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Littoral sediments of The Wash and North Norfolk Coast SAC

The 1998 surveys of intertidal sediment and invertebrates

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Littoral sediments of the Wash and North Norfolk Coast SAC: The 1998 and 1999 surveys of intertidal sediment and invertebrates

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Summary

Two surveys of the sediments and macro-invertebrates of intertidal areas of the Wash were undertaken during late September to early November 1998 and 1999. In 1998, 113 sites, each 1 ha in area were sampled, 91 of which were sampled in Institute of Terrestrial Ecology's survey of 1986. 1n 1999, 103 sites were sampled, 82 of which had been first sampled in 1986.

The sampling methods followed those specified in the Procedural Guidelines 'Quantitative Sampling of Intertidal Sediment Biotopes and Species Using Cores' Davies *et al* 2001). Any alterations to the Procedural Guidelines were described.

The sediment particle size distribution, determined by a particle size analyser, and its organic content, determined by weight loss on ignition (LOI), were described and compared with similar data from the 1986 survey.

Sites on the west shore between Gibraltar Point and the outfall of the Rivers Welland and Witham were predominantly sand at all levels of the shore. Sites on the more sheltered south-west, south-east and east shores tended to be mud or mud-sand. Sand sites on these shores were generally confined to the mid- and lower-shore levels. Sites on the outer banks were predominantly sandy.

The sediment in 28 (31%) of 91 sites sampled in 1986 had changed by 1998. The most extreme changes were from either mud to sand (8 sites) or from sand to mud (2 sites). In 82 sites sampled in both 1986 and 1999, 31 (38%) had changed sediment of which only 7 exhibited an extreme change from mud to sand. Of the 89 sites sampled in 1998 and 1999, 23 (26%) changed from one sediment category to another but there were no extreme changes from either mud to sand or sand to mud.

The changes in sediment category between 1986 and 1998 and 1986 and 1999, indicated that areas on the shore to the east of the river Great Ouse had less fine sediment. That is to say, they were sandier in 1998 and 1999 than they had been in 1986. Between the surveys of 1998 and 1999, most sites also became sandier except those sites to the west of the Gt Ouse which became muddier. Elsewhere in the Wash, sediments changed little between any of the surveys.

In all three surveys the organic content (%LOI) of the sediment was positively and highly correlated with the percentage of fine particles (<63 μm) in the sediment. The relationship was linear when $\log_e$ %LOI was plotted against % fines.

After taking into account the percentage of fines in the sediment, the organic content of the sediment was significantly higher in 1999 than in either 1986 or 1998. This finding applied to the whole Wash and not just to sites near to the river outfalls.

The abundance of intertidal invertebrates, identified to species level where possible, was recorded for the 1998 and 1999 surveys and the 10 biotopes that were identified were described and mapped.

The distribution and abundance of the 30 invertebrate species and species size categories, which earlier studies has indicated contributed most to the biomass of the macrobenthic fauna and which were the major prey of the wading birds, were mapped for both the 1998 and 1999 surveys and compared with the1986 survey.

The mean Wash-wide densities of 10 of these 30 invertebrate were significantly lower, and one was significantly higher, in 1998 than in 1986. The densities of 13 of them were significantly lower in the 1999 than in 1986 but none increased significantly. Compared with 1998, three of the invertebrates had increased in density in 1999 while 4 of them decreased significantly. Between-survey comparisons of invertebrate densities in sample transects associated with the river outfalls indicated that changes in density were similar there as throughout the Wash.

With few exceptions, those invertebrates whose densities decreased significantly between surveys also occurred in fewer sample sites, so had become less widespread. Those whose density increased were more widespread.

Together these changes implied that, as measured by invertebrate abundance and distribution, the productivity of the Wash was higher in 1986 than in 1998 and 1999. A further comparison for a limited number of invertebrates between these surveys and one carried out in 1973 indicated that densities then were similar to those recorded in 1998 and 1999. This implies that the 1986 survey coincided with a peak in productivity of invertebrates in the Wash.

The changes in the densities of many of the invertebrates were significantly, but not strongly, associated with changes in sediment particle size and organic content. Declines in those invertebrates like *Arenicola marina* and *Bathyporeia* spp that are known to be associated with sandy, organically poor sediments occurred where the sediment became muddier or more organically rich. In contrast, those like *Hediste diversicolor*, *Hydrobia ulvae* and the oligochaete worms that are known to be associated with muddy, organically rich sediments, increased in density in response to increases in muddiness and organic content. Multiple regression analysis indicated that some of the residual variation not accounted for by changes in sediment variables correlated with density changes of other invertebrates suggesting interactions occurred between invertebrates.

The sediment characteristics and invertebrate densities recorded in the 1998 and 1999 surveys of the whole Wash were compared with those of the Gt Ouse study area in the same years to determine if the changes in that area were different to those in the whole Wash. There was no evidence that this was so.

Contents

1. Introduction

1.1 Background to this study

The Wash and North Norfolk Coast has been designated as a candidate Special Area of Conservation (cSAC) under the EC Habitats Directive. One of the features of interest for which it was designated is ‘mudflats and sandflats not covered by seawater at low tide’. The Wash is the largest marine embayment in Britain, with the second largest expanse of intertidal sediment flats in the country. These include extensive areas of fine sands and drying banks of coarser sand which support communities characterised by large numbers of polychaete worms, bivalve molluscs, and crustaceans.

One initiative to help implement the Habitats Directive is the UK Marine SAC’s LIFE Project, which involves a partnership between English Nature, Scottish Natural Heritage, Countryside Council for Wales, Environment and Heritage Service, Department of the Environment for Northern Ireland, Joint Nature Conservation Committee, and Scottish Association of Marine Science. The overall goal of the Project is to establish management schemes on 12 of the candidate marine SAC sites. The Project aims to collate and develop scientific and procedural knowledge to support the design of management schemes. An important prerequisite to achieving this aim is to determine methods of surveillance and monitoring that aid the development of a means of reporting on the condition of features on marine sites.

1.2 Objectives

This study had four objectives:

i. To test the advised monitoring methodology in the Wash

The need to design a monitoring programme of the sediments and invertebrates arises because the mud- and sandflats of the Wash present particular challenges in terms of monitoring and surveillance. The massive expanse of the intertidal poses both logistical and financial limitations on the applicability of traditional intertidal monitoring techniques as a means of monitoring and reporting on the condition of features on a frequent basis. Consequently, the present study was initiated to look at the logistics of how to monitor the Wash in order to assess the condition and long-term conservation status of the mudflats and sandflats. The attributes that were selected for monitoring were the distribution, extent, invertebrate species composition and sediment characteristics of the biotopes occurring in the Wash (Anon 2000). Taking these attributes into account, this study focused on sampling design and replication, repeatability and practical considerations such as permanent site markers. The results informed not only the development of appropriate monitoring and surveillance techniques, but also revision of the marine monitoring handbook (Davies *et al* 2001) developed by JNCC and the country agencies.

ii. To establish a new baseline datasets

Legislation to implement the EC Habitats Directive requires that studies be carried out to establish an up to date baseline against which any future changes in the Wash ecosystem can be compared.

iii. To compare the new baseline with previous datasets

Unusually for cSACs, the Wash had been surveyed in the past. The intertidal sediments, macro-invertebrates and shorebirds of the Wash had all been surveyed by the Institute of Terrestrial Ecology (ITE) in the autumn and winter of 1986 and 1987 (Goss-Custard *et al* 1988). This provided an opportunity to compare the present day sediments and invertebrates with those of 15 years ago.

iv. To compare sediments and invertebrates between areas within the Wash

In 1996-97 ITE conducted a survey of intertidal sediments, macro-invertebrates and shorebirds (Yates *et al* 1998) in areas adjacent to the outfall of the River Great Ouse in response to the imminent up-grading of the King's Lynn sewage treatment works and granting of the Essex and Suffolk Water's Denver Licence Variation (Binnie, Black and Veatch 1997). This survey revealed statistically significant decreases between 1986 and 1996 in the densities of 50% of the categories of macro-invertebrate studied. However, it was unclear whether this was a Wash-wide phenomenon or was restricted just to the south-east Wash. In addition to the other objectives this study also resolved this uncertainty by re-surveying the whole Wash.

2. Methods

The sampling methods generally followed those set out in the Procedural guidelines *Quantitative sampling of intertidal sediment species using cores* (Davies *et al* 2001). However, because comparability with our previous Wash survey of 1986 was an objective of this study, it was necessary to alter certain of the procedures specified in those guidelines. Attention will be drawn to these alterations in each of the following methodology sub-sections to which they apply; they are also summarised at the end of this section for ease of reference.

Statistical methods used in analysis of the data are detailed in the parts of the Results sub-section to which they apply.

2.1 The 1998 and 1999 study sites

2.1.1 Site selection for 1998 sampling

The 118 sites sampled in 1998 (Figure 2.1) included 91 of 192 sites first established in 1986 ITE survey of the Wash (Goss-Custard *et al* 1988). This was essential for the comparative and compatibility purposes that were required in order to assess temporal variability between years. This selection was made primarily on the basis of a community and biotope analysis performed by JNCC's Marine Information Team on our 1986 dataset to ensure that sites representative of all the Wash intertidal biotopes identified by that analysis were included in the 1998 survey. Efforts were also made to concentrate sites in areas that would be expected to show the greatest variation in sediments and infauna.

A further consideration that had to be taken into account was the site selection that was necessary to meet the requirements of the work carried out simultaneously for Essex and Suffolk Water. The consequence of this was that the sampling intensity, in terms of numbers of transects and sites within transects, was greater in those areas adjacent to the Gt Ouse outfall than it was elsewhere in the Wash (Figure 2.1).

The 1986 survey did not include sample sites on the outer banks of the Wash because those areas were beyond the remit of that earlier survey. This omission was rectified in the 1998 survey by the addition of sampling sites located on the outer banks, Long Sand, Roger/Toft Sand, Gat Sand, Daseley's Sand and Pandora Sand (Figure 2.1). Again the primary selection criterion was that these sites represented the different sediment types and shore levels present on the outer banks and their initial location was based on examination of aerial photographs taken at low tide in October 1995. Their final location was chosen at the time of sampling when the sediment type and other attributes could be better identified on the ground.

To reconcile the need to make the 1998 survey more extensive by including outer bank sites while staying within budget, it was agreed that five replicate invertebrate samples would be taken from all sites, but only three of these would be sorted.

2.1.2 Site selection for 1999 sampling

The 1999 sampling programme was further refined by results gained in 1998 and led to 103 sites being sampled. The purpose of this refinement process was mainly to avoid unnecessary duplication of effort and to minimise practical problems.

From the 1998 survey it was apparent that the outer banks, Roger and Toft Sands had a very similar sediment character and species composition to inner bank areas already included in the survey and like the other outer banks it was costly to access. Consequently it was not proposed for sampling again in 1999. Both Long Sand and Gat Sand were very different in character and composition to any inner bank area, so they were retained for sampling.

Transect 10 was not included in 1999 because of difficulties in gaining safe access to its sampling sites. Instead, transect 9 was included in 1999. It was considered a suitable replacement because of it being located near to the outfalls of the rivers Welland and Witham, like transect 10 and having a similar biotopes.

Transect 21 was sampled in the 1986 survey, but had not been included in the 1998 survey because it was thought results from a sampling programme undertaken by other workers would be available. This was not the case at the time the 1999 survey was being planned consequently transect 21 was included in the 1999 survey.

2.2 Field sampling methods

All field sampling was done during low water of spring tides over the period 17 September to 6 November in 1998 and 21 September to 8 November in 1999 and so coincided with the timing of the 1986 survey.

2.2.1 Site arrangement and marking

Each site was a 100 m square (1 ha in area). Sites were arranged down the shore in a series of line transects (Figure 2.1). Wooden marker posts were placed at the upshore left-hand corner of the uppermost site of each transect to aid future relocation of the site and transect. Marker canes were also placed at the left-hand upshore corner of all other sites. These canes were 1.5 m in length and were pushed into the sediment to a depth that left approximately 30 cm extending above the surface. We opted for this method of marking sites because canes used in this manner to mark sites on intertidal areas both in the Wash and elsewhere had proved very durable lasting for at least 3 years.

Locations of all sites were recorded both in Ordnance Survey Great Britain (OSGB) co-ordinates and in terms of compass bearings and distances relative to permanent features in the vicinity. These data are tabulated in Appendix 1. The surveyors did not have access to a differential portable Global Positioning System (GPS) receiver so OSBG co-ordinates were determined by taking non-differential GPS readings at the centre of each 100 m square site. Given that the error on non-differential receivers is in the order of 30 m, the recorded readings will still be within the boundary of the 1 ha sample sites.

2.2.2 Sediment sampling

Within each 1 ha sample site, surface sediment samples were taken to a depth of 5 cm from each of five randomly located sampling points. These sub-samples were then combined to form a single sample that was thoroughly mixed prior to analysis to provide an average value for each sample site. Samples were frozen as soon as possible (within 24 hours) and stored in that state until needed for analysis.

Our sediment sampling procedure differed to that specified in the Procedural Guidelines in two respects. First, the depth to which the sample was taken was 5 cm, rather than 15 cm. This was to ensure comparability with the sediment sampling procedure adopted in the 1986 and because we considered that unless the sediment was severely disturbed, it was the upper 5 cm that had the greatest effect on the invertebrate fauna. The second difference was that the sample was a combination of five sub-samples taken from random locations within the site instead of a sample taken from a single location. The reason for this was that we wanted to incorporate any variation in sediment within the whole sample block.

Site features, as specified in the Procedural Guidelines, were recorded and a site photograph taken at each site at the time of sampling.

2.2.3 Invertebrate sampling

Within each 1 ha sample site, 5 pairs of cores, each 10 cm in diameter and 30 cm deep (total area 0.016 m^2) were dug out from five randomly located points and the combined contents of each pair sieved through a 0.5 mm mesh. The sieve contents were placed in plastic pots and fixed in a 4% mix of formalin (formaldehyde) and seawater as soon after collection as possible (within 4 hrs). The density of lugworms, *Arenicola marina*, was determined by counting the number of casts in an undisturbed 1 m square adjacent to each of the five sample points. In addition, at four of the five sample points, a 0.5 m square was dug over to detect larger, less abundant, macro-invertebrates, like cockles *Cerastoderma edule*, that may have occurred at densities below those which would have been adequately sampled by the cores.

These sampling procedures differed to those specified in the Procedural Guidelines in the following four ways. First, the core sizes differed both in area, being 0.016 m^2 rather than 0.01 m^2, and depth, being 30 cm rather than 15 cm deep. We took deeper cores to ensure that the tubeworm, *Lanice conchilega*, the ragworm, *Hediste diversicolor*, and large specimens of the bivalve molluscs, *Scrobicularia plana* and *Mya arenaria*, all of which can occur at depths of at least 20 cm, were adequately sampled. Second, the randomised location of the five sample points within a sample site meant that sources of down-shore, as well as along-shore, variation within each 1 ha site were incorporated rather than along-shore alone. Third, samples were sieved on site rather than transported back to the laboratory to be sieved. This enabled us to reduce the volume of material that had to be carried from the intertidal areas and allowed us to complete sampling of all sites in a transect within a single low tide period thereby reducing time and labour costs. Fourth, we opted to dig over four replicate 0.5 m squares rather than a single 1 m square to improve the precision of the mean invertebrate density estimated from the procedure, as well as to provide a measure of the within-site variability in invertebrate distribution and abundance.

2.3 Sample analysis

2.3.1 Sediment particle size analysis

Sediment particle size distribution, for particles in the size range 0.1-900 µm, was determined using a ‘Coulter LS 130’ particle size analyser. Frozen sediment samples were thawed, thoroughly mixed and then a sub-sample free of macro-invertebrates and any pieces of organic debris was introduced into the analyser. The sub-sample was circulated through the analyser in tap water while being subjected to sonic agitation to ensure complete separation of the particles.

Sediment particle size distribution of samples taken in our 1986 survey had been determined by sieving and hydrometry (Goss-Custard *et al* 1988). However, because samples from that survey had been retained, we were able to re-analyse a selection them by the 'Coulter' method and use the results to 'calibrate' the remainder of the sieving and hydrometry determined values. A total of 78 samples, that were selected to be representative of the full range of particle size distributions present in the 1986 survey, were re-analysed. The particle size parameters of the remaining samples were calculated using data from the 78 re-analysed samples to determine a regression equation that related the % fines measured by sieving to the % fines in the measured by the 'Coulter' analyser. The equation was:

$$y = 3.008+1.276x-0.0036x^2$$

where y = the % fine sediment measured by 'Coulter' analysis and x = the % fines measured by sieving. This relationship is graphed in Appendix 2.

2.3.2 Sediment organic content determination

To measure the organic content of the sediment, a sub-sample free of macro-invertebrates and pieces of vegetation was dried to constant weight at 105^{o} C. The organic fraction of the dried sample was then determined by burning at 550 ^{o}C in a muffle furnace for a period of 5 hrs. The difference in weight, or loss on ignition (LOI), of the burned sample from the dried one was expressed as a percentage of the dry weight.

Unused sediment remaining in the sample was stored frozen for future examination or re-analysis if required.

2.3.3 Invertebrate sample sorting

After at least two weeks from collection the invertebrate samples were washed clean of the formaldehyde fixative and preserved in industrial methylated spirit (IMS).

All five replicates from each 1 ha site were sorted from those study sites sampled in 1998 and 1999 that were within the Gt Ouse area of the Essex and Suffolk Water study. Three of the five replicates from those sites outside that area were sorted as required by this study's specification to keep the labour costs within budget.

All the invertebrates were sorted to species, where possible, under a binocular microscope. All were counted individually except those species that were particularly numerous. When this occurred the whole sample was spread evenly over the bottom of the sorting dish and a sub-sample, usually occupying a quarter of the area of the dish, was counted and then multiplied up to determine the total number in the sample.

All the sorted samples were retained in IMS for future reference if the need arises.

2.4 Summary of alterations to the *Procedural guidelines* methodology

Our sampling methods differed from those specified in the *Procedural guidelines* (Davies *et al* 2001) as follows:

Sediment sampling

i. Sample depth was 5 cm, rather than 15 cm.

ii. Sediment samples were the combined contents of five sub-samples taken from random locations within the site instead of a sample from a single location.

Invertebrate sampling

i. Core size was 0.016 m^2 in area rather than 0.01 m^2 and 30 cm deep rather that 15 cm.

ii. Sample points were randomly located within the 1 ha sample site and so incorporated both down-shore and along-shore variation rather than along-shore variation alone.

iii. Samples were sieved on site rather than being transported back to the laboratory for sieving.

iv. Four, 0.5 m squares were dug over rather than a single 1 m square to determine the abundance of larger, less abundant, macro-invertebrates.

3. Results of the 1998 and 1999 surveys

The results are given both for the whole Wash and for groups of sites within the Wash that were determined by their proximity to the river outfalls. These groups are defined in sub-section 3.1.2 and their arrangement illustrated in Figure 3.1.3. We chose to group sites in this manner for the following reasons:

i. the array of sample sites could be divided into those adjacent to the river Gt Ouse outfall which were sampled as part of the work carried out on behalf of Essex and Suffolk Water and those elsewhere in the Wash;
ii. it was anticipated that the proximity of a sample site to the river outfall might influence the organic content of the sediment and as a consequence the distribution and abundance of the intertidal invertebrate fauna as well
iii. the location of the river outfalls within the Wash meant that sites near to the rivers were situated in the more sheltered parts of the Wash. There, wave action was generally less severe than in those areas farther away from the rivers that were more exposed to such physical forces.

3.1 Sediment particle size and organic content

3.1.1 Particle size

Figure 3.1.1 shows the sediment particle size distribution of each site sampled in 1998 and 1999 as three sediment categories each expressed in terms of the percentage of fine sediment, or '%fines' (particles <63 μm). These categories we defined as 'mud' (>50% fines), 'mud-sand' (30%-50% fines) and 'sand' (<30% fines). The particle size analysis data for all sediment samples are presented in Annex 4.

Sites located on the west shore of the Wash between Gibraltar Point and the outfall of the Rivers Welland and Witham (Figure 2.1) were predominantly sand at all levels of the shore. The exceptions were upper sites in transect 7 and three of the four sites in transect 9, which were mud-sand and an upper shore site in transect 8 which was mud in 1998 but mud-sand in 1999 (Figure 3.1.1). Sites on the more sheltered south-west, south-east and east shores of the Wash tended to be mud or mud-sand. Sand sites on these shores were generally confined to the mid- and lower-shore level. Sites on the outer banks Roger/Toft Sand, Gat Sand, Daseley's Sand and Pandora Sand were predominantly sandy.

Detailed sediment surface feature data are presented in Appendix 4 and are summarised here. Typically, the sediment in sandy sites at mid-shore levels, was firm to walk on, relatively stable, and well sorted. The black anoxic layer occurred at depths of 2 – 5 cm, while the surface was rippled and had *Arenicola* casts and standing water present. Lower-shore sandy sites tended to be softer and less stable with black layer depths somewhat deeper and surfaces usually free of casts and standing water. Mud-sand and mud sites tended to be relatively firm and stable where they occurred at upper shore levels, whereas they were much softer and less stable at mid- and lower shore levels. The black layer was much nearer the surface than in sandy sediments and the surface relief more uneven due to the presence of drainage channels or pools. They were usually free of *Arenicola* casts, while in areas particularly associated with mussel beds they often had algal mats present. At the upper shore levels where muddy sediment was more compacted, crab burrows were often present.

3.1.2 Organic content

The sediment's organic content was positively correlated with its muddiness throughout the Wash, with muddy sites having a higher organic content than sandy ones. This relationship was curvilinear when %LOI was plotted against %fines, but was linear (Figure 3.1.2a and b) when the %LOI was transformed using logarithms to the base *e* ($\log_e$).

The data have also been grouped in relation to a sample transect's proximity to the major river outfalls into the Wash in anticipation that organic enrichment of the sediment might, in part, be the consequence of river-borne nutrient input. The sites in transects 2, 4, 5 and on Long Sand were considered together and defined as the 'west' group. They represented sandy sites that were most distant from any river outfall. Sites in transects 7 to 11 and on Roger/Toft Sand were defined as the 'Welland' group being nearest to the outfall of that river and of the R Witham. Similarly, sites in transects 12, 14, 15 and on Gat Sand were defined as the 'Nene' group and those in transects 16, 17, B, C, 18, E, 19, 20 and 21 and those on Daseley's and Pandora Sand were defined as the 'Ouse' group. Figure 3.1.3 shows which sample sites were assigned to each grouping in the 1998 and 1999 surveys.

Least squares regression analysis was used to determine the relationship between organic content and fine sediment for each of the groupings defined above. Any differences in the relationship between groupings within each survey were tested for by analysis of covariance using the General Linear Model (GLM) statistical procedure.

There was no significant difference in the relationship between sediment fines and organic content between the river-related groupings in 1998 so a single regression could be fitted to all the data (Figure 3.1.4). In contrast there were differences between groups in 1999 (Figure 3.1.5) In the 'west' grouping there was no relationship between the fine sediment and its organic content. Furthermore, although the slope of the relationship for the Welland, Nene and Ouse groups did not differ significantly, the intercept term for the Ouse group was significantly lower ($p<0.0001$) than the other two groups. That is to say, that for a given percentage of fine sediment the organic content was lower in sediment from sites in the Ouse group than it was in those sites in the Welland and Nene groups. Possible explanations for this difference are considered in Section 3.3.1.

3.2 Invertebrate distribution and abundance

This sub-section deals with both the 1998 and 1999 surveys and considers the distribution and abundance of individual species and the communities and the biotopes identified by analyses undertaken by English Nature.

3.2.1 Distribution and abundance of invertebrates in the 1998 and 1999 surveys

All full species list and the number of sites in which they occurred each survey is given in Appendix 3. Here we consider a suite of 30 invertebrate species and species size categories which were identified in our 1986 surveys (Goss-Custard *et al* 1988) as those contributing most to the biomass of the macrobenthic fauna and which were the major prey of the wading birds (Charadrii). Their distribution and abundance are summarised in a series of maps (Figures 3.2.1-29).

Of the worms, the phyllodocids (Figure 3.2.1) were the most widespread. The nephtyd worm, *Nephtys hombergii*, (Figure 3.2.4) and the spionids, *Pygospio elegans* and *Spio martinenis* , (Figure 3.2.6 and 7) were also widespread. The ragworm, *H. diversicolor*, (Figure 3.2.2) which occurs in muddy sediment was, not surprisingly, absent from those sites that were predominantly sandy. In contrast, the lugworm, *A. marina* (Figure 3.2.10) was confined to predominantly sandy sites.

Of the crustacean families/species categories, the shrimp, *Crangon crangon*, (Figure 3.2.17) was the most widespread. Those species known to be associated with well-sorted sandy sediments, for example those in the genera *Urothoe* and *Bathyporeia*, (Figure 3.2.13 and 3.2.14) were confined to the predominantly sandy areas.

Of the mollusc species recorded, the mud snail, *Hydrobia ulvae*, (Figure 3.2.19) the cockle, *C. edule* (Figures 3.2.22-24) and the Baltic tellin, *Macoma balthica* (Figures 3.2.25-27) were the most widespread. The bivalve, *S. plana* (Figure 3.2.29) which is associated with muddy sediment was widespread in upper and mid-shore areas except in those transects that were predominantly sandy.

The results of digging the four, 0.25 m^2 squares confirmed, not surprisingly, that large invertebrates that occurred at densities below that which, on average, would be detected by the cores (ie densites <13 m^{-2}) were recorded by sampling a larger area. Because the results derived from these samples are not comparable with those of the 1986 survey, especially in terms of presence/absence data, they were not considered here, but are given in Appendix 5.

