A broadscale mapping survey was carried out in 2001 as part of a series of surveys (1997-2004) carried out by Envision Mapping Ltd (formerly SeaMap) and the Eastern Sea Fisheries Joint Committee (ESFJC) in the Wash. The sampling strategies employed during these surveys are discussed in this case study, and optimal survey strategies discussed based upon these.

The survey design was based on stratified and nested sampling of selected sites, designed around the broadscale predictive maps from the broadscale mapping project (BMP) and more recent surveys, using AGDS to predict areas likely to support *Sabellaria spinulosa*.

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. The strategy correctly stratifies the area into habitats likely to support *Sabellaria* and associated infaunal communities and those areas less likely to support these communities.
Sampling, acoustic ground discrimination, AGDS, biotope mapping.

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1. Introduction

As part of the development of a Management Scheme for the Wash and North Norfolk cSAC it has been necessary to establish 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.

A broadscale mapping survey was carried out in 2001 as part of a series of surveys (1997-2004) carried out by Envision Mapping Ltd (formerly SeaMap) and the Eastern Sea Fisheries Joint Committee (ESFJC) in the Wash. The sampling strategies employed during these surveys are discussed in this case study, and optimal survey strategies discussed based upon these.

1.1. Goals of Mapping

Initially, the BMP surveys were designed to map the distribution of a wide range of biotopes and *Sabellaria spinulosa* reefs were not specifically targeted, but subsequent surveys have been undertaken with varying objectives. Specifically, a series of surveys have been undertaken in the Wash, for the specific purpose of developing techniques for the detection, mapping and monitoring of the biogenic reef builder, *Sabellaria spinulosa*, to support the UK’s Biodiversity Action Plan. The sampling methods developed to support this are discussed in detail in this case study.

1.2. Pilot Sites

The Wash and inshore waters adjoining the Lincolnshire and north Norfolk coasts (see Figure 1) comprise one of the trial areas for the Broadscale Mapping Project (BMP). This area contains sites of nature conservation importance and the Wash and north Norfolk coast have been put forward as a candidate marine Special Area of Conservation (cSAC). There are a number of important fisheries and a wide variety of activities take place within the area including aggregate extraction, military use and recreational activities. Additionally, the Wash receives waters from agricultural land, urban complexes and industrial sites that carry pollutants that impact on the ecosystem.

![Figure 1: Survey area of the Wash and various features of interest](image)

The area has been the subject of integrated management plans, such as the Wash Estuary Management Plan and a management plan is being formulated for the cSAC. Many agencies have responsibility for managing aspects of the marine environment and the need for sharing information has been identified as crucial to the development of a more integrated approach.
One of the objectives of the Broadscale Mapping Project is to promote the use of the techniques developed so that all organisations involved in area management have the capability to undertake similar mapping surveys. This is believed to be central to the strategic management of the area and therefore rigorous and easily repeatable, reliable methodologies must be developed to support this.

2. Characteristics of the habitat type

A review of all previous grab sample data collected 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 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.

2.1. Survey design

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.

2.1.1. Spatial association of samples

Fine scale association (where two samples lying close to each other are more likely to be similar than more distant samples) underpin replicate (at one point in time) and repeat sampling (samples taken in same place at two or more points in time). If the benthic habitats are very heterogeneous, then there will be a high degree of variability between samples that are very close to each other (as compared with the variability between all samples).

This may have two different impacts on a survey: (1) descriptions of spatial distributions based on point samples will need to be structured to show the variability that might be expected; (2) apparent temporal changes may simply reflect heterogeneity, and; (3) correlations between sample data and other data (such as acoustic information) may be compromised due to a combination of resolution and positional inaccuracies. Fine scale heterogeneity is often termed 'noise' when at or below the limits of resolution of a survey.

There may or may not also be broadscale trends whatever the nature of fine scale heterogeneity. Thus, statistical trends in habitat may appear as a signal over and above a high level of 'noise'. However, it may also be the case that a habitat that has mappable patches may show no broad scale trend in the distribution of these patches.

For these reasons, it is important to examine the point data and establish the level and scale of spatial variation in order to assess the 'noise', patchiness and broad scale trends (Foster-Smith et al., 2001). This should assist in the determination of whether the sampling strategy employed has been effective at capturing the real nature of the ground, rather than merely inconsistently capturing heterogeneity over a very small scale.
Envision Mapping Ltd has conducted analysis based on previous surveys to assess the rigour of the stratified-random sampling methods employed, and identify whether or not there were any overall spatial association in the data. In order to test this question all the ground-truth (GT) data were analysed in terms of the lag distances between samples over time versus the percentage of similarity. In this way temporal associations between conventional grab sample data can be used to help identify the heterogeneity of the ground type and sampling strategies for drop down video can be more easily assessed.

