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Technical Report **no.130**

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Cefas

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Contents

1. Executive summary

In the year 2000 the UK government commissioned Cefas to undertake a 4-year programme of research designed to investigate the physical and biological 'recovery' of the seabed following cessation of marine aggregate dredging. Work was undertaken at a number of relinquished or fallow extraction areas previously subjected to commercial dredging. This allowed an assessment of whether the previous predictions on rates of recolonisation, largely based on work carried out at experimentally dredged sites, were applicable to commercially exploited sites. Results from this 4-year programme were reported in Boyd *et al.*, (2004) and showed that whilst 'recovery' was identified within areas of 2 of the 4 study sites, the 'recovery' process appeared to be proceeding at a much slower rate than anticipated. As such there was a clear need to extend the programme in order to determine the length of time required for 'recovery'. In 2004 Cefas obtained funds to allow the extension of the existing time-series for a further year through the support of the ALSF (Marine Environmental Protection Fund 04/00) and the Crown Estate. Data from 2004 were added to the existing time series (2001-2003) and an assessment of the status of sites, in terms of progress towards 'recovery' was carried out. The results of this work are described in this report.

During 2004 work was undertaken at the four extraction sites investigated during the initial research programme (see Boyd *et al.*, 2004). These included Area 222 off Felixstowe in the outer Thames Estuary, Area 408 off the Humber estuary and Area X and Area Y off Hastings on the south coast of the England. These sites were purposefully chosen to encompass a range of environmental conditions and dredging practices. They also varied in the times since dredging operations had ceased. This was intended to allow investigation of the different stages of recolonisation. As such this research programme has the potential to provide valuable insights into the 'recovery' process at other extraction sites.

The approach taken in this one year extension follows that of Boyd *et al.*, (2004), with samples taken from within areas of high and lower dredging intensity and compared to samples taken from local reference sites. The specific aim of this 1-year extension was to assess the status of dredged sites in 2004 in terms of progress towards 'recovery'.

Results show that sites can be categorised into three groups. These include sites which have recovered, those where 'recovery' is ongoing and lastly sites where there is, at present, no change.

In 2004, the lower dredging intensity sites within Area 222 and Area X remain substantially recovered, The similar period of time taken for 'recovery' may be explained by the fact that, of all the study sites, Area 222 and Area X have had the longest period for 'recovery' (both sites were last dredged in 1996), both sites have been subject to low levels of dredging intensity and sediments within these areas have both been similar, in terms of particle size composition, to local reference conditions. In contrast sediments within the site of higher dredging intensity at Area 222 were finer than those of the low dredging intensity and reference sites. However sediments within this site have become coarser, possibly as a result of the transport of sands away from the site, and the communities present are becoming increasingly similar to local reference conditions.

Area X high dredging intensity site is also showing signs of progress towards 'recovery' in 2004. Following a five year period of 'recovery' from 1996 to 2001, dredging resumed within this site in 2002 and continued into 2003. However in 2004 the site had not been dredged for 12 months and provided an opportunity to investigate an area in the early phases of recolonisation. In this year large numbers of juvenile *Sabellaria spinulosa* were found in this site. Further work would be required to determine whether these individuals were able to establish themselves.

In contrast to these two sites where 'recovery' has occurred or is ongoing there is less evidence, as yet, for 'recovery' at Area Y. However, this is perhaps not surprising given that this site has had less time to recover. Dredging ceased at Area Y in 2001 and given that 'recovery' took seven years at nearby Area X it is perhaps not surprising that Area Y remains disturbed.

At Area 408 results show very little evidence of progress towards 'recovery' after five years since dredging operations ceased. This appears to be largely a result of sediment differences between dredged and reference sites. Dredged sites have much more surficial sand than the reference sites.

Overall, results from 2004 have confirmed the suspected 'recovery' identified at Area 222 and Area X during 2003. In addition this study has identified possible progress towards 'recovery', not apparent in 2003, within the Area 222 and Area X high dredging intensity sites and also within the Area 408 low dredging intensity site. The extension of this programme of research has shown the importance of time-series to allow quantification of natural variability so as to allow judgements concerning 'recovery' to be made.

This programme of research offers the potential to provide invaluable insights into the ‘recovery’ process at other marine aggregate extraction sites. However this relies on the research being able to answer the question of how long study sites take to recover. At this stage, while significant progress has been made, the question remains unanswered. However, a modest amount of continued monitoring could reveal the answers and this information will be of significant value for the development of models designed to predict ‘recovery’ times.

2. Introduction

2.1 Background

Prior to the year 2000 much of our understanding with regards the physical and biological 'recovery' of the seabed at marine aggregate extraction areas came from a limited number of largely experimental studies where 'recovery' was investigated following 'one-off' dredging events. As a result, judgements concerning 'recovery' times were based on predictions rather than data from areas commercially exploited over many years. Recognising the need to improve understanding, the UK government funded a 4-year programme of research, beginning in 2000, to investigate the status of a number of commercially operated areas, varying in dredging practice, locality and time since dredging operations ceased. Results of this work are described in Boyd *et al.*, (2004). Whilst 'recovery' was identified within sites of low dredging intensity at 2 of the 4 areas studied the process in all other sites was ongoing. As such there was a clear need to continue the work if the fundamental question of "how long do sites take to recover" was to be answered.

In 2004 Cefas obtained funds to allow the extension of the existing time-series for a further year through the support of the ALSF (Marine Environmental Protection Fund 04/00) and the Crown Estate. Data from 2004 were added to the existing time series (2001-2003) and an assessment of the status of sites, in terms of progress towards 'recovery' was carried out. The results of this work are described in this report.

The aim of this one-year study was to assess the status of study sites in 2004, in terms of their progress towards 'recovery'.

In common with other 'recovery' studies it is necessary to consider what is meant by the term ecological 'recovery'. McCauley *et al*. (1977) has argued that the term 'recovery' should be avoided in connection with studies of dredging disturbance, as it implies restoration of functional properties such as benthic production, energy flow to higher trophic levels etc. that may take many years to develop, as well as the return of more measurable variables such as abundance levels. In addition, in cases where the impact of dredging is severe, the final community may never return to the pre-dredging structure and internal integrity although abundance levels may be restored (McCauley *et al.*, 1977). This can occur when dredging results in alterations to the topography or sediment composition, preventing re-establishment of the benthic community as it existed prior to the onset of dredging (Shelton and Rolfe, 1972; van der Veer *et al.*, 1985). Therefore the term 'recovery' needs to be properly defined. For practical purposes, our definition of 'recovery' for this study is the establishment of a community that is virtually indistinguishable (determined using both uni- and multi-variate analysis techniques) from surrounding, non-impacted reference sites. The advantage of this definition and the use of non-impacted reference sites is that the assessment of 'recovery' takes account of any natural variability in community composition. However the approach relies on the chosen reference sites being similar to the dredged seabed, had it not been dredged. Whilst this study deals with 'recovery' of the benthos at marine aggregate extraction sites, a significant body of literature exists in relation to the impacts and subsequent 'recovery' of the seabed following beam trawling (e.g. Duplisea *et al.*, 2002).

2.2 Study sites

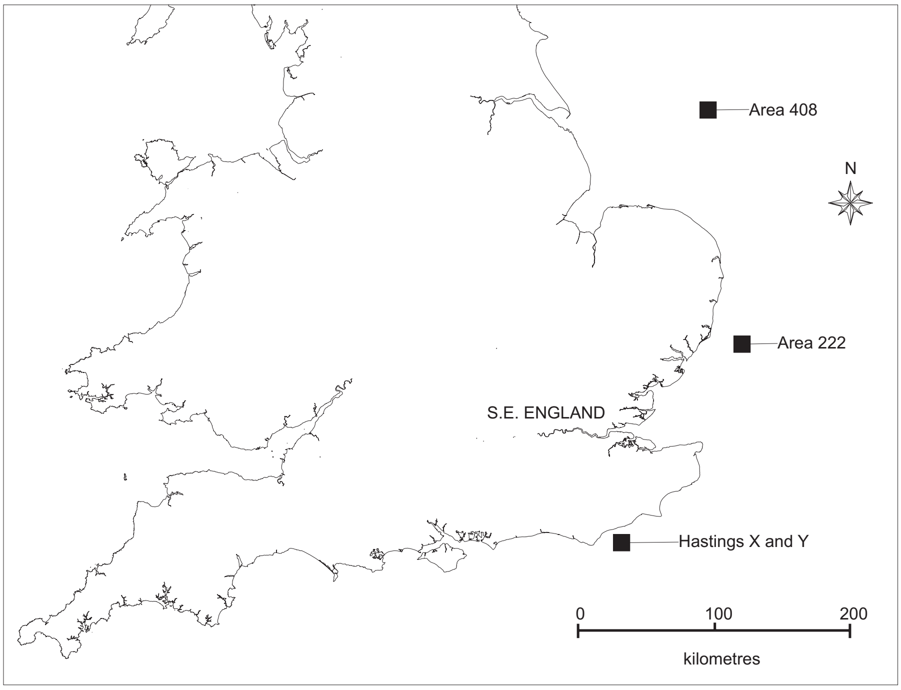
Figure 2.1 shows the location of the four marine aggregate extraction areas where 'recovery' of the seabed is being investigated as part of this research programme. These sites were purposefully chosen to be subject to a range of dredging and environmental conditions and also time since cessation of dredging (see Table 2.1). In this way the results help to provide a better understanding of 'recovery' at other marine aggregate extraction areas, and may be of help in the development of generic models of response.

Two of the study sites are located in the North Sea, one offshore of Felixstowe in the outer Thames region (Area 222) and the other offshore from the Humber estuary (Area 408). Both these extraction areas are isolated from the possible impacts of dredging from other licensed areas. In addition, two extraction areas within the eastern English Channel were targeted for study, both located on the Hastings Shingle Bank (Hastings Areas X and Y). These latter sites were selected on the grounds that both contained similar deposits and biological habitats, but were exposed to different dredging regimes in terms of the frequency and intensity of extraction operations (with the potential to force differing degrees of impact between areas). Detailed information for each area can be found below.

2.2.1 Area 222

Area 222 is located approximately 20 miles east of Felixstowe off the southeast coast of England in water depths of between 27 m and 35 m Lowest Astronomical Tide (LAT). This area, with an overall area of approximately 0.3 km^2, was first licensed for sand and gravel extraction in 1971 with a peak in extraction activity recorded as 872,000 t in 1974. Extraction continued at levels >100,000 t per annum

Figure 2.1. Map showing location of aggregate extraction areas surveyed between 2001 –2004.



until 1995, before the area was relinquished by the industry in 1997. Limited historical information exists on the dredging practices employed at this area, although it is believed that sand:gravel ratios of dredged cargoes were adjusted by screening, with excess sand being discharged overboard at the site of dredging (BMAPA, pers. comm.). It is thought that both trailer suction hopper dredgers and static suction hopper dredgers may have operated at and within the vicinity of the licensed area (BMAPA, pers. comm.). Gravel deposits in this region tend to have a relatively impoverished epifauna dominated by 'resilient' motile species such as hermit crabs and the starfish *Asterias rubens* and with a much reduced sessile faunal component. This is a consequence of the resuspension and scouring action of sands, which are naturally disturbed by peak spring tidal currents in this region. Such communities are characteristically able to tolerate disturbance.

The geology of the area is characterised by an eroded basal unit of London Clay which is overlain by Pleistocene sediment deposited during the drainage of the land surface that existed at the end of the Pleistocene. These sediments were re-worked during the Holocene to form thin (generally <1 m) veneers of gravelly sediments. Thicker deposits of these sediments are present within palaeovalleys (Harrison, 1998). Dredging activity at Area 222 appears to have been concentrated within a thickened section of these sediments that encroaches into the northern part of the area and is also present to the north east of the area (ARC Marine Ltd, 1997).

2.2.2 Area 408

To augment the range of possible dredging scenarios, Zone 2 in Area 408 was selected for this study, since it is representative of a 'fallow' area within a currently zoned licence. Dredging at Zone 2 in Area 408 commenced relatively recently, in 1996, reaching a peak in 1998 with the extraction of 948,459 tonnes of sand and gravel (Newell *et al.*, 2002), but extraction operations were temporarily suspended in this zone from 2000. Zone 2 is located approximately 60 miles east of the Humber estuary and was exploited for marine aggregate using trailer suction hopper dredgers. This zone has an overall area of approximately 2.6 km^2. Water depths range from approximately 20 m to 25 m LAT.

The geological resource targeted within Zone 2 of Area 408 is comprised of a 1-2 m thick discrete lens of gravelly sand, formed as a result of the re-working and winnowing of Pleistocene sediments (Coastline Surveys Europe Limited, 2001). The geological setting of Area 408 is comprehensively described in Coastline Surveys Europe Limited (2002).

In comparison with Area 222, there is a greater volume of historical information on the pattern, duration and intensity of dredging activities at Area 408. Screening of dredged cargoes was routinely carried out at Area 408, with sands being returned to the seabed. Recent work by Coastline Surveys Europe Limited (2002) and by Evans (2002) suggest that marine aggregate extraction and screening activities at this area may contribute to the deposition of well-sorted fine sands which may subsequently be transported distances up to at least 2000 metres to the south east. Deposits located at Area 408 are characterised by opportunistic polychaete worms and crustacea (Newell *et al.*, 2002). Such species would be expected to rapidly recolonize sediments following the cessation of dredging.

Areas 408 and 222 are located off the east coast of England where aggregate deposits are present as relatively thin layers. Such deposits are typically dredged using trailer

Table 2.1. Main characteristics of the extraction areas studied as part of this research programme.

Parameter	Area 222	Hastings Area X	Hastings Area Y	Area 408 (Zone 2)
Geographic location of study site	20 miles east of Felixstowe, southern North Sea	Hastings Shingle Bank, 6 miles south of Hastings, eastern English Channel	Hastings Shingle Bank, 6 miles south of Hastings, eastern English Channel	60 miles east of Humber Estuary, North Sea
Size of licensed area	0.3 km^2	1.35 km^2 (prior to 2001)	3.1 km^2 (prior to 2001)	2.6 km^2
Total quantities extracted over lifetime of dredging activity	10.2 Mt. Unknown proportion of this extracted from outside licensed area	The only dredging campaign prior to 2002 was in 1996, when 1.3 Mt was extracted	Total of 16 Mt extracted during annual campaigns between 1988 and 2000	1.5 Mt in annual campaigns between 1996 and 1999
Lifetime of dredging activity	1971-1996	Dredged during 1996, extraction resumed during 2002	1988-2000	1996-1999
Maximum hours of dredging per year in hours, in the high dredging intensity box recorded in 100 m by 100 m area (since 1993)	39.5	28.5	10.25	14.25
Type of dredger employed	Static suction hopper dredger and trailer suction hopper dredgers	Trailer suction hopper dredgers	Trailer suction hopper dredgers	Trailer suction hopper dredgers
Screening	There is limited information from historical records, although it is probable that screening occurred at this site	All-in cargoes	All-in cargoes	Sand returned to seabed as screened material
Water Depth	27-35 m	15-21 m	16-25 m	20-25 m
Geological provenance of the resource	Localised thickened layer of reworked lag deposits ~3 m thick	Infilled palaeovalley >10 m thick	Infilled palaeovalley >10 m thick	Reworked lag sediments in localised lens ~1-2 m thick
Maximum tidal velocity	2.3 kn (1.17 m s^{-1})	2.6 kn (1.32 m s^{-1})	2.6 kn (1.32 m s^{-1})	1.4 kn (0.71 m s^{-1})

suction hopper dredgers, with the cargoes being screened and sands being the main sediment fraction which are returned to the seabed. The thickness of the worked layer in these areas is normally of the order of a few metres, although localised deposits of considerable thickness do exist in these regions. In contrast, extraction licences on the south coast of England tend to exploit discrete deeper deposits of coarser aggregate. The cargoes dredged from such areas are typically ‘all-in’ (i.e. the dredged material is retained entire). Therefore, to account for some of the dredging practices employed on the south coast, two areas (Hastings Area X and Y) on the Hastings Shingle Bank were targeted for study.