3.2.2 Biotopes identified in the 1998 and 1999 surveys

A total of 10 biotopes have been identified for the intertidal sediments surveyed during the surveys. These have been labelled with the standard codes from the marine biotope classification for Britain and Ireland (Connor *et al* 1997). Descriptions of the 10 biotopes are given below and the changes between the surveys are discussed. Their distribution in the Wash is shown in Figure 3.2.30.

LGS.AP
Burrowing amphipods and polychaetes in clean sand shores.

Lower shore clean sandy shores in the north and east areas of the Wash support a community of burrowing amphipods and polychaetes, sometimes with bivalves such as *Angulus tenuis*. The medium to fine-grained sand remains damp throughout the tidal cycle. The community consists of burrowing amphipods (*Urothoe poseidonis*, *Bathyporeia pelagica*, and *B. sarsi*), numerous the cumacean species and polychaetes (including *Nephtys cirrosa*, *Scolelepis foliosa* and *A. marina*). The sediment is often rippled and typically lacks an anoxic black sub-surface layer. Sites on Long Sand (Figure 2.1) were good examples of this biotope.

LGS.Lan
Dense *Lanice* conchilega in tide-swept lower shore sand

Medium to fine sand, which contains a small amount of fines supports dense populations of *Lanice conchilega*, on waterlogged mid shore of the eastern Wash (transect 21 in Figure 2.1). The biotope is distinguished from others by the presence of *L. conchilega* at as the main polychaete component. Other polychaetes present are tolerant of sand scour or mobility of the surface levels of the sediment and include glycerid polychaetes, *Anaitides maculata*, *N. hombergii* and *P. elegans*. Few crustaceans, with the exception of Mysid shrimps are found regularly and the bivalve component is restricted to cockles, *C. edule*.

LMS.Pcer
Polychaetes and *Cerastoderma edule* in fine sand or muddy sand shores

This community is found mainly on the mid and lower shore in fine sand where the sediment is water-saturated most of the time. The community consists of polychaetes *N. hombergii*, *Scoloplos armiger*, *P. elegans*, *S. martinenis* and *Capitella capitata*, oligochaetes, the amphipod *B. sarsi*, and the bivalves *C. edule* and *Macoma balthica*. This biotope carries commercially viable stocks of cockles, *C. edule*. It is therefore possible to find areas of this habitat where the infauna may have been changed through recent cockle dredging. LMS.PCer has broad transition areas with LMS.MacAre, LMU.HedMac.Pyg and LMU.HedMac.Are. LMS.MacAre and LMU.HedMac.Are are indicated by the presence of *A. marina*, the latter also having *H. diversicolor*, oligochaetes and other species that indicate a more sheltered, muddy sand biotope. LMU.HedMac.Pyg has a greater proportion of the polychaetes *H. diversicolor*, *P. elegans* and *Eteone longa*, oligochaetes and the amphipod *Corophium volutator*. The mid-shore sites of the south-east Wash are good examples of this biotope.

LMS.MacAre
***Macoma balthica* and *Arenicola marina* in muddy sand shores**

Muddy sand and fine sand flats on the mid and lower shore generally remains water-saturated during low water and the habitat may be subject to variable salinity conditions on extensive sediment flats.

There are two distinctive variations of this community on the Wash, which is worth highlighting for monitoring purposes.

Variation 1 - MacAre: This biotope is similar to the national description, where the lugworm *A. marina* and *S. armiger* are typically common along with the Baltic telling, *M. balthica* and cockle, *C. edule*. Amphipods such as the mud burrowing-amphipod *C. volutator* can be common, as well as polychaetes *P. elegans* and *N. hombergii*. Many of the sites in the northern-most upshore areas of the west Wash were examples of this biotope.

Variation 2 - MacAre1: This biotope has a lower silt content and slightly coarser sediment type. The polychaete composition is essentially similar to MacAre, although with greater numbers of *A. marina* and *Nephtys cirrosa*. Oligochaetes and *Corophium* spp. are absent from this variation, and the bivalve density is generally lower or absent. There are higher numbers of burrowing amphipods such as *U. poseidonis* and *Bathyporeia* spp. There are similarities to LGS.AP, although there is generally a degree of silt content and a black layer is present in the sediment. Mid- and lower shore areas of the northern parts of the west Wash were examples of this biotope.

LMS.MacAre.Mare
***Macoma balthica, Arenicola marina* and *Mya arenaria* in muddy sand shores**

Sheltered muddy sand and fine sand with polychaetes and bivalves is distinguishable from LMS.MacAre by the high abundance of *Mya arenaria* and other bivalves. The polychaetes, *N. hombergii, S. armiger, P. elegans* and *A. marina* and the bivalves *C. edule, M. balthica* and *M. arenaria* are characterising species. The presence of *M. arenaria* is often very localised, but may show consistently high populations of the bivalve over many years. Sites on the upper shore of the southern parts of the east Wash were examples of this biotope.

LMU.HedMac
***Hediste diversicolor* and *Macoma balthica* in sandy mud shores**

Littoral sandy mud and mud in sheltered, conditions with a community of polychaetes together with the bivalve *M. balthica*. The most abundant polychaete is typically *H. diversicolor*, other polychaetes include *E. longa, N. hombergii, Aphelochaeta marioni, P. elegans* and *A. marina*. Oligochaete worms (e.g. *Tubificoides benedii, T. pseudogaster* and enchytraeids) are common or abundant and the amphipod *C. volutator* may be abundant. The mud snail *H. ulvae* is also abundant; the bivalve *M. balthica* may be accompanied by *C. edule, Abra tenuis* and *M. arenaria*. The surface of the mud may be covered with green algae such as *Enteromorpha* spp. or *Ulva lactuca*. There is usually a black anoxic layer close to the sediment surface. Just one example of this biotope was identified. It was located on Gat Sand (Figure 2.1) in 1999.

LMU.HedMac.Are
***Hediste diversicolor, Macoma balthica* and *Arenicola marina* in muddy sand or sandy mud shores**

This is the least sheltered and least muddy sub-type of LMU.HedMac, with the lugworm *A. marina* usually abundant or as the numerically dominant polychaete and *C. edule* relatively frequent. The following characterising species are typically present *E. longa, H. diversicolor, P. elegans*, oligochaetes, the mud-burrowing amphipod *C. volutator*, the mud snail *H. ulvae* and the Baltic tellin *M. balthica*. Typically a black anoxic layer is present below 5 cm and this can be seen in the *A. marina* casts. The community differs from LMS.MacAre in the muddiness of the sand and the high abundance of certain species including *H. diversicolor*, oligochaetes and *C. volutator*. Examples of this biotope occurred on the lower parts of the south east and south west shores of the Wash.

LMU.HedMac.Pyg
***Hediste diversicolor, Macoma balthica* and *Pygospio elegans* in sandy mud shores**

Mid and lower shore muddy sand in estuaries, sheltered bays and marine inlets sometimes subject to variable salinity. This sub-type of LMU.HedMac is characterised by the polychaetes *E. longa, H. diversicolor, P. elegans, Capitella capitata*, oligochaetes (particularly *T. benedii*), the mud-burrowing amphipod *C. volutator*, the mud snail *H. ulvae* and the Baltic tellin *M. balthica*. Bivalves other than *M. balthica, S. plana* and the cockle *C. edule* are typically only present in low abundance, as is the polychaete *A. marina*. There were many examples of this biotope on the east and south shores of the Wash. The similar biotope LMU.HedMac.Are contains the polychaetes *A. marina* and *S. armiger* in higher abundance than in this biotope, and *N. cirrosa* is also usually found in LMU.HedMac.Are. LMU.HedMac.Pyg is typically muddier than LMU.HedMac.Are.

LMU.HedMac.Mare
***Hediste diversicolor, Macoma balthica* and *Mya arenaria* in sandy mud shores**

This sub-type biotope of LMU.HedMac is differentiated from other LMS.HedMac biotopes in having *M. arenaria* in high densities in most cases. Polychaetes *E. longa*, *H. diversicolor*, *P. elegans*, oligochaetes, the mud-burrowing amphipod *C. volutator*, the mud snail *H. ulvae*, the cockle *C. edule*, the Baltic tellin *M. balthica* and the soft clam *M. arenaria* are the most frequently recorded and characterising species. The sediment is typically anoxic below 1 cm. The lower sites of the south east shore were examples of this biotope. LMU.HedMac.Pyg is similar to this biotope, but contains very few *M. arenaria*. This biotope is more muddy and is probably more influenced by variable salinity than LMS.MacAre.Mare.

Changes in biotope between 1998 and 1999 were confined primarily to sites on the northern parts of the west shore of the Wash (Figure 3.2.30). Those sites changed from being classified as the LMS.MacAre biotope in 1998 to being the variant of that biotope LMS.MacAre1 in 1999. The sediment characteristic that changed most between the surveys at those sites was the sediment organic content. It was significantly higher in 1999 than in 1998 even though the particle size of the sediment had changed little (Figure 3.3.4). The only significant change in invertebrate density in that same group of sites occurred in the phyllodicid worms whose density was lower in 1999 than in the previous year's survey (Table 3.3.5).

3.3 Comparisons between the results of the 1986 survey and the 1998 and 1999 surveys

In this section we compare the results of all three Wash surveys that have been made by ITE/CEH. Because the sites that were surveyed differed between years, the comparisons involve only those sites common to a pair of surveys or to all three surveys. This ensured comparison of like with like.

There were 91 sites common to the 1986 and 1998 surveys, 82 common to the 1986 and 1999 surveys and 89 common to the 1998 and 1999 surveys. In total there were 68 sites common to all three surveys

In all comparisons the raw data were the mean values for each 1 ha sample site.

3.3.1 Changes in sediment particle size and organic content

Sediment particle size

Sediment particle size distribution was summarised in terms of the %fines (particles <63 µm) in the sediment as three sediment categories, mud, mud-sand and sand which were described in section 3.1.1.

The sediment in 28 (31%) of 91 sites sampled in 1986 had changed by 1998 (Figure 3.3.1a). The most extreme changes were from either mud to sand (8 sites) or from sand to mud (2 sites). In the 82 sites sampled in both 1986 and 1999, 31 (38%) had changed sediment (Figure 3.3.1b) of which only 7 exhibited and an extreme change from mud to sand. Of the 89 sites sampled in the 1998 and 1999 surveys, 23 (26%) changed from one sediment category to another but there were no extreme changes from either mud to sand or sand to mud.

The changes in sediment category between 1986 and 1998 and 1986 and 1999 (Figures 3.3.2a and b), indicated that areas on the shore to the east of the river Gt Ouse had less fine sediment. That is to say, they were sandier in 1998 and 1999 than they had been in 1986. Between 1998 and 1999 (Figure 3.1.1), most sites also became sandier except those sites to the west of the Gt Ouse which became muddier. Elsewhere in the Wash sediments changed little between any of the surveys.

It would be expected that the shorter time interval between the 1998 and 1999 surveys would lead to fewer changes in sediment than the 12-13 year interval between those surveys and the 1986 survey. However, to further put the time-scale over which these changes may have occurred into perspective, it is worth noting that the change to sandier sediment on the east shore (Figure 2.1) was known from our work for Essex and Suffolk Water to have occurred between 1997 and 1998. Therefore, it is not necessarily the case that any changes in sediment elsewhere in the Wash necessarily represent a steady cumulative change over the period 1986 to 1998 or 1999.

Sediment organic content

In all three surveys the organic content (%LOI) of the sediment was positively and highly correlated with the percentage of fines (%fines) in the sediment. The relationship was linear when $\log_e$ transformed %LOI was plotted against % fines (Figure 3.3.3a). Furthermore, after taking into account the percentage of fines present, there was an indication that the organic content of the sediment was higher in 1999 than in either 1986 or 1998, and that the slope of the relationship was steeper.

These differences were explored using the GLM procedure, in which the response variable was $\log_e$ %LOI and the %fines, the year and the interaction between year and %fines were the explanatory variables with %fines also identified as a covariate in an ANOVA. Data for the 68 sites sampled in all three surveys were used. This analysis confirmed (Table 3.3.1) that in 1999, the organic content was higher and the slope of the relationship was significantly steeper ($p<0.0001$) than in either of the other two surveys (Figure 3.3.3b). That is to say, the rate at which the organic content increased in relation to increases in the fine sediment present was greater in 1999 than in the other two surveys. The analysis also indicated that in 1986 and 1998, although the slopes of the relationship were similar, the intercepts were significantly different ($p<0.0001$) confirming that the organic content of the sediment was significantly and consistently higher in 1986 than in 1998.

Further analyses using the GLM procedure were conducted to determine whether the between-survey differences in the relationship between sediment organic content and particle size for the whole Wash applied to all of the river-related groupings defined in section 3.1.2 or just to certain ones.

Table 3.3.1. The least squares regression parameters that relate sediment organic content, expressed as log*e* percentage Loss on Ignition (%LOI) to the percentage of fines (particles <63 µm) in the sediment of the 68, 1 ha sample sites common to the 1986, 1998 and 1999 surveys. Significance levels are ** p<0.01 and ****p<0.0001.

Survey	Intercept	S E	Slope	S E	Rsquare %
1986	0.20****	0.04	0.0258****	0.0009	93.4
1998	0.07**	0.03	0.0255****	0.0007	94.9
1999	0.25****	0.05	0.031****	0.0016	85.3

In the west Wash group (Figures 3.3.4), there was no significant relationship between organic content and fine sediment except in the 1998 sites that were also sampled in 1999, primarily because of the limited range in the proportion of fine sediment present. Nevertheless, the organic content was significantly higher in 1999 compared to 1986 and to 1998 ($p<0.0001$ in both comparisons). Organic content did not differ significantly between 1986 and 1998.

In the Welland and Nene group there was a strong and significant relationship ($p<0.0001$) between organic content and fine particles in the sediment in all comparisons. Sediment organic content was higher in 1999 compared to 1986 and 1998 and the slope of the relationship was significantly steeper ($p<0.0001$ in both comparisons) (Figures 3.3.5). That is to say, the rate at which the organic content increased in relation to increases in the fine sediment present was greater in 1999 than in the other two surveys. Although the slope of the relationship was similar between 1986 and 1998, the organic content was significantly higher in 1986 than in 1998 ($p<0.0001$), in other words the organic content was consistently higher irrespective of the amount of fine sediment present.

In the Ouse group there was a strong and significant relationship ($p<0.0001$) between organic content and fine particles in the sediment in all comparisons (Figures 3.3.6). A similar pattern of change to that in the Welland and Nene group between 1999 and the other two surveys was also identified. In both comparisons the slope of the organic content and fine sediment relationship was significantly steeper in 1999 ($p<0.0001$ in both comparisons). There was, however, no significant difference between the 1986 and 1998 surveys.

These analyses confirmed that the sediment's organic content was indeed significantly higher in 1999 than in either of the other two surveys in all river-related groups and not just certain ones, in other words it was a Wash-wide phenomena. This suggests that the cause of the increased organic content could just as likely be attributable to marine influences as to river-borne influences. In contrast the difference between 1986 and 1998 for the whole Wash (in Figure 3.3.3b) was mainly attributable to the sediment organic content being significantly higher in the Welland and Nene group suggesting in this instance increased organic content being associated with these rivers.

3.3.2 Changes in invertebrate abundance and distribution

In these comparisons the raw data were the mean invertebrate density at each 1 ha sample site. In the case of the 1986 survey and those sites sampled in the 1998 and 1999 surveys for Essex and Suffolk Water, the mean was derived from all five samples taken at each site. In the case of the remainder of the sites sampled in the 1998 and 1999 surveys, the mean was derived from the three of the five samples for the reason given in section 2.1.1 (Site selection for the 1998 survey).

As in section 3.2.1, the invertebrates considered here were those families, species and species size categories that we identified in the 1986 survey as being both the most abundant and the main prey of the over-wintering shorebirds (Charadrii) for which the Wash is of particular conservation importance.

Both whole Wash and river group comparisons of invertebrate densities between pairs of surveys were made. In the latter, the 'Welland' and 'Nene' groups were combined into a single group, named 'Welland and Nene' because the results of the analysis of sediment particle and organic content (see sections 3.1.2 and 3.3.1) indicated that the two groups did not differ significantly.

Because, in statistical terms, the sample sites within a transect were not independent of each other, each paired unit was considered to be a transect rather than the individual sample sites. Consequently the $\log_e$ transformed means of transect densities ($\log_e$ density+1) were used to test for significant differences in invertebrate densities between surveys for the whole Wash and the river-related groups by paired t-tests.

Changes over the whole Wash

It should be noted that when considering the results summarised in this section and the statistics presented in Table 3.3.3a-c, the results from the 'Ouse' group of sample transects may have had a greater influence on the whole Wash densities than would the other groups. This is because the sampling intensity, in terms of numbers of transects and sites within transects, was greater in this group than it was elsewhere in the Wash (section 2.1.1).

Of the 30 invertebrates compared, the mean density of 10 of them was significantly lower in 1998 than in 1986 (Table 3.3.3a). These included two worm species, *H. diversicolor* and *A. marina*, whose 1998 density was 40-50% of that in 1986, and three crustacean species whose densities in 1998 were as low as 10% of their 1986 density. All three size-classes of the bivalve mollusc, *M. balthica*, were significantly lower in 1998 as were the 20-30 mm size-class of *C. edule* and *M. arenaria*. Only one invertebrate had a significantly higher density in 1998 than in 1986. This was the cirratulid worms whose 1998 density was almost twice its 1986 density.

Table 3.3.3 a-c. Between-survey comparisons of the mean densities (nos/m^{-2}) of invertebrates recorded in the 1986, 1998 and 1999 surveys of the Wash.
a, the 1998 survey compared to the 1986 survey; b, the 1999 survey compared to the 1986 survey; and c, the 1999 survey compared to the 1998 survey. The statistical significance of differences between pairs of surveys was determined by paired t-tests performed on log$_e$ transformed mean density using sampling transects as paired units. Levels of significance are indicated as follows, ns=not significant *=p<0.05, **=p<0.01, ***p<0.001 and ****=p<0.0001. Those invertebrates whose density differed significantly between surveys are shown in bold text.

a. The 1998 survey compared to the 1986 survey

Invertebrate family, species or species size category	1998 compared to 1986 (N=16 paired sample units)					
	1986 density		1998 density		ratio 1998:1986	statistical significance
	mean	SD	mean	SD		
Phyllodocids	385	518	275	211	0.7	ns
Hediste diversicolor	84	85	41	70	0.5	***
Nephtys hombergii	121	61	81	60	0.7	ns
other *Nephtys* species	28	28	25	32	0.9	ns
Scoloplos armiger	42	39	90	121	2.1	ns
Pygospio sp	948	1408	436	348	0.5	ns
Spio sp	115	153	81	149	0.7	ns
Cirratulids	216	616	380	623	1.8	*
Capitellids	127	281	48	63	0.4	ns
Arenicola marina casts	5	6	2	3	0.4	**
Clymenella torquata	1	2.5	0	0	0.0	ns
Lanice conchilega	16	37	4	8	0.3	ns
Oligochaetes	6304	12636	1213	1674	0.2	ns
Urothoe spp	82	155	12	27	0.1	*
Bathyporeia spp	37	62	23	33	0.6	ns
Corophium arenarium 3+ mm	165	376	2	4	0.0	****
Corophium volutator 3+ mm	735	2121	332	730	0.5	ns
Crangon crangon	29	20	10	6	0.3	****
Carcinus maenus	10	21	3	2	0.3	ns
Hydrobia ulvae 3+ mm	3610	2881	6060	4987	1.7	ns
Retusa obtusa 3+ mm	33	47	57	132	1.7	ns
Mytilus edulis 5+ mm	108	296	5	19	0.0	ns
Cerastoderma edule 4-10 mm	1016	1668	265	337	0.3	ns
Cerastoderma edule 16-40 mm	45	39	48	111	1.1	ns
Cerastoderma edule 20-30 mm	30	29	12	17	0.4	**
Macoma balthica <9 mm	2379	3017	181	161	0.1	****
Macoma balthica 6-15 mm	331	217	161	137	0.5	***
Macoma balthica 9-20 mm	179	126	48	45	0.3	****
Mya arenaria	121	141	4	8	0.0	***
Scrobicularia plana 20+ mm	6	8	7	11	1.2	ns

Table 3.3.3 a-c. continued

b. The 1999 survey compared to the 1986 survey

Invertebrate family, species or species size category	1999 compared to 1986 (N=14 paired sample units)					
	1986 density		1999 density		ratio 1999:1986	statistical significance
	mean	SD	mean	SD		
Phyllodocids	427	544	129	113	0.3	*
Hediste diversicolor	86	90	50	60	0.6	ns
Nephtys hombergii	131	65	73	31	0.6	ns
other *Nephtys* species	25	26	8	14	0.3	**
Scoloplos armiger	52	57	50	68	1.0	ns
Pygospio spp	980	1502	803	876	0.8	ns
Spio spp	110	163	159	197	1.4	ns
Cirratulids	304	868	434	748	1.4	ns
Capitellids	145	299	639	2158	4.4	ns
Arenicola marina casts	5	6	3	5	0.6	*
Clymenella torquata	1	1	0	0	0.0	ns
Lanice conchilega	26	48	19	46	0.7	ns
Oligochaetes	7170	13328	1961	2538	0.3	ns
Urothoe spp	86	165	13	36	0.2	ns
Bathyporeia spp	40	65	12	25	0.3	*
Corophium arenarium 3+ mm	63	100	2	6	0.0	****
Corophium volutator 3+ mm	719	2273	691	1370	1.0	ns
Crangon crangon	41	57	17	17	0.4	**
Carcinus maenus	12	24	2	2	0.2	*
Hydrobia ulvae 3+ mm	3063	2838	1596	1708	0.5	**
Retusa obtusa 3+ mm	33	51	6	11	0.2	ns
Mytilus edulis 5+ mm	132	313	0	0	0.0	ns
Cerastoderma edule 4-10 mm	828	1524	542	999	0.7	*
Cerastoderma edule 16-40 mm	44	42	82	117	1.9	ns
Cerastoderma edule 20-30 mm	29	32	35	47	1.2	ns
Macoma balthica <9 mm	2433	3237	457	519	0.2	****
Macoma balthica 6-15 mm	331	241	208	213	0.6	**
Macoma balthica 9-20 mm	182	137	60	67	0.3	**
Mya arenaria	124	151	1	2	0.0	***
Scrobicularia plana 20+ mm	6	8	10	14	1.7	ns

Table 3.3.3 a-c. continued

c. The 1999 survey compared to the 1998 survey

Invertebrate family, species or species size category	1999 compared to 1998 (N=18 paired sample units)					
	1998 density		1999 density		ratio 1999:1998	statistical significance
	mean	**SD**	**mean**	**SD**		
Phyllodocids	280	264	153	183	0.5	**
Hediste diversicolor	31	68	42	62	1.4	ns
Nephtys hombergii	89	86	68	63	0.8	ns
other *Nephtys* species	47	58	22	39	0.5	*
Scoloplos armiger	52	83	39	57	0.8	ns
Pygospio spp	313	329	946	985	3.0	ns
Spio spp	130	181	209	254	1.6	ns
Cirratulids	345	572	516	763	1.5	ns
Capitellids	40	62	478	1909	12.0	ns
Arenicola marina casts	2	3	2	5	1.0	ns
Clymenella torquata	0	0	0	0		ns
Lanice conchilega	6	11	10	18	1.7	ns
Oligochaetes	1055	1540	2306	5070	2.2	ns
Urothoe spp	8	22	10	32	1.3	ns
Bathyporeia spp	24	35	11	22	0.5	*
Corophium arenarium 3+ mm	1	3	3	10	3.0	ns
Corophium volutator 3+ mm	562	1263	1285	3262	2.3	*
Crangon crangon	10	7	14	14	1.4	ns
Carcinus maenus	2	3	1	2	0.5	ns
Hydrobia ulvae 3+ mm	5074	5255	1243	1641	0.2	****
Retusa obtusa 3+ mm	22	36	5	10	0.2	*
Mytilus edulis 5+ mm	4	18	0	0	0.0	ns
Cerastoderma edule 4-10 mm	494	1306	422	904	0.9	ns
Cerastoderma edule 16-40 mm	13	22	70	106	5.4	*
Cerastoderma edule 20-30 mm	6	12	32	44	5.3	**
Macoma balthica <9 mm	160	148	479	592	3.0	ns
Macoma balthica 6-15 mm	131	123	177	200	1.4	ns
Macoma balthica 9-20 mm	39	45	49	63	1.3	ns
Mya arenaria	10	24	1	2	0.1	ns
Scrobicularia plana 20+ mm	4	7	7	13	1.8	ns

The distribution of those invertebrates whose density differed significantly between the 1998 and 1986 surveys also changed (Figure 3.3.7a-k). Without exception, the ones whose densities were lower in 1998 occurred in fewer sample sites in that survey, while the only invertebrate whose densities were higher in 1998, the cirratulid worms, occurred in more sites (Table 3.3.4, Figure 3.3.7b). This suggests that the lower densities occurred as a consequence of invertebrates being less widespread rather than there being fewer animals in the same number of sites. The opposite was true of the cirratulids. They increased density and became more widespread.

The densities of 13 invertebrates were significantly lower in the 1999 survey than they were in the 1986 survey (Table 3.3.3b). Seven of these were the same invertebrates whose densities were significantly lower in the 1998 survey than in the 1986 one. In addition the phyllodocids and *Nephtys* spp other than *N. hombergii* amongst the worms, *Bathyporeia* spp, *C. arenarium* and *Carcinus maenas* amongst the crustaceans and *H. ulvae*, and the 4-10 mm size-class of *C. edule* amongst the molluscs also had significantly lower densities in 1999 compared to 1986. None increased significantly in density between the two surveys.

