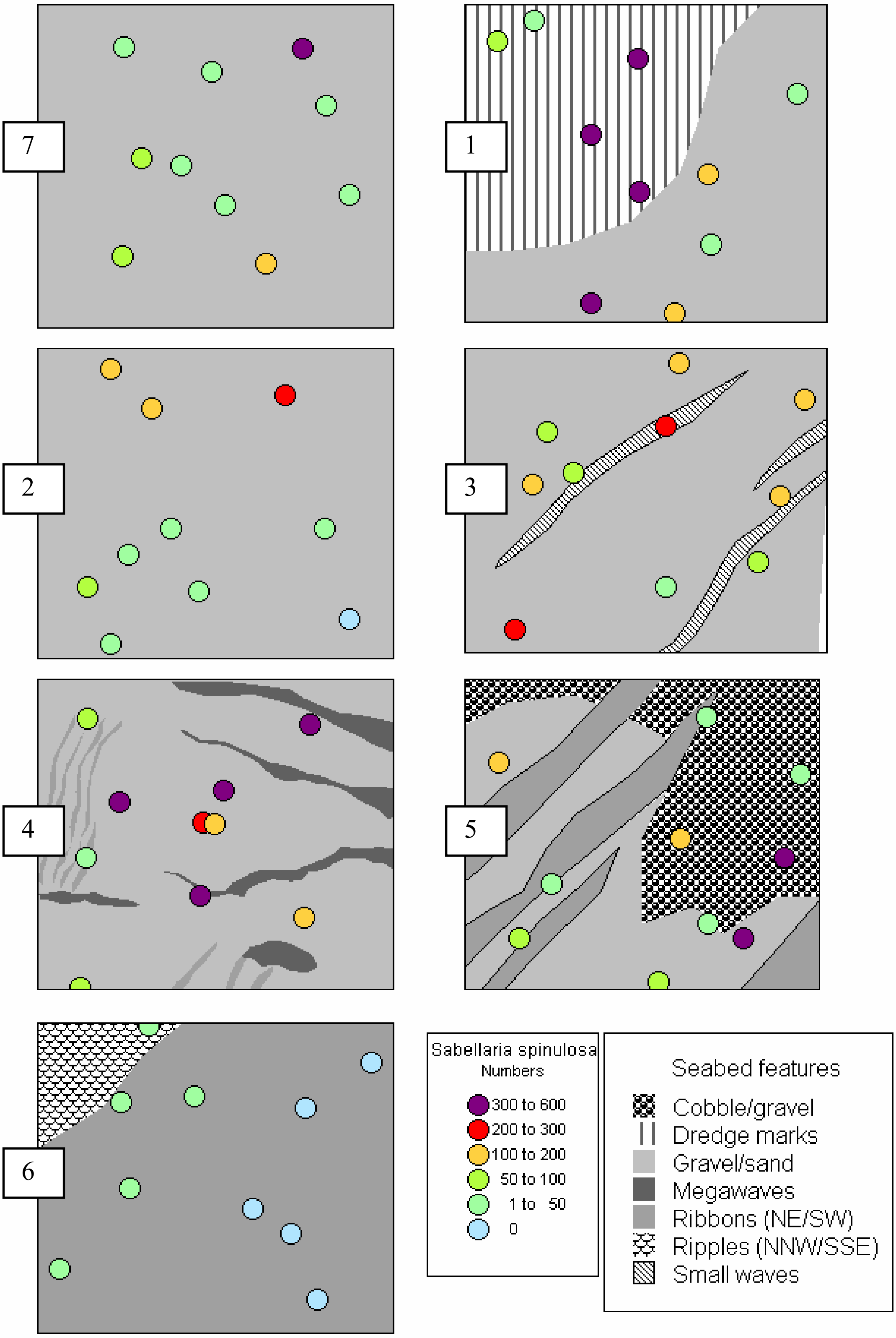

Figure 21. Seabed sediment features digitised from the sidescan images. Sabellaria densities have been superimposed.