2.2.3 Hastings Areas X and Y

The Hastings Shingle Bank forms a distinctive topographic feature aligned in an ENE - WSW direction at water depths of between 16 m and 25 m LAT (EMU, 1999). The outline of Area X, prior to the introduction of the new licence boundary in 2001, formed an irregular polygon with a total area of 1.35 km^2. Area Y also had an irregular outline and a total licensed area of 3.1 km^2. The aggregate resources that are present in sub-areas X and Y are associated with infilled palaeovalleys which meander over the Hastings Shingle Bank and are truncated at their southern extent. These palaeovalleys are characteristically infilled with deposits of sandy gravel up to 15 m thick and 500 m wide (Evans, 1998; EMU, 1999) and it is these localised resources that are targeted by the industry. Extraction of marine aggregate has been licensed on the Hastings Shingle Bank since 1988. Since then, there have been numerous alterations to the boundaries of the extraction licences on the Bank. Dredging licences at sub-areas X and Y were both relinquished in 2001 and replaced by a new licence in the same year. Although this new licence encompassed parts of the old sub-areas X and Y, areas of the seabed from both these relinquished areas lie outside of the new licence boundaries. This presented the opportunity to investigate benthic recolonization in two disused areas of the bank. Despite the location of two sub-areas X and Y within close geographical proximity, they have very different extraction histories. Sub-area Y was actively dredged between 1988 and 2001, with extraction activity at its peak between 1996-1998. Over 7 million tonnes of material was removed during this period. However, at sub-area X, dredging was only carried out in 1996 and again in 2002. Cargoes were 'all in' at both these sites i.e. no screening activity was undertaken.

Historical studies of the benthic fauna in the Hastings region have been conducted to address monitoring conditions associated with dredging licences (Kenny, 1998; EMU, 1999), and as part of R&D programmes (Kenny *et al.*, 1991; Brown *et al.*, 2001,2004; Hewer *et al.*, 2002; Foster-Smith *et al.*, 2004). R&D investigations were also conducted prior to the commencement of dredging operations and therefore provide a useful baseline (Shelton and Rolfe, 1972; Rees, 1987) against which later studies can be judged. A range of sampling techniques have been employed in such studies including conventional approaches such as grabs, dredges and divers or remote methods such as video, sidescan sonar and Acoustic Ground Discrimination Systems. A significant feature of all these studies is the reported range and diversity of macrobenthic species encountered within undredged gravel deposits on the Hastings Shingle Bank. For example, gravel substrates within the undredged parts of the Hastings Shingle Bank are characterised by a range of epifaunal species including the soft coral, dead man's fingers (*Alcyonium digitatum*), the sea urchin *Psammechinus miliaris*, the sea anemone *Metridium senile*, the hydroid *Sertularia*, the serpulid polychete *Pomatoceros triqueter* and the encrusting bryozoan *Schizomavella* (Brown *et al.*, 2001, 2004; Hewer *et al.*, 2002). In contrast, dredged deposits in this region are reported to be sandier and support a more limited range of sessile epifaunal species compared to elsewhere on the Hastings Shingle Bank (Brown *et al.*, 2001; 2004; Hewer *et al.*, 2002).

Whilst the differing dredging histories (in terms of the rate of extraction, particular dredging practices and intensity of extraction etc) complicate a direct geographic comparison of effects, the four selected sites account for some of the current and historic dredging practices employed in English waters and are representative of several habitats where dredging is occurring. However, it was not within the scope of the project to account for all combinations of dredging scenarios practiced in the UK across the full range of habitats currently exploited for marine aggregate. Nevertheless it is hoped that data arising from this study will provide the means to make inferences to other areas and improve the predictive capability with regard to the environmental effects of dredging activity, whether recently ceased, ongoing or planned.

3. Methods

3.1 Sampling design

Since 1993, every vessel dredging on a Crown Estate licence in the UK has been fitted with an Electronic Monitoring System (EMS). It consists of a PC electronically linked to a Global Positioning System (GPS) and one or more dredging status indicators. This automatically records the date, time and position of all dredging activity, every 30 seconds, to disk. EMS information was interrogated in order to locate areas of the seabed within the extraction licences which had been subjected to different levels of dredging intensity. Limited records exist on the level of the dredging intensity that these locations were subjected to prior to the introduction of the EMS in 1993. Stations were randomly distributed within each treatment site ('stratified random sampling') and allocated in proportion to the size of the sampling box. Replicate samples were also collected from nearby reference sites, which were considered to be representative of the wider environment surrounding the extraction licences and outside of the influence of any potential effects on the benthos from aggregate extraction.

Selection of appropriate reference sites was aided by the use of sidescan sonar and video images of the seabed (see below for methodology) and following criteria given in Anon (1997) and Boyd (2002). Data arising from this design provide a comparative evaluation of 'treatment' and 'reference' sites. In this way, the outcome of survey work can be used to test whether there are differences in the structure of macrobenthic communities from reference sites compared with sites that have previously been exposed to different levels of dredging intensity. Note that the 'reference' sites are not considered representative of baseline conditions, as there was insufficient information on which to determine what actually constitutes the likely predredging status of an area.

Figure 3.1. A 0.1 m^2 Hamon grab with attached video camera supported on an open frame to facilitate retrieval of the sample into a moveable container following controlled release from the grab bucket.

3.2 Sample collection

Sample collection followed the methodology given in Boyd (2002). Samples for analysis of the macrobenthic fauna and sediment particle size were collected with a 0.1 m^2 Hamon grab (Figure 3.1) from *RV Cirolana* in 2001- 2002 and from *RV Cefas Endeavour* (Figure 3.2) in 2003 - 2004.

All locations were sampled at the same time of year between May and July. Replicate samples were collected from areas of the seabed that had been identified from EMS as being of high and lower dredging intensity. Replicate samples were also collected from nearby reference sites.

Following estimation of sample volume, a 500 ml subsample was removed for laboratory particle size analysis. The whole sample was then washed over 5 mm and 1 mm square mesh sieves to remove the fine sediment. The two resultant fractions (1-5 mm and >5 mm) were back-washed into separate containers and fixed in 4-6% buffered Formaldehyde solution (diluted in seawater).

3.3 Acoustic and video surveys

Sidescan sonar surveys were undertaken using the Datasonics™ SIS 1500 digital chirp system (Figure 3.3) using the Triton Isis™ data acquisition software. The Delphwin™ software package was used to postprocess the data, and provided georeferenced mosaiced images of the sonar data. Such surveys were undertaken in order to provide an indication of the spatial distribution

Figure 3.2. *RV Cefas Endeavour.*

Figure 3.3. Digital sidescan sonar towfish.

of sediments in the wider area encompassing the dredged sites and to estimate the spatial extent of both direct and indirect effects of dredging. Furthermore, the sidescan sonar surveys provide information on the distribution and stability of bedforms.

Where conditions allowed, photographic surveys using underwater video and stills techniques were conducted using a Simrad™ video camera and a Benthos DSC™ 4000 digital stills camera mounted within a robust metal frame. These surveys were used to obtain additional groundtruth information on the physical and biological status of the seabed. The camera frame was lowered close to the seabed as the vessel drifted with the tide. Video images were recorded automatically onto both high-resolution SVHS and digital tapes.

Multibeam surveys were carried out using a dual head, hull mounted, Kongsberg Simrad EM 3000D high resolution multibeam sonar. The data were corrected in real time for vessel movements using a Simrad motion reference unit (MRU5). Soundings were acquired using TEI Inc, Triton Isis™ software and data were tidally corrected and gridded using the TEI Inc, Bathypro™ processing package. The data was presented using TEI Inc, Delphmap™ software. Given the depths of water encountered, multibeam swath widths were typically half of the sidescan sonar swath widths.

3.4 Macrofaunal sample processing

Macrofauna samples were processed according to the guidelines given in Boyd (2002). The >5 mm sample fraction was first washed with fresh water over a 1 mm mesh sieve in a fume cupboard to remove excess Formaldehyde solution, then back-washed onto a plastic sorting tray. Specimens were removed and placed into labelled glass jars containing a preservative of 70% Industrial Methylated Spirits. Specimens were identified, where possible, to species level. The 1-5 mm fraction was first washed over a 1 mm sieve then backwashed into a 10 litre bucket. The bucket was filled with fresh water and the sample was then gently stirred in order to separate the animals from the sediment. Once the animals were in suspension, the sample was decanted over a 1 mm mesh sieve. This process was repeated until no more material was recovered. Specimens from this fraction were placed into labelled petri-dishes for identification and enumeration. The sediment was then placed on plastic trays and examined under an illuminated magnifier for any remaining animals, such as bivalves, not recovered in the decanting process, which were then added to the petri-dishes. The blotted wet weight (in milligrams) for each species, from replicate samples, was also recorded.

3.5 Sediment particle size analysis

The sediment sub-samples from each grab were analysed for their particle size distributions. Samples were first wet-sieved on a 500 µm stainless steel test sieve using a sieve shaker. The <500 µm sediment fraction passing through the sieve was allowed to settle from suspension in a container for 48 h. The supernatant was then removed using a vacuum pump and the remaining <500 µm sediment fraction was washed into a petri-dish, frozen for 12 h and freeze-dried. The total weight of the freeze-dried fraction was recorded. A sub-sample of the <500 µm fraction was then analysed using a laser sizer. The >500 µm fraction was washed from the test sieve into a foil tray and oven dried at ~ 90°C for 24 h. It was then dry sieved on a range of stainless steel test sieves, placed at 0.5 phi intervals, down to 1 phi (500 µm). The sediment on each sieve was weighed to 0.01 g and the values recorded. The results from these analyses were combined to give a full particle size distribution for each sample.

3.6 Data analyses

The particular data analyses chosen were designed to answer 2 basic questions. Firstly, whether there were statistically significant differences between the dredged and reference locations and secondly if so, whether there was any evidence of a trend towards increasing similarity over time.

3.6.1 Sediment variables

Particle size data have been presented to show annual comparisons of mean particle size composition of sediments (major sediment classes) taken from the high, low and reference sites.

3.6.2 Macrofaunal assemblage structure

Univariate analyses

Ash free dry weights (AFDW) were calculated using standard conversion factors (Ricciardi and Bourget, 1998). The univariate measures, total abundance (N), numbers of macrofaunal species (S) and biomass (AFDW) were calculated. This allows a visual interpretation of any trends (e.g. increasing or decreasing abundance at different sampling locations and over time) and their statistical significance, whereas this judgement is more difficult for results obtained by multivariate data analyses. The significance of differences between treatments was tested using one-way ANOVA.

Multivariate analyses

Non-parametric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure (Bray and Curtis, 1957) was applied to species abundance data. Initially, the overall similarity between every pair of samples is calculated taking all the species into consideration. The samples are then plotted in such a way that distances between pairs of samples reflect their relative dissimilarity in species composition. The MDS ordination can therefore be used to identify groups of samples having similar faunal assemblages. A stress value gives an indication of how well the two-dimensional plot represents the multi-dimensional sample relationship. Values between 0.05 and 0.2 generally correspond to a good representation of sample similarities (Clarke and Warwick, 1994).

Analysis of similarities (ANOSIM, Clarke, 1993) was performed to test the significance of differences in macrofauna assemblage composition between samples. The ANOSIM 'R' value provides a measure of the difference between groups of samples and ranges from 0 (similarities within and between sites the same. i.e. not different) to 1 (replicates within sites more similar to each other than any replicates from different sites. i.e. sites different). The nature of the community groupings identified in the MDS ordinations was explored further by applying the similarity percentages program (SIMPER) to determine the contribution of individual species to the average dissimilarity between samples.

All multivariate analyses were performed using the software package PRIMER v. 6 Beta, developed at the Plymouth Marine Laboratory (Clarke and Gorley, 2001).

4. Temporal investigations of the physical and biological status of Area 222

4.1 Methods

4.1.1 Study site

The study site (designated 'Area 222') is located approximately 20 miles east of Felixstowe off the southeast coast of England (Figure 4.1) in water depths of between 27 m and 35 m LAT. The tidal ellipse in the region is rectilinear and is aligned in a NNE - SSW direction. The predicted net bed sediment transport direction in the area is to the north east (HR Wallingford, 2002). The dredging history and geological setting of the site are described in Section 2.

4.1.2 Sampling design

Area 222 was not dredged in the 5 years prior to sampling (Figure 4.2). Sampling was conducted in July 2001-2004, i.e. 5, 6, 7 and 8 years after the cessation of dredging. Historical information (from 1993 onwards) on the location and intensity of dredging was used to direct sampling. Replicate samples of the macrofauna and sediments were collected from sites representing 2 different levels of dredging intensity: 1) >10 hours of dredging within a 100 m by 100 m block during 1995 and 2) <1 hour of dredging within a 100 m by 100 m block during 1995 (Figure 4.3). In addition, two reference sites (Reference site 1 and 2) were sampled in 2001-2004.

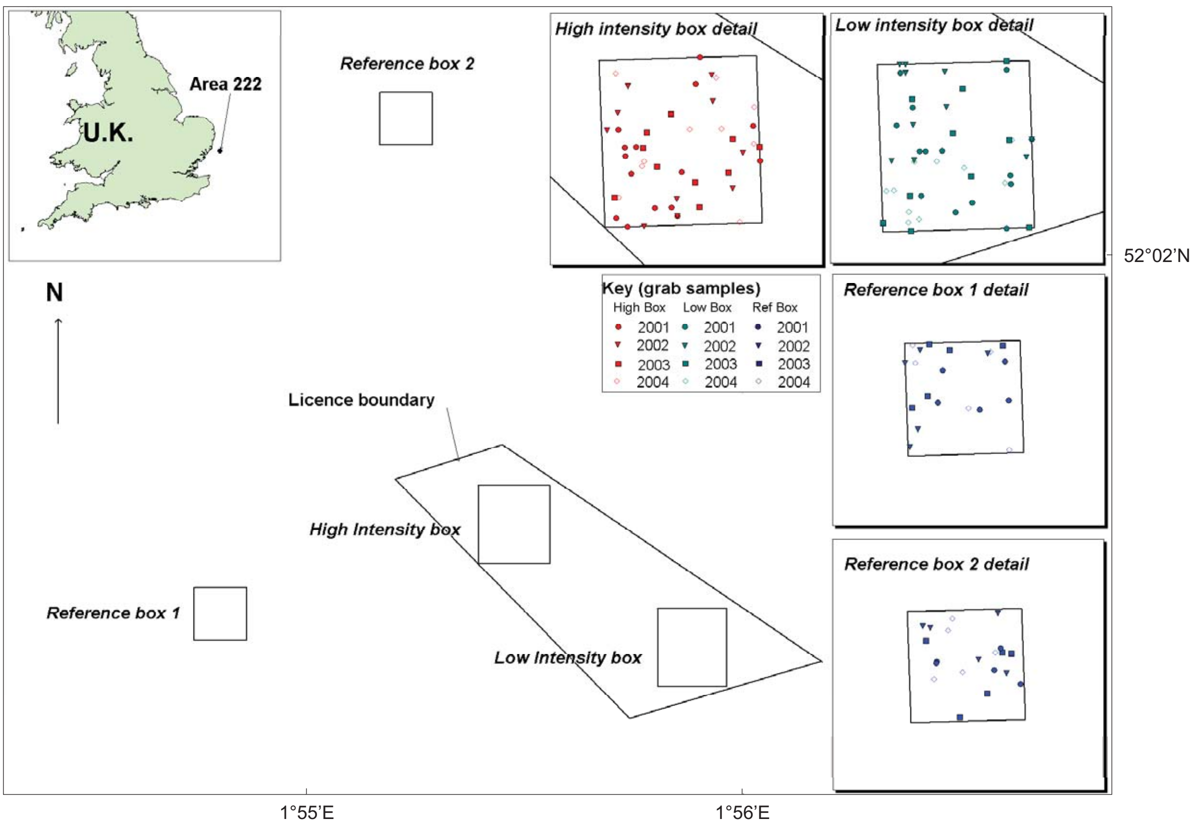


Figure 4.1. Map showing the location of Area 222 aggregate extraction licence and sampled stations from the surveys carried out in 2000-2003.

Figure 4.2. Annual quantity of aggregate extracted from Area 222 over the period 1972-1996.