The distribution of those invertebrates whose density was lower in 1999 than in 1986 was also less widespread, that is, they occurred in fewer sites in 1999 than in 1986 (Table 3.3.4, Figure 3.3.8a-m). The only exception was the phyllodocids. Though having a lower density over the whole Wash, they occurred in the same number of sites in both the 1986 and 1999 surveys.

The densities of seven invertebrates changed significantly between the 1998 and 1999 surveys (Table 3.3.3c). *Corophium volutator* (Figure 3.2.16) and cockles, *C. edule* , in the 16-40 mm and the 20-30 mm size-classes (Figure 3.2.23 and 24) increased in density. In contrast, the densities of phyllodocids (Figure 3.2.1), *Nephtys* spp (Figure 3.2.3), *Bathyporeia* spp (Figure 3.2.14) and the mollusc *Retusa obtusa* (Figure 3.2.14) were all significantly lower in 1999 than they were in 1998.

Again the changes in invertebrate density were matched by changes in the extent of their distribution. Those whose density increased were more widespread, while those whose density decreased were less widespread in 1999 than in 1998 (Table 3.3.4). This general relationship between invertebrate density and distribution is shown graphically in Figure 4.2.1 and discussed in section 4.2.

It is not surprising given the time periods involved between the three surveys, that more invertebrates exhibited significant changes in density between both the 1998 and 1999 surveys compared to the 1986 than between the 1998 and 1999 surveys. What is of particular interest is the direction of these changes. The densities of 10 invertebrates in 1998 and 13 in 1999 were significantly lower than those in 1986 while only one was higher. A further 14 invertebrates in 1998 and 9 in 1999, were also lower in density than in 1986 though not significantly so. In other words the densities of 80% of the invertebrates considered in 1998 and 73% of those in 1999 were lower than they had been in 1986. The invertebrates whose densities were lower in 1998 and 1999 compared to 1986, were also less widespread in those years. The conclusion to be drawn from this is that the productivity of the Wash, as measured by invertebrate abundance and distribution, was higher in 1986 than it was in 1998 and 1999.

Table 3.3.4. Between-survey comparisons of the number of sites in which an invertebrate was present. A total of 91 sample sites were sampled in 1998 and 1986, 82 sites were sampled in 1999 and 1986 and 89 sites were sampled in 1999 and 1998. Those invertebrates whose density differed significantly between pairs of surveys (see Table 3.3.3) are shown in bold text.

Invertebrate family, species or species size category	Number of sites in which invertebrate was present								
	1998 vs 1986			1999 vs 1986			1999 vs 1998		
	1986	1998	%change	1986	1999	%change	1998	1999	%change
Phyllodocids	81	81	0.0	**73**	**73**	0.0	**79**	**73**	-8.2
Hediste diversicolor	**44**	**24**	-83.3	40	28	-42.9	19	28	32.1
other *Nephtys* species	38	24	-58.3	**33**	**8**	-312.5	**36**	**19**	-89.5
Nephtys hombergii	77	69	-11.6	69	64	-7.8	61	64	4.7
Scoloplos armiger	42	42	0.0	35	35	0.0	38	39	2.6
Pygiospio spp	73	76	3.9	68	65	-4.6	66	65	-1.5
Spio spp	42	35	-20.0	41	37	-10.8	43	45	4.4
Cirratulids	**25**	**43**	41.9	24	44	45.5	47	51	7.8
Capitellids	58	43	-34.9	51	42	-21.4	38	39	2.6
Arenicola marina casts	**64**	**57**	-12.3	**56**	**43**	-30.2	49	40	-22.5
Clymenella torquata	7	0		2	0		0	0	
Lanice conchilega	10	12	16.7	10	12	16.7	14	13	-7.7
Oligochaetes	64	52	-23.1	57	53	-7.5	50	51	2.0
Urothoe spp	**26**	**9**	-188.9	24	13	-84.6	7	13	46.2
Bathyporeia spp	27	25	-8.0	**24**	**15**	-60.0	**25**	**19**	-31.6
Corophium arenarium **3+ mm**	**29**	**4**	-625.0	**23**	**3**	-666.7	2	4	50.0
Corophium volutator 3+ mm	26	20	-30.0	21	24	12.5	**24**	**26**	7.7
Crangon crangon	**62**	**35**	-77.1	**56**	**35**	-60.0	34	35	2.9
Carcinus maenus	27	13	-107.7	**25**	**7**	-257.1	11	6	-83.3
Hydrobia ulva **3+ mm**	75	71	-5.6	**67**	**56**	-19.6	**67**	**54**	-24.1
Retusa obtusa **3+ mm**	25	28	10.7	20	11	-81.8	**26**	**11**	-136.4
Mytilus edulis **5+ mm**	11	2	-450.0	10	0		1	0	
Cerastoderma edule **4-10 mm**	47	45	-4.4	**45**	**33**	-36.4	36	33	-9.1
Cerastoderma edule **16-40 mm**	61	32	-90.6	49	34	-44.1	**25**	**34**	26.5
Cerastoderma edule **20-30 mm**	**48**	**16**	-200.0	40	27	-48.1	**11**	**28**	60.7
Macoma balthica **<9 mm**	**83**	**59**	-40.7	**77**	**63**	-22.2	55	63	12.7
Macoma balthica **6-15 mm**	**76**	**59**	-28.8	**69**	**57**	-21.1	56	57	1.8
Macoma balthica **9-20mm**	**68**	**42**	-61.9	**61**	**47**	-29.8	39	47	17.0
Mya arenaria	**42**	**11**	-281.8	**39**	**6**	-550.0	14	6	-133.3
Scrobicularia plana 20+ mm	20	14	-42.9	16	21	23.8	11	17	35.3

Table 3.3.5 The change in the densities of invertebrates in pair-wise comparisons between surveys within river groups and the whole Wash. Statistically significant decreases in density are indicated by 'L' and increases by 'H', while '.' indicates no significant change. Levels of significance are indicated as follows, *=p<0.05, **=p<0.01, ***p<0.001 and ****=p<0.0001. Refer also to Appendix 6 that tabulates mean densities within each river group.

Invertebrate family, species or species size category	1998 compared to 1986				1999 compared to 1986				1999 compared to 1998			
	Group			whole Wash	Group			whole Wash	Group			whole Wash
	West Wash	Welland & Nene	Ouse		West Wash	Welland & Nene	Ouse		West Wash	Welland & Nene	Ouse	
	n=3	n=7	n=6	n=16	n=3	n=4	n=7	n=14	n=4	n=4	n=10	n=18
Phyllodocids	.	.	.	.	.	**L***	.	**L***	**L***	.	**L***	**L****
Hediste diversicolor	.	.	**L***	**L*****	.	.	**L***	.		.	.	.
Nephtys hombergii	.	.	.	.	.	**L***	.	.	.	.	.	.
other *Nephtys* species	.	.	.	.	**L***	.	.	**L****	.	.	**L***	**L***
Scoloplos armiger	.	.	.	.	.	.	.	.	.	**L***	.	.
***Pygospio* spp**	.	.	.	.	.	.	.	.	.	.	**H***	.
***Spio* spp**	.	.	.	.	.	.	.	.	.	**H***	.	.
Cirratulids	.	.	**H***	**H***	.	.	**L***	.	.	.	.	.
Capitellids	.	.	.	.	.	.	.	.	.	.	.	.
***Arenicola marina* casts**	**L***	.	.	**L****	.	.	.	**L***	.	**L***	.	.
Clymenella torquata	.	.		.								
Lanice conchilega	.	.	.	.	.	.	.	.	.	.	.	.
Oligochaetes	.	.	.	.	.	.	.	.	.	.	.	.
***Urothoe* spp**	.	.	.	**L***	.	.	.	.	.	.	.	.
***Bathyporeia* spp**	.	.	.	.	.	.	**L***	**L***	.	.	.	**L***
***Corophium arenarium* 3+ mm**	.	**L***	**L***	**L*******	.	.	**L****	**L*******		.	.	.
***Corophium volutator* 3+ mm**	.	**L***	.	.	.	.	.	.	.	.	.	**H***
Crangon crangon	.	**L****	.	**L*******	.	**L****	**L***	**L****	.	.	.	.
Carcinus maenus	.	.	.	.	**L***	.	.	**L***	.	.	.	.
***Hydrobia ulvae* 3+ mm**	**L***	.	.	.	.	.	**L***	**L****	.	.	**L*******	**L*******
***Retusa obtusa* 3+ mm**	.	.	.	.	.	.	.	.	.	.	.	**L***
Mytilus edulis 5+ mm		.	.	.		.	.	.		.		.
***Cerastoderma edule* 4-10 mm**	**H***	.	**L***	.	.	.	.	**L***	.	.	.	.
***Cerastoderma edule* 16-40 mm**	**L***	.	.	.	.	.	.	.	.	**H****	.	**H***
***Cerastoderma edule* 20-30 mm**	.	.	.	**L****	.	.	.	.	.	.	.	**H****
***Macoma balthica* <9 mm**	**L***	.	**L****	**L*******	**L*******	**L*******	**L***	**L*******	.	.	**H****	.
***Macoma balthica* 6-15 mm**	**L***	**L***	.	**L*****	**L***	**L****	.	**L****	.	.	.	.
***Macoma balthica* 9-20 mm**	**L***	**L***	**L***	**L*******	**L***	**L****	**L***	**L****	.	.	.	.
Mya arenaria		.	**L****	**L*****		.	**L*******	**L*****		.	.	.
Scrobicularia plana 20+ mm		.	.	.		.	.	.	.	.	.	.

Changes in invertebrate densities within the river groups

Statistically significant between-survey changes in invertebrate densities within the three river-related groups, west Wash, Welland and Nene and Ouse are summarised, and compared with those for the whole Wash, in Table 3.3.5 and in more detail in Appendix 6.

If there was a significant change in density of an invertebrate between a pair of surveys in the whole Wash then a similar change also occurred within the river groups. In some cases, for example the changes in *Macoma* densities between both the 1998 and 1999 surveys and the 1986 one, change within groups was also significant. In other cases, for example *Urothoe* spp between 1998 and 1996, there was no significant change within individual groups but the direction of change was the same in all of them, consequently a significant change was recorded for the whole Wash. In 10 cases significant change occurred only within a single group, while in only one case, *C. edule* 4-10 mm in size, did a significance increase occur in one group and a significant decline occur in another.

It was concluded from this analysis that with few exceptions, the pattern of change in invertebrate densities between surveys was similar throughout the Wash and not just confined to a particular group of sites.

3.3.3 Changes in invertebrate abundance in relation to changes in sediment particle size and organic content and to other invertebrates

Because the sediment particle size distribution and its organic content have been shown to influence invertebrate densities in the Wash (Yates *et al* 1993), it was anticipated that changes in invertebrate densities between the surveys might relate to changes in these sediment variables. For example, an invertebrate like the ragworm, *H. diversicolor,* which is associated with muddy, organically rich sediment would be expected to increase in density in areas in which had become muddier and more organically rich. It was also anticipated that changes in an individual invertebrate's density might also be related to that of other invertebrates as well as changes in sediment.

We explored this using stepwise multiple regression procedures. First we regressed the difference in the $\log_e$ mean density of individual invertebrates at each sample site against the difference in %fines and %LOI of the sediment. This allowed us to determine whether changes in invertebrate density were significantly related to changes in these sediment variables. We then repeated the procedure, this time including the changes in densities of the other invertebrates as well as the sediment variables. Because of the overlap in species size categories, only the <9 mm and the 9-20 mm categories of *M. balthica* and the 4-10 mm and 16-40 mm categories of *C. edule* were included in this second procedure. This allowed us to determine if the change in invertebrate density between pairs of surveys was significantly related to some combination of sediment and invertebrate variables.

Twenty of the 30 invertebrates considered were significantly related to changes in one or both of the sediment variables in one or more surveys (Table 3.3.6 and Appendix 7). Declines in the density of *A. marina*, *Bathyporeia* spp, *C. crangon* and *M. balthica* in the 9-20 mm size class were greatest in sites where either the %fines or the %LOI increased. In other words the relationships were negative indicating that increased muddiness or organic content of the sediment was associated with a decline in the invertebrate's density. In contrast, the densities of *H. diversicolor*, oligochaetes and *H. ulvae* increased where either the %fines or %LOI had increased, that is they were positively associated with the sediment variables. Some examples of these relationships are presented in Figure 3.3.9a-d.

For other invertebrate's, notably the cirratulid worms, the crab *C. maenas* and *C. edule* 16-40 mm in size and *M. balthica* 6-15 mm in size, the change in density was positively associated with increases in % fines but negatively associated with decreases in %LOI. That is to say their densities increased in sites whose sediment became muddier but less organically rich. In contrast, changes in the density of *Bathyporiea* spp was negatively associated with increased % fines, but positively associated with increased %LOI, that is they decreased in sites that were muddier but less organically rich.

In two instances, *Pygospio* worms and *M. balthica* 6-15 mm in size, the association with the sediment variables differed between pairs of surveys. In the 1999 and 1986 survey comparison, *Pygospio* was negatively associated with %LOI, but in the 1999 to 1998 comparison it was positively associated with %LOI. A similar anomaly occurred between the 1998 and 1986, and the 1999 and 1998 comparisons of changes in densities of *M. balthica* 6-15 mm in size. We cannot explain these apparent anomalies but we would draw attention to the fact that considering the 90 comparisons being made (30 invertebrates times 3 pair-wise survey comparisons), it is likely that spurious associations might occur by chance.

Although the density changes of many of the invertebrates was significantly related to change in one or both of the sediment variables the strength of the relationship was generally weak. At best the sediment variables explained 24% of the variation in change in invertebrate density (see R squared values tabulated in Appendix 7) and there was clearly a great deal of unexplained variation even in those examples where the relationship was the strongest (Figure 3.3.9).

The inclusion of changes in density of other invertebrates along with the sediment variables in the stepwise regression analysis led to more of this residual variation being explained. That is to say change in density of the invertebrate being considered (the dependent variable) was significantly associated with changes in other invertebrates along with the sediment variables. Table 3.3.7 shows that this occurred in 18 of the 31 instances in Table 3.3.6 in which either one or both sediment variables were significant. In a further 6 instances the sediment variables became significant when the significant contributions of other invertebrates were taken into account. In most cases, density changes of the dependent invertebrates were a combination of positive associations with some and negative association with other invertebrates. Typically those that were positively related were those known to occur in a similar type of sediment, while those that were negatively associated were those that occurred in a different type of sediment. The likely biological mechanisms for these associations are discussed in section 4.3.

Only in the case of changes in density of *Urothoe* spp between 1998 and 1999, *C. arenarium* between 1986 and both 1998 and 1999, and of *C. volutator* between 1998 and 1999, was there no significant association with either sediments or other invertebrates (Table 3.3.7). The most likely explanation for this is that these species occurred in too few sites for any associations to be detected by the analyses.

Table 3.3.6 The slope of the relationship between the change in invertebrate density ($\log_e$ mean density) between surveys to the change in sediment particle size (%<63 µm) and organic content (%Loss On Ignition). Positive (pos) slopes occurred where the change in an invertebrate's density increased, while negative slopes (neg) occurred where the change decreased, relative to an increase in the change of one or both sediment variables. Slopes are tabulated only in those instances were the relationship was significant. Levels of significance are indicated as follows, *=p<0.05, **=p<0.01, ***p<0.001 and ****=p<0.0001. Refer also to Appendix 7 that tabulates the parameters of these relationships.

Invertebrate family, species or species size category	slope of relationship between change in invertebrate density and change in sediment variables					
	1998 and 1986		1999 and 1986		1999 and 1998	
	%<63 µm	%LOI	%<63 µm	%LOI	%<63 µm	%LOI
Phyllodocids	.	.	.	.	.	**pos****
Hediste diversicolor	.	**pos******	**pos******	.	.	**pos****
Nephtys hombergii	.	**neg***	.	**neg******	.	.
other *Nephtys* species	.	.	.	.	.	.
Scoloplos armiger	.	.	.	.	.	.
Pygospio spp	.	.	**pos****	**neg***	.	**pos***
Spio spp	.	.	.	.	.	.
Cirratulids	.	.	.	.	**pos******	**neg****
Capitellids	.	.	.	**neg******	.	.
***Arenicola marina* casts**	.	**neg******	**neg******	.	.	.
Clymenella torquata	.	.	.	.	.	.
Lanice conchilega	.	.	.	.	.	.
Oligochaetes	.	**pos******	.	**pos******	.	**pos***
***Urothoe* spp**	.	**neg***	**neg***	.	.	.
***Bathyporeia* spp**	.	.	**neg***	**pos***	.	.
***Corophium arenarium* 3+ mm**	.	.	.	.	.	.
Corophium volutator 3+ mm	.	.	.	.	.	.
Crangon crangon	.	**neg****	.	.	.	.
Carcinus maenus	.	.	**pos*****	**neg****	.	.
***Hydrobia ulvae* 3+ mm**	.	.	.	.	**pos****	.
***Retusa obtusa* 3+ mm**	.	.	.	.	.	**neg***
Mytilus edulis 5+mm	.	.	.	.	.	.
***Cerastoderma edule* 4-10 mm**	.	.	.	.	.	**pos******
***Cerastoderma edule* 16-40 mm**	**pos***	**neg****	.	.	.	.
***Cerastoderma edule* 20-30 mm**	.	.	.	.	.	.
***Macoma balthica* <9 mm**	.	.	.	.	.	**pos******
***Macoma balthica* 6-15 mm**	**pos*****	**neg******	**neg****	.	.	**pos****
***Macoma balthica* 9-20 mm**	.	**neg****	**neg****	.	.	.
Mya arenaria	.	.	.	.	.	.
Scrobicularia plana 20+ mm	**pos***	.	.	.	.	.

Table 3.3.7a-c. Correlates of the change in $\log_e$ mean density of invertebrates within sample sites between each pair-wise comparison of the 1986, 1998 and 1999 surveys. The correlates were determined for each invertebrate (dependent variable) by stepwise multiple regression procedures in which the changes in sediment variables and the densities of other invertebrates between surveys were the explanatory variables. Only those explanatory variables that explained a significant amount ($p<0.05$) of the variation in the dependent variable are tabulated. The sediment variables relating to the difference in the percentage of fine sediment (particles <63 µm) and the difference in the organic content (percentage Loss On Ignition) between surveys are abbreviated as '%<63 µm' and '%LOI' respectively.

a. Annelids

Dependent variable. Family, species or species size category of invertebrate	survey comparison	positively correlated sediment and invertebrate variables	negatively correlated sediment and invertebrate variables	R squared as %
Phyllodocids	'98 to '86	*Pygospio* sp, *Bathyporeia* spp	none	16
	'99 to '86	*M. balthica* (<9 mm), *M arenaria*	none	34
	'99 to '98	*M. balthica* (<9 mm), Oligochaetes	none	16
Hediste diversicolor	'98 to '86	**% LOI**, *C edule* (4-10mm), *M arenaria*, *S plana* (>20 mm)	*N hombergii*	47
	'99 to '86	Oligochaetes, *C maenus*, *C. edule*(4-10 mm)	*C arenarium* (>3mm)	38
	'99 to '98	Capitellids, Oligochaetes, *L conchilega*, *S plana* (>20 mm)	*A marina*, other *Nephtys*, *N hombergii*	40
Nephtys hombergii	'98 to '86	*H ulvae*, *A marina*, *Spio* spp, *Pygospio* spp	*H diversicolor*	36
	'99 to '86	none	**% LOI**, *C edule* (16-40 mm)	27
	'99 to '98	*C maenus*, *Spio spp*	other *Nephtys*, *H ulvae*, *H diversicolor*	44
other *Nephtys* species	'98 to '86	*R obtusa*, *Spio* spp	%<63 um, *C edule* (4-10 mm), *C edule* (16-40 mm), *N hombergii*	32
	'99 to '86	*S armiger*, Capitellids	*C edule* (16-40 mm), *Pygospio* spp	38
	'99 to '98	*Spio* spp	*N hombergii* , *H diversicolor*, *S armiger*, *A marina*, *Urothoe* sp	41
Scoloplos armiger	'98 to '86	*C crangon*, *A marina*	none	14
	'99 to '86	*Spio* spp	%LOI, *C edule* (4-10 mm), *H ulvae*	26
	'99 to '98	*C edule* (4-10 mm), *C crangon*	Oligochaetes	15
Pygospio sp	'98 to '86	Phyllodocids	*Spio* spp, *Bathyporeia* spp	32
	'99 to '86	*M balthica* (9 mm)	*C edule (16-40 mm)*, other *Nephtys*, *Bathyporeia* sp	41
	'99 to '98	**% LOI**	*Spio* sp, *M arenarium*, *M balthica* (6-15 mm)	35
Spio sp	'98 to '86	*N hombergii*	*Pygospio* spp, *H ulvae*	26
	'99 to '86	Cirratulids	*M balthica* (6-15 mm)	11
	'99 to '98	*N hombergii*, Cirratilids, other *Nephtys* spp	*Pygospio* spp	41
Cirratulids	'98 to '86	other *Nephtys* spp, *C maenus*	*M arenaria*, *R obtusa*, *A marina*	33
	'99 to '86	*C maenus*, *L conchilega*, *M balthica* (6-15 mm), *N hombergii*	*M arenaria*, *C edule* (16-40 mm), *H ulvae*	55
	'99 to '98	**% <63 um**, *M balthica* (<9 mm), *S plana* (>20 mm)	**% LOI**	27
Capitellids	'98 to '86	none	*M arenaria*	7
	'99 to '86	%LOI, other *Nephtys* spp	none	16

Dependent variable. Family, species or species size category of invertebrate	survey comparison	positively correlated sediment and invertebrate variables	negatively correlated sediment and invertebrate variables	R squared as %
	'99 to '98	*H diversicolor*, *N hombergii*, *Urothoe* sp	*S plana* (>20 mm), *L conchilega*	34
Arenicola marina casts	'98 to '86	*N hombergii*, *Bathyporeia* sp	**% LOI**, Oligochaetes, *Corophium arenarium*	38
	'99 to '86	*Urothoe* sp, Phyllodocids, *Spio* sp	**% <63 um**, *C arenarium*, *H ulvae*, Cirratulids	47
	'99 to '98	none	*H diversicolor*, other *Nephtys* sp	12
Clymenella torquata	'98 to '86	none	none	
	'99 to '86	none	none	
	'99 to '98	none	none	
Lanice conchilega	'98 to '86	*Mytilus edulis* (5+ mm), *M balthica* (6-15 mm), *C maenus*	*C edule* (16-40 mm), Phyllodocids, *C crangon*	48
	'99 to '86	*M edulis* (5+ mm), Cirratulids, Oligochaetes	other *Nephtys* spp, *C edule* (20-30 mm)	31
	'99 to '98	*C edule* (4-10 mm)	none	7
Oligochaetes	'98 to '86	**% LOI**, *S plana* (>20 mm)	*A marina*	33
	'99 to '86	**% LOI**, *S plana* (>20 mm), *H diversicolor*, *Pygospio* spp, *C volutator*	none	49
	'99 to '98	*C maenus*, *C edule* (4-10 mm), *M balthica* (9-20 mm), Phyllodocids	none	40

Table 3.3.7 continued. b. Crustaceans

Dependent variable. Family, species or species size category of invertebrate	survey comparison	positively correlated sediment and invertebrate variables	negatively correlated sediment and invertebrate variables	R squared as %
Urothoe sp	'98 to '86	*A marina*, *Bathyporeia* spp	*M arenaria*	25
	'99 to '86	*Bathyporeia* spp, *A marina*, Capitellids	*M arenaria*	31
	'99 to '98	none	none	
Bathyporeia sp	'98 to '86	*Urothoe* sp, Phyllodocids	*Pygospio* spp	20
	'99 to '86	*Urothoe* spp, *Spio* spp, *R obtusa*	*Pygospio* spp, *C edule* (20-30 mm)	30
	'99 to '98	%LOI, *C crangon*,	%<63 um, *M balthica* (6-15 mm), *S armiger*	26
Corophium arenarium 3+ mm	'98 to '86	none	none	
	'99 to '86	none	none	
	'99 to '98	none	other *Nephtys* sp.	5
Corophium volutator 3+ mm	'98 to '86	*M arenaria*, *C maenus*	*H diversicolor*	20
	'99 to '86	*C maenus*, *A marina*	*Bathyporeia* spp	21
	'99 to '98	none	none	
Crangon crangon	'98 to '86	*S armiger*, *M arenaria*	**% LOI**, *L conchilega*	25
	'99 to '86	none	none	
	'99 to '98	%<63 um, *A marina*, *S armiger*, *Bathyporeia* sp, *M balthica* (6-15mm)	*C edule* (4-10 mm)	31
Carcinus maenus	'98 to '86	*L conchilega*, *C volutator*	none	21
	'99 to '86	*M edulis (5+ mm)*, *C volutator*, *H diversicolor*, *Spio* spp	none	40
	'99 to '98	Oligochaetes	*Pygospio* spp, *C edule (20-30 mm)*	21