4.3 Summary of Box statistics

It is concluded from the analysis of grab, video and acoustic remote data that there are few obvious spatial patterns at scales ranging from the maximum resolution of the grab sample (ie, the positional margin of error of the grab samples, estimated at 50m) to the 1km quadrat size. There is weak evidence that at the latter scale, broad scale trends are beginning to be detected and it would be expected that as sampling area is increased that a greater range of biotopes would be sampled and the trends would become more apparent and the 'pieces of the jigsaw puzzle' would fit together to resemble the broadscale map of the Wash (see Figure 2).

There is also some evidence for fine scale physical patterns (eg, large gravel waves, gravel ribbons and small sand waves/cobble troughs) and biological patchiness (*Sabellaria* reef patches) although sampling is not precise enough to determine if these features could explain the heterogeneity inherent at the maximum sampling resolution.

Thus, the samples could be regarded as having been drawn at random from an area with an inherently variable fauna. This suggests that summary statistics drawn from the samples can describe the Boxes and be used to (1) summarise the nature of the seabed within the Boxes and assess the statistical significance of change and (2) illustrate very broad scale trends.

4.3.1 Summary of infaunal species composition

Univariate sample statistics on diversity and eveness may be of some use in summarising data on species composition. Table 9 gives average values (and standard deviations) of species counts, number of individuals and more sophisticated indices such as Margalef's species richness, Pielou's eveness, Shannon diversity and Simpson's index. They all indicate that Boxes 1-5 and 7 are fairly similar but Box 6 has a much lower diversity.

Table 9. Summary of diversity indices for Boxes (average values with standard deviation below in smaller format).

Diversity index	Box						
	1	2	3	4	5	6	7
Species number	**90.30** 22.75	**72.00** 20.70	**87.30** 8.35	**76.90** 16.04	**66.60** 16.04	**48.70** 8.73	**75.50** 9.23
Individuals	**1227.80** 517.53	**742.00** 324.98	**1168.00** 356.90	**1546.00** 443.40	**803.90** 394.47	**3434.40** 3107.72	**1277.40** 455.95
Margalef species richness	**12.66** 2.41	**10.76** 2.54	**12.27** 0.89	**10.37** 1.68	**9.94** 1.68	**6.52** 1.91	**10.47** 1.11
Pielous eveness	**0.64** 0.11	**0.72** 0.09	**0.69** 0.04	**0.60** 0.08	**0.69** 0.08	**0.34** 0.30	**0.57** 0.10
Shannon	**2.85** 0.34	**3.07** 0.52	**3.09** 0.18	**2.61** 0.46	**2.90** 0.46	**1.34** 1.23	**2.45** 0.43
Simpson	**0.83** 0.08	**0.89** 0.08	**0.90** 0.03	**0.83** 0.09	**0.86** 0.09	**0.40** 0.37	**0.75** 0.12

The multivariate nature of infaunal communities can be summarised using statistical techniques such as Multidimensional Scaling (MDS) to reduce variability to two or three axis representing the major trends in dissimilarity in faunal composition between sites. The plots shown in Figures 22 a & b have been overlain on a contoured plot of the overall similarity of each site to a single reference yardstick 'site' derived from the average composition of all sites where *Sabellaria* was present at densities about 200/ 0.1m^2 (similar to the plot in Figure 5). The purpose of the plot is to show the relative similarity of the various samples. The samples themselves have been colour coded to show Box number (Figure 22a) and *Sabellaria* density (Figure 22b).

Most of the boxes are tightly clustered and are equally similar to the yardstick reference composition with considerable overlap between samples from different Boxes. There is even greater overlap in the distribution of *Sabellaria* amongst the samples. Box 6 is clearly distinct both in terms of faunal composition and *Sabellaria* density. Thus, the faunal composition of the samples within Boxes 1-5 and 7 are very similar, despite the high variability of the *Sabellaria* densities (it must be remembered that the numbers individuals have been double square root transformed analysis and this will reduce the influence of large numbers of a few species on the outcome of the MDS analysis).

Note that Boxes 1, 2 and 5 have a single outlier apiece. These outliers, when plotted geographically, also lie towards the outside of the Boxes.