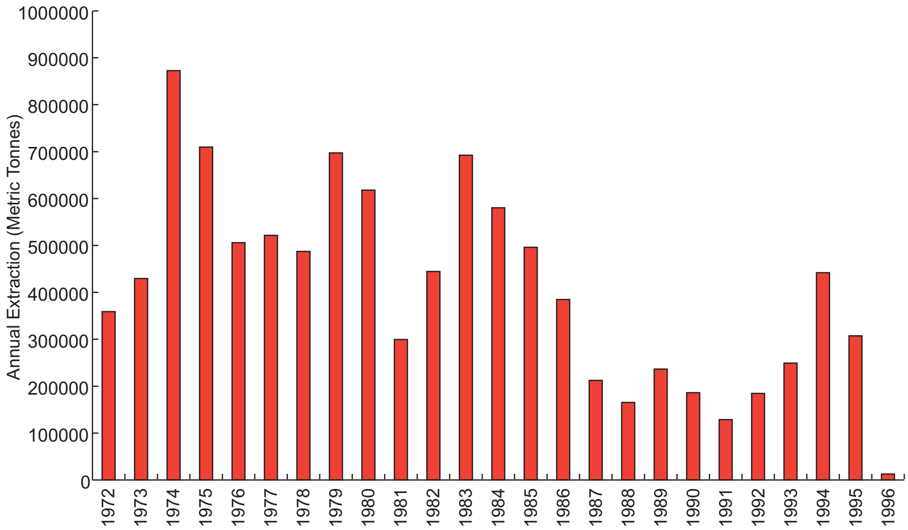
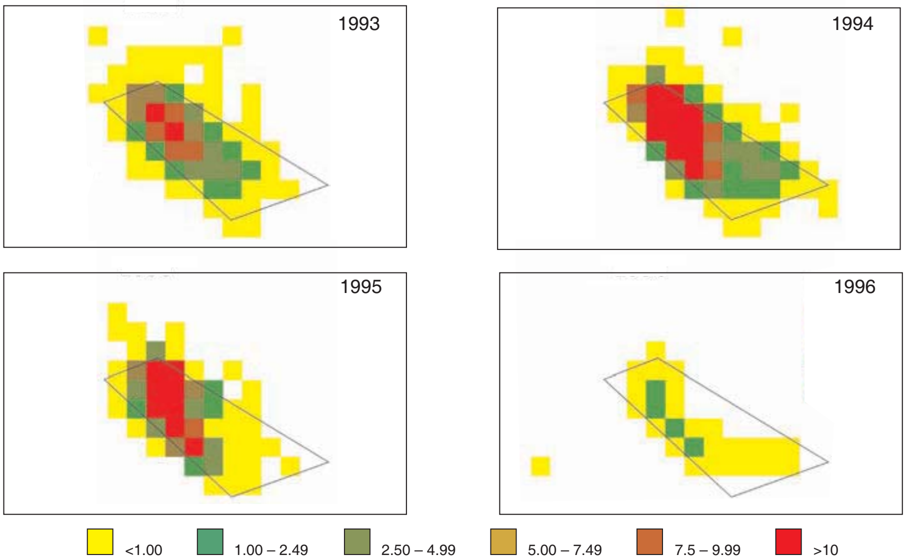


Figure 4.3. Location and intensity of dredging (in hours) over each 100 m x 100 m block at Area 222 between 1993 and 1996.



Direct studies on sediment settlement suggest that sand is deposited at distances up to 300-600 m down current from a dredger, with the possibility of plume effects and the remobilization of sediments extending significantly beyond this (Hitchcock and Drucker, 1996; Newell *et al.*, 2001, 2002). Therefore, the site of lower intensity was potentially subjected to any indirect effects (e.g. transport of unconsolidated sediments) associated with the nearby more intensive dredging activity. Sampling details for locations sampled as part of the Area 222 time-series investigations are presented in Table 4.1.

Table 4.1. Sampling details for locations sampled as part of the time-series investigations at Area 222. Box co-ordinates given as positions in WGS 84 from top right and bottom left hand corners of the sampling box.

Treatment	Code	Box co-ordinates		Area (m^2)	Number of samples collected			
		Latitude	Longitude		2000	2001	2002	2003
High intensity box	HIGH '00 to '03	52° 01.686' N 52° 01.572' N	01° 55.554' E 01° 55.536' E	~40,000	5	10	10	10
Low intensity box	LOW '00 to '03	52° 01.506' N 52° 01.392' N	01° 55.968' E 01° 55.806' E	~40,000	5	10	10	10
Reference site 1	REF 1 '00 to '03	52° 01.530' N 52° 01.470' N	01° 54.828' E 01° 54.726' E	~20,000	5	5	5	5
Reference site 2	REF 2 '01 to '03	52° 02.256' N 52° 02.184' N	01° 55.278' E 01° 55.158' E	~20,000	0	5	5	5

4.2 Results

4.2.1 Sediment characteristics

Figure 4.4 allows inspection of the differences, in terms of mean particle size composition, between the high and lower dredging intensity and the reference sites in each year of the study (Figure 4.4a) and also within each sampling site over the course of the investigation time (Figure 4.4b).

In terms of the mean particle size composition, sediments from the lower dredging intensity and reference sites are similar and have changed little over the period of investigation. However, although sediments from both sites are dominated by gravel there are small differences between them. For example, sediments from the reference site contain higher proportions of silt/clay and less medium sand than the lower dredging intensity site. In addition, sediments from the reference site are more variable in composition.

In contrast, sediment samples collected from within the site of high dredging intensity in 2001 were much finer, containing proportionally less gravel and more coarse sand than either the low dredging intensity or reference sites. However, the high dredging intensity site has become coarser and increasingly similar to low dredging intensity and reference sites over the period of investigation. This has resulted from an increase in the proportion of gravel and a corresponding decrease in the proportion of coarse sand over time (see Figure 4.5.).

4.2.2 Acoustic surveys

Annual sidescan sonar surveys were undertaken within and in the vicinity of Area 222 over the period 2001-2004. Mosaiced images from these surveys, focusing on the licensed area, a disturbed area to the NE of the licensed area and the reference sites are shown in Figures 4.5 - 4.8. In addition Figure 4.9 shows multibeam bathymetric data collected across the site in 2004. Together these sources of information allow an assessment of the existence and persistence of dredging related impacts and also information on the distribution of sediments across the survey area.

Dispersed sandy sediments interspersed with patches of sandy gravel and occasional small outcrops of consolidated clay predominate in the northern part of the extraction area. In contrast, sediments in the southern half of the licensed extraction area appear coarser and more uniform. These differences were clearly evident from underwater images taken in 2000 (Figure 4.10).

Within the extraction licence there is evidence, most clearly visible from the bathymetric data, of a uneven hummocky seabed possibly resulting from static suction hopper dredging. In addition, a number of parallel features consistent with the impact of trailer dredging are evident from both sidescan and bathymetric data in the northern part of the licence. Both extraction techniques are thought to have been used in the area (BMAPA, pers comm.) Whilst these features appear to have undergone weathering, the sidescan sonar data are not of high enough resolution to be able to make an assessment of whether these features are disappearing. In comparison, Figures 4.7 and 4.8 showing sidescan sonar data from the two reference sites, indicate a relatively homogenous seabed composed of stable mixed sediments.

Figures 4.6 and 4.9 show a disturbed area to the NE of the extraction licence consisting of a series of interconnected pits. This area was previously recognised as a zone of "out of area dredging" and the impacts remain obvious to date.

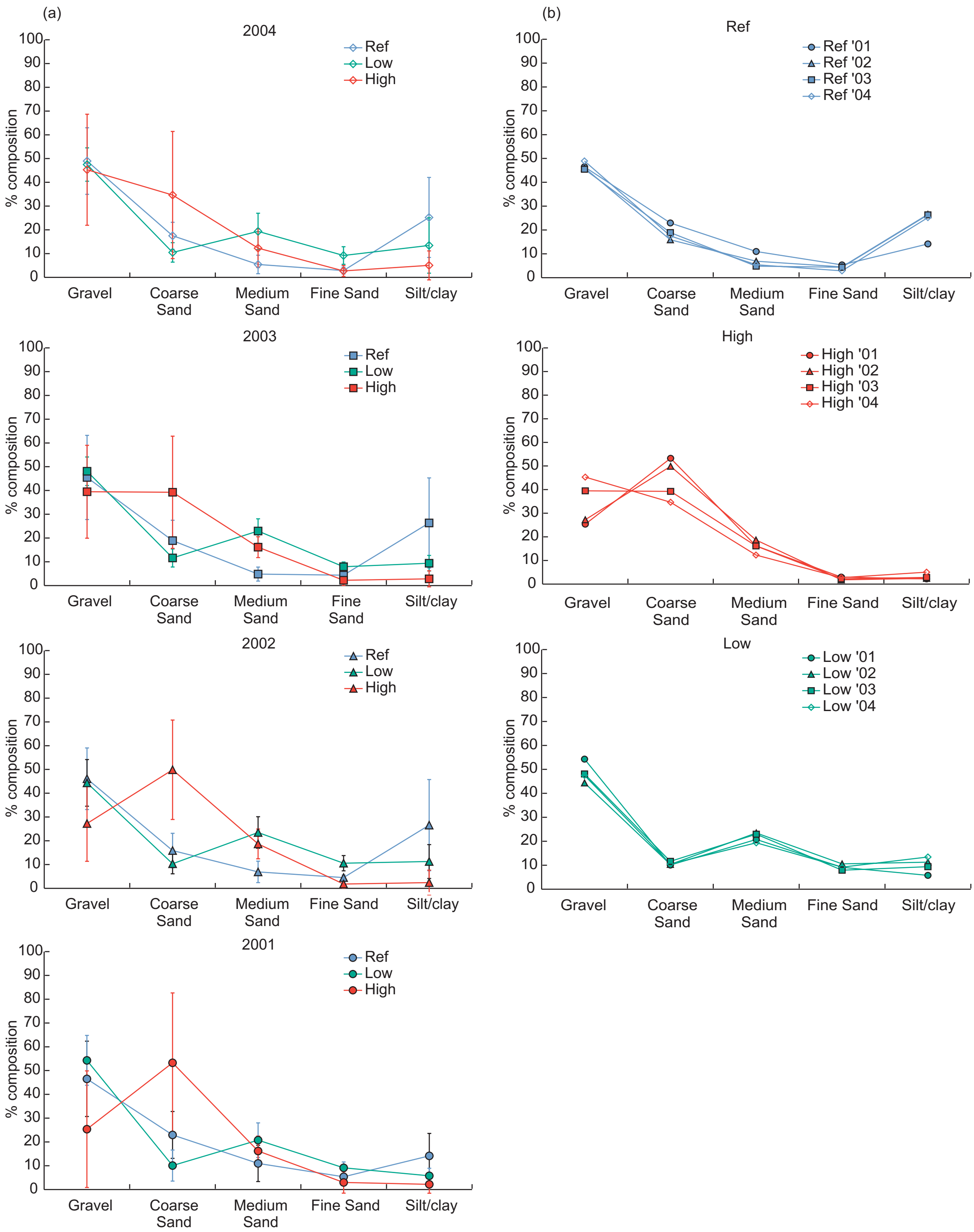


Figure 4.4. a) Annual comparisons of mean particle size composition of sediments taken from high and lower dredging intensity and reference sites (2001-2004). b) Annual records from each site are displayed together to allow inspection of the between year variation in average sediment composition (2001-2004).

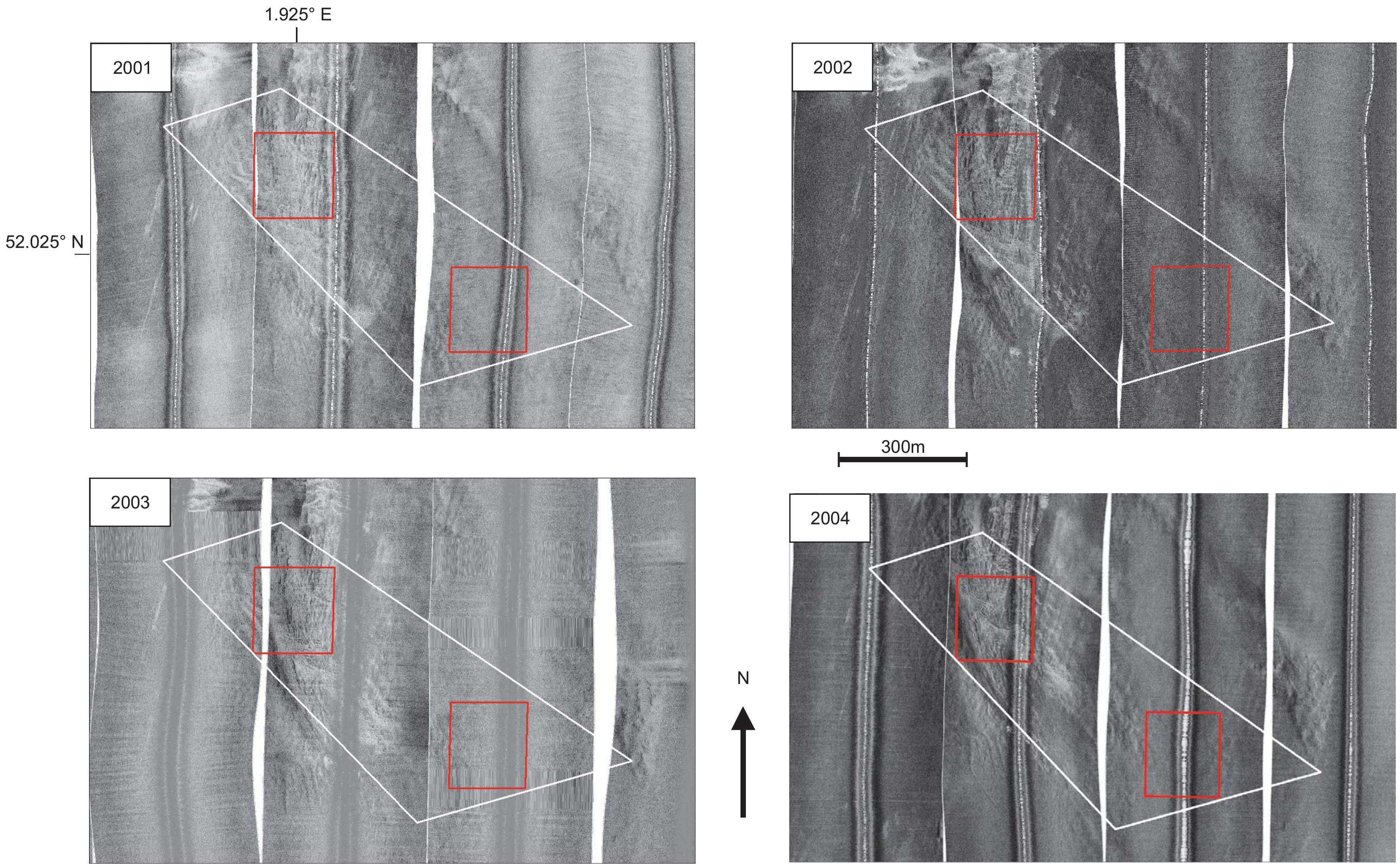


Figure 4.5. Sidescan sonar images of the relinquished Area 222 aggregate extraction licence, collected in 2001-2004. The boundary of the former extraction licence is outlined in white and the high (top left red box in each image) and low (bottom right red box in each image) intensity sampling sites are in red.

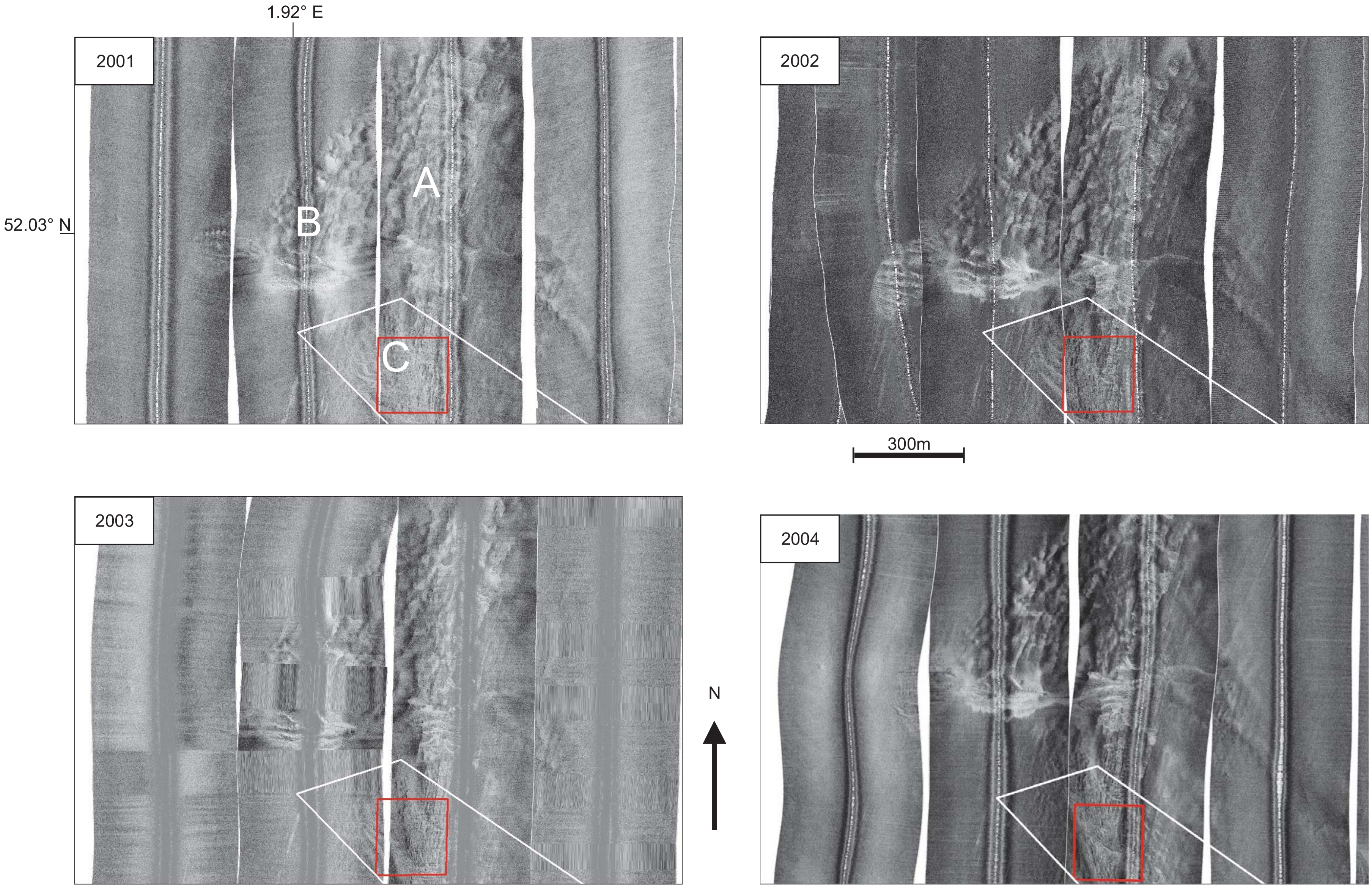


Figure 4.6. Sidescan sonar images of a disturbed area of seabed to the north of Area 222 (2001–2004). A) Area of disturbed seabed to the north of the extraction site. B) Large sand waves. C) Disturbed area within the extraction site.