Table 3.3.7 continued. c. Molluscs

Dependent variable. Family, species or species size category of invertebrate	survey comparison	positively correlated sediment and invertebrate variables	negatively correlated sediment and invertebrate variables	R square as %
Hydrobia ulvae 3+ mm	'98 to '86	*N hombergii*, *C edule* (4-10 mm), Capitellids	*Spio* spp	29
	'99 to '86	*M balthica* (<9 mm), C *edule* (4-10 mm)	Cirratulids	29
	'99 to '98	*C edule* (4-10 mm), Phyllodocids, *M arenaria*	*N hombergii*	29
Retusa obtusa 3+ mm	'98 to '86	*C edule* 16-40 mm), other *Nephtys* spp, *H ulvae*, *S plana* (>20 mm), *M balthica* (<9 mm)	Cirratulids	36
	'99 to '86	*M arenaria*, *C edule* (16-40 mm)	none	11
	'99 to '98	none	**% LOI**	5
Mytilus edulis 5+ mm	'98 to '86	*L conchilega*, *M arenaria*	none	31
	'99 to '86	*C maenus*, *M arenaria*, other *Nephtys* sp, *L conchilega*	*Spio* spp	42
	'99 to '98	*M arenaria*	*S plana* (>20 mm)	19
Cerastoderma edule 4-10 mm	'98 to '86	*H diversicolor*, *M arenaria*, *H ulvae*	%<63 um, other *Nephtys* spp, Phyllodocids	39
	'99 to '86	*H ulvae*, *C edule* (16-40 mm)	*S armiger*	24
	'99 to '98	**% LOI**, *H ulvae*, *M balthica* (6-15 mm), *M edulis* (5+mm), *S armiger*, Oligochaetes	*C crangon*	52
Cerastoderma edule 16-40 mm	'98 to '86	*R obtusa*	*L conchilega*, other *Nephtys* sp, Oligochaetes, *Pygospio* spp	38
	'99 to '86	*M balthica* (6-15 mm), *R obtusa*	*Pygospio* spp, other *Nephtys* spp, *C maenus*, *Bathyporeia* spp, *M edulis*(5+ mm)	43
	'99 to '98	none	none	
Cerastoderma edule 20-30 mm	'98 to '86	*R obtusa*	other *Nephtys* sp, Oligochaetes	20
	'99 to '86	*M balthica* (6-15 mm)	other *Nephtys* spp, *Pygospio* spp	27
	'99 to '98	none	none	
Macoma balthica <9 mm	'98 to '86	*M balthica* (9-20 mm), *Pygospio* spp, *L conchilega*	none	26
	'99 to '86	*M balthica* (9-20 mm), Phyllodocids, *S plana* (>20 mm)	*A marina*, *M arenaria*	47
	'99 to '98	**% LOI**, Cirratulids, *M balthica* (9-20 mm)	*Bathyporeia* spp	42
Macoma balthica 6-15 mm	'98 to '86	**% <63um**, *L conchilega*	**% LOI**	27
	'99 to '86	*S plana* (>20 mm), Phyllodocids, *C edule* (20-30 mm), *Pygospio* sp, *C maenus*	**% <63 um**, *M arenaria*	41
	'99 to '98	*C edule* (4-10 mm)	*M edulis (5+ mm)*	24
Macoma balthica 9-20 mm	'98 to '86	*M balthica* (6-15 mm), *S plana* (>20mm), *Bathyporeia* spp, *C edule* (20-30 mm)	**% LOI**	34
	'99 to '86	*M balthica* (<9 mm)	**% <63 um**, other *Nephtys* spp	41
	'99 to '98	*S plan* (>20 mm), *M balthica* (<9 mm)	*Pygospio sp*, *C edule* (20-30 mm)	29
Mya arenaria	'98 to '86	*H diversicolor*, *C volutator*, *L conchilega*, *C edule* (4-10 mm)	Cirratulids, *C edule* (16-40 mm)	49
	'99 to '86	*C maenus*, Phyllodocids	Cirratulids, *Urothoe* spp, *C edule* (16-40 mm)	47
	'99 to '98	*M edulis* (5+ mm), *H ulvae*, %LOI, *R obtusa*	*Pygospio* spp,	37
Scrobicularia plana 20+ mm	'98 to '86	Oligochaetes	none	15
	'99 to '86	Oligochaetes, *M balthica* (<9 mm)	*C maenus*	26
	'99 to '98	*M balthica* (9-20 mm), Cirratulids	Capitellids	25

4. Discussion and conclusions

In this section we discuss, and where appropriate, make conclusions about specific issues addressed by this study. We consider the procedural guidelines and offer suggestions has to how they might be made more specific in terms of addressing the practicalities of sampling very large intertidal areas like the Wash. We discuss the suitability of the sampling strategy adopted in this study for monitoring cSAC's and comment on quality control procedures and resource requirements of future surveys of this kind. We discuss the changes in intertidal sediment and invertebrate fauna that the comparisons between the 1998 and 1999 surveys and 1986 survey identified and consider likely explanations. We also consider how the whole Wash surveys of 1998 and 1999 aid interpretation of the monitoring studies being undertaken in the areas adjacent to the river Great Ouse outfall on behalf of Essex and Suffolk Water. Finally, we recapitulate the objectives of this study and how these have been met.

4.1 Comments on the procedural guidelines

We followed, where applicable, the Procedural Guidelines set out in *Quantitative Sampling of Intertidal Sediment Biotopes and Species using Cores* (Davies *et al* 2001). However, to ensure comparability with the previous survey ITE had performed, it was necessary to alter certain procedures. These alterations have been summarised in section 2.4. The comments discussed here summarise those made in a separate review/questionnaire of Procedural Guidelines submitted with this report.

We found the guidelines clearly and well presented. The content was comprehensive and the methodologies were clearly and logically set out and were applicable to the conservation and survey objectives it sought to address. Clearly, the authors had a wide experience of surveying sediments and invertebrates of intertidal areas.

We thoroughly endorsed the points made in the Health and Safety section but thought that it should be placed in a prominent position at the beginning of the guidelines, say before the 'Equipment required' section, rather than at the end. H&S issues cannot be overstated when considering very large intertidal areas such as the Wash. In addition to the points made, we would advise that considering vaccination for Hepatitis is mentioned as well as the need for precautions against Weil's disease (Leptospirosis).

We had some detailed comments concerning certain methods. These were as follows:

- With regard to site location, we would strongly advise that full use be made of any recent aerial photography of the intertidal areas to be surveyed. Aerial photographs provide an excellent source of up-to-date topographical information, such as creek and sediment patterns, that is rarely, if ever, recorded on charts or maps, probably because of their variable nature. Such information we considered to be invaluable both from a health and safety perspective and to aid site selection.
- With regard to timing of surveys, we consider autumn to be the best because of the disadvantages of the invertebrate populations being subjected to large perturbations due to juvenile recruitment and ephemeral populations in the summer months or to weather in winter noted in the guidelines. We thoroughly agree that if results are to be compared over periods of years the need for the survey to take place at the same time of year as the previous ones is of primary importance.

- With regard to the subjective scoring of sediment stability and sorting, we found the former to be difficult to apply consistently, probably due to confusion over the spatial scale to which the score applied. For example, on mid-shore sandflats, the sand particles themselves could be considered mobile but an area, say a square metre or even hectares of that sediment considered to be stable in that they have remained of that type for many years. We thought that, when sediment samples were also taken, the particle sorting would best be scored using summarised particle size analysis data.
- With regard to the size of cores used, we would strongly advise that a 30 cm core depth would be better than one of 15 cm. This would ensure that the tubeworm, *Lanice*, the ragworm, *Hedister*, and large specimens of the molluscs, *Scrobicularia* and *Mya*, all of which can occur at depths of at least 20 cm, were adequately sampled. However, we do realise that the 1 m^2 dig achieves this as well as providing an estimate of the density of those invertebrates too sparse to be represented in the cores.
- With regard to the sieving of samples, transporting complete core samples back for sieving in the laboratory is a problem when large intertidal areas are to be surveyed because of the limitations on the volume and weight of material that can be transported over mud and sandflats.
- With the previous comment in mind, we thoroughly agreed with the recommendation that at least two, and preferably three field workers are required.
- With regard to the 1 m^2 dig, we would advise that four, 0.25 m^2 areas were dug in preference to a single 1 m^2, so that some within-site replication and measure of variability was achieved.

4.2 Sampling strategy and its suitability for monitoring cSAC's

We considered the primary need for monitoring the Wash cSAC to be a sampling strategy that provided the most extensive spatial coverage that resources and existing surveys allowed. Consequently, we adopted the general sampling principle of taking a small number of samples in as many widely dispersed sites as possible, while ensuring comparability with previous surveys (1986 survey) and the requirements of on-going surveys (Gt Ouse study for Essex and Suffolk Water). It was for this reason that we chose to take fewer samples from a site than had been previously taken to minimise the cost of sorting samples.

Given that the sampling strategy was, in part, already based on ensuring the inclusion of a representative selection of biotopes, it seems unlikely that the numbers of sample sites could be reduced without losing the extensiveness of the coverage and an acceptable degree of replication of the Wash biotopes. Superficially, there appears to be some scope for reducing sample sites in some transects on the west shore (Figure 3.2.2). Likewise, reducing the concentration of sample sites in the vicinity of the Gt Ouse could be considered in future surveys. But even in those areas there was sufficient variation in biotopes between surveys to make it unwise to consider reducing the number of sample sites. Consequently, we would always advise against reducing the number of sample sites in preference to their being a reduction in the number or size of samples taken from within a site, whether the purpose was to determine invertebrate density or the biotope. In other words sacrificing some detail, or precision, in determining the number of species and their abundance within a site is preferable to reducing the number and hence the extent of coverage of sites. This conclusion is equally applicable to developing sampling strategies for other areas.

The suitability of the study's sampling strategy for detecting change in invertebrate was assessed by a power analysis of the change in invertebrate density between the 1986 and 1998 surveys (Table 4.2.1). On average, and given the same variability in invertebrate densities as was recorded in the 1998 survey, a four-fold increase and a three-fold decrease could be detected using the array of sites sampled in that survey. Obviously, for a more uniformly distributed species, like *A. marina*, an acceptable level of detection might still be achieved with a reduced number of sample sites. But for other invertebrates, particularly those whose abundance is extremely variable and spatially aggregated, for example *Corophium* spp, the level of detectable change is much higher than the average so it would require a sampling strategy that increased the number of sample sites to improve the level of change detection.

We would conclude, therefore, that overall the sampling strategy we adopted represents the minimum required for the purposes of the study. If changes in invertebrate density or of biotope are to be quantified then it is necessary for the sediment characteristics and invertebrate abundance to be quantified also.

However, while statistically significant changes in sediment particle size and organic content and invertebrate density can be easily defined and quantified if suitable data are available, what is biologically significant is considerably harder to define. It is quite conceivable that changes in an invertebrate's density could be statistically significant but of no biological significance and *vice versa*. The criteria by which biological significance is defined must themselves be biological. Such a criterion might be to establish the autumn biomass of invertebrate prey that would keep over-wintering shorebird mortality at their present levels having taken shorebird numbers into account. Considering the feasibility of such an approach was the purpose of a report submitted to English Nature by West *et al* (2001).

Recommendations and considerations for future monitoring

As was stated at the beginning of this section we considered the primary need for monitoring cSAC's to be a sampling strategy that provided the most extensive spatial coverage that resources allowed. In so doing it would be expected that a representative and replicated selection of all the habitats or biotopes would be included. To achieve this we would recommend the following points were considered.

i. Adopt a sampling strategy that is based on small samples taken from a large number of sites to ensure extensive coverage and adequate replication within the limits of available resources.
ii. To aid site selection, make full use of any existing information concerning the area. This would include data from previous surveys and aerial photography as well as 'local knowledge' from fishermen, bait diggers and birdwatchers for example, that would give an insight to the location of shellfish beds, areas preferred by feeding birds and those little used by them. It would also provide valuable information on accessibility and safety.
iii. It is useful to arrange sites in transects for two reasons. First, by aligning them in a shore normal direction, that is from upper to lower levels of the shore, a major source of variation in both sediment type and invertebrate is spanned and second, arrangement in this manner, say along a compass bearing, makes them easier to locate when revisited.

iv. Congregate sampling sites on areas showing, or expected to show, greatest spatial variation in sediment type, biotope and invertebrate biomass or assemblages. In other words, increase sampling intensity in the most variable areas.

Perhaps the major constraint in undertaking surveys of the kind reported here is the cost of sorting invertebrate samples. This being so, it is worth considering alternative methods of assessing invertebrate abundance. In this study invertebrate abundance, expressed as log density, was positively and quite strongly correlated with the proportion of sites in which they occurred (Tables 3.3.3 and 3.3.4 and Figure 4.2.1). Furthermore, there was no significant difference in the relationship between surveys. This suggests that where limited resources preclude the processing of invertebrate samples in detail, density changes could perhaps be estimated by comparing the proportion of sites in which the invertebrates occurred between surveys using this relationship. For example, if the percentage of sites in which an invertebrate occurred increased by 10 percentage points, say from 40% to 50%, a 1.8 fold increase in density would expected. Obviously, the parameters of this relationship may be Wash specific and not directly applicable to other areas in which case abundance/occurrence relationships would have to be established first.

Another modification aimed at cutting the cost of sorting samples might involve reducing the number of invertebrate species that were identified. For instance, many invertebrates that are easily identified by eye could be counted by sieving samples on site so totally removing the need for further sample processing. A similar approach might be to count only those invertebrates that could be considered indicators of some feature of the sample site, such as the biotope or of evidence of physical disturbance for example. We discuss selecting such ‘indicators’ in the following section.

Clearly, if future surveys that are comparable with those of 1986, 1998 and 1999 are to be made, quality assurance procedures need to ensure that both timing of sampling and sampling methodologies remain the same. Unsurprisingly, the major constraint for surveys of intertidal areas the size of the Wash is the scale of the operation. The main consequence of this is high labour costs both in conducting the sampling programme and more particularly, in sorting and analysing the samples.

4.3 Comparisons between the 1986 and the 1998 and 1999 surveys

The largest changes in sediment particle size were recorded on the east shore of the Wash between 1986 and both 1998 and 1999. However, we know from the annual surveys of this area performed from 1996 onwards that these occurred between 1997 and 1998. It was not necessarily the case, therefore, that changes between 1986 and 1998 elsewhere in the Wash were the consequences of cumulative change over that period. Nevertheless, in sites at higher shore-levels increased muddiness would be an expected consequence of accretionary processes over such a time period. This would be particularly so in sites adjacent to the more recent saltmarsh reclamation in the Wash.

Table 4.2.1. The change in invertebrate density over the whole Wash which would be detectable with at least 80% statistical power (5% probability level) by using the same number of sampling transects as that used in the 1998 survey and assuming the same variability in invertebrate density. For example, with the sampling strategy used in 1998 a 1.5-fold increase and a 0.7-fold decrease in *A. marina* would be detectable. The change was derived by power analysis of the 1986 and 1998 survey data using the following calculation. Detectable increase = e^{x} and detectable decrease = e^{-x}, where x is 3 times the standard error of the difference between the $\log_e$ density in 1998 and $\log_e$ density in 1999.

Invertebrate family, species or species size category	detectable increase	detectable decrease
Arenicola marina	1.5	0.7
Phyllodocids	1.8	0.6
Hediste diversicolor	1.8	0.5
Nephtys hombergii	3.4	0.3
other *Nephtys* species	5.3	0.2
Scoloplos armiger	2.8	0.4
Pygospio spp	5.1	0.2
Spio spp	5.7	0.2
Cirratulids	11.2	0.1
Capitellids	4.4	0.2
Clymenella torquata	1.8	0.6
Lanice conchilega	4.1	0.2
Oligocheates	4.5	0.2
Urothoe spp	5.0	0.2
Bathyporeia spp	2.5	0.4
Corophium arenarium 3+ mm	6.0	0.2
Corophium volutator 3+ mm	14.0	0.1
Crangon crangon	2.0	0.5
Carcinus maenus	2.3	0.4
Hydrobia ulvae 3+ mm	3.4	0.3
Retusa obtusa 3+ mm	4.0	0.3
Mytilus edulis 5+ mm	3.9	0.3
Cerastoderma edule 4-10 mm	5.8	0.2
Cerastoderma edule 16-40 mm	3.2	0.3
Cerastoderma edule 20-30 mm	3.3	0.3
Macoma balthica <9 mm	1.9	0.5
Macoma balthica 6-15 mm	2.0	0.5
Macoma balthica 9-20 mm	2.7	0.4
Mya arenaria	5.7	0.2
Scrobicularia plana 20+ mm	2.6	0.4
average change	**4.1**	**0.3**

The mean Wash densities of many of the invertebrates were significantly lower in both 1998 and 1999 than they were in 1986 (Table 3.3.3). However, interpolation from distribution maps presented in the Wash Water Storage Scheme Feasibility Study (NERC 1976) suggests that some invertebrate densities recorded in 1998-9 were similar to those recorded in 1973 while most were highest in 1986. For example, *Corophium* spp had mean densities of 383 m^{-2} in 1973, 2088 m^{-2} in 1986 and 368 m^{-2} in 1998. Similarly mean cockle (*C. edule*) densities were 218 m^{-2}, 1177 m^{-2} and 320 m^{-2} in 1973, 1986 and 1998 respectively. Mean *Macoma* densities in 1973 were 815 m^{-2}, 2088 m^{-2} in 1986 and 244 m^{-2} in 1998, while *Arenicola* densites were 5 m^{-2}, 6 m^{-2} and 2 m^{-2} in those years. There is an indication, therefore, that the Wash may have been more productive in 1986 than in 1973 or in 1998 and 1999.

The changes in the densities of many of the invertebrates were significantly associated with changes in sediment characteristics (Table 3.3.6). Declines in those invertebrates, like *A. marina* and *Bathyporeia* sp that are known to be associated with sandy, organically poor sediments occurred where the sediment became muddier or more organically rich. In contrast, those like *H. diversicolor, H. ulvae* and the oligochaete worms that are known to be associated with muddy, organically rich sediments, increased in density in response to increases in muddiness and organic content. Nevertheless, it was evident that although changes in invertebrate density did correlate with changes in sediment characteristics there was much variation in invertebrate densities that was not accounted for by changes in sediment. Multiple regression analysis suggested that some of this residual variation correlated with density changes of other invertebrates (Table 3.3.7). In some cases the change in density of the dependent invertebrate was positively associated with that of another invertebrate, in other cases it was negative. Although significant correlations do not necessarily identify a cause and effect, they do implicate the influence of biological mechanisms that can give rise to these associations. In the simplest case, the change in density of one invertebrate could be associated with that of another because they both respond independently to a change in sediment particle size. For example, associations between *H. diversicolor* and both oligochaete and *S. plana* probably arise because they are all favoured by increased muddiness of the sediment. In other cases, the implication may be that either a predator prey or a competitive exclusion mechanism may be operating. An example of the former could explain the positive association between adult *C. edule* and *R. obtusa*, in the comparison of 1986 and 1998 surveys (Table 3.3.7) because the latter is known to be a predator of cockles. The negative association between *C. volutator* and *H. diversicolor* in the comparison of the same surveys (Table 3.3.7) is probably a combination of predator prey interaction and competitive exclusion because *Hediste* will both eat *Corophium* and the diatoms on which they feed.

Even though the multiple regression analysis identified numerous associations (Table 3.3.7) the inclusion of both sediment variables and other invertebrates accounted for less than 55% of the variation in change in invertebrate density between surveys. This indicates that there were likely to be other unexplored variables influencing invertebrate densities.

The associations identified in Table 3.3.7 may also aid the selection of 'indicator species'. For example, declines in the density of *N. hombergii, S. armiger* and *A. marina* were all associated with increased organic content in at least one of the survey by survey comparisons suggesting that such declines could be used as indicators of organic enrichment of the sediment. However, it is important to note that any selection should be based ultimately on known biological mechanisms and not solely on associations identified by correlative statistics.

4.4 Comparisons between the Gt Ouse intertidal surveys and those elsewhere in the Wash in 1998 and 1999

One of the objectives of this study was to provide a whole Wash dataset against which the monitoring of sediment and invertebrates in the areas adjacent to the Gt Ouse could be compared and interpreted.

There was little evidence of any difference between the changes in sediment type occurring in the Gt Ouse group of sites and sites elsewhere in the Wash (Figure 3.1.1) in 1998 and 1999. Nor was there any evidence of a difference in changes in organic content – all areas were similarly effected by the increased organic content of the sediment between 1998 and 1999 (Figures 3.3.4c, 3.3.5c and 3.3.6c).

It is not surprising therefore, that there was little evidence of differences in the changes in invertebrate density between the Ouse sites and the others (Table 3.3.5 and Appendix 6). Even when the differences between 1998 and 1999 were significant in the Ouse group alone, the direction of the change was similar, if not statistically significant, in other areas (Appendix 6). In those instances, it was likely that the significance of the difference in the Ouse group was attributable to the sampling intensity in that group being more intense than elsewhere.

We concluded therefore, that changes between 1998 and 1999 were not confined to those areas around the Gt Ouse but were widespread around the Wash.

The benefit of the Wash wide coverage of sites provided by the 1998 and 1999 surveys was clear in that allowed annual changes to be examined both at local and Wash-wide scales. We would also recommend that further comparisons should be made with quarterly studies on changes in invertebrate densities that are being undertaken as part of the Gt.Ouse study as that data become available (Binnie, Black and Veatch, 1997). These will give an indication of within year variation that occurs in densities as a consequence of recruitment of juveniles to the populations.

4.5 Concluding comments

The surveys and the accompanying data analysis from the work undertaken in 1998 and 1999 that is reported here provides a demonstration example of setting up a condition monitoring study for Wash and North Norfolk SACs. It draws heavily on both the methodology and results of the survey carried out by ITE in 1986. Consequently, it benefits from the baseline dataset that survey provided both in terms of providing a framework on which the sampling strategy for the 1998 and 1999 surveys could be developed and of allowing valuable comparison with that earlier survey. More importantly perhaps, the 1998 and 1999 surveys together provide an up to date baseline dataset against which more frequent future surveys can be compared.

5. Acknowledgements

We are pleased to acknowledge Essex and Suffolk Water and Binnie, Black and Veatch for permission to use data from the Great Ouse surveys and members of the UK Marine SACs project for their input into this study. We are also grateful to the Commanding Officers of RAF Holbeach and RAF Wainfleet for granting access to the RAF ranges and to all land-owners who gave us permission to cross their land. Thanks are also due for the help and guidance given us by the crew of Eastern Sea Fisheries' vessel Surveyor and to RSPB staff at Snettisham, Norfolk.

6. References

ANON, 2000. Wash & North Norfolk Coast European marine site: English Nature's advice given under Regulation 33(2) of the Conservation (Natural Habitats &c) Regulations 1994. Peterborough: English Nature.

BINNIE BLACK & VEATCH, 1997. Denver Licence Variation Ist Monitoring Group Meeting, Agenda and Reports. Binnie, Black and Veatch.

CONNOR, D. W., BRAZIER, P. D., HILL, T.O. & NORTHEN, K.O., 1997 Marine biotope classification for Britain and Ireland, Volume 1 Littoral biotopes. *Marine Nature Conservation Review*: *JNCC Report No 229*. 362pp. Peterborough: Joint Nature Conservation Committee.

DAVIES, J., BAXTER, J., BRADLEY, M., CONNOR, D., KHAN, J., MURRAY, E., SANDERSON, B., TURNBULL, C. & VINCENT, M. (Eds), 2001. *Marine Monitoring Handbook*. A report to UK Marine SAC's project on behalf of the Marine Monitoring Group. Peterborough: Joint Nature Conservation Committee.

GOSS-CUSTARD, J.D., YATES, M.G. MCGRORTY, S., LAKHANI, K.H. DURELL, S.E.A. LE V DIT, CLARKE, R.T., RISPIN, W.E., MOY, I. PARSELL, R. & YATES, T.J., 1988. Wash birds and invertebrates. *Report to Dept of the Environment*. Vol 1 text pp 122, Vol 2 figures pp 109.

NERC, 1976. The ecology of the Wash. A report of studies undertaken as part of a feasibility study of the proposals to construct reservoirs for fresh water storage in the Wash. *NERC publications series C No. 15*.

WEST, A.D., DURELL, S.E.A. LE V DIT, GOSS-CUSTARD, J.D. & STILLMAN, R.A. 2001. Estuary Special Protection Areas: establishing baseline targets for shorebirds. Report to English Nature.

YATES, M.G., GARBUTT, R. A., WYATT, C. L., SHORE, R.F., EASTWOOD, J.A., YATES, T.J., MCGRORTY, S., GOSS-CUSTARD, J.D., DURELL, S.E.A. LE V DIT, RISPIN, W.E., WOODS, C. & PARRINGTON, J., 1998. Environmental assessment of increased Ely Ouse absraction: final report Volume 2. 1996-97 surveys of sediment, invertebrates and birds. *Report to Binnie, Black and Veatch for Essex and Suffolk Water*. 60 pages.

YATES, M.G., GOSS-CUSTARD, J.D., MCGRORTY, S., LAKHANI, K.H., DURELL, S.E.A. LE V DIT, CLARKE, R.T., RISPIN, W.E., MOY, I., YATES, T.J., PLANT, R.A. & FROST A.J., 1993. Sediment characteristics, invertebrate densities and shorebird densities on the inner banks of the Wash. *Journal of Applied Ecology*, **30**, 599-614.

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3.3.9d. change in *Nephtys hombergii* density between 1986 and 1999 in relation to change in sediment organic content (%LOI).

Figure 4.2.1 The relationship between $\log_e$ invertebrate density and the percentage of sites they occupied in the 1986, 1998 and 1999 surveys of the Wash.

Each point represents one of the 30 invertebrate families, species or species size categories considered in this study in each survey. The fitted regression line is:

$\log_e$ invertebrate density = 1.75+0.0546(% of sites occupied). On average, for each 10 percentage point increase in sites occupied, there was a 1.8-fold increase in invertebrate density.

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Appendix 7. Regression parameters relating change in invertebrate density between surveys to change in particle size and organic content of the sediment.