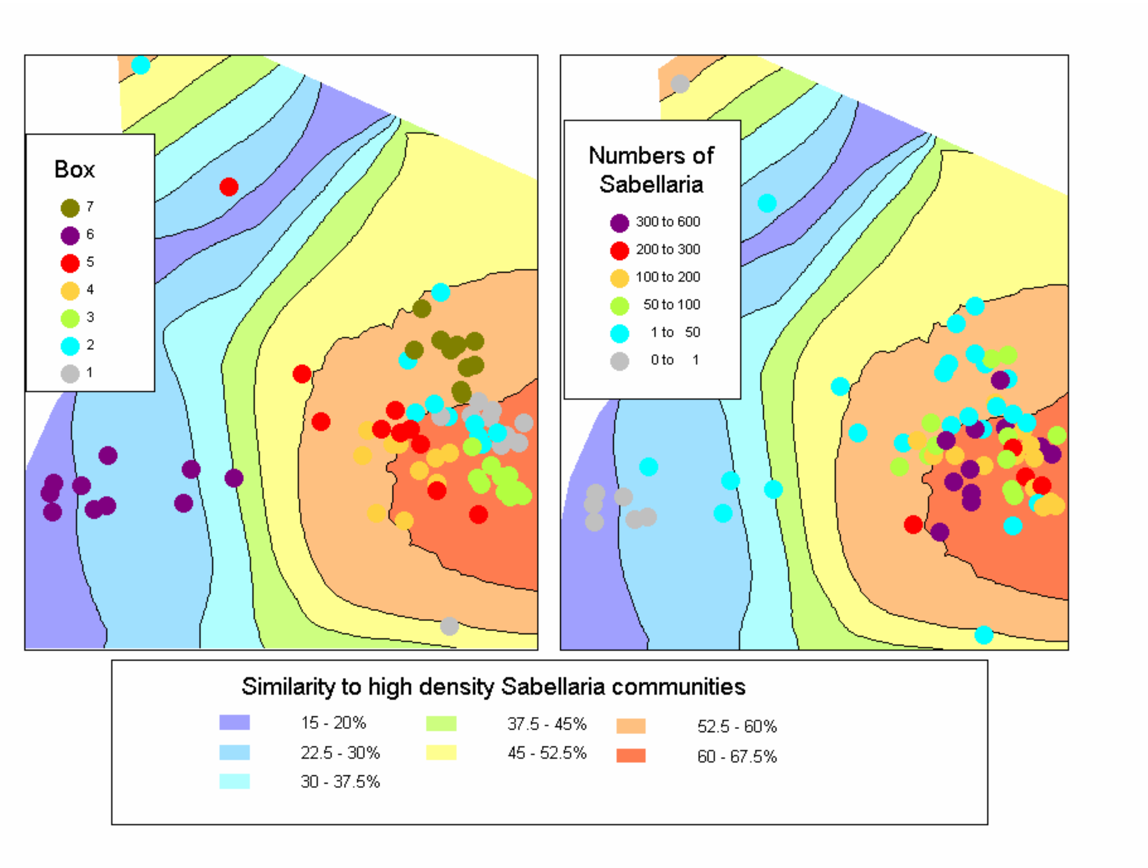

Figure 22. MDS plots of species dissimilarity for all samples coded to show Box (left) and Sabellaria density. Contours are levels of similarity to a yardstick derived from the average faunal composition of samples with dense *Sabellaria*.

An examination of the faunal composition of the samples, and particularly the most dominant species, was undertaken to try to identify the major faunal trends in the 2001 data. This analysis has been based on a multivariate plot of correlation between the top 100 species, selecting those species which are (1) characteristic of natural clusters and (2) present in some samples at relatively high densities. Four quite distinctive groups of species emerged with a minimum of overlap except that the most numerous species were also fairly ubiquitous. All samples were then assigned to these four groups and the average composition is shown in Table 10.

Table 10. Composition of four main community types from the grab samples. Note that there were also some minor classes (*Mytilus edulis*, sparse infauna and rich /diverse infauna).