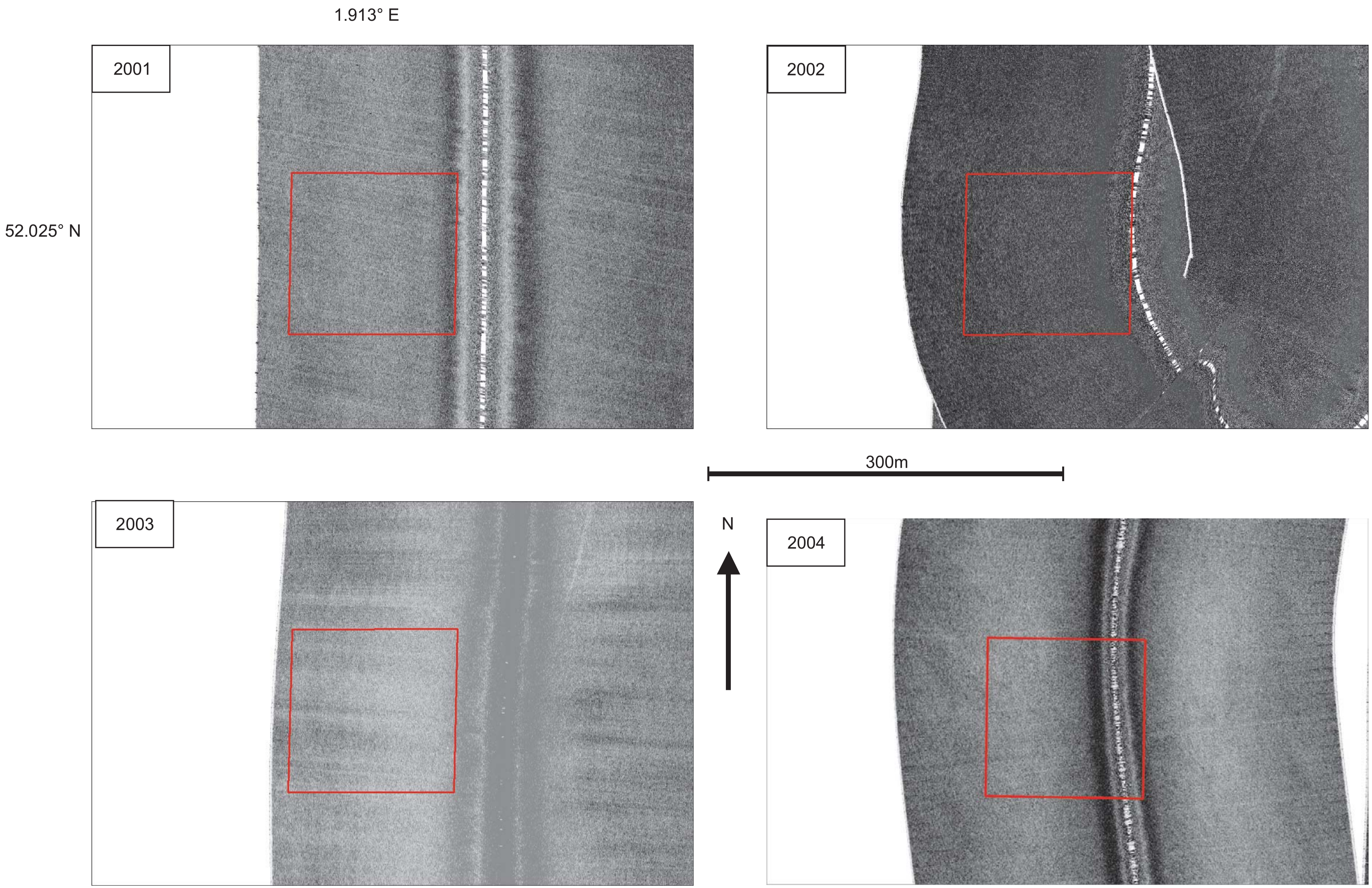


Figure 4.7. Sidescan sonar images of Area 222 reference site 1 (2001–2004).

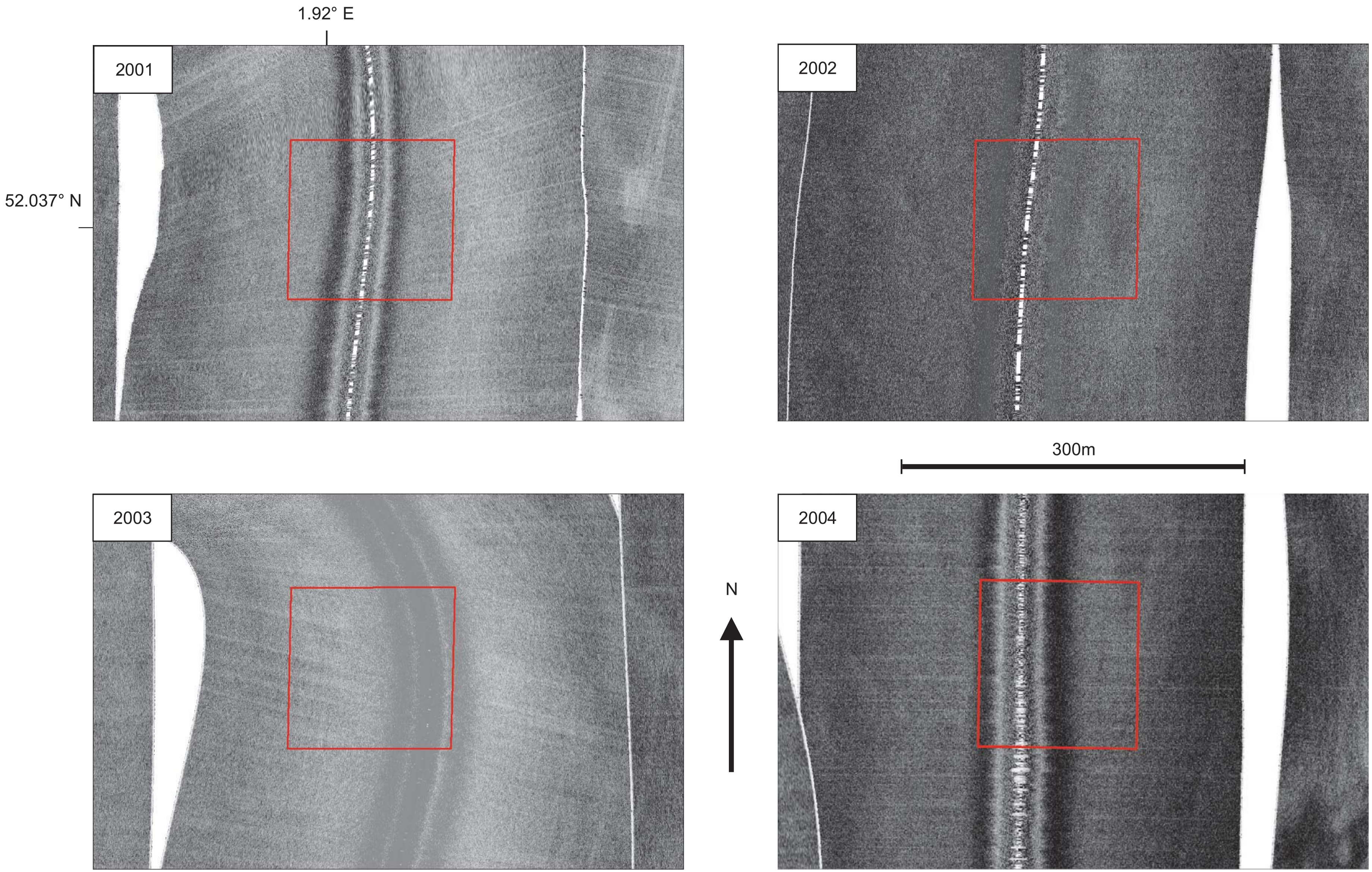


Figure 4.8. Sidescan sonar images of Area 222 reference site 2 (2001–2004).

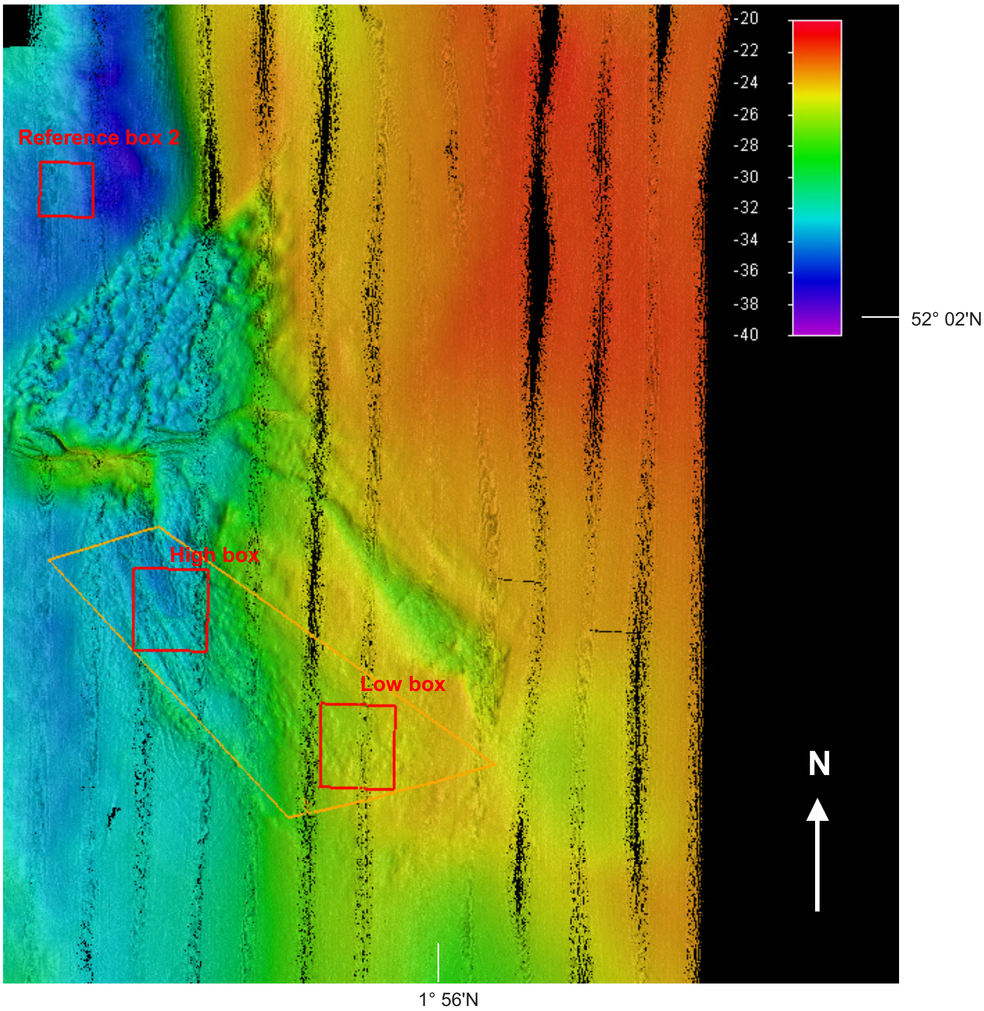


Figure 4.9. Overview of the Area 222 multibeam survey results from 2004. The orange line shows the outline of the former licensed extraction sites. Red boxes show the location of the study sites.

Figure 4.10. Underwater photographic images taken within and outside Area 222 in 2000. Each image represents an area of seabed of approximately 1.5 m by 1.0 m.

4.2.3 Macrofaunal assemblage structure

Univariate analyses

By 2003, 7 years after cessation of dredging, the macrofaunal assemblage found within the site of lower dredging intensity was not significantly different from the reference sites in terms of all calculated univariate measures (Figure 4.11). This situation remains the same in 2004 except that in this year significantly higher numbers of individuals were found at lower dredging intensity site compared to both the reference sites and the site of higher dredging intensity. The reasons for this increase are, as yet, unclear and possibilities include natural variability and also the possibility that the site is undergoing successional changes, prior to final stabilisation of abundance values (see Boyd *et al.*, 2004).

In contrast, significantly lower numbers of species, individuals and biomass were found within the site of high dredging intensity in comparison to both the lower dredging intensity and reference sites in 2001-2004 (with the exception of biomass in 2004, which was not significantly different to the reference sites). However, values of all calculated univariate measures increased at the high dredging intensity site in 2004 indicating possible progress towards 'recovery' at this site.

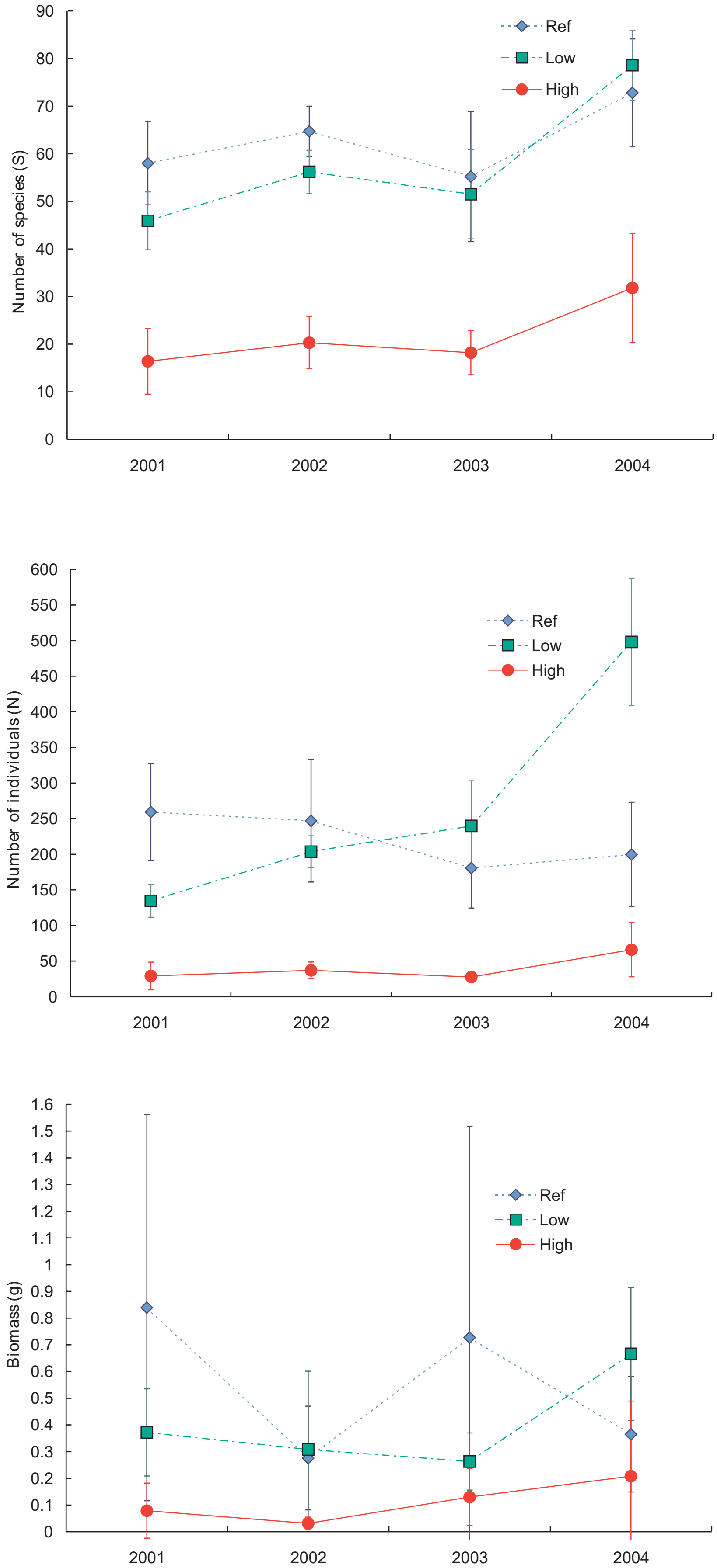
In general, differences between the site of high dredging intensity and other sample locations were due to the reduced abundance of a range of macrofaunal species characterising nearby sediments including *Pomatoceros lamarcki*, *Pisidia longicornis* and *Lumbrineris gracilis*. Densities of these species varied greatly between different locations and between different years (Figure 4.12). Figure 4.12 also reveals that the large increase in abundance at the lower dredging intensity site in 2004 was largely explained by increases in keel worms such as *Pomatoceros lamarcki*.