Appendix 8. Catalogue of photographic slides taken of the sites sampled in the 1998 and 1999 surveys that were submitted separately to this report.

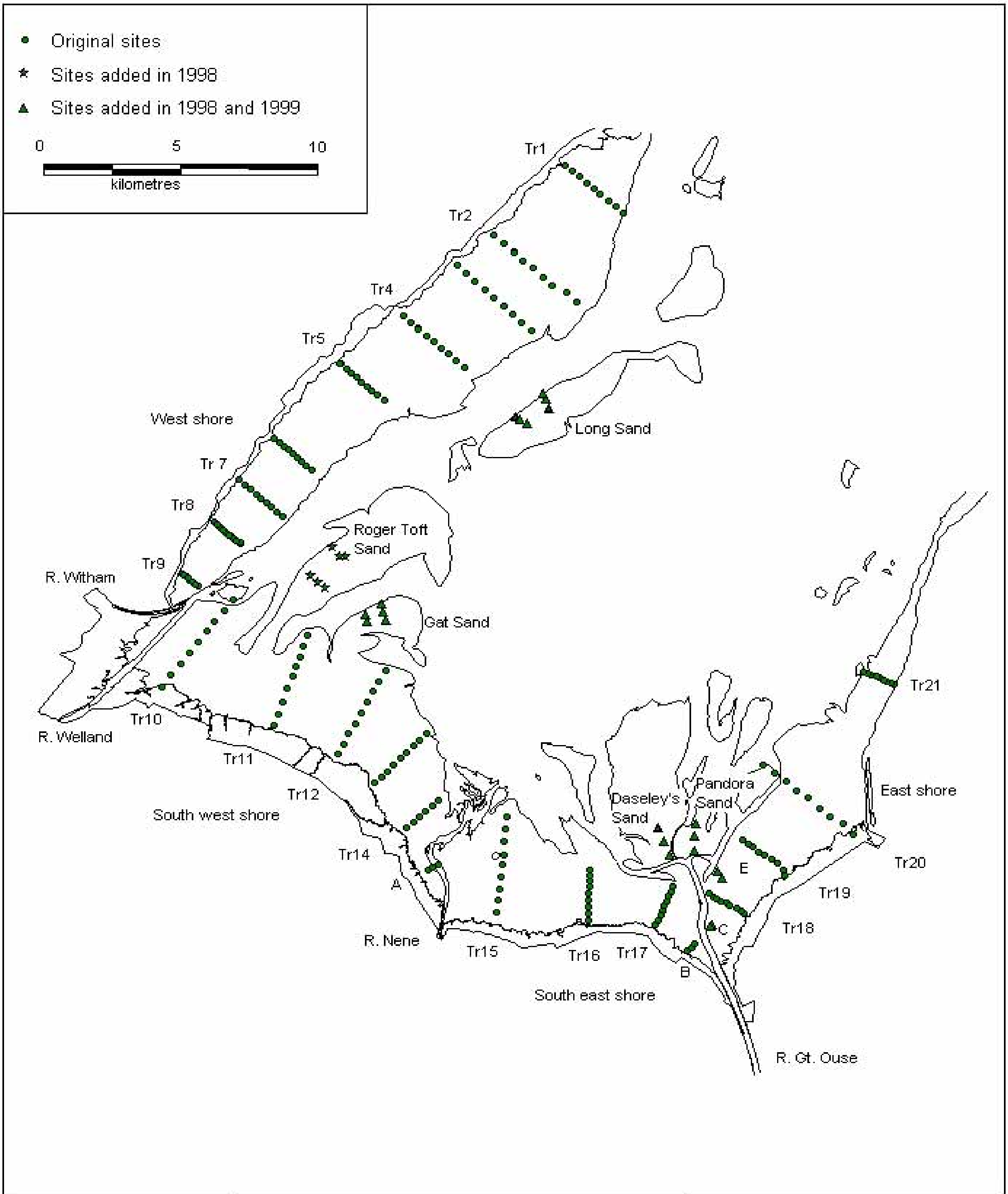

Figure 2.1 The Wash sampling sites

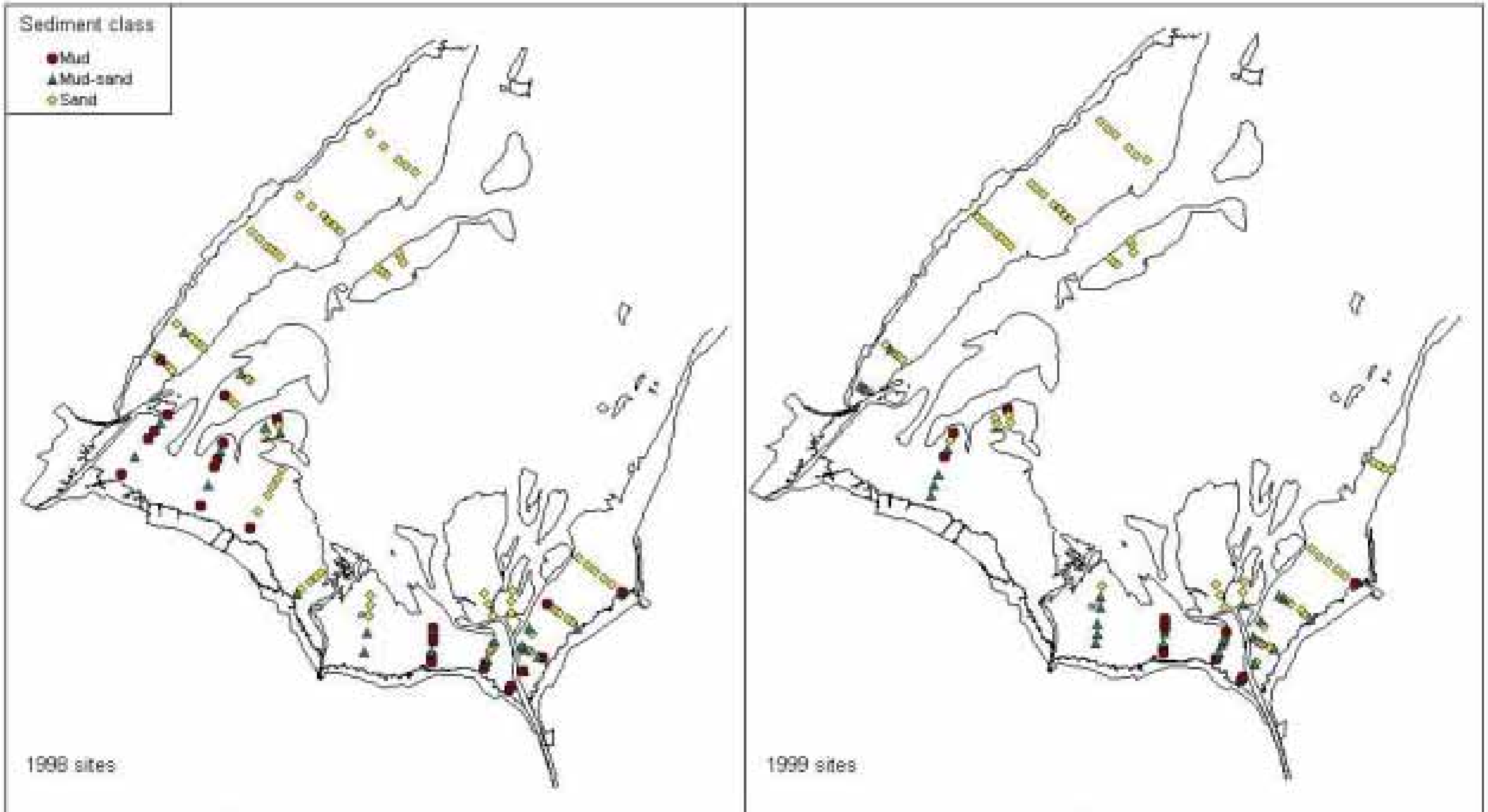

Figure 3.1.1 Sediment class maps for sites sampled in the 1998 and 1999 surveys

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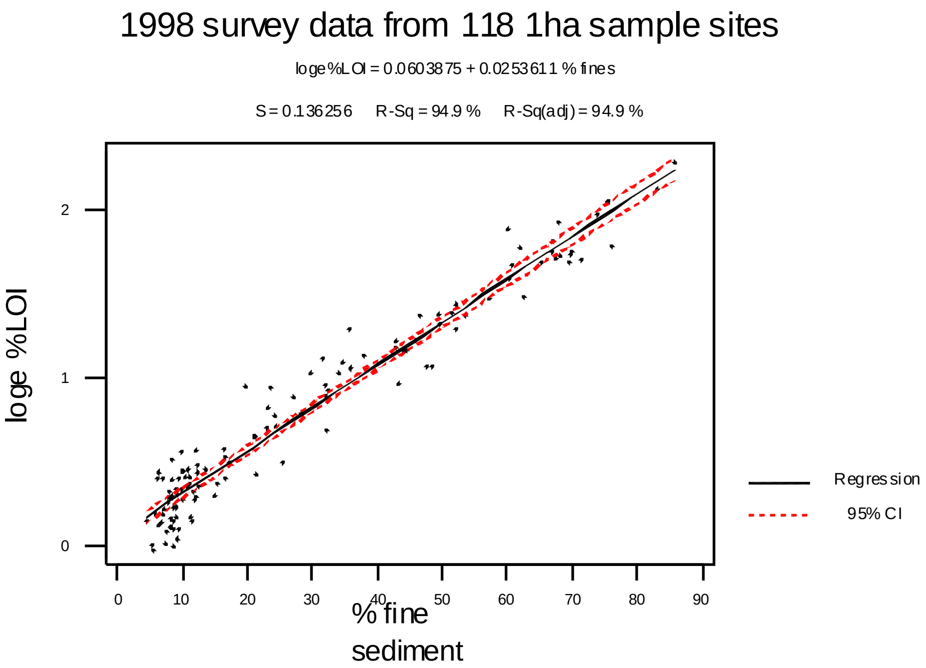
a.



b.

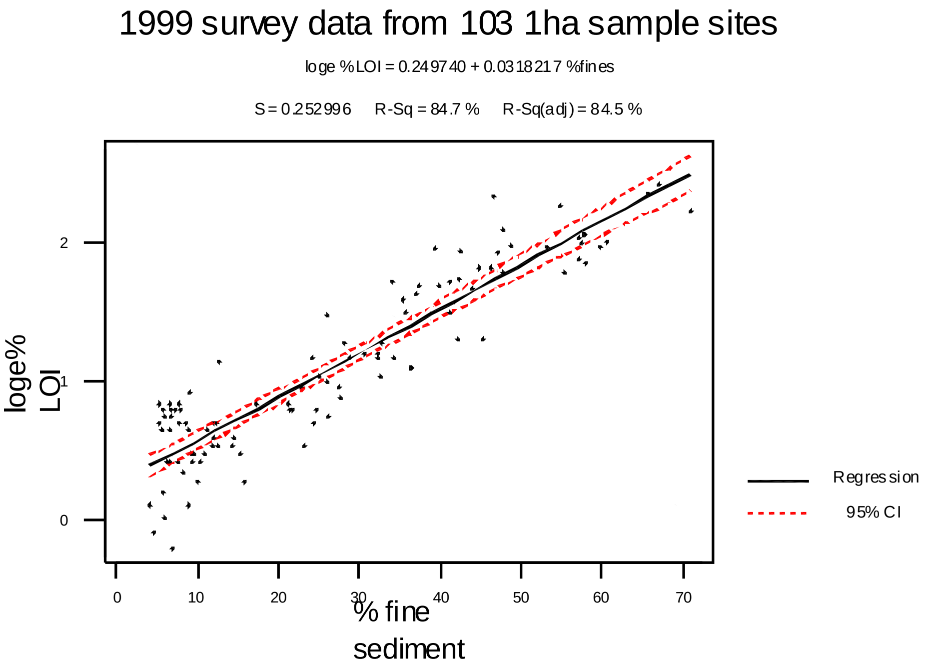


Figure 3.1.2 a and b. The relationship between the organic content of the sediment, expressed as log*e* percentage Loss on Ignition (%LOI), and the percentage of fines (particles <63 µm) in a, the 1998 and b, 1999 surveys of the Wash.

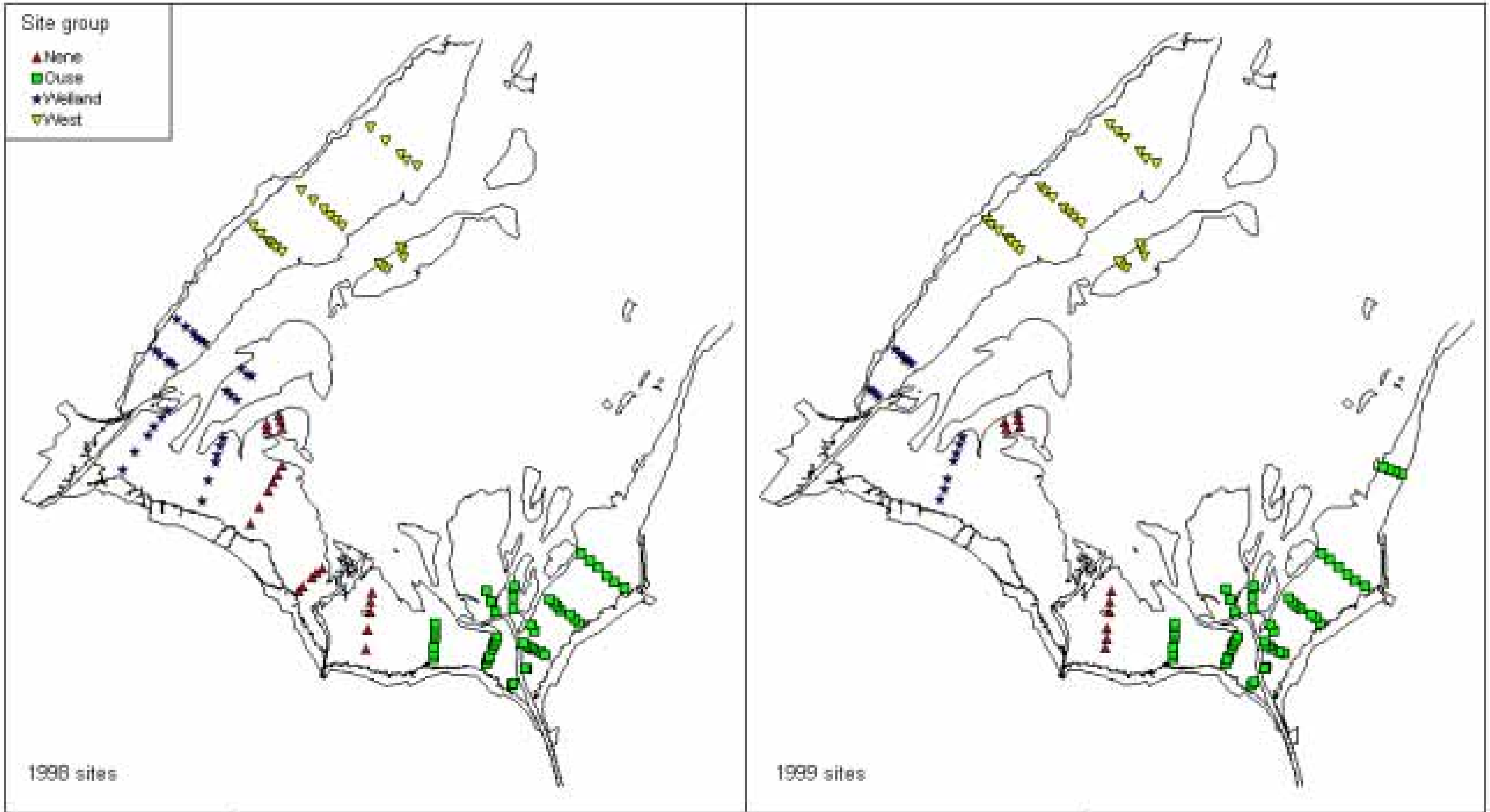


Figure 3.1.3 River group categories assigned to sites sampled in the 1998 and 1999 surveys

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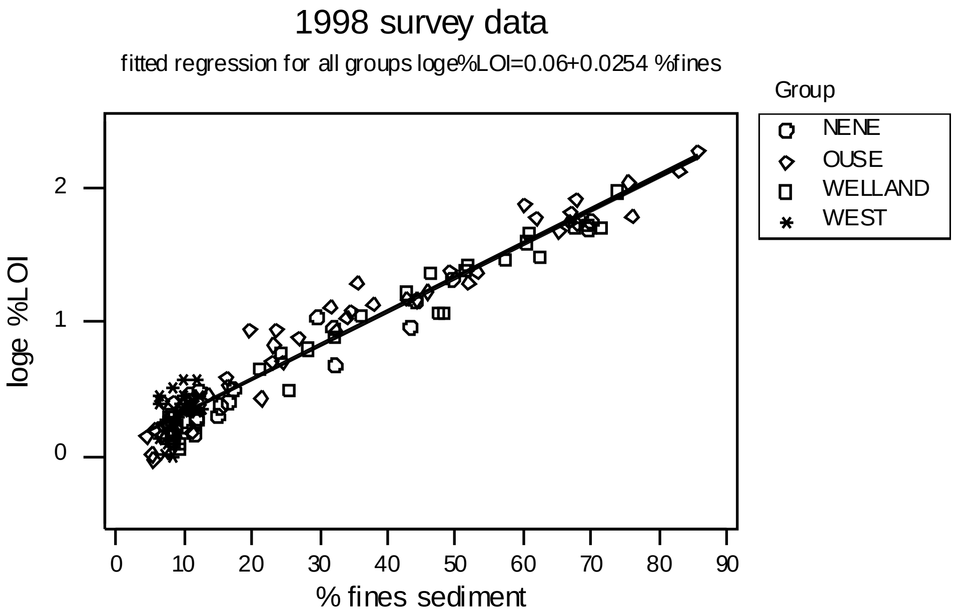

Figure 3.1.4 The relationship between the organic content of the sediment, expressed as log*e* percentage Loss on Ignition (%LOI), and the percentage of fines (particles <63 μm) in the 1998 survey of the Wash. Sites within groups are assigned similar symbols. There was no significant difference in the relationship between different groups so a single regression line is fitted to the data.

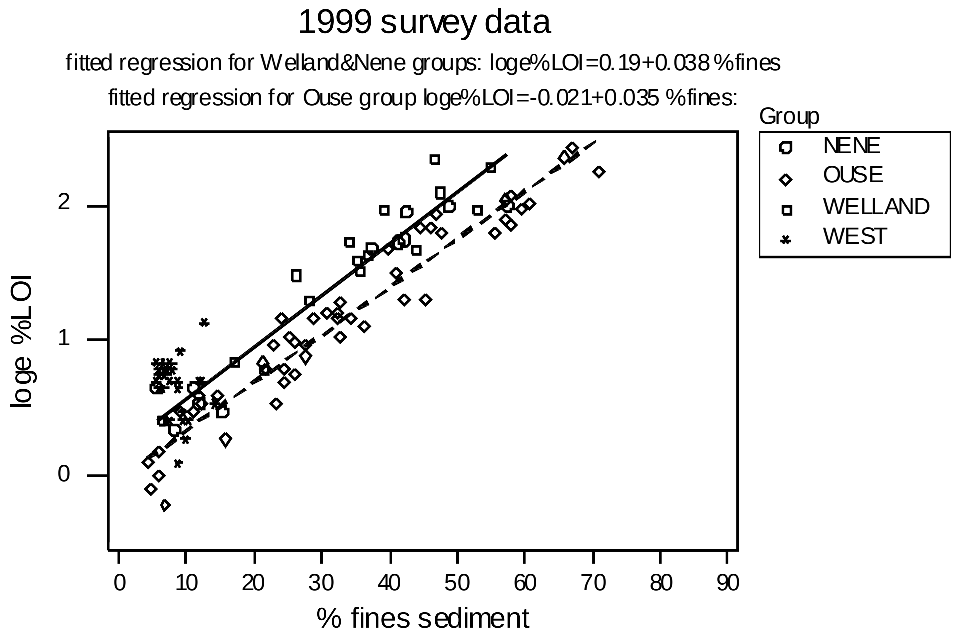

Figure 3.1.5 The relationship between the organic content of the sediment, expressed as log*e* percentage Loss on Ignition (%LOI), and the percentage of fines (particles <63 μm) in the 1999 survey of the Wash. Sites within groups are assigned similar symbols. There was no significant relationship between organic content and fine sediment for the west group. There was no significant difference in the relationship between the Welland and Nene groups so a single regression (solid line) is fitted to the combined data. However, there was a significant difference between the combined Welland and Nene data and the Ouse group, the latter have a lower organic content for a given amount of fine sediment (dashed line).

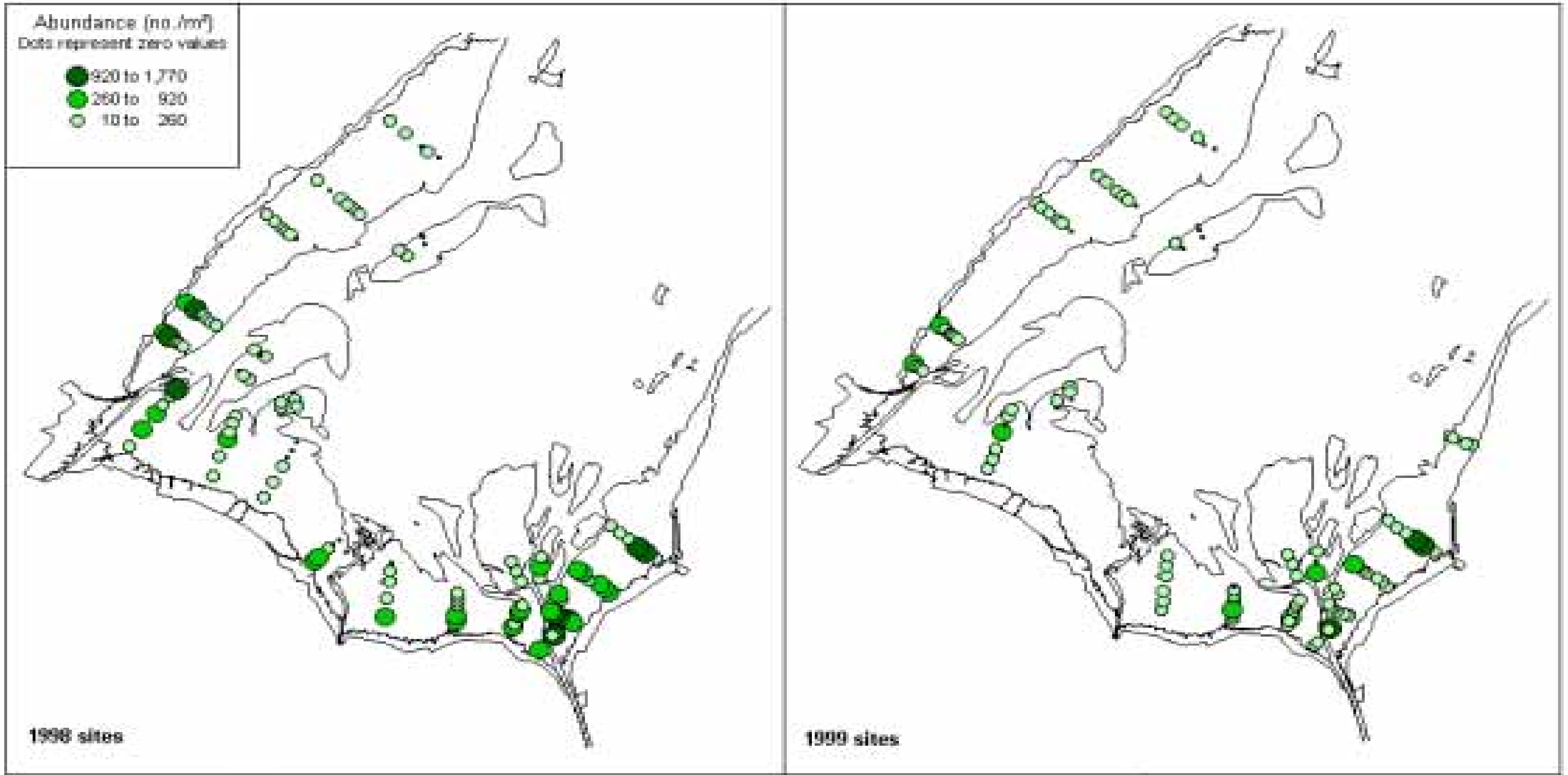

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Figure 3.2.1 Phyllodocid indet. distribution 1998 compared to 1999