	Sabellaria	Ampelisca	Ensis	Scoloplos
Sabellaria spinulosa	25.8	3	2.3	1.1
Mytilus edulis	7.6	0.9	4.2	2.5
Pisidia longicornis	6.1	0.6	0.7	0.1
Ampelisca diadema	5.7	23.9	2.6	0.1
Ampelisca juv	0.7	8.2	0	1.1
Ampelisca spinipes	0.2	3.5	0.6	0.1
Abra alba	3.1	3.1	1.2	3.9
Mya truncata	1.7	3.8	0.2	1
Pholoe spp	3	2.9	0.7	1.8
Harmothoe indet	3	0.9	0.8	1.2
Mediomastus fragilis	1.1	2.9	0.8	3.8
Ensis americanus	2.1	2.4	50.9	2.5
Scoloplos armiger	3	0.9	4.2	28.2
Protodorvillea kefersteini	1.4	1.9	0.6	3.1
Caulleriella zetlandica	1.3	1.9	0.9	5.1
Tubificidae indet	0	0.1	1.7	6.3

Future surveys could resample the Boxes and the infaunal composition compared with the results from 2001. Re-calculation of the MDS plots would indicate any drift in composition. It is difficult to estimate the likely power of the sampling strategy to detect change. However, the similarity of samples to the Box average (see Figure 6) composition for 2001 could provide a measure of change for each Box. Table 11 summarises the mean similarity and standard deviation of the samples to the Box averages. The values for Boxes 1, 2 and 5 are presented with all 10 samples and then with the outliers (see above; marked * in Table 11) removed. The means and standard deviations are quite constant between Boxes. Note that if a second set of samples were compared to the first (say, samples taken in 2002), the statistical significance of any difference could be calculated. Usually, a confidence limit of 95% is set for judging significance. This should be interpreted that there is a small risk (5%) that we might claim that there is a difference between populations when there is none – a Type 1 error. However, in environmental studies where populations are highly variable and samples expensive to collect, we usually run the risk of claiming there to be no significant difference when (if we were to sample much more exhaustively) there IS a difference between the two populations from which the limited samples were drawn (termed a Type 2 error). The chance of this happening is measured through the estimation of the power of the sampling regime and the statistical test used. It is important for environmental studies that sampling strategies have a reasonable prospect of detecting any change, but the significance levels for Type 1 errors are often reduced to avoid Type 2 errors. The power of the sampling procedures to detect 5% and a 10% change have been calculated assuming that it is desirable to maintain a 95% confidence that a Type 1 statistical error has not been made (ie, that a difference between two samples is claimed when no difference exists). The results suggest that the procedures have a 55-99% chance of detecting a real change of 5% in faunal composition and a 98-100% chance of detecting more profound changes of 10%.

Table 11. Summary statistics for similarity of samples to Box averages. The power of the tests have been estimated for changes in composition (effect sizes) of 5% and 10%, assuming a confidence of 95% for avoiding a Type 1 error is maintained.

Site	Mean	Standard deviation	Effect size	
			5%	10%
1	64.45	12.39	0.21	0.62
1*	68.12	4.67	0.85	1.00
2	57.64	13.57	0.18	0.55
2*	61.50	6.30	0.61	0.99
3	71.02	3.82	0.96	1.00
4	66.21	4.98	0.81	0.99
5	60.28	12.51	0.21	0.62
5*	63.67	6.81	0.55	0.98
6	64.32	4.65	0.86	1.00
7	66.09	3.12	0.99	1.00

4.3.2 Summary of *Sabellaria* density

Summarising *Sabellaria* statistics for the Boxes is more straightforward and the densities (number/0.1m^2) are given in Table 12. Note that the numbers have been square root transformed to ensure the distribution approximates normality and the values back transformed.

Table 12. Mean numbers of *Sabellaria* in the Boxes and likely chance of detecting any difference in numbers expressed in magnitudes of change. The blue cells indicate power levels that might be regarded as acceptable. Note that the very small numbers in Box 6 means that power analysis is not appropriate.