### 2.1.2. Stratified and nested sampling

The survey design was based on stratified and nested sampling of selected sites, designed around the broad scale predictive maps from the BMP project and more recent surveys. The survey strategy consisted of the following stages:-

1. Highlight areas likely to support *S.spinulosa* identified from previous broadscale surveys.
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. 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.

### 2.1.3. Acoustic survey

Acoustic techniques were also used to try to obtain a broad coverage of the boxes (*Roxann AGDS and sidescan*). The description of the sidescan and AGDS equipment, procedures for data collection and analysis are well documented and not discussed here (see ENV CS09 Prior Probability Classification.doc and ENV CS12 Appropriate use of multi-beam vs AGDS.doc). 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.

### 2.1.4. Video

Direct observations were made with a digital video system and the tows were also recorded simultaneously on the surface unit in Hi8 format. After 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.
2.2. **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 this was not considered to be sufficiently large considering the spatial imprecision of the grab sampling, bearing 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.](image)

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.
2.2.1. 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 (e.g., due to static fishing gear) and in such cases a duplicate grid location was selected at random. The final selection of locations is shown in Figure 2, above.

2.3. Visual analysis

It is apparent from a visual inspection that there is a high degree of spatial heterogeneity even within each box.

![Figure 3: All field samples from the Longsands site (Box 5, Figure 2) colour coded to biotope. An example of the spatial heterogeneity within the boxes.](image)

This heterogeneity can be analysed by determining pair-wise similarity/dissimilarity over increasing separation distance (termed ‘lag’). If the area were homogeneous, then it would be expected that the similarity between samples would be high where samples lie close to each other. If, on the other hand, the area were heterogeneous, it would be expected that the similarity would be low. Figure 4 illustrates the relationship between similarity and lag and even at the closest spacing (within 200m), the similarity is low (0.2) compared with the frequency that would be expected if the samples were completely randomly distributed (0.11 – the red horizontal line).

![Figure 4: The frequency with which samples are of similar biotopes with increasing separation distance (lag). The red horizontal line indicates the frequency expected by chance.](image)

Intriguingly, the frequency has a second peak at a lag of about 1000m. This coincides with the distance across the deeps and may represent a repeated pattern in this direction. However, the main point is that the biotopes are probably very patchily distributed, which would make
accurate and detailed mapping very difficult. The problem is compounded because the various biotopes are not clearly distinct even from the field samples. They have many of the same component habitat features and conspicuous species, but in varying proportions.

3. Implications for survey strategies

Choosing the scale for sampling and the area for survey for the Wash and its environs must be matched to the priority questions that need to be addressed for monitoring the status of the reefs and related *Sabellaria* biotopes (as well as the techniques available and survey cost). Some example options are given in Table 1, with reference to Figure 5.

Table 1: Examples of options for monitoring the status of reefs in the Wash.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Techniques</th>
<th>Positioning precision</th>
<th>Cost/effort</th>
<th>Issues addressed</th>
<th>Issues not addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrat (25m x 25m)</td>
<td>Continuous coverage: Videography, photography and diver sampling</td>
<td>Very precise: DGPS and acoustic beacons</td>
<td>High for sample quadrat; prohibitive for large survey area</td>
<td>Patch dynamics of reef; sequence of reef construction and decline</td>
<td>Significance of change hard to assess in broader context</td>
</tr>
<tr>
<td>Box (500m x 500m)</td>
<td>AGDS; random sampling within box: videography, grab samples, diver – collected samples</td>
<td>GPS (assuming no selective availability)</td>
<td>Videography low; grab low to moderate depending on infaunal analysis</td>
<td>Statistics of box used to assess change</td>
<td>Hard to extrapolate change to whole area; little information on patch dynamics</td>
</tr>
<tr>
<td>Box (500m x 500m)</td>
<td>As above plus acoustic imaging</td>
<td>As above; Imaging unknown</td>
<td>As above plus boundary changes within box associated with patch dynamics</td>
<td>Hard to extrapolate change to whole area</td>
<td></td>
</tr>
<tr>
<td>Whole area</td>
<td>AGDS survey plus selected sampling using videography and grabs</td>
<td>As above</td>
<td>High to achieve adequate coverage and sample intensity for repeat survey; Moderate if indicative only</td>
<td>Broad scale changes mapped; comprehensive statistic for whole area</td>
<td>Even intensive survey is imprecise for measurement of change; If indicative then statistics unreliable</td>
</tr>
<tr>
<td>Box and belt transect</td>
<td>AGDS for belt; as option 2 &amp; 3 for boxes</td>
<td>As above</td>
<td>Moderate to high depending on number of boxes and sampling</td>
<td>Broad scale changes along preselected gradient</td>
<td>Changes outside transect not assessed, changes between samples extrapolated and therefore imprecise (indicative only)</td>
</tr>
</tbody>
</table>