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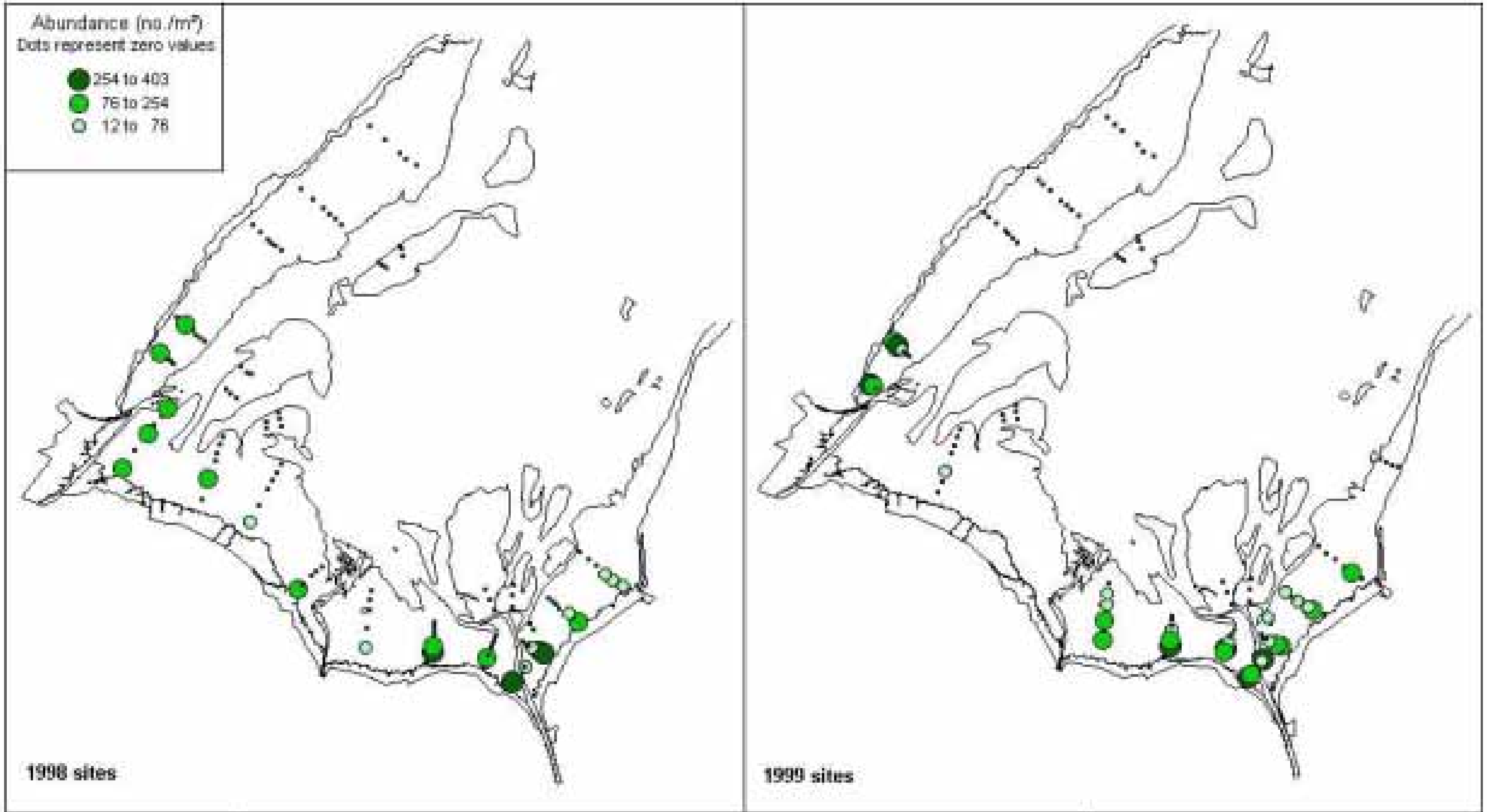

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Figure 3.2.2 Hediste diversicolor distribution 1998 compared to 1999

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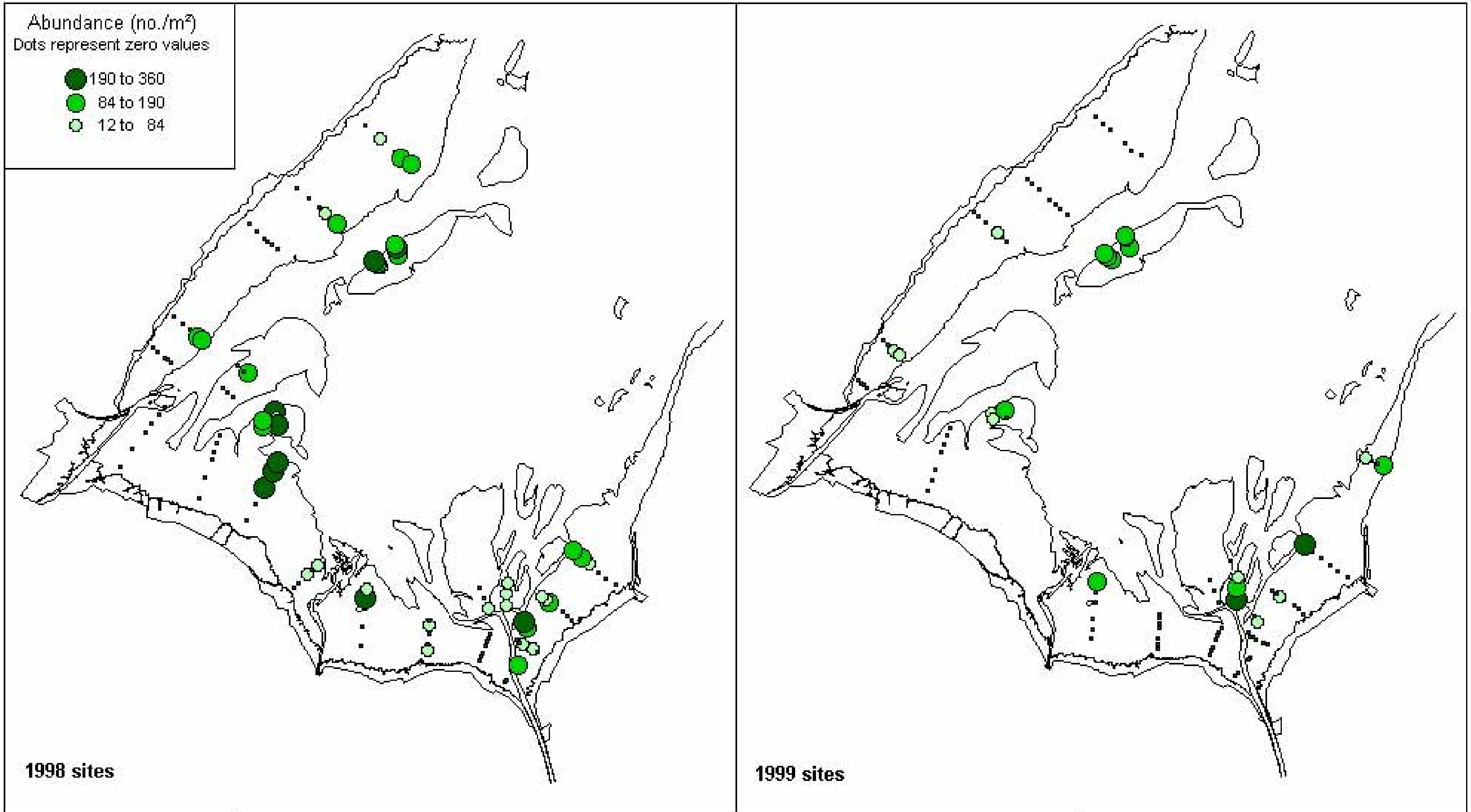

Figure 3.2.3 Other Nephtys spp distribution 1998 compared to 1999

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Figure 3.2.4 Nephtys hombergii distribution 1998 compared to 1999

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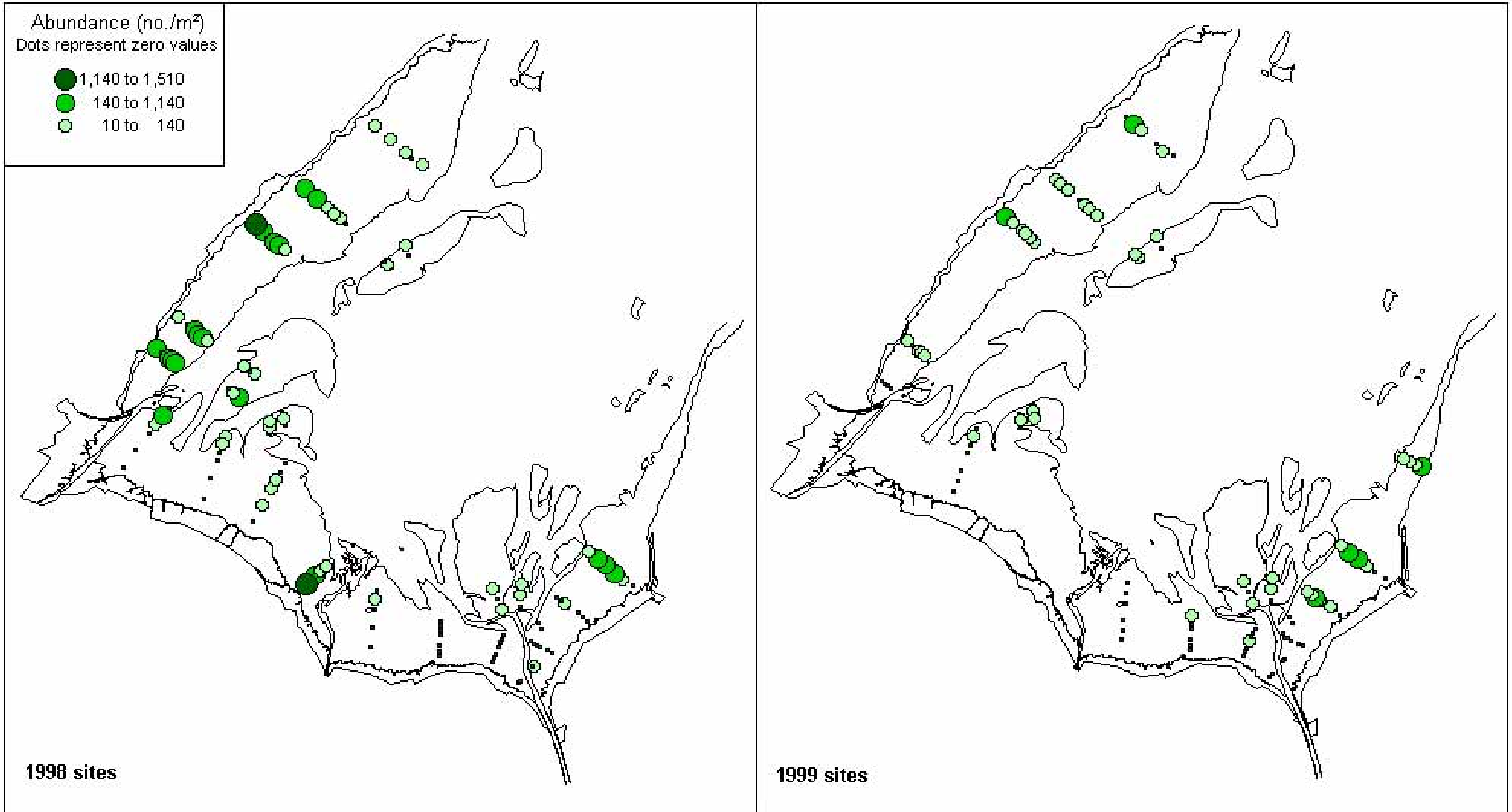

Figure 3.2.5 Scoloplos armiger distribution 1998 compared to 1999

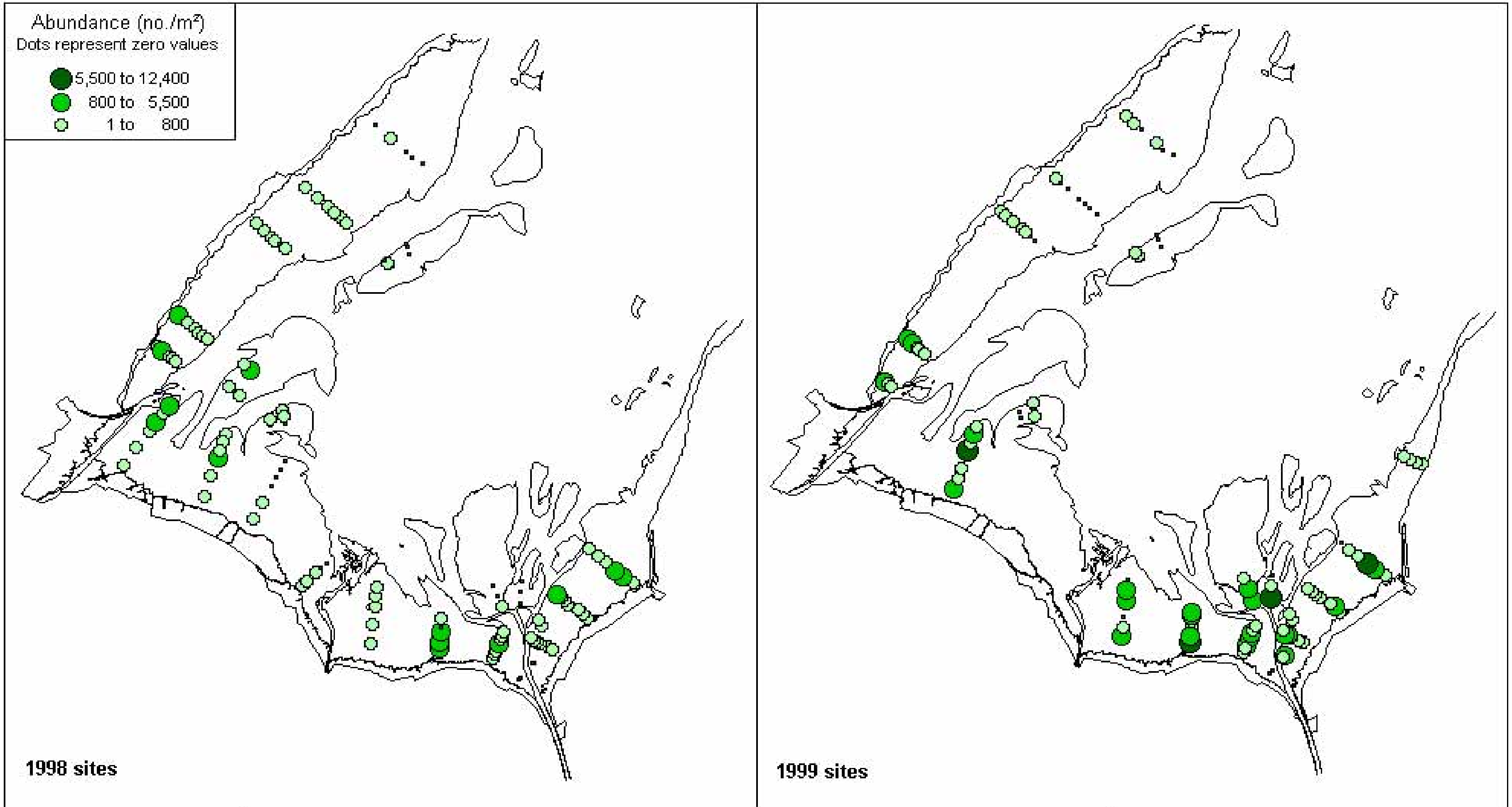

Figure 3.2.6 Pygospio elegans distribution 1998 compared to 1999

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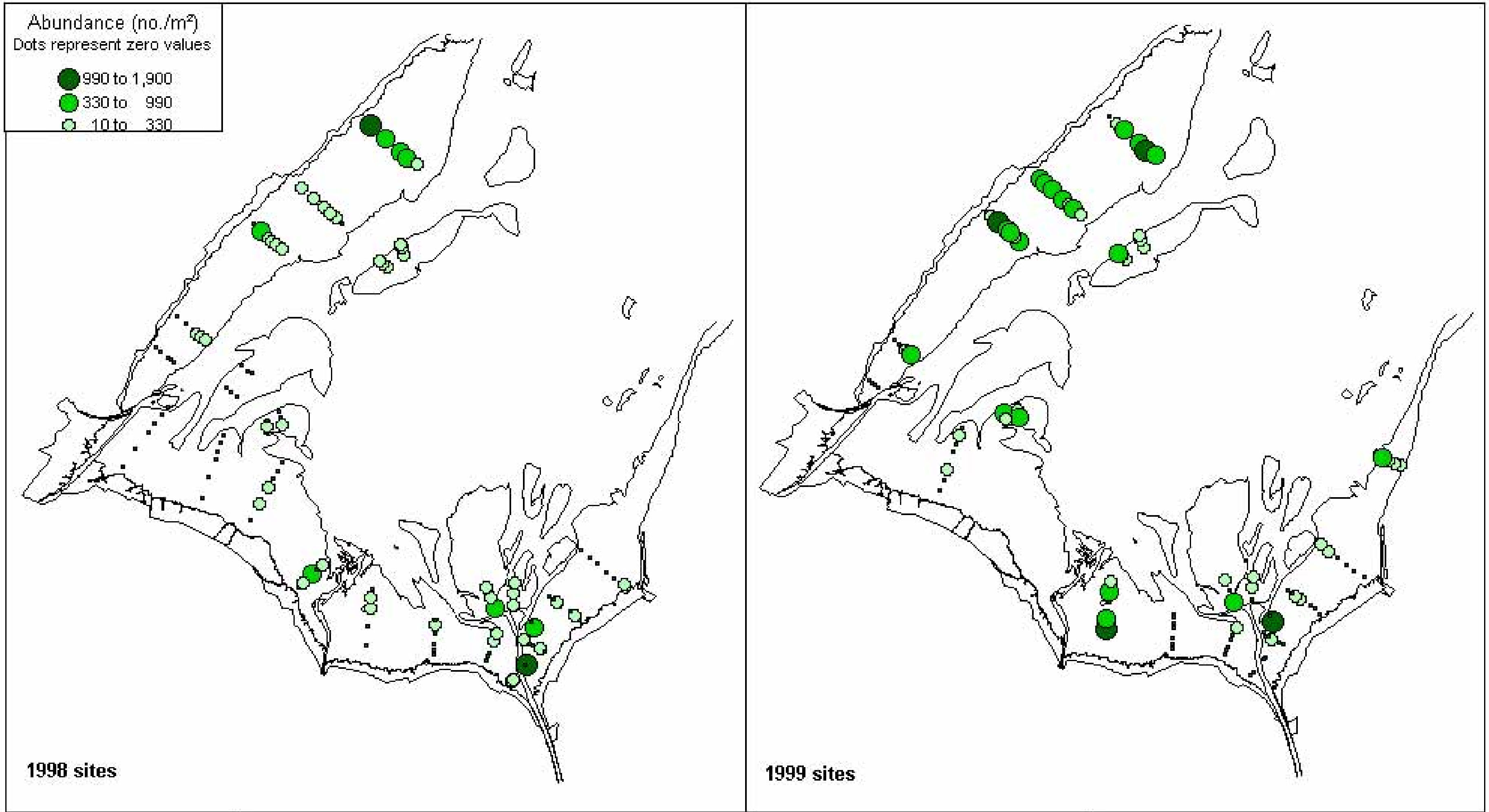