Site	Mean	Standard deviation	Effect size			
			x2	x3	x5	x10
1	229.4	212.0745	0.28	0.5	0.73	0.89
2	87.8	96.94305	0.23	0.44	0.64	0.81
3	123.1	61.05817	0.92	0.99	1	1
4	249.8	166.443	0.56	0.87	0.98	0.99
5	114.6	129.7701	0.23	0.43	0.65	0.83
6	2.4	4.742245	n/a	n/a	n/a	n/a
7	95.7	127.0206	0.26	0.48	0.7	0.86

Power analysis suggests that substantial changes in densities would need to occur before there was a reasonable chance of being detected with the sampling strategy, although this varies considerably between Boxes (the effect sizes are changes in sample numbers). Environmental tests are noted for their low power (often due to cost of sampling and high variability as is the case in this situation). Many workers have suggested that lower levels of confidence for Type 1 error combined with a modest power may be an acceptable compromise. In the case of the *Sabellaria* sampling, it is suggested that a 70% chance of detecting a five-fold change in numbers might be achieved on a two-year comparison. This would seem a very modest target, but it must be remembered that the variations in *Sabellaria* numbers are very large between samples within one Box due to patchiness. Also, it is anticipated that the sample design will be more capable of detecting trends over a number of years than simply a comparison between two years.

Another factor to be considered is the very loose correlation that appears to exist between *Sabellaria* density and reefs (see discussion in previous reports). If approximately 200 worms per sample and above are taken to represent a dense *Sabellaria* biotopes, then the statistical significance change in new samples can be calculated (Table 13) and an assessment can be made of statistical power for detecting changes in the proportion of samples meeting this criterion in a quadrat.

Table 13. Levels of significance expected between 2001 samples (with proportions of dense *Sabellaria* ranging from 0 – 0.6) and possible ranges from 0 – 1.0. Note that these 'results' do not show how likely it is that the tests will detect change.

Proportion dense Sabellaria	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
New proportion	Significance (P values)					
1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
0.9	<0.05	<0.05	<0.05	0.68	0.051	0.121
0.8	<0.05	<0.05	<0.05	0.178	0.16	*
0.7	<0.05	<0.05	0.074	*	*	*
0.6	<0.05	0.068	0.178	*	*	*
0.5	0.051	0.16	*	*	*	*
0.4	0.121	*	*	*	*	*
0.3	*	*	*	*	0.16	0.178
0.2	*	*	*	0.121	0.051	0.68
0.1	*	*	0.264	<0.05	<0.05	<0.05

Table 14 shows the relationship between effect size and proportion for approximately an 80% chance of detecting a change. Note that power determines how likely it is that a change will be detected by picking 10 samples at random from a large population in which the proportions of dense:sparse *Sabellaria* varies as per the effect size. Thus, it is possible to find two samples to have no significant difference (Table 13) and yet, if more samples were available, a real difference might be detected. The chance of this happening (Type 2 error) is 1-Power (Table 14).

Table 14. Power to detect changes in proportions of samples with densities greater than about 200/0.1m^2 for a full range of effect sizes (new sample proportions) and for sample numbers of 10 (as at present) and 20 (in red: to show marginal increase in statistical power for greatly increased sampling effort).

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

Again, the sampling design is likely to detect only major changes in *Sabellaria* numbers. For example, proportions in the population would have to drop from 0.6 to 0.2 before the test are likely to detect the change.

4.4 Very broad scale trends along transect: trends in species assemblages

The infaunal composition of the Boxes as summarised by the statistics indicate that they are quite internally variable, but are also similar to each other in terms species numbers, species diversity and densities of *Sabellaria* (except for Box 6). Are there any trends in composition along the broad transect?

4.4.1 Trends in species composition

The proportions of the main community types (see Table 10) represented in the Boxes have been shown in Figure 23 (one extra location has been included further into the Wash than Box 6 to extend the transect) and there would appear to be some major progressive changes in faunal composition from the outer to the inner sample areas. *Ampelisca* (Amphipoda) communities were more typical of offshore sites whilst *Ensis americanus* (Bivalvia: a small, introduced species) and *Scoloplos* (Polychaeta) were more characteristic of inner sites. *Sabellaria* was little found in the inner Wash, but abundant in Boxes 7 and 1-4. When the trends are plotted graphically (Figure 24) the change in composition between the inner sites (Boxes 6, 5 and site 8) and the remaining outer Boxes appear to occur between Boxes 5 and 4.

Any trends are, of course, determined by the choice of position of the broad transect and different trends would have been observed if the transect had, for example, run north-south across the mouth of the Wash. Given the broad biotope distribution patterns (Figure 2) it is hardly surprising that trends exist over such large distances. However, the major ‘elbow’ in the trend would seem to occur between Boxes 5 and 4. Box 6 is obviously different from the remaining Boxes and the inclusion of site 8 reinforces the distinction between inner and outer Wash sites.