Figure 5: Examples of sampling scales and survey sizes for monitoring the status if reefs in the Wash.
3.1. **Random sampling within areas of broad environmental gradient**

One of the issues raised in this survey series was that of random sampling within monitoring areas that follow a broad environmental gradient. It is clear that limited sampling in an area is insufficient to be able to sample the full range of biotopes (e.g., *Sabellaria* biotopes were not sampled at the Longsands site in months with more limited samples available). A larger number of samples would allow an assessment to be made of the *Sabellaria* population within a sampling area and the spatial heterogeneity (dispersion) of the population. These sampling areas might be about 500m x 500m and arranged following the northern flank of the Lynn Deeps/Scott Patch feature. The analysis would produce summary statistics for each site that could be used to detect broad scale spatial and temporal trends.

3.1.1. Pattern and Patches

The distinction between pattern and patchiness depends on the scale of observation used: broad scale survey (low resolution) may render an area as being patchy whilst a fine scale survey (high resolution) may show pattern. For mapping, this will be determined by the combined errors from the sample area and positional inaccuracies of the acoustic image and the ground truth observation. Essentially, if two locations in the survey area cannot be spatially distinguished, then the information from the two points must be integrated into a combined description. If the benthos at these two points are different, then the descriptive statistic will need to measure the level of variability. This variability is a measure of patchiness. In other words, patchiness is a measure of the variability of the data at and beyond the limits of spatial resolution of the survey. This inherent variability is termed the ‘nugget’ in variography.

3.2. **Survey design for variability**

What is the level of this variability? A standard approach to mitigate against fine scale heterogeneity is to take a small number of replicate grabs (taken at the same location, but allowing for drift and spatial imprecision to space the samples). In 2000 five sites (3 at area 107 and 2 at Long Sand) were sampled three times and the positions logged as accurately as possible (dGPS close to point of deployment of grab, but with no control over drift of the grab). The number of *Sabellaria* in each grab were used to calculate similarity between pairs of grabs and the similarity have been plotted against lag distance (distance between the pairs) (Figure 6, overleaf). The variability between samples that are close together is extremely high and there is no obvious decrease in similarity as lag distance increases. Thus, over short distances, closely spaced samples are no more similar to each other than more distant samples. This would indicate that there are no very local patterns within the 80m (± the estimated drift error). The local mean value of the samples is the best estimate for any point within the area encompassed by the samples.

![Figure 6: Percentage similarity between pairs of samples (based on *Sabellaria* numbers) plotted against the distance between the pairs (lag distance in m).]

This strategy has two main drawbacks: (1) three
samples are too few to estimate variability or a mean that can be used as a yardstick for measuring change, and (2) the area encompassed by the samples is small (100m) and any apparent change measured by repeating the sample might reflect patchiness at a slightly broader scale rather than any real change. The strategy for the 2001 survey was based on random samples within a large quadrat in an attempt to overcome these problems.

### 3.2.1. Assessing spatial variation for sample area selection, using grab samples

Samples with counts (numbers of *Sabellaria spinulosa*) can be subjected to another graphic demonstration of spatial correlation in which variance between pairs of samples is plotted over increasing lag distance (Burroughs and McDonnell, 1998). In the following analysis, the variances in the similarity between pairs of samples over lag distances have been calculated for each of the Boxes separately. The pair-wise similarities were placed into bins of increasing lag distances. The exact bin ranges varied between Boxes depending upon the spread of pair-wise lag distances and bins with less than 4 pairs were discarded. Since variance depends on the absolute numbers, the variances for each lag bin have been standardised by dividing by the total variance within each box to enable the plots for the Boxes to be more easily compared. The variance/lag graph for each Box has been plotted separately in Figure 7. 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 7: 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.](image)

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.

### 3.2.2. Indices of dispersion

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

Moran’s I tends towards a slight negative value at the larger lag distances and at small lags (where the significance of the indices is low because of the smaller number of pairs in the calculation) I is very variable. Two sites (Boxes 2 and 6) show a gradual decrease in I which might indicate some positive correlation at small lags. But the highest values are not large (approximately 0.25) and it is doubtful if the trend is interpretable. If all data are pooled, then there is only a weak trend in spatial association (Figure 9).

**Figure 9: Median and mean Moran’s I for the 7 Boxes for lag distances ranging from 150m to 1050m.**

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

Numerous analyses have been carried out on the data. Table 2 summarises the strategy for the analysis of grab and video samples.

Table 2: Analyses of the grab and video data. Grab sample data from previous surveys have been used.