Figure 3.2.7 Spio martinensis distribution 1998 compared to 1999

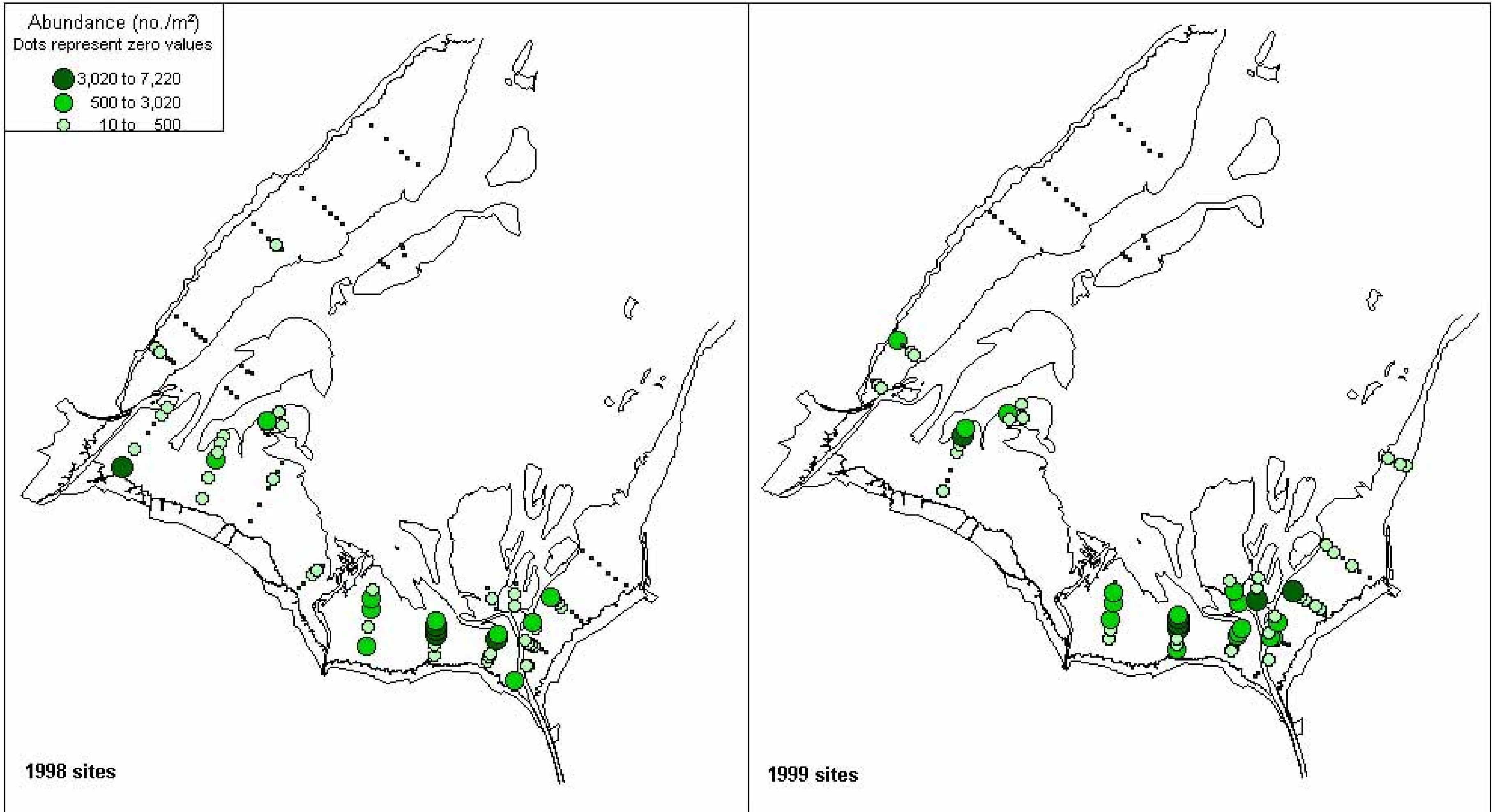

Figure 3.2.8 Cirratulid distribution 1998 compared to 1999

Figure 3.2.9 Capitellid distribution 1998 compared to 1999

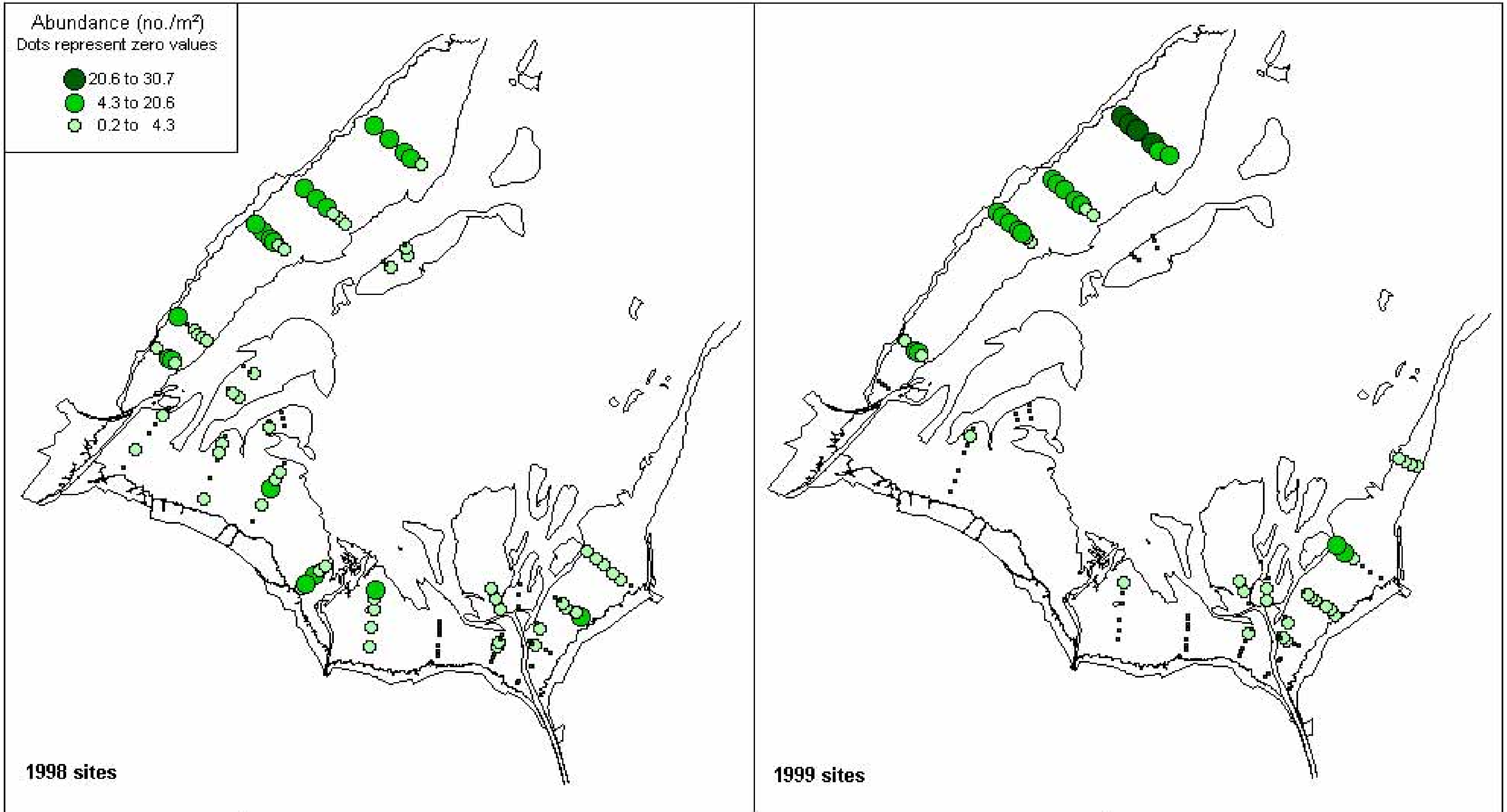

Figure 3.2.10 Arenicola marina distribution 1998 compared to 1999

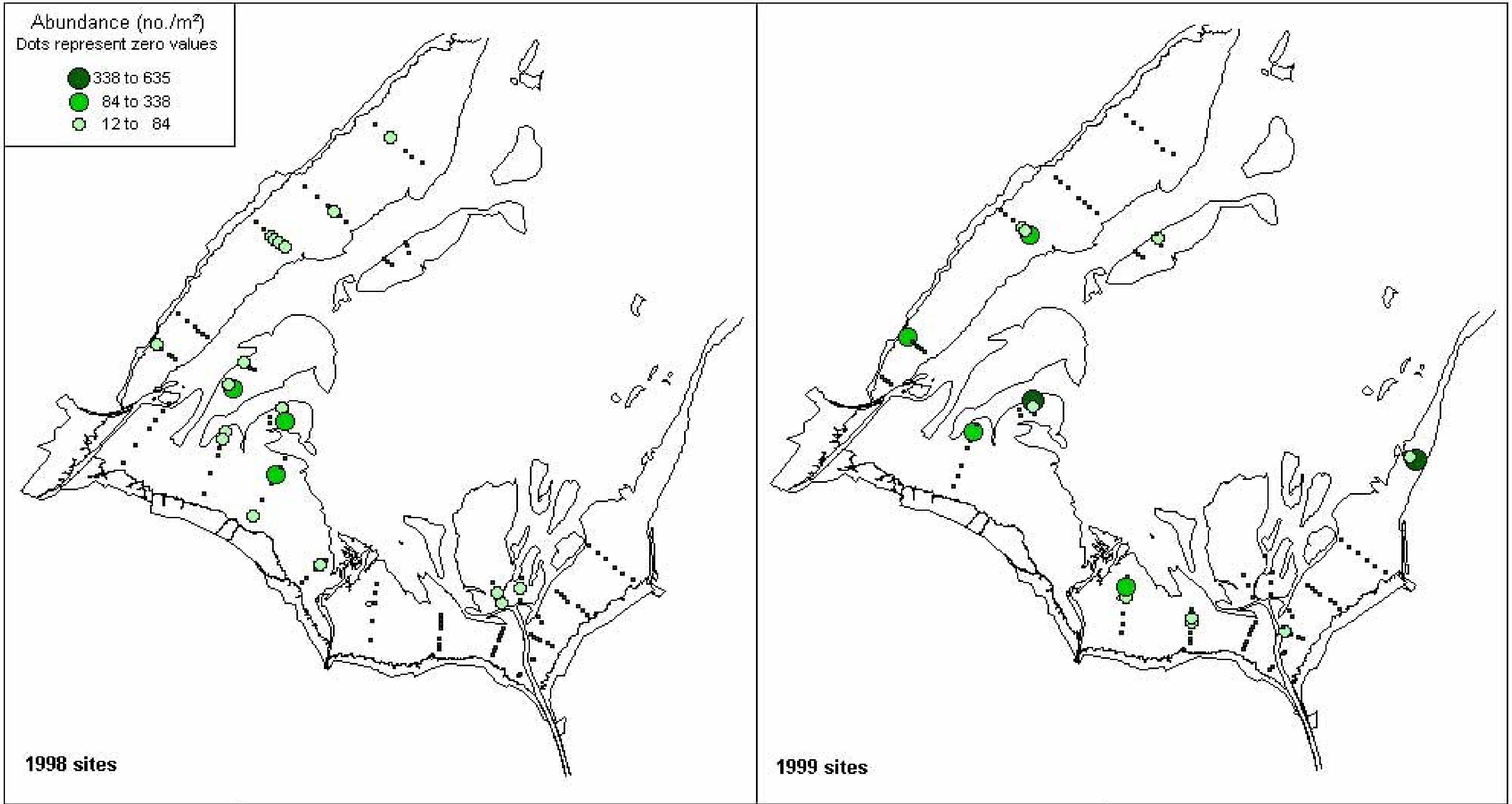

Figure 3.2.11 Lanice conchilega distribution 1998 compared to 1999

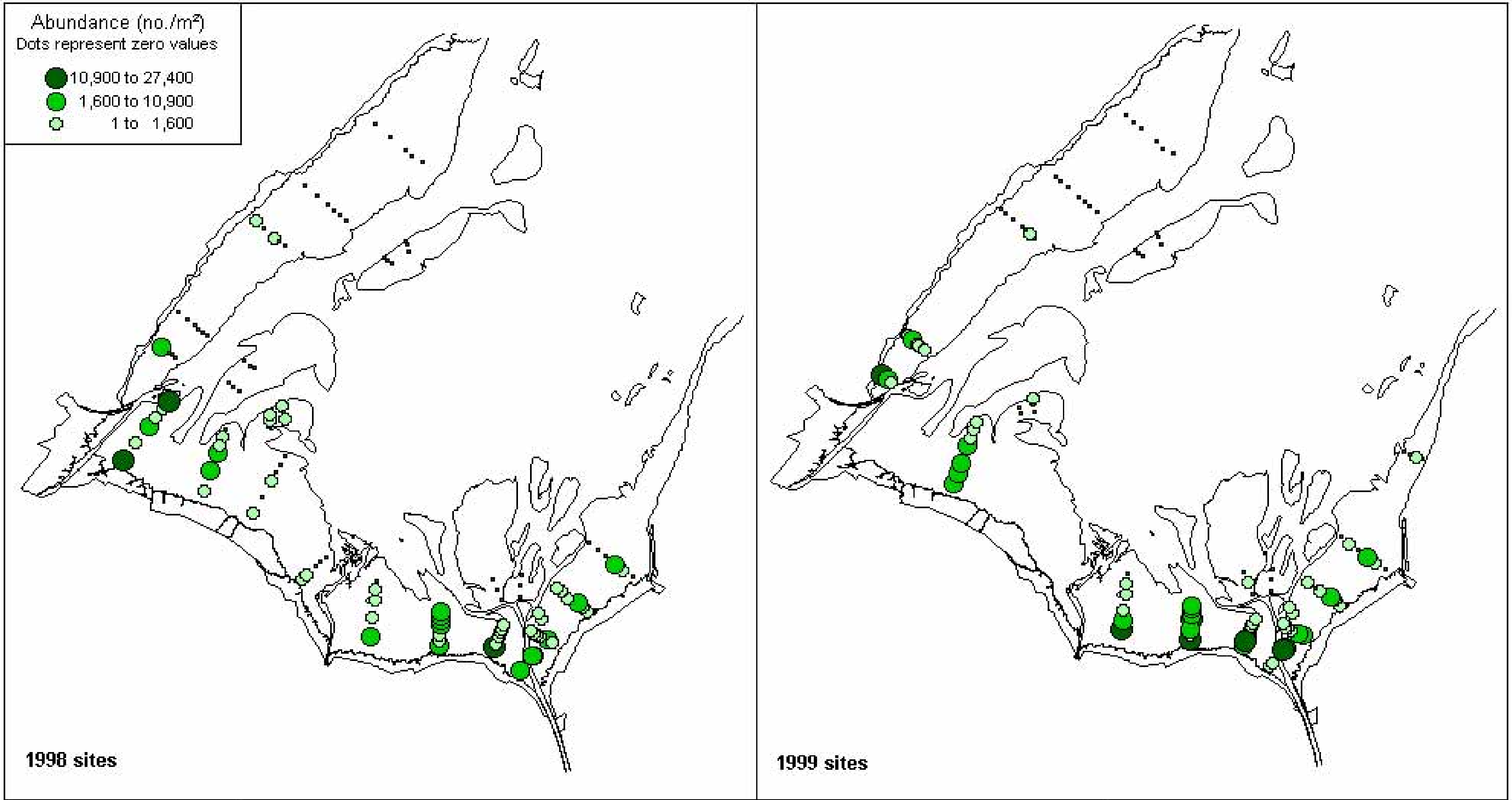

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Figure 3.2.12 Oligochaeta distribution 1998 compared to 1999

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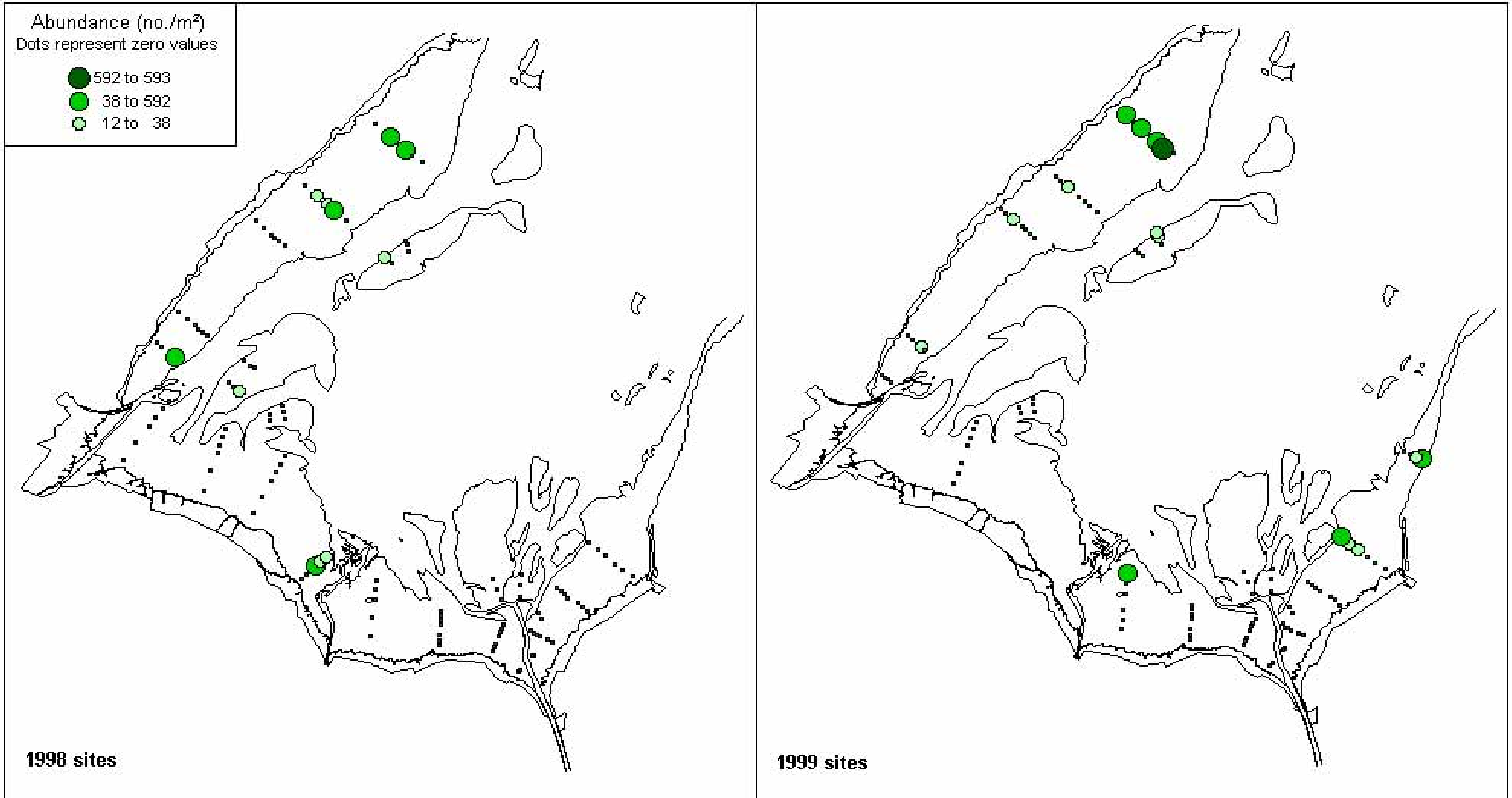

Figure 3.2.13 Urothoe poseidonis distribution 1998 compared to 1999

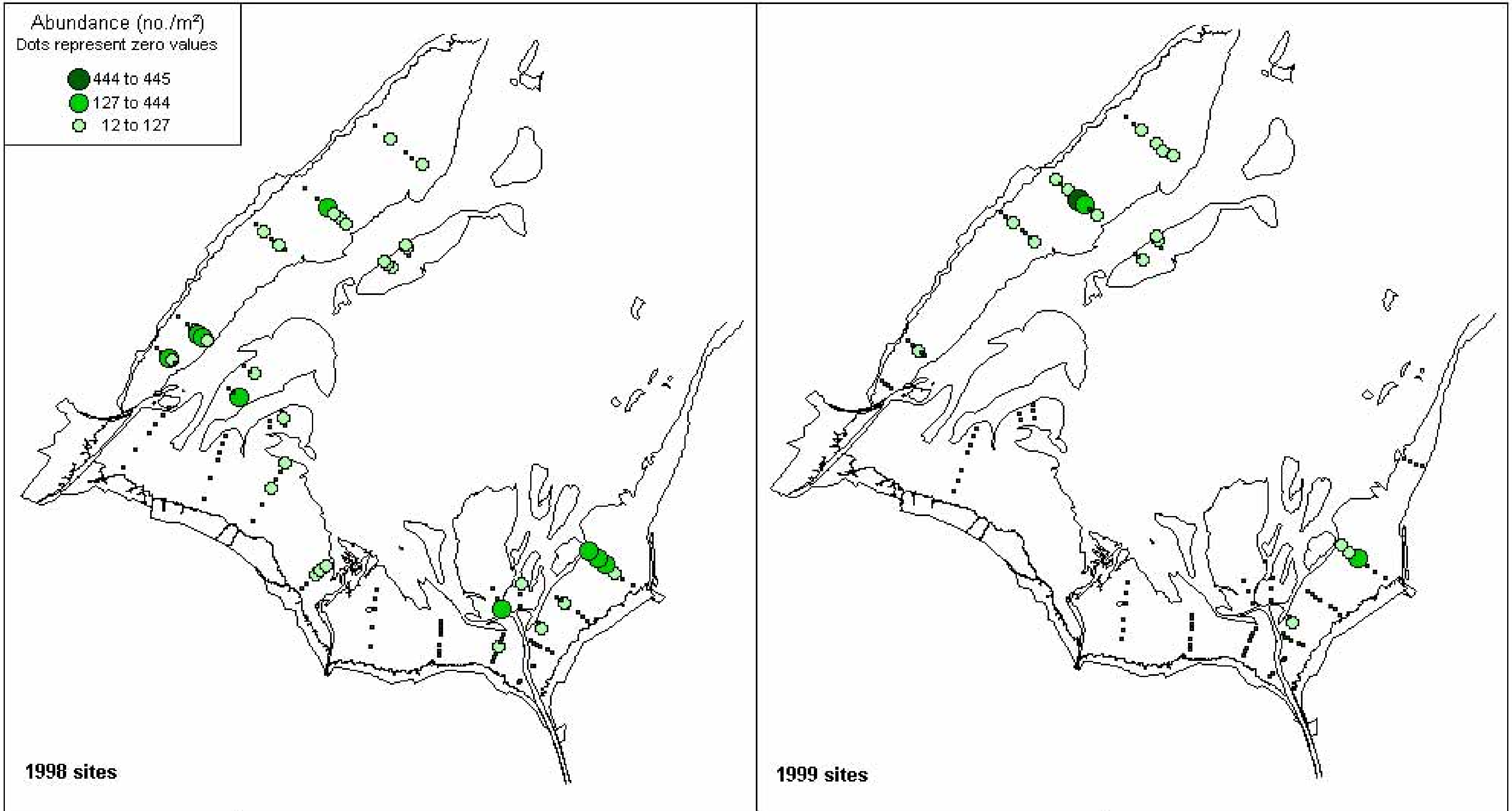

Figure 3.2.14 Bathyporeia species distribution 1998 compared to 1999

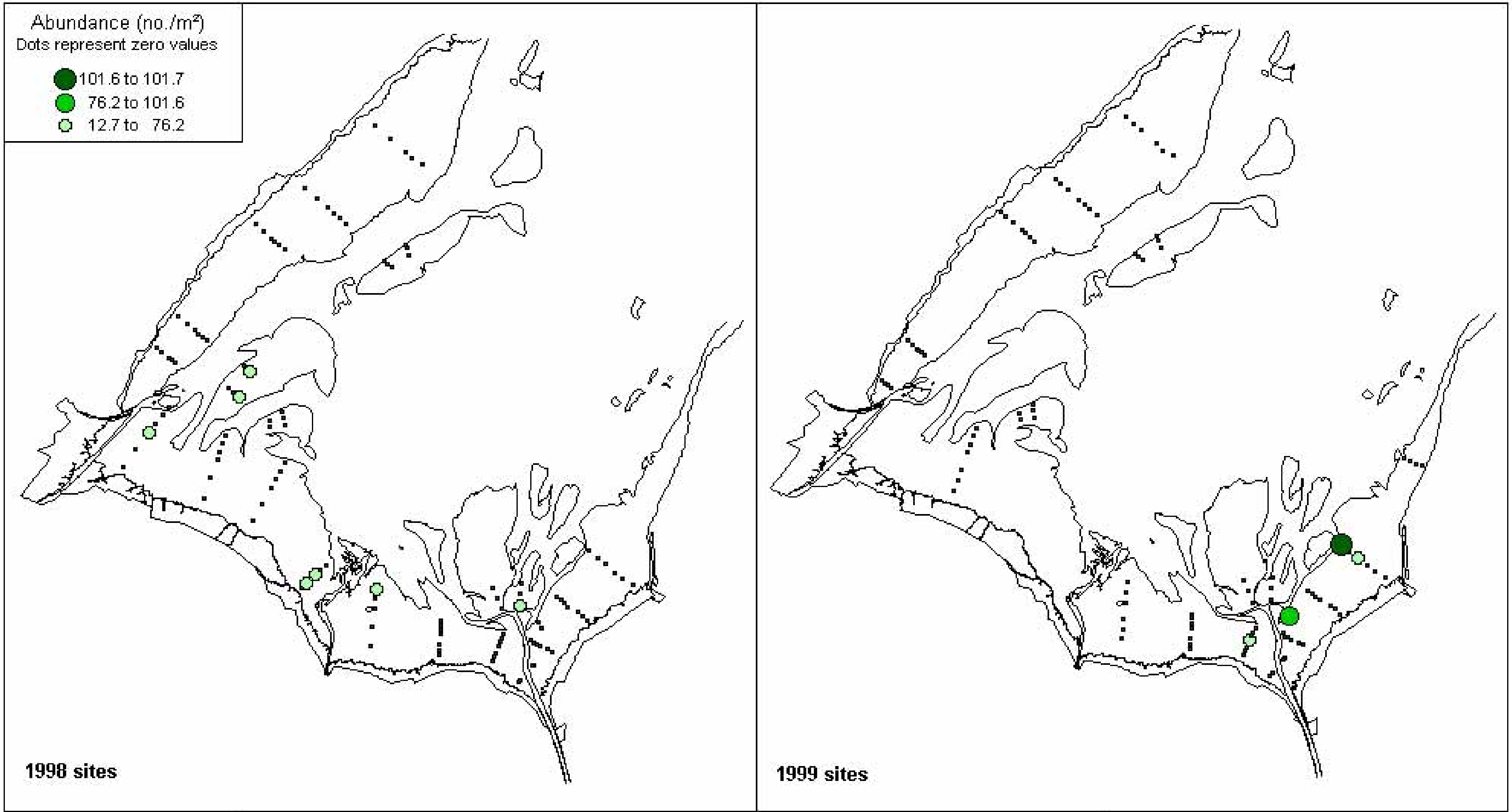

Figure 3.2.15 Corophium arenarium (3+mm) distribution 1998 compared to 1999

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Figure 3.2.16 Corophium volutator (3+mm) distribution 1998 compared to 1999

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Figure 3.2.17 Crangon crangon distribution 1998 compared to 1999

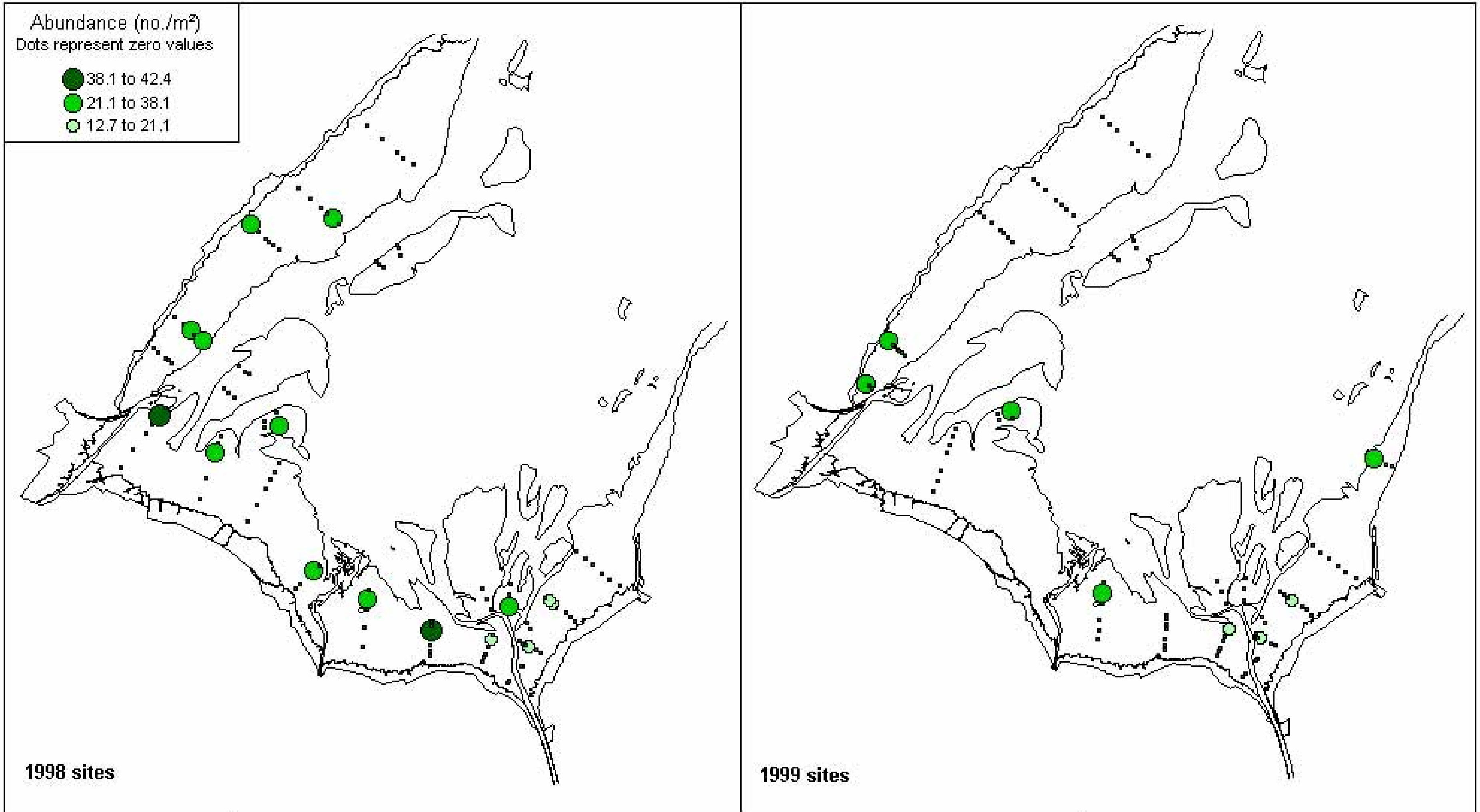

Figure 3.2.18 Carcinus maenas distribution 1998 compared to 1999

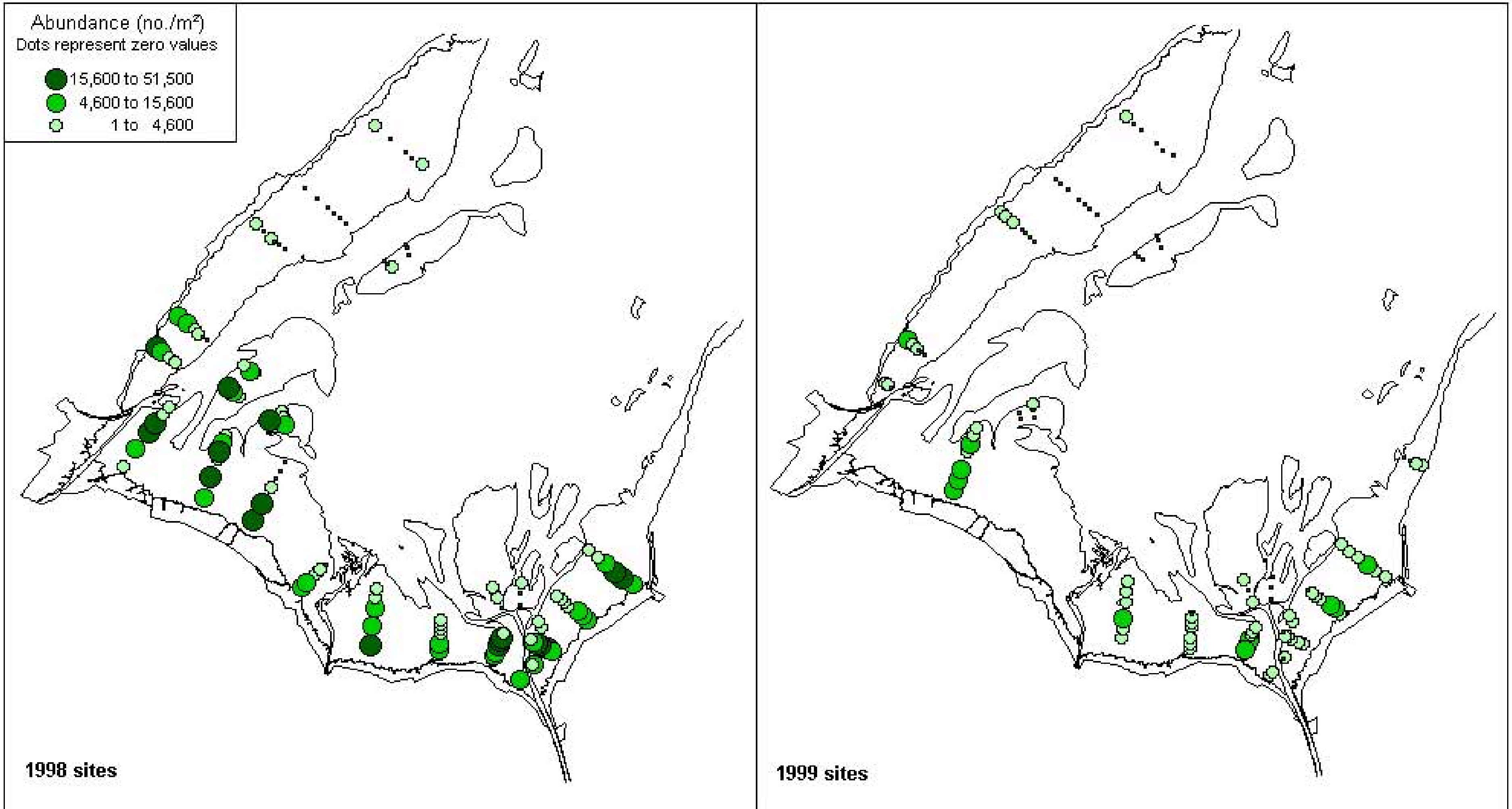

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Figure 3.2.19 Hydrobia ulvae (3+mm) distribution 1998 compared to 1999