However, the trends which look convincing as shown in the Figures below, must be viewed with extreme caution, especially the apparent lack of *Sabellaria* in the inner Wash. Records from previous surveys as well as more recent opportunistic observations from the ESFJC have indicated that *Sabellaria* has been present in substantial numbers at certain locations. These seem to fit in with the favoured habitat described above (sides of banks with a good supply of sand and possibly shell/gravel/cobble substrata for colonisation). The evidence also seems to suggest rapid changes in reef development. This pattern of *Sabellaria* distribution in space and time, with differences in rates of fluctuation between inner and outer Wash sites, still requires investigation.

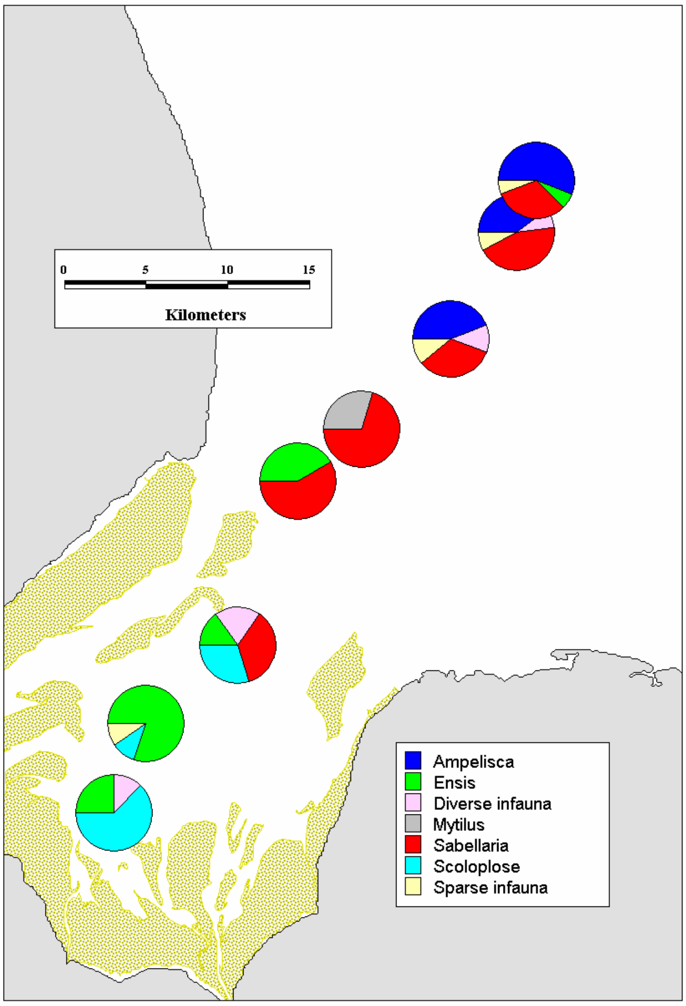

Figure 23. Trends in the proportion of major community types along the transect. Note that an extra site has been included from 1999 samples in the inner Wash for the purpose of extending the trends observed in the Boxes. It is purely illustrative and must be viewed with caution when drawing conclusions about trends.

Whilst it would clearly not be sensible to pool data over the transect to derive some overall statistic for the whole survey area, there may be some justification for pooling Boxes 1-4 and 7 to derive an index for the status of *Sabellaria* backed up by large sample numbers. It would also seem that the variability of the samples within these boxes is much the same and this may make analysis of power easier if variance can be more accurately estimated from pooled data than for each Box separately.