Multivariate analyses

The MDS ordination for macrofaunal assemblages collected at sites of high and lower dredging intensity and at the two reference sites is presented in Figure 4.13. The tight clustering of lower dredging intensity and reference samples indicates a high degree of similarity between these two sites and this is confirmed by the results of an ANOSIM test showing that differences, although significant, are nevertheless small (Table 4.2). In contrast, samples from the high dredging intensity site are much more diffusively separated, both from each other and from the lower dredging intensity site and reference sites. However, declining ANOSIM 'R' values provide some evidence that the difference between high dredging intensity and reference sites is becoming smaller. Continued monitoring at this site would be needed to confirm this trend.

The results of a SIMPER analysis show the species characterising the high and lower dredging intensity and reference sites in 2004 (Table 4.3). Overall characterising species from each of the sites are similar over time. From the site of high dredging intensity, characterising species tended to be infaunal species typically associated with sandy sediments. In contrast, those species characterising the sites of lower dredging intensity and reference sites were typically larger and included both infaunal and epifaunal species from a range of different phyla.

Figure 4.11. Summary of means and 95% confidence intervals for numbers of species (S), number of individuals (N) and biomass (AFDW (g)) from sites of high and lower levels of dredging intensity and two nearby reference sites at Area 222 in 2001-2004.



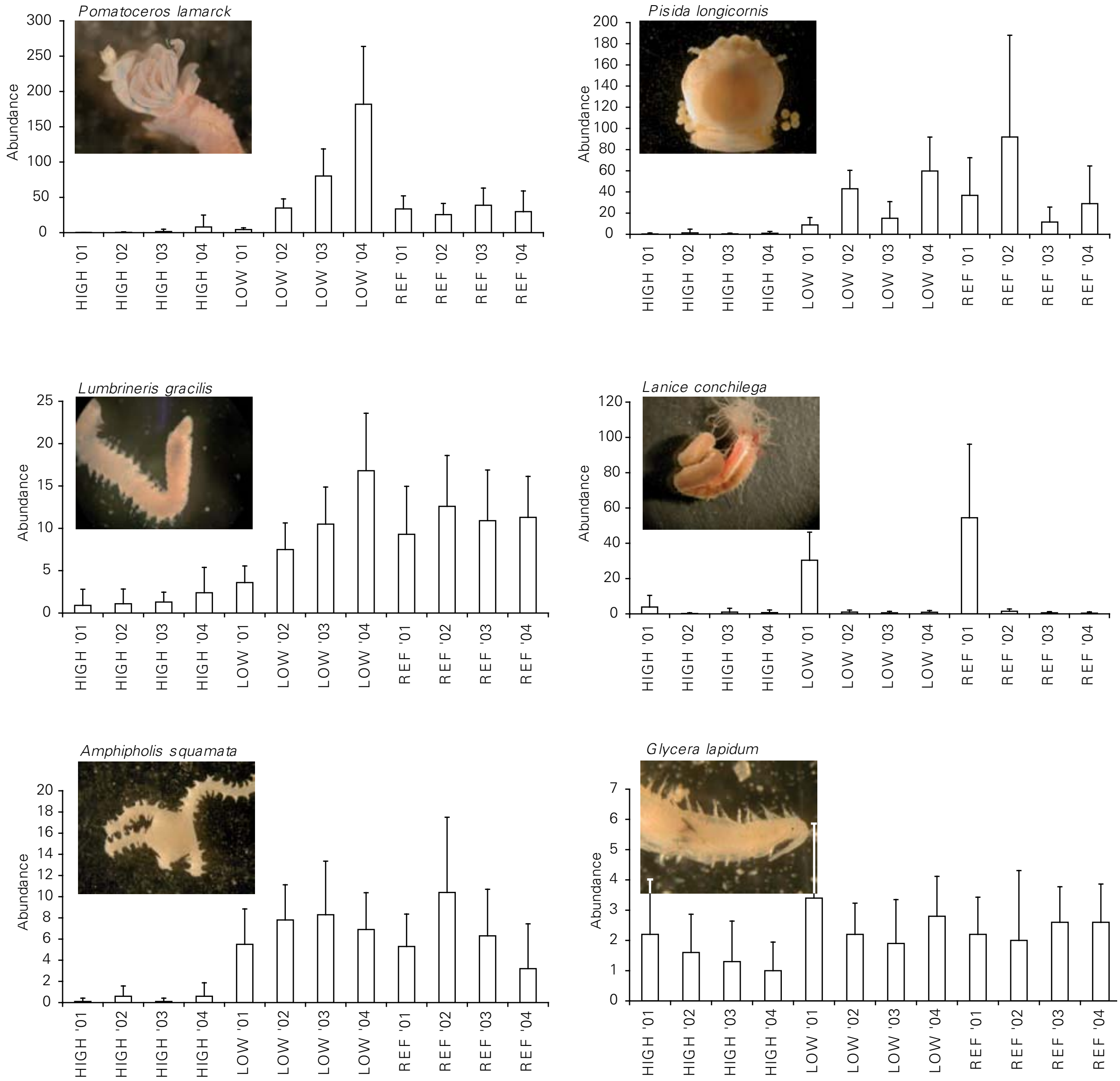


Figure 4.12. Means (±SD) of abundances of selected macrofaunal species sampled in 2001-2004 at sites of high and lower levels of dredging intensity and two reference sites (codes as in Table 4.1).

Figure 4.13. MDS of Bray-Curtis similarities from 4th root transformed species abundance data 5-8 years (2001-2004) after the cessation of dredging at sites of high and lower dredging intensity and at the reference sites.

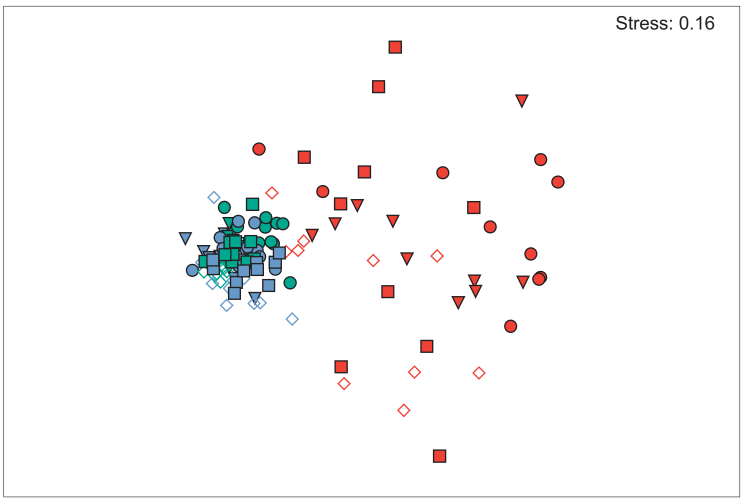


Table 4.2. R-values derived from the ANOSIM test for macrofaunal assemblages from locations of high and lower dredging intensity and from the reference sites in 2001-2004 at Area 222. ** denotes significant difference at p<0.05.

Year	HIGH/REF	LOW/REF	HIGH/LOW
2001	0.777**	0.332**	0.715**
2002	0.741**	0.372**	0.746**
2003	0.547**	0.344**	0.569**
2004	0.475**	0.331**	0.609**

Table 4.3. Results from SIMPER analysis of macrofauna data from Area 222 (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from samples subject to differing levels of dredging impact in 2004. Average abundance, average similarity and the % contribution to the similarity made by each characterising species is shown. Also listed is the cumulative percentage and the overall average similarity between replicate samples from within each group.

Group	Taxon	Average abundance	Average similarity	Similarity/ St. Dev.	% Contribution	Cumulative %	Overall average similarity
HIGH '04	*Echinocyamus pusillus*	5.50	4.62	2.33	15.86	15.86	29.12%
	NEMERTEA	2.50	2.44	1.04	8.36	24.23	
	Aonides paucibranchiata	1.80	2.39	1.10	8.20	32.42	
	NEMATODA	0.70	1.90	0.77	6.53	38.95	
	Glycera lapidum (agg.)	1.00	1.72	0.79	5.91	44.86	
LOW '04	*Pomatoceros lamarcki*	182.00	4.02	17.51	6.46	6.46	62.27%
	Pisidia longicornis	59.80	2.94	5.21	4.72	11.18	
	Serpulidae	46.80	2.85	9.15	4.58	15.76	
	Ophiura (juv.)	33.40	2.64	10.00	4.24	20.00	
	Lumbrineris gracilis	16.80	2.27	9.97	3.65	23.65	
	Echinocyamus pusillus	14.60	2.02	7.21	3.25	26.90	
	Scalibregma inflatum	7.70	1.85	11.61	2.96	29.86	
	Amphipholis squamata	6.90	1.76	7.48	2.83	32.69	
	Harmothoe impar	4.70	1.63	8.46	2.62	35.31	
	Abra alba	4.50	1.58	12.66	2.54	37.85	
	Gibbula tumida	4.40	1.54	5.64	2.48	40.32	
REF '04	*Pomatoceros lamarcki*	29.80	3.00	6.05	6.55	6.55	45.70%
	Lumbrineris gracilis	29.00	2.70	6.32	5.92	12.47	
	Pisidia longicornis	11.30	2.62	3.51	5.74	18.22	
	Serpulidae	16.30	2.50	5.38	5.47	23.68	
	Glycera lapidum (agg.)	2.60	1.85	3.77	4.05	27.74	
	Ampelisca spinipes	6.00	1.81	1.73	3.97	31.70	
	Marphysa bellii	1.90	1.69	4.77	3.70	35.41	
	Ophiura (juv.)	8.90	1.33	1.22	2.90	38.31	
	Echinocyamus pusillus	4.50	1.15	1.19	2.52	40.84	

5. Temporal investigations of the physical and biological status of Hastings areas X and Y

5.1 Methods

5.1.1 Study site

The study site is located approximately 6 nautical miles south of Hastings off the south coast of England (Figure 5.1) in water depths of between 14 m and 40 m below chart datum. The tidal ellipse is aligned in a NE - SW direction with a maximum spring tidal current velocity of 2.6 knots (Admiralty Chart 536). On the flood tide the flow is in a northeast direction, whilst water flows southwest on the ebb. Current meter studies in the area (HR Wallingford, 1993; HR Wallingford, 1999; Rees *et al.*, 2000) and observations of seabed transport features (EMU, 1999) indicate that the net sediment transport is in a north-easterly direction.

Hastings Shingle Bank has been licensed for aggregate dredging since September 1988. Over this period there have been a number of changes to the boundaries of the extraction licences at this site. Sub-areas X and Y, shown in Figure 5.1, were both relinquished in 2001 and replaced by a new licence in the same year. This new licence encompasses parts of the old sub-areas X and Y (see Figure 5.1). However, parts of both of these relinquished areas, which were dredged at various intervals in the past, fall outside of the new licence making them suitable for an investigation of benthic recolonization following the cessation of dredging activity.

5.1.2 Sampling design

Hastings Area X

Areas of high and lower levels of dredging intensity were identified from 1996 EMS data (the year when dredging had last taken place in the study area) (see Figure 5.2). The area of high dredging intensity represents >4.99 hours of dredging whereas the area of lower dredging intensity is

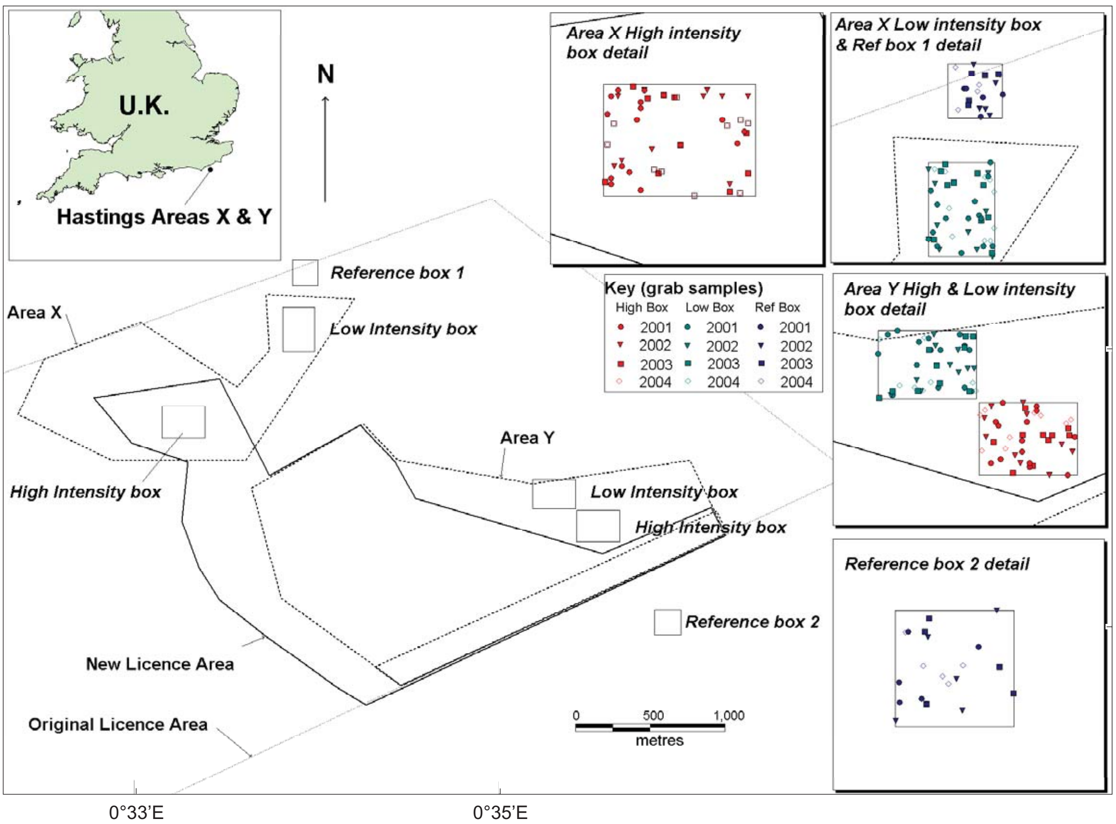


Figure 5.1. Location of grab sampling in relation to positions of historic (original, Area X and Area Y) and current (new licence area) aggregate extraction licences on the Hastings Shingle Bank.

equivalent to <1 hour of dredging, within each 100 m by 100 m block. Treatment boxes, measuring 300 m by 200 m, were assigned to these two areas of seabed. Within each treatment box, 10 randomly positioned 0.1 m^2 Hamon grab samples were collected in each year from 2001 to 2004 (5-8 years after the cessation of dredging). However, dredging resumed in the north of the new extraction area during May 2002, an area which coincided with the Hastings Area X high dredging intensity site. Dredging intensity ranged between 2.5 – 14.99 hours within each 100 m by 100 m block. Results from the Area X high dredging intensity site in 2002 and 2003 therefore represent conditions within a current aggregate extraction area. In addition, two reference boxes (Reference box 1 and 2) were also sampled over the same period. The area of each reference box was half that of the treatment boxes with 5 random samples taken at each site in each year. As described in earlier sections, this approach was adopted in order to achieve the same sampling density per unit area at both dredged and reference locations. Details of the locations sampled as part of the Area X time-series investigations are presented in Table 5.1.