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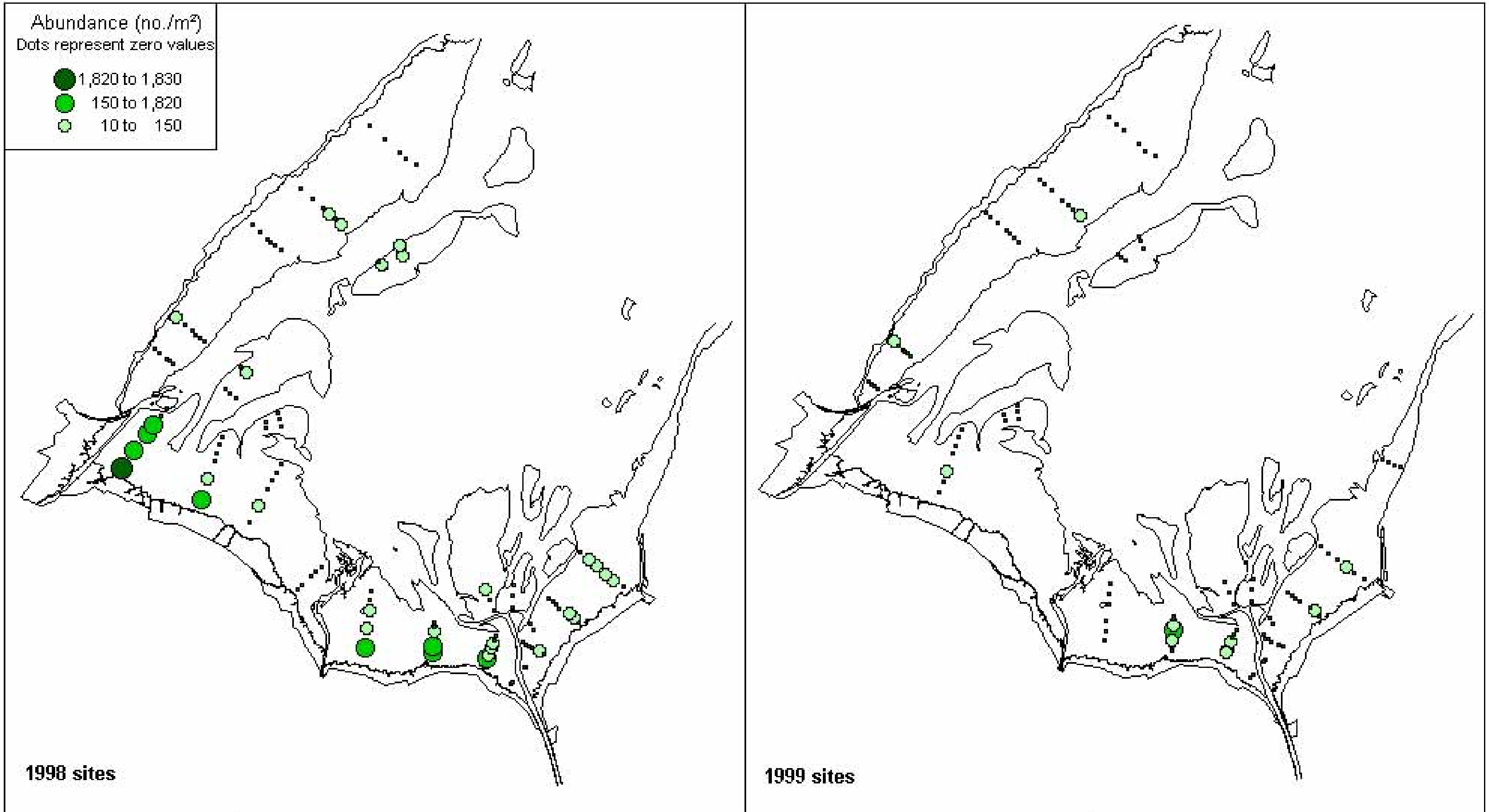

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Figure 3.2.20 Retusa obtusa (3+mm) distribution 1998 compared to 1999

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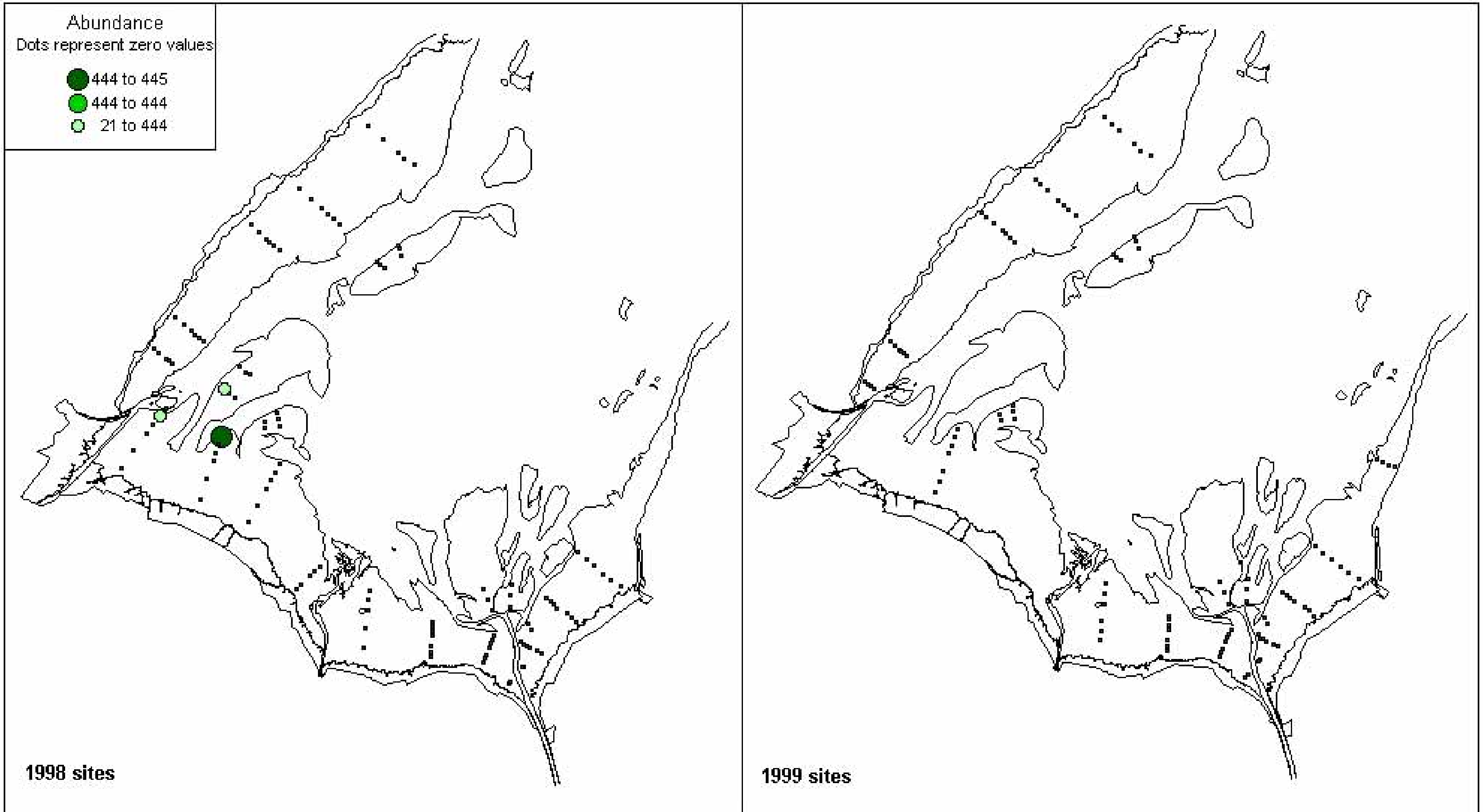

Figure 3.2.21 Mytilus edulis (5+mm) distribution 1998 compared to 1999

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Figure 3.2.22 Cerastoderma edule (4-10mm) distribution 1998 compared to 1999

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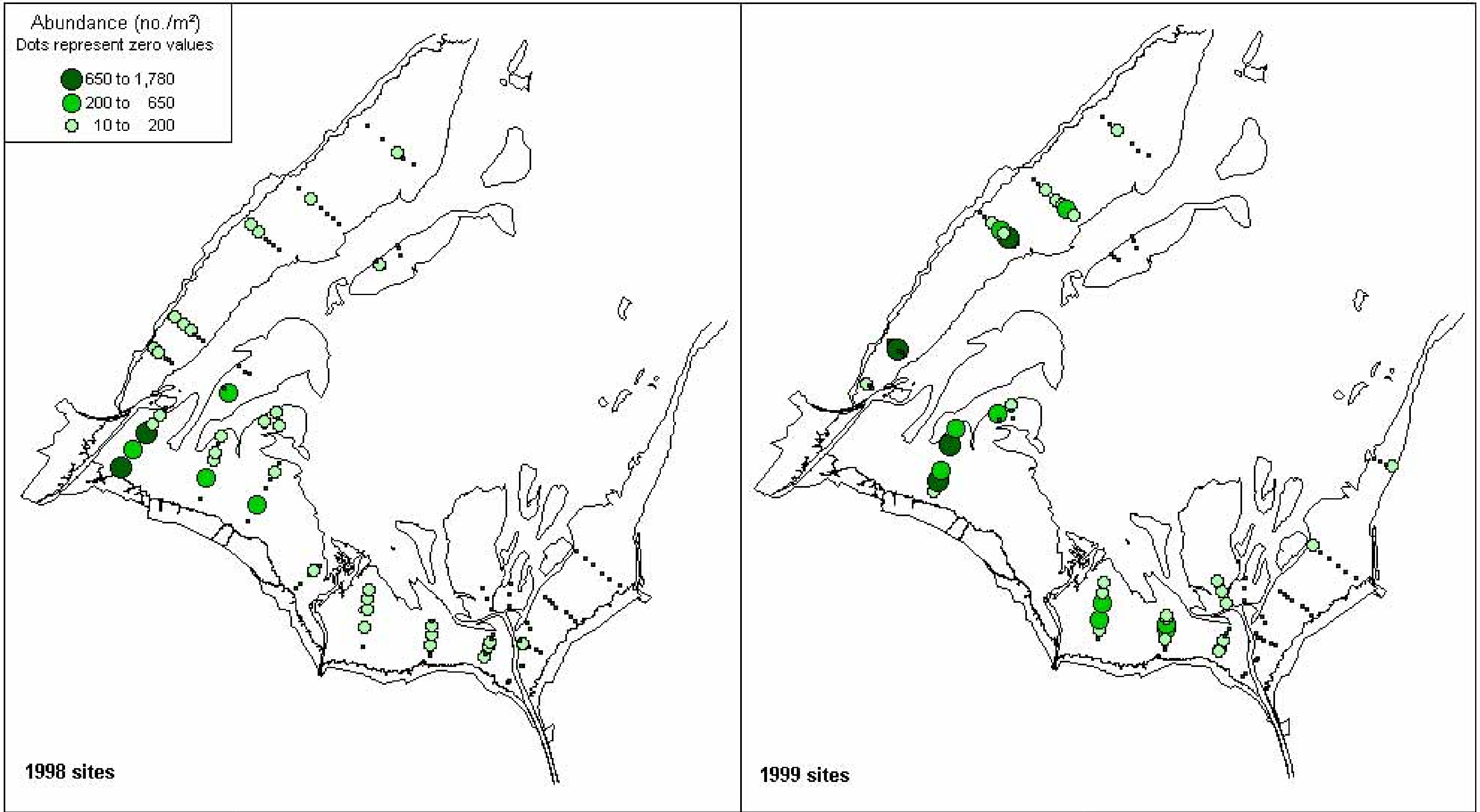

Figure 3.2.23 Cerastoderma edule (16-40mm) distribution 1998 compared to 1999

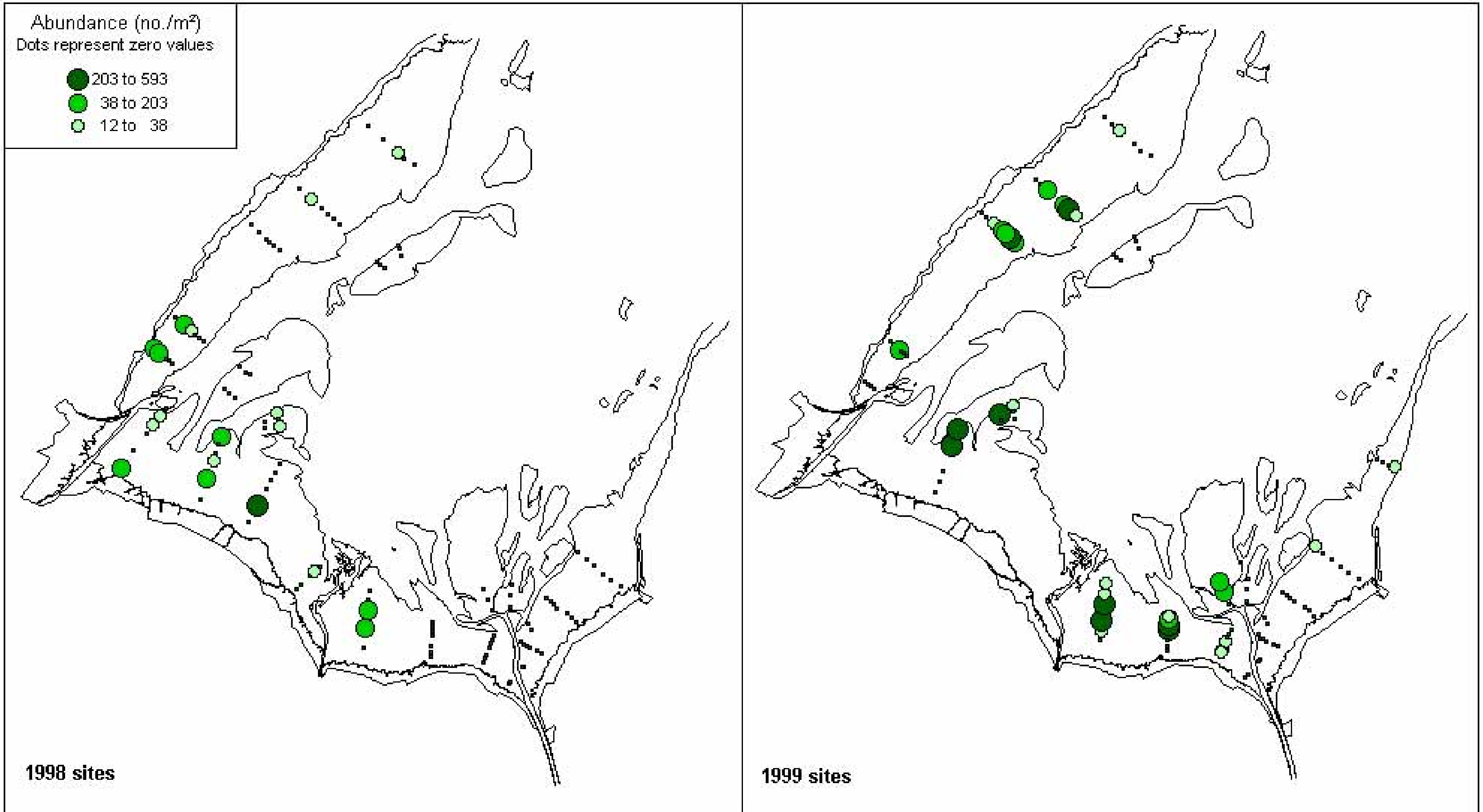

Figure 3.2.24 Cerastoderma edule (20-30mm) distribution 1998 compared to 1999

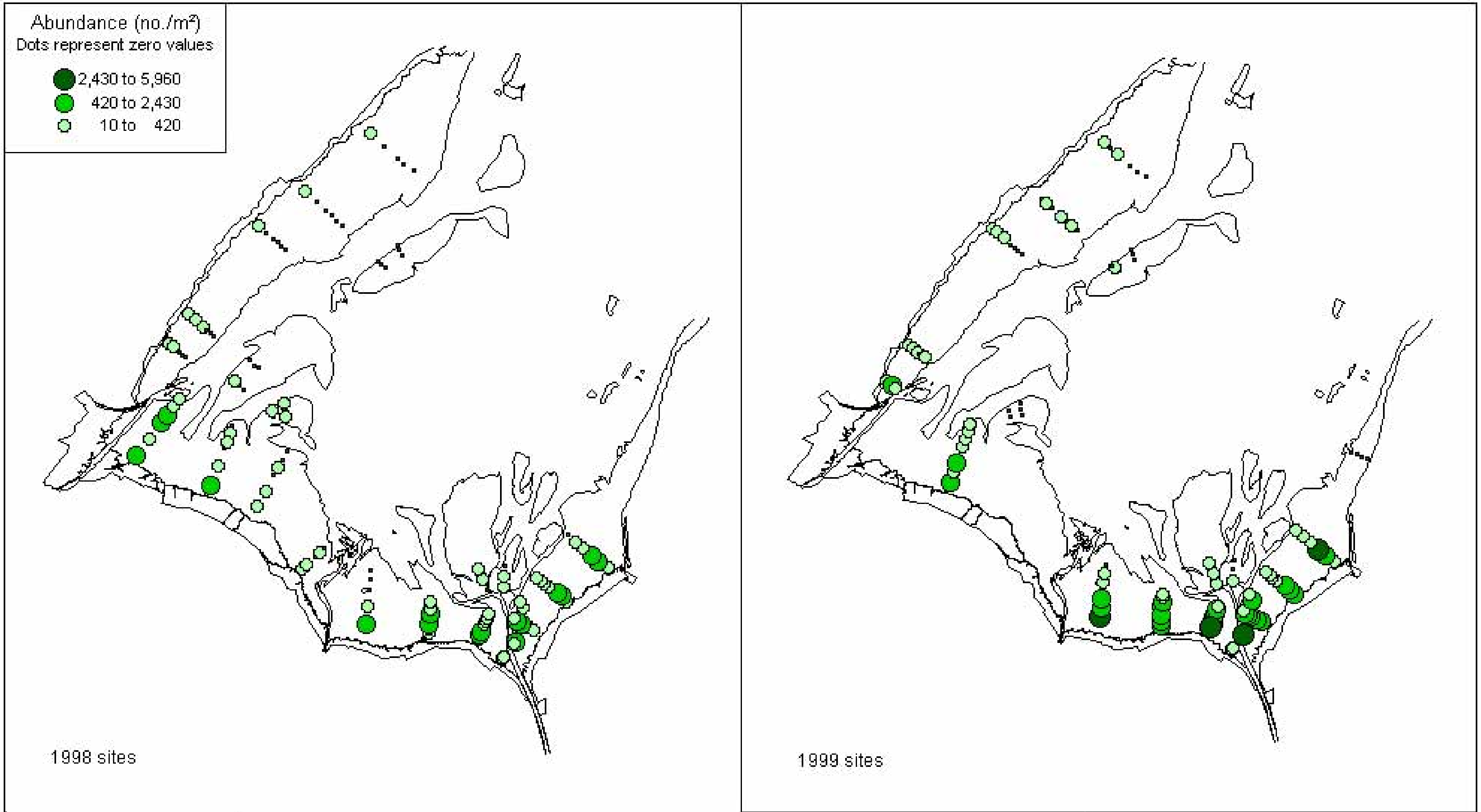

Figure 3.2.25 Macoma balthica (<9mm) distribution 1998 compared to 1999

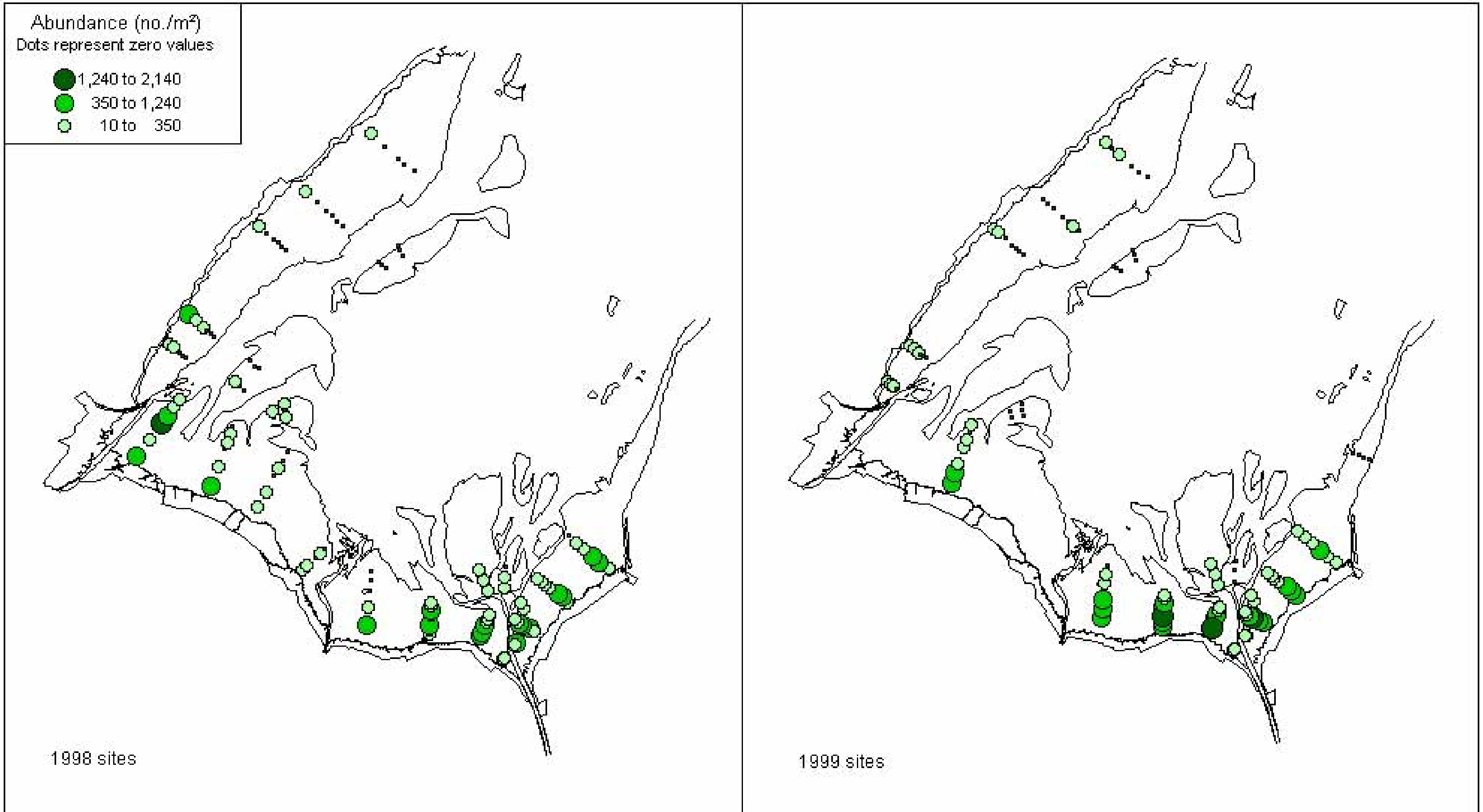

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Figure 3.2.26 Macoma balthica (6-15mm) distribution 1998 compared to 1999

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