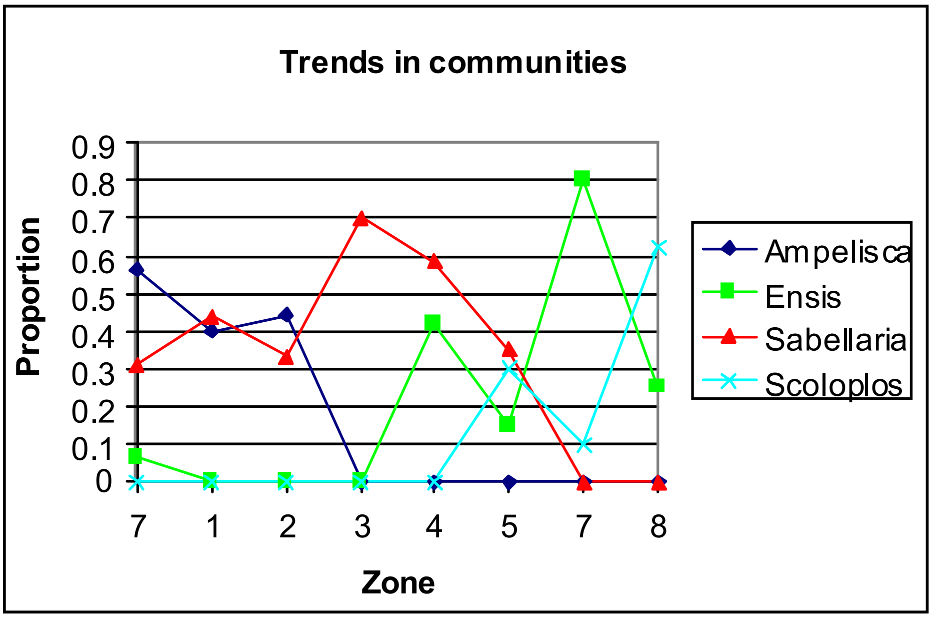

Figure 24. Trends along the transect from outer to inner Wash. Note the warning regarding site 8 referred to in the legend for Figure 23.

5. Final summary and recommendations

The main conclusions are as follows:

1. Selecting sample areas likely to support substantial populations of *Sabellaria* on the basis of broad scale biotope maps combined with real-time prospecting using AGDS appear to be successful in that all Boxes selected had at least some samples that contained dense populations and the similarity between the samples from the selected areas was much greater than between the full range of biotopes present in the Wash. In other words, the strategy successfully stratified the area into habitats likely to support *Sabellaria* and associated infaunal communities and those areas less likely to support these communities.
2. Dense populations of *Sabellaria* were associated with a wide range of acoustic ground types and depths that were associated with gravely silty habitats, but not clean sandy, muddy sand or cobble habitats. However, not all favourable habitats had dense populations of *Sabellaria*. Indeed, *Sabellaria* would generally appear to be much more variable than the infaunal community in which it is found.
3. Area 107 supports dense populations of *Sabellaria* and all indications are that this is bounded (within 107) by shallow cobble ground to the west and deeper silty sand to the east. It is also bounded by clean sand to the north and this habitat change coincides exactly with the northern boundary of 107. There are very clear signs of dredging activity south of this boundary, none to the north. This is a striking distribution linked to dredging activity.
4. Dense populations of *Sabellaria* do not necessarily correspond to the occurrence of visible reef. The Area 107 reef seems to have disappeared between 2000 and 2001, but Box 1 still had very dense populations. It would seem that reef development is an extreme growth response of the worms to high densities, but low growth over the substratum seems to support similar communities. It would seem to make little sense to differentiate the forms of *Sabellaria* reef when assessing status.
5. Video is the only technique able to determine if well developed reefs are present. Lower growth forms are not detectable by video when they are obscured by rich epifauna. Thus, grab sampling is the only tested way to sample the full range of *Sabellaria* communities.
6. Although there are clear patterns in the distribution of biotopes, spatial patterns at fine scales are hard to quantify. It would appear that there is no spatial correlation between samples separated by distances ranging from the minimum inter-sample distance (approximately 25m) up to 1km, although some spatial trends begin to emerge at the upper distance. A quadrat size of approximately 0.5km^2 may be appropriate for a random sampling design.
7. It is difficult to detect and then relate very fine scale habitat structure to data from the grab samples because (1) limits to sediment discrimination with sidescan, especially in situations where habitats grade into each other and (2) the poor positional accuracy of grab. However, it is unlikely that such precision would be required to monitor the status of *Sabellaria*. A more robust strategy based on integrating data randomly collected from a quadrat sampling may overcome problems of fine scale variability.

8. Since variability between samples is quite high (particularly with respect to *Sabellaria* densities) it is likely that repeat sampling would be able to pick up (1) major changes community composition and (2) long term trends.