Hastings Area Y

EMS data suggest that dredging took place within the relinquished zone of Area Y in 2001 (Figure 5.2). However, following consultation with Posford Haskoning Limited, it was established that the only dredging event that took place in the relinquished zone after 2000 was an isolated 'out of area' dredging incident on the 16th of May 2001 within

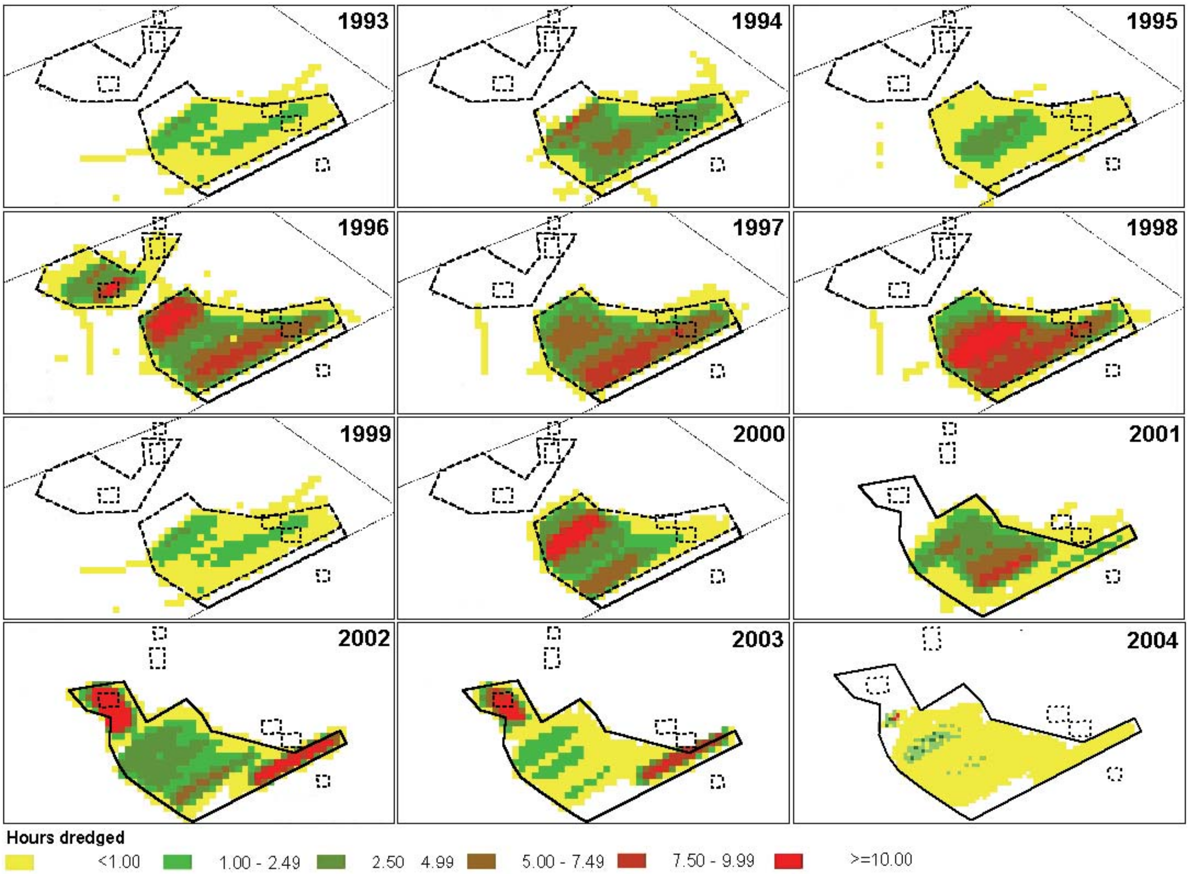


Figure 5.2. Location and intensity of dredging (hours) over each 100 m x 100 m block at Hastings Area X & Y in relation to the positions of the high and low sampling sites in years 1993 to 2003 (source EMS data provided by the Crown Estate).

Table 5.1. Co-ordinates of treatment boxes in Areas X and Y.

	Treatment	Code	Box co-ordinates		Area (m^2)	Number of samples collected			
			Latitude	Longitude		2001	2002	2003	2004
Area X	High intensity box	HIGH '01 to '04	50° 44.784'N	00° 33.090'E	~60,000	10	10	10	10
			50° 44.670'N	00° 33.336'E					
	Low intensity box	LOW '01 to '04	50° 45.144'N	00° 33.780'E	~60,000	10	10	10	10
			50° 44.982'N	00° 33.960'E					
	Reference box 1	REF '01 to '04	50° 45.314'N	00° 33.833'E	~30,000	5	5	5	5
			50° 45.221'N	00° 33.980'E					
Area Y	High intensity box	HIGH '01 to '04	50° 44.406'N	00° 35.454'E	~60,000	10	10	10	10
			50° 44.292'N	00° 35.700'E					
	Low intensity box	LOW '01 to '04	50° 44.520'N	00° 35.202'E	~60,000	10	10	10	10
			50° 44.412'N	00° 35.448'E					
	Reference box 2	REF '01 to '04	50° 44.046'N	00° 35.898'E	~30,000	5	5	5	5
			50° 43.954'N	00° 36.047'E					

the southern half of the Hastings Area Y high dredging intensity site (details are shown in Figure 5.3). The other apparent episodes of dredging relate to the vagaries of the EMS system and not the contact of a dredger draghead with the seabed. The 2001 field sampling programme did not commence until after this date and consequently the results from some stations within the high dredging intensity site may reflect conditions 2 months, and others 1 year 2 months after cessation of dredging. Historical information on the location and intensity of dredging within the relinquished zone of Area Y between 1993-2000 was used to identify areas of high and lower levels of dredging activity. During 1997 and 1998, values of dredging intensity ranged between 5 and 14.99 hours per annum within each 100 m by 100 m block in the site of high dredging intensity. Dredging activity declined thereafter from 2.5 - 4.99 hours in 1999 to <1 - 2.49 hours in 2000. Within the site of lower dredging intensity the intensity of dredging has consistently remained below 2.49 hours and between 1998 and 2000 was not greater than 1 hour per annum for any 100 m by 100 m block. Within each treatment box, 10 randomly positioned 0.1 m^2 Hamon grab samples were collected from 2001-2004, that is 1-4 years after the cessation of dredging. Again, the samples collected from reference sites 1 and 2 were used to compare results from the high and lower dredging intensity sites with the wider environment. Details of the positions of sampling sites are given in Table 5.1.

5.2 Results (Hastings Area X)

5.2.1 Sediment characteristics

Figure 5.3 allows inspection of the differences, in terms of mean particle size composition, between the high and lower dredging intensity and the reference sites in each year of the study (Figure 5.3a) and also within each site over the course of the investigation time (Figure 5.3b). In 2001, all sites showed a high degree of similarity, especially between the site of lower dredging intensity and reference sites, although the dredged sites contained a number of sandy stations not encountered at the reference sites. During 2002 and 2003 dredging resumed within the high dredging intensity site and sediments became coarser in comparison to the lower dredging intensity and reference sites, which remained similar to one another. Underlying gravel may have been exposed at the high dredging intensity site as a consequence of extraction operations or sands may have been mobilised away from the area during dredging. By 2004 (after the cessation of dredging) the high dredging intensity site had become sandier and in general, more similar to the lower dredging intensity and reference sites.

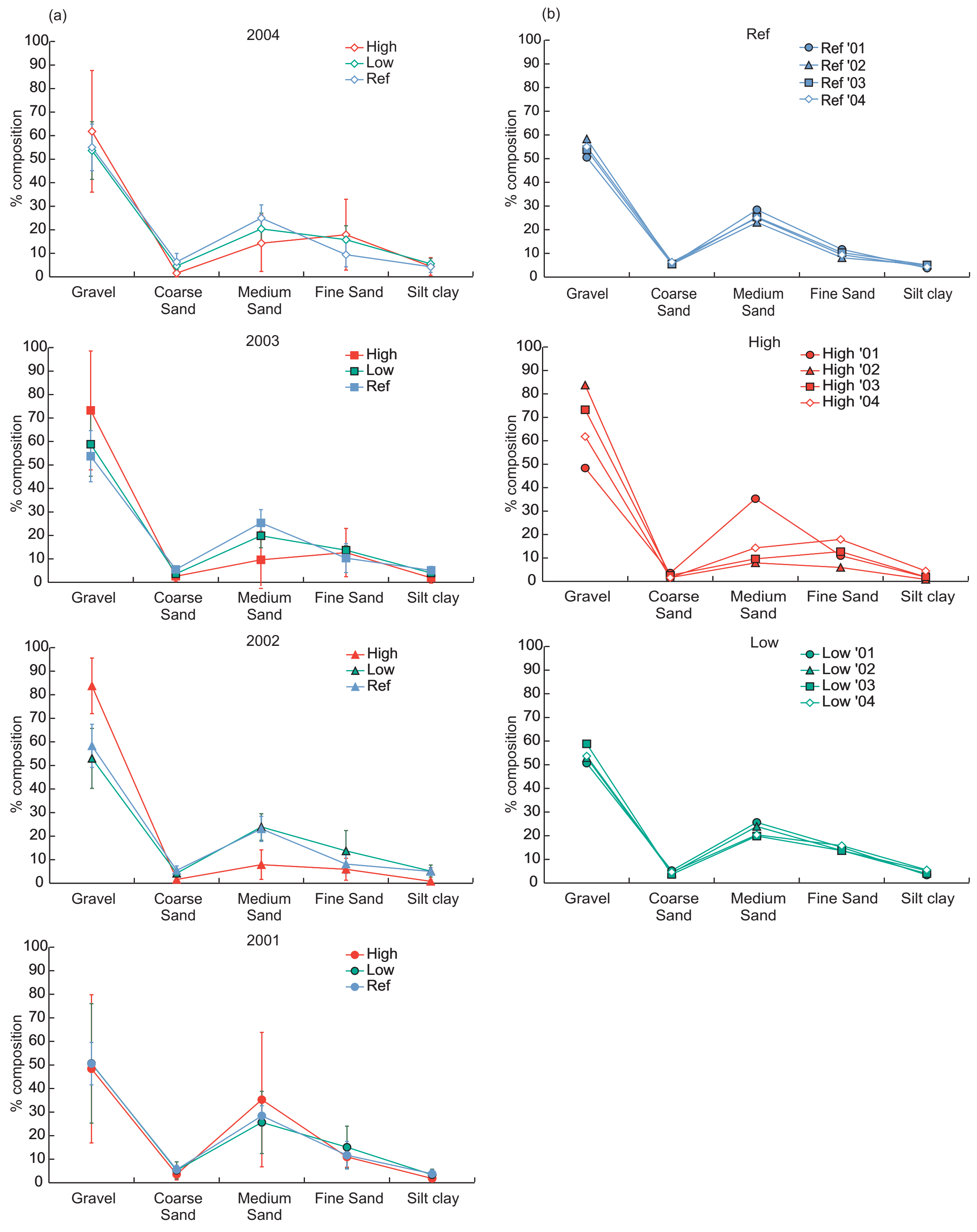


Figure 5.3. a) Annual comparisons of mean particle size composition of sediments taken from sites of high and lower dredging intensity and reference sites (2001-2004). b) Annual records from each site are displayed together to allow inspection of the between year variation in average sediment composition (2001-2004).

5.2.2 Acoustic surveys

Figures 5.4 to 5.7 show sidescan sonar images collected from the Area X high and lower dredging intensity sites and reference sites 1 and 2, between 2001 and 2004. In 2001, weathered dredge tracks, orientated in a NE - SW direction, were clearly visible within the area of high dredging intensity. These observations are consistent with other studies in the area (Brown *et al.*, 2001, 2004). The tracks were infilled with sand and it appeared that a number of these individual tracks had agglomerated into larger, elongated sandy features. In 2002, recent dredging activity (characterised by a generally N/S track orientation) had begun to mask these historic dredging related features (EMU, 1999) and in 2003 they had all but disappeared. The 2004 sidescan sonar images showed little evidence of pre-2002 dredging. However there was some evidence to suggest that tracks created during 2002 had weathered over time. West of the lower dredging intensity site there was clear evidence of fishing activity in the sandier area. Underwater video evidence from 2003 shows that the seabed within the high dredging intensity site was extremely uneven. Dense dredge tracks covering the seabed were characterised by steep ridges of clean gravel on either side of the track, the bases of which were infilled with sand. This is in contrast to video images collected in 2001, prior to the recommencement of dredging, when the seabed within the high dredging intensity site was relatively flat and consisted of gravelly sand, sandy gravel and patches of rippled sand. This is consistent with the sidescan sonar imagery collected in that year.

Weathered dredge tracks are apparent from the sidescan sonar image within the lower dredging intensity site in all four years, but to a far lesser degree than in the high dredging intensity site. Video images collected in the lower dredging intensity site in 2003 were similar to those collected in 2001, with a smooth flat sediment profile comprising of flat sandy gravel occasionally masked by sand veneers.

Sidescan sonar images of the reference sites show that the surrounding sediments are generally similar year on year, including the 2004 sidescan sonar survey. The seabed consists of flat generally featureless sandy gravels, with occasional sand veneers. However, in 2002, the sidescan sonar image provides some evidence that demersal fishing activity has occurred in this area (Figure 5.6). Sediments at reference site 2 do not appear to have changed between 2001 and 2004. However, two sets of paired tracks, probably caused by demersal trawlers, crossed the site in 2002 (Figure 5.7).

The multibeam bathymetry survey carried out in 2003 shows that the seabed within the high dredging intensity site at Area X is very uneven and has been lowered by approximately 3 metres when compared with the surrounding seabed (Figure 5.10). This is consistent with the information provided by a parallel survey also carried out in 2003 (Coastline Surveys Europe Ltd, 2003). Multibeam bathymetric data collected at Area X in 2004 is shown in Figure 5.8. Using this data, 200 m profiles of the seabed through each of the sites have been generated and are shown in Figure 5.9. Clearly the seabed profile across the area of high dredging intensity is very uneven and contains a number of depressions. These features have resulted from recent dredging activities in 2002 and 2003. In contrast, the seabed profile through the lower dredging intensity is smoother. However, the seabed within both dredged sites is relatively rough in comparison with the seabed at reference site 1.

In addition to looking at the profile across the study sites multibeam bathymetric data collected in 2003 (Figure 5.10) has been used to compare the profiles of individual dredge tracks from the area of high and lower dredging intensity (Figure 5.11). This figure shows dredge tracks within the high dredging intensity site are narrow and deep, whereas the dredge track profile for the lower dredging intensity site proved to be wider and shallower. The track within the high dredging intensity site is thought to be a result of recent dredging activities, whereas the track from the lower dredging intensity site must be a result of dredging activities in 1996 or before 1993, according to the EMS data. Therefore this comparison can give a view on the possible physical ‘recovery’ of the seabed of a dredging furrow over time. It is thought that a gradual infill of the furrow with sediments from the steeper sides may explain the widening and shallowing of the furrow.