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<th>Procedure</th>
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<td>Variability across range of biotopes</td>
<td>All SeaMap records for all years</td>
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<td>Variability at a very fine scale</td>
<td>2000 data set of replicate samples</td>
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<td></td>
<td>Variability within 1km Boxes</td>
<td>2001 data set</td>
</tr>
<tr>
<td>Spatial patterns of biota within 1km Boxes</td>
<td>Patterns in similarity of infauna</td>
<td>2001 infauna</td>
</tr>
<tr>
<td></td>
<td>Pattern of Sabellaria numbers</td>
<td>2001 numbers of Sabellaria</td>
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<tr>
<td>Spatial patterns video data within 1km Boxes</td>
<td>Patterns of faunal classes</td>
<td>2001 video records</td>
</tr>
<tr>
<td></td>
<td>Patterns of sediment classes</td>
<td>2001 video records (supplemented by grab data)</td>
</tr>
<tr>
<td>Match infauna from grab samples and video faunal classes</td>
<td>Match video class and (1) Sabellaria numbers and (2) grab infaunal classes</td>
<td>2001 video records and grab infaunal samples</td>
</tr>
<tr>
<td></td>
<td>Match sediment category and (1) infauna and (2) video classes</td>
<td>Summary sediment data (video and grab) and (1) grab infauna and (2) video</td>
</tr>
</tbody>
</table>
4.1.1. Variability across the range of biotopes

Measurement of the variability between grab samples across the whole range of biotopes from the Wash and its environs have been used 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 11).

![Figure 11: 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 fine scale as a further reference for assessing in box variability

Replicate grabs 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 with an average similarity of only 61.8%. 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.

4.1.3. Spatial patterns of biota within 1km Boxes

If the 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. 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 12, below). Clearly, some Boxes are more variable than others, but there is no pattern to similarity: i.e. 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.

4.1.4. Patterns in similarity of infauna: Exploratory geographic plots

![Figure 12: Grab samples plotted within each of the 7 Boxes colour coded to show their similarity to the average faunal composition for each Box.](image)

4.1.5. Similarity/lag plots

The similarities between samples have been plotted against the distance separating them (lag distance) in Figure 13. 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 this 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 are 61.5% and 15, respectively.

Figure 13: 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 13 that there is a spread of similarity values within the range expected from the ground likely to support *Sabellaria* without any clear indication of spatial auto correlation.

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.

4.1.6. 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 14). 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.

4.1.7. Patterns of faunal and sediment classes.

The predominant epifaunal communities are shown in Figure 14. 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.

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.
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.

The predominant sediment classes for the sample sites are shown in Figure 15. The sediments are diverse for most Boxes, although most are gravely sediments. Only Box 6 has predominantly fine sediment samples.

Figure 14: Left: Samples plotted within each of the 7 Boxes, coloured to show Sabellaria numbers in each grab. Right: Samples plotted within each of the 7 Boxes showing the predominant epifaunal community.
5. 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.

6. Conclusions

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. 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. 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.

3. 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.

4. 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.

5. 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.

6. 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.

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

7. Discussion

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

The problem of variability remains at very fine scales (e.g., 1:1,000-10,000), and even between close samples this may be high, making detection of local patterns very difficult and uncertain. However, the restricted geographic scale makes replicate sampling more feasible and it may be possible to pin down the mean, range and variability of the population through sampling such
that populations can be compared statistically. It is easy to integrate data over quadrat-scales and work with statistics that summarise the nature of the quadrat.

It is the scales between broad and very fine scale maps which are most difficult to address. Patches become large enough to require mapping rather than integration into a summary description, while the processes that drive these patterns start to assume more importance and operate at the scale of management.

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

Stratified sampling was based on the random sampling within a quadrat with sides of 1km. The size of the box (quadrat) is important: too large and the samples will not be from a uniform (or uniformly patchy) area due to broader scale spatial trends, too small and the samples may not be representative of a significant area (i.e. be influenced by patchy habitats and seabed features). Thus, the validity of random sampling as a strategy is based on the assumption that there are no strong spatial trends within the boxes, although there may be heterogeneity of biota and even quite large seabed features (as in Box 4). This may not be true and even within Box 1 there was a depth gradient and the north west sector showed more striking evidence of sand extraction than other parts of the box. One drawback to this strategy is its restricted spatial coverage. The extent to which the results from one quadrat reflect wider trends is doubtful: a severe decline in numbers of *Sabellaria* and subsequent recovery in one quadrat, for example, may simply reflect local changes and not be replicated elsewhere. However, is does indicate that reefs can change significantly at the scale of the quadrat. The detection of broader spatial trends through replication of the quadrat will have implications for survey cost. An alternative approach might be the use of widespread stratified sampling of habitat types. But scattered samples are susceptible to apparent change through fine scale patchiness and the number of samples required to obtain any degree of certainty in the results might be large.

### 8. Acknowledgements

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### 9. References