9. Spatial separation of the Boxes along the transect also spreads the chance of detecting an overall change in *Sabellaria* and reduces the risk of simply measuring very local changes (patchiness).

10. This design is also well placed to detect relative differences in fluctuating community structure between inner and outer Wash.

All indications are that *Sabellaria spinulosa* is a common species that reaches high levels of abundance in a wide range of habitats where it may co-occur with other conspicuous biotope-forming groups, particularly epifaunal species. The community on well developed reefs does not appear to be qualitatively different from dense non-reef communities. The tube structure and typical growth over hard objects suggests that the worms build independently of each other (unlike the related *Sabellaria alveolata*) and these tubes coalesce and grow upwards away from the seafloor at high worm densities. But this is not an obligatory growth form and lack of a well developed reef structure does not imply sub-optimal conditions for growth. At high densities, *Sabellaria* is associated with diverse and productive communities linked to commercial shellfish stocks.

Conditions favourable for *Sabellaria* are silty sand and cobble/shell often on areas where sand supply might be high, such as the edges of sand banks and where there are sand waves. Although it would seem obvious that reef structure would be damaged by certain physical activities, the best reefs seen in the area were associated with ground clearly scarred by dredging activity, perhaps because reducing the overburden of sand has resulted in a cobble/sand habitat more suitable for *Sabellaria* colonisation.

Its distribution appears to be patchy at fine scales and to be variable. There is now clear evidence of a reef disappearing in Area 107 after persisting for many years, although *Sabellaria* still occurred at high densities. Other reef has been observed, although always in small clumps.

In summary, *Sabellaria spinulosa* would seem to be a species that favours a wide range of conditions. It is patchily distributed and suitable habitats may or may not have high *Sabellaria* densities and may have other community types. *Sabellaria* is an abundant species that must contribute substantially to the productivity of the area and provide food and refuge for a variety of commercial species. Unless details of recruitment, growth and decay of reefs are required knowledge, it makes little sense to undertake high precision and high resolution sampling to make an assessment of the status of a species that fluctuates spatially and temporally to the extent that *Sabellaria* appears to do. It is suggested that integration of samples over large sized quadrats that are positioned along a transect may be the most efficient way of providing data for monitoring the status of this species and its associated communities.

Other strategies might also be adopted. For example, we have a much better idea about the habitat conditions likely to favour *Sabellaria* and the corresponding acoustic ground characteristics. It should be possible to identify a wide range of potentially suitable sites within the Wash and 'prospect' for *Sabellaria*, measure the parameters and ground truth using grabs/video and relate *Sabellaria* presence to these habitat conditions. This could rapidly provide information on critical habitat characteristics and the likelihood of *Sabellaria* colonisation. What are the conditions favourable for *Sabellaria* colonisation? What proportion of potentially favourable conditions are colonised? Are there any geographic differences in distribution 'rules'? The advantages of this strategy would be (1) it would test a wider range of conditions than is possible with the more focussed quadrat survey, (2) it is predictive, and (3) the rules could be applied to new areas and any differences in favourable conditions determined.

A more holistic approach could also be justified on ecological and general area management grounds, although this might present problems with the more restricted objectives of condition monitoring of selected features. *Sabellaria* is just one of the important structuring species found in the Wash. Others are *Modiolus* (the horse mussel), *Lanice* (the sand mason) and epifaunal species (hydroids and bryozoans). Yet other species occur in such large numbers that they must contribute greatly to the trophic web in the Wash. *Sabellaria* overlaps and interacts with other biotopes characterised by all these species and life forms. Ultimately, the richness of these biotopes will be reflected in the abundance and population structures of predators, some of which are commercially exploited fish and shellfish. Monitoring these populations may provide a useful integration of the health of many biotopes over a wide area and reduce the need for exhaustive survey of the biotopes at the bottom of the food chain. For example, a small survey of selected biotopes might give a very rough indication of the likelihood of major changes in the benthos whilst monitoring fish catches would alert management to possible broad scale stresses in the ecosystem, so providing an overall health-check. This might have the advantages of (1) linking in with other management objectives within the Wash, (2) make use of other on-going monitoring and (3) reduce sampling sensitivity to patchiness and fluctuations in populations.

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