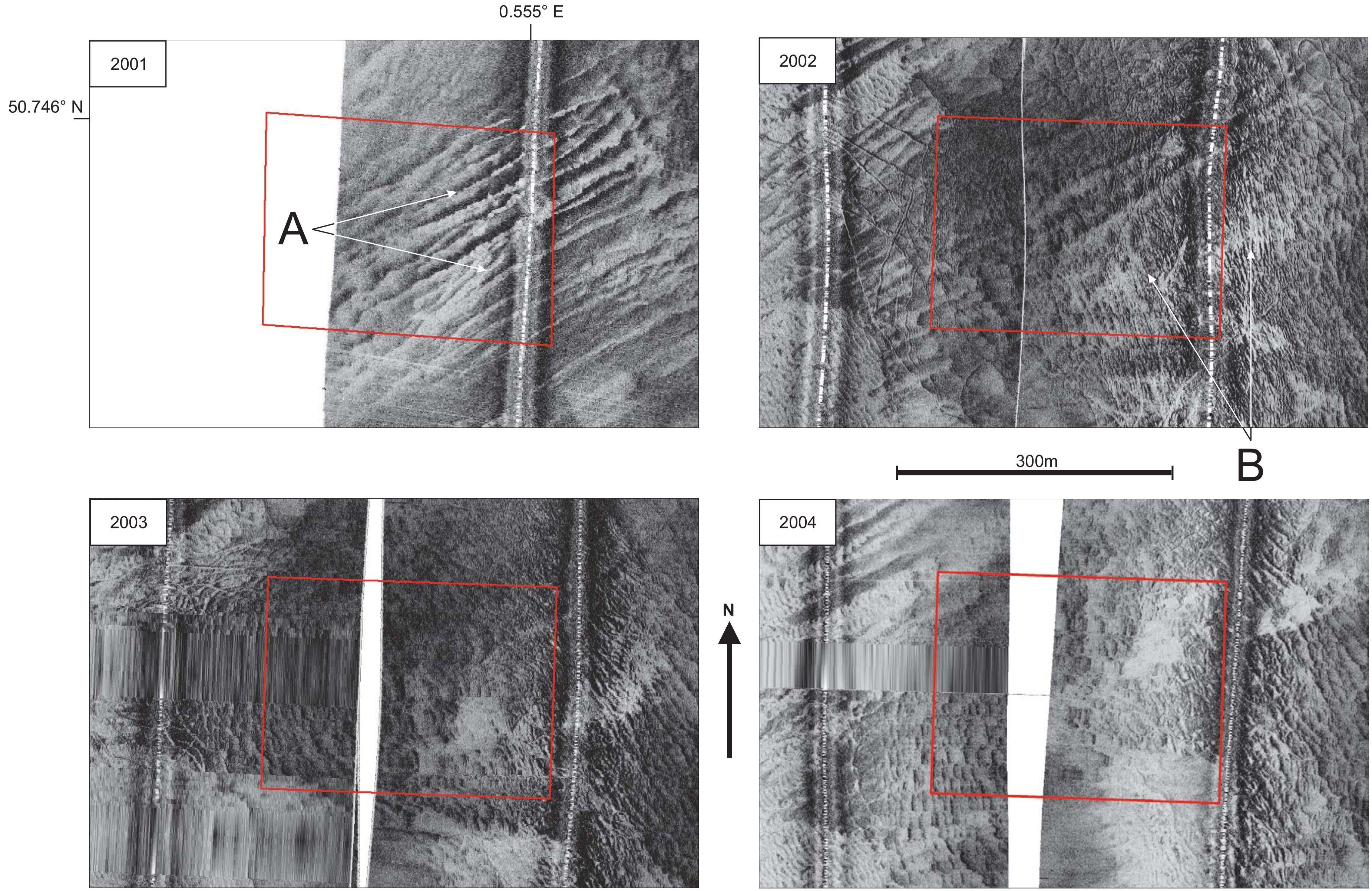


Figure 5.4. Sidescan sonar images of the high dredging intensity site at Area X (2001-2004). A) Weathered dredge tracks in 2001 in NE/SW orientation. B) Tracks generated by recent dredging activity

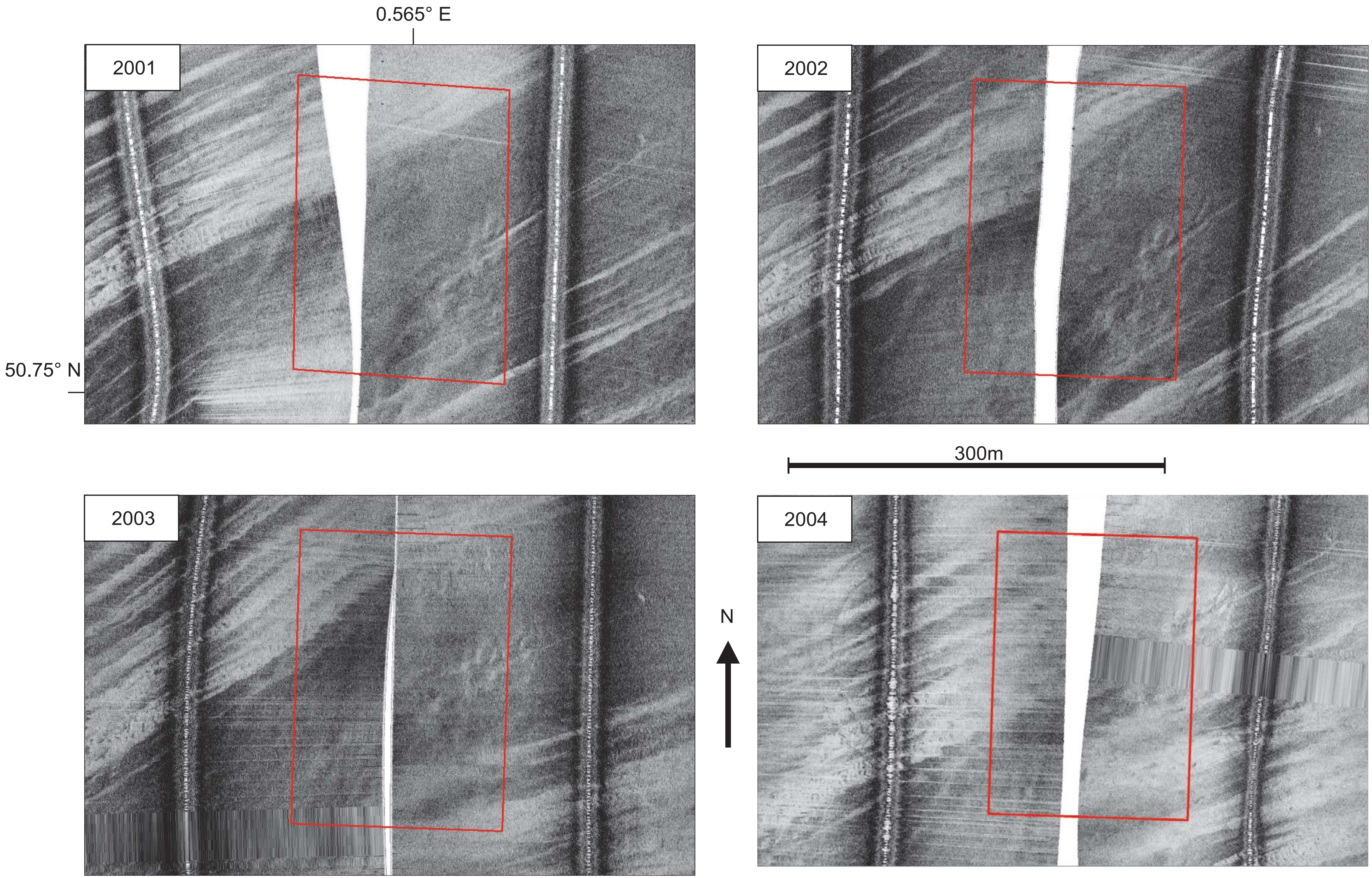


Figure 5.5. Sidescan sonar images of the low dredging intensity site at Area X (2001-2004).

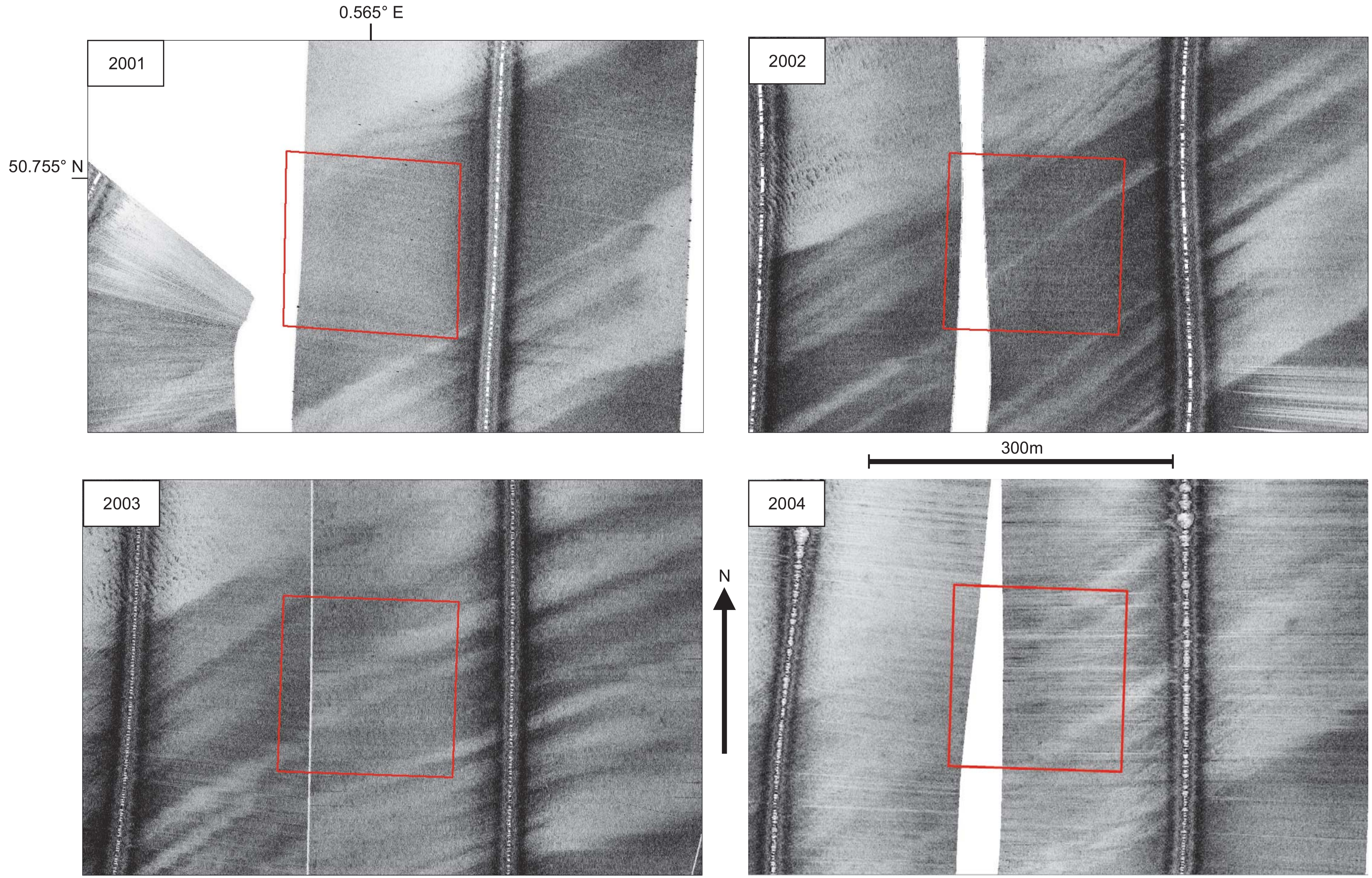


Figure 5.6. Sidescan sonar images of reference site 1 (Area X) (2001-2004).

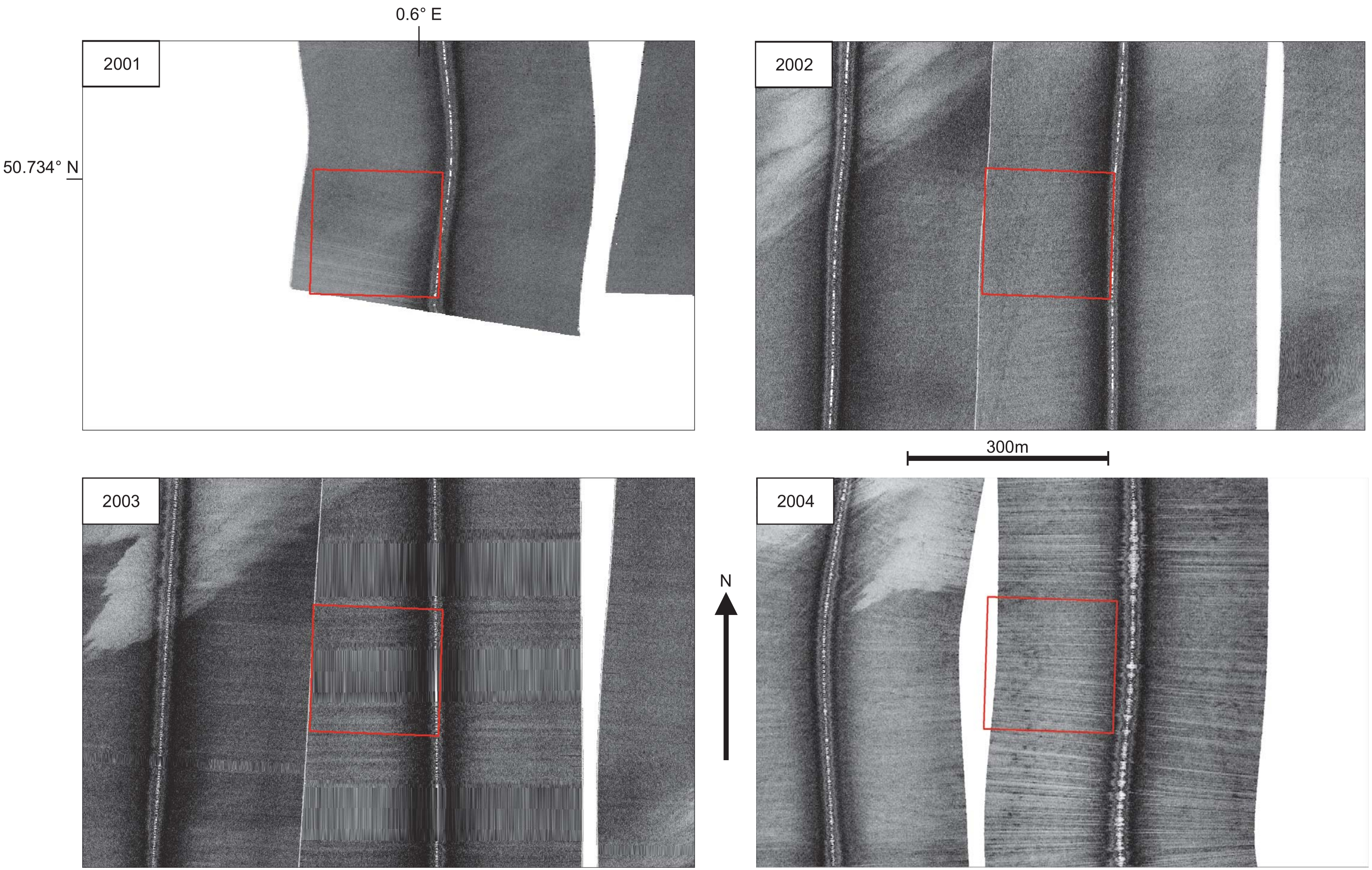


Figure 5.7. Sidescan sonar images of reference site 2 (Area Y) (2001-2004)

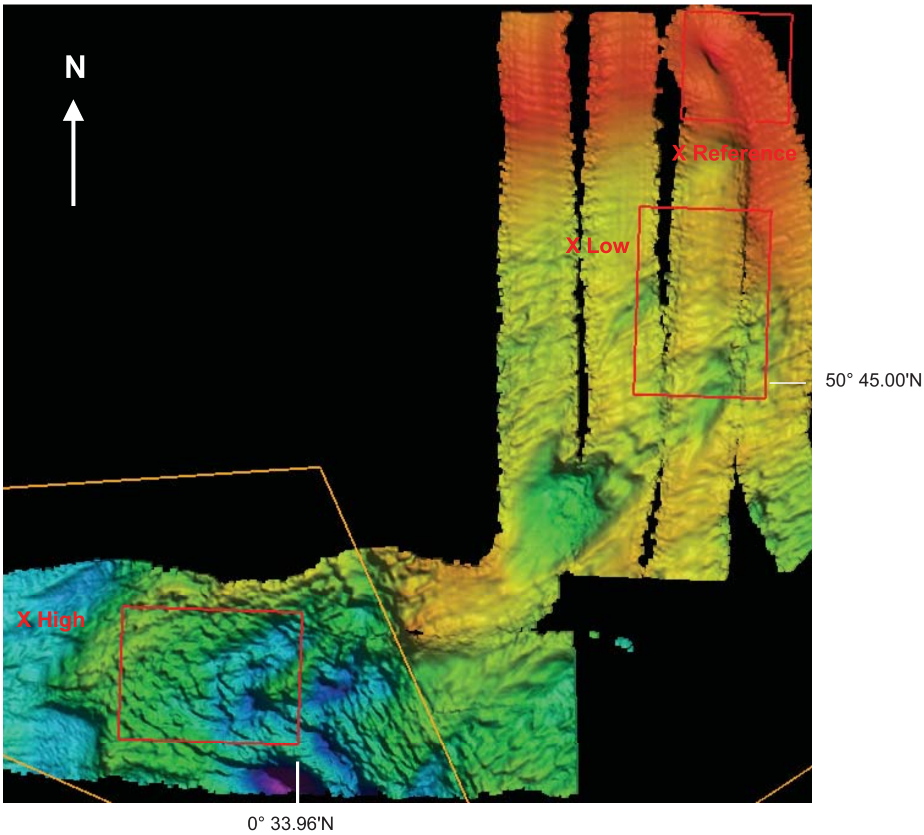


Figure 5.8. Multibeam bathymetry from the 2004 survey of Hastings Area X. The high dredging intensity site shows signs of recent intensive dredging activities.

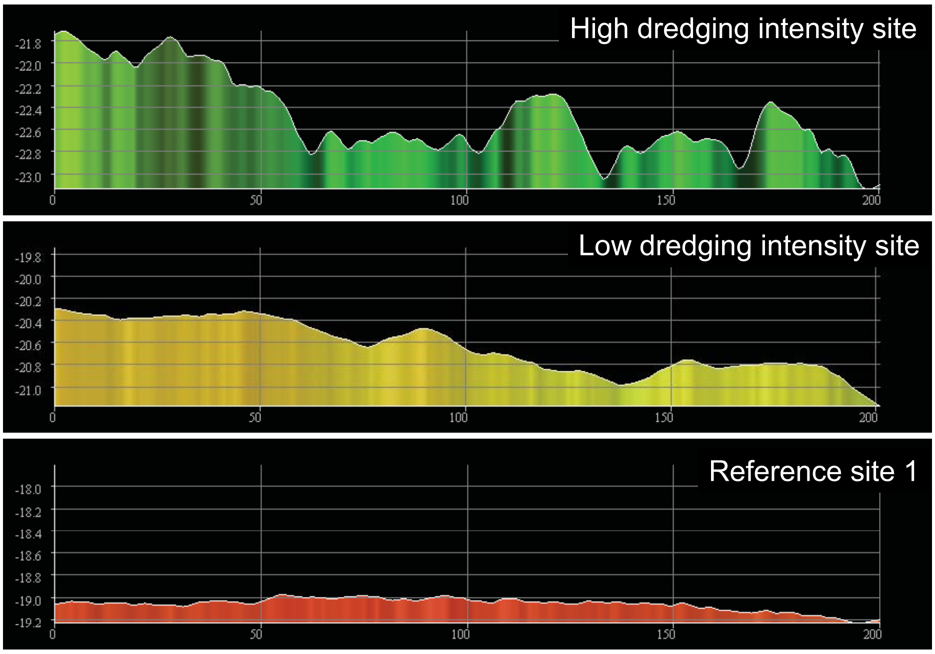


Figure 5.9. Seabed profiles from Area X generated using multibeam bathymetric data collected in 2004.

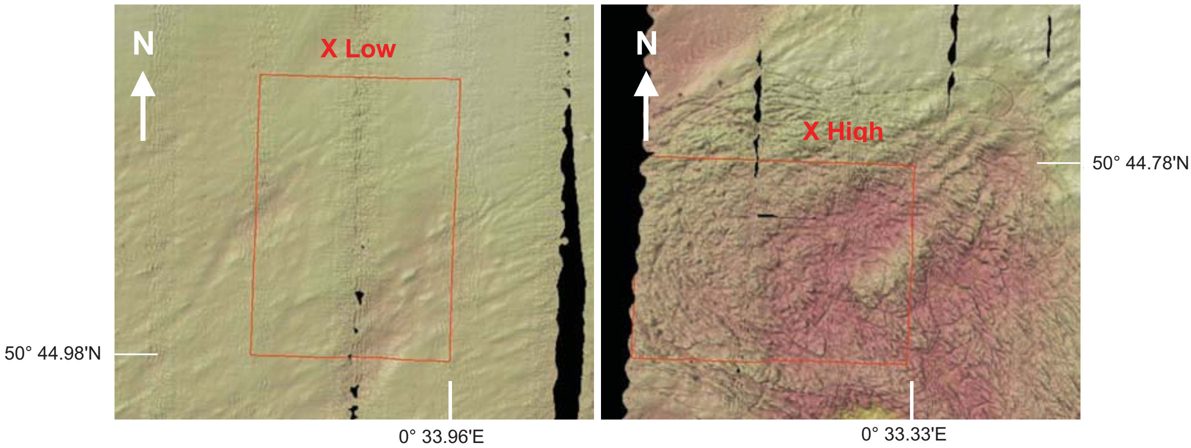


Figure 5.10. 2003 Multibeam bathymetric data collected at Hastings Area X in 2003. This data has been used to generate the dredge furrow profiles in Figure 5.11

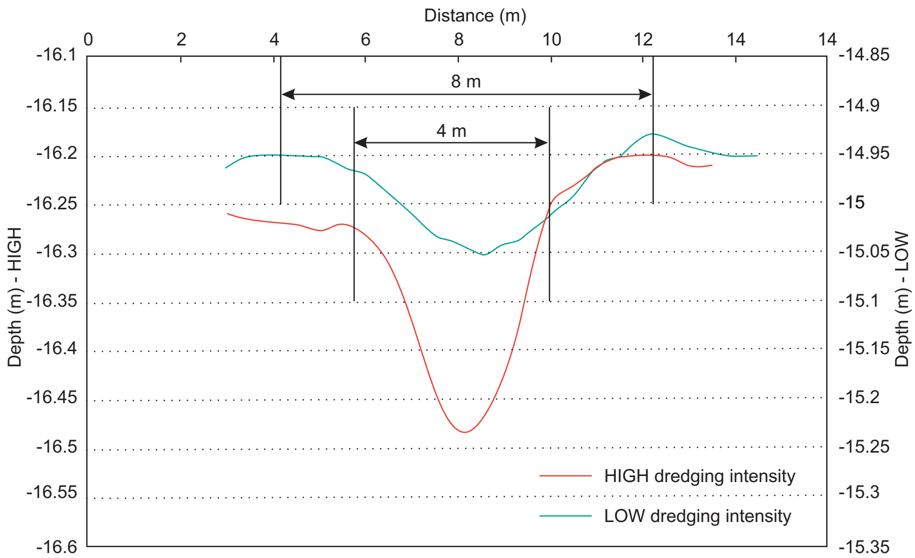


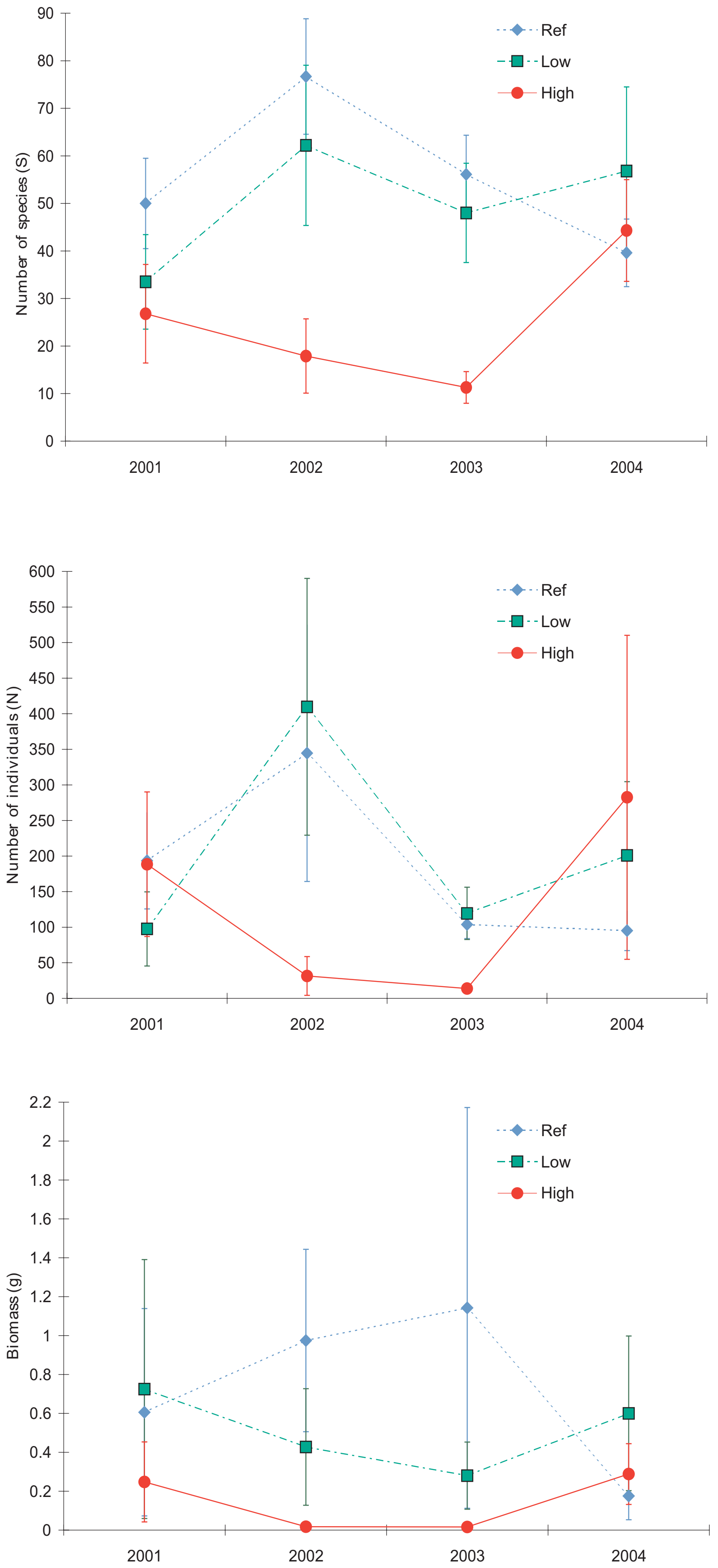
Figure 5.11. Profile across a representative furrow in the high and lower dredging intensity sites from the 2003 survey results. The furrow in the high dredging intensity site is a result of recent dredging activities, whereas the furrow in the lower dredging intensity site is a result of historic dredging activities.

5.2.3 Macrofaunal assemblage structure

Univariate analyses

Figure 5.12 shows the average values (±SD) for the number of species, abundance and biomass of the high and lower dredging intensity sites and reference sites over the four years of the study. In 2001, abundance and biomass at the site of high dredging intensity were not significantly different to the reference and lower dredging intensity sites. However, the numbers of species at the high dredging intensity site were significantly lower. The similarity in species abundance between all sites in 2001 can be attributed to elevated numbers of the barnacle *Balanus crenatus* within the high dredging intensity site. High numbers of this species were also found at a few gravelly stations at the lower dredging intensity site. Throughout the study period, the lower dredging intensity site did not significantly differ from the reference sites for any univariate indices with the exception of biomass in 2002. Following the resumption of dredging in 2002 and continuing in 2003, values of all indices at the site of high dredging intensity fell and were significantly lower than the reference site. In 2004, no dredging occurred at the high dredging intensity site and values for all indices increased significantly, such that they did not differ from the reference sites. The numbers of individuals were actually higher at the high dredging intensity site in 2004, mainly as a result of large numbers of the polychaete worm *Sabellaria spinulosa* (Ave. 133.7 ± 278.6) being present within several samples. This may have been due to a shift in sediment composition to a gravelly/sandy habitat, which is known to be suitable for *S. spinulosa* colonisation (Foster-Smith and Hendrick, 2003).

Figure 5.12. Summary of means and 95% confidence intervals for numbers of species (S), number of individuals (N) and biomass (AFDW (g)) from sites of high and lower levels of dredging intensity and two nearby reference sites at Area X in 2001-2004.



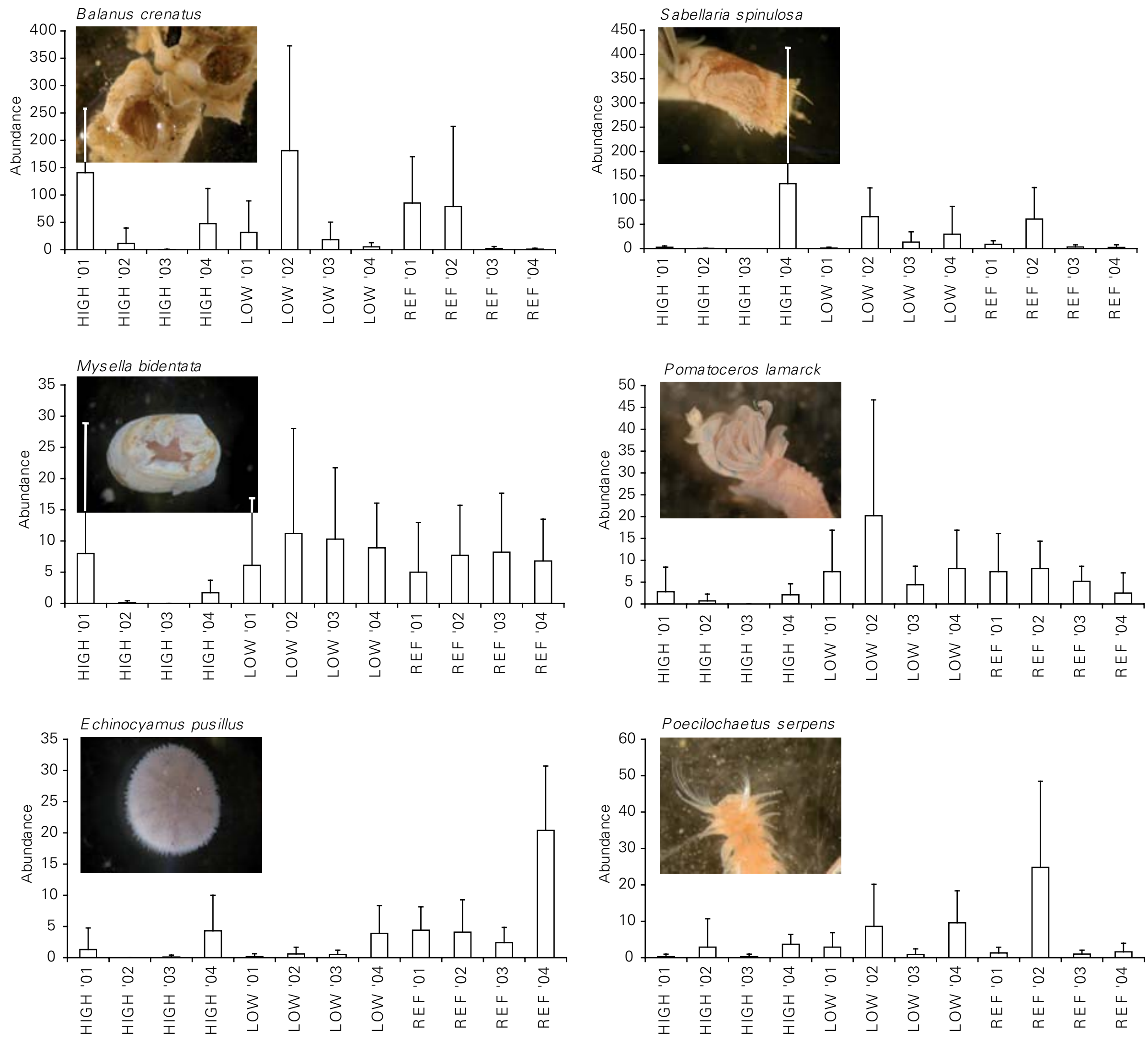


Figure 5.13. Means (± SD) of abundances of selected macrofaunal species sampled in 2001-2004 at sites of high and lower levels of dredging intensity and at two reference sites (codes as in Table 5.1).

The responses of selected macrofauna species were also examined at the three sites (Figure 5.13). In 2002 and 2003, following the resumption of dredging, the abundances of many species fell sharply (e.g. *Balanus crenatus* and *Mysella bidentata*) at the high dredging intensity site. However, in 2004, after dredging had ceased, abundances of all the species of interest had started to increase, especially that of *Sabellaria spinulosa*. Changes at the low dredging intensity and reference sites were less distinct.

Multivariate analyses

The results of a non-metric multi-dimensional scaling ordination based on species sampled from all three sites are presented in Figure 5.14. It is apparent that samples from the site of lower dredging intensity and reference sites are more similar to one another than to the samples obtained from the site of high dredging intensity. Samples surrounding the main cluster are composed largely of the high dredging intensity stations from 2002 and 2003. Univariate analysis has previously shown that numbers of species, abundance and biomass significantly decreased during these years due to dredging. The resulting communities were impoverished and significantly different to the lower dredging intensity and reference sites, as shown by the ANOSIM results in Table 5.2. By 2004, community structure at the high dredging intensity site was more similar to the lower dredging intensity site than in the previous years. However, communities were still significantly different between the high dredging intensity and reference sites. These differences are largely due to the large abundances of *S. spinulosa* at the high dredging intensity site. The ANOSIM result between the lower dredging intensity and reference sites suggested 'recovery' by 2003, however in 2004 small shifts in community structure at both sites resulted in significant differences, possibly as a result of natural variability.

Figure 5.14. MDS of Bray-Curtis similarities from 4th root transformed species abundance data at the high and lower dredging intensity sites and at the reference sites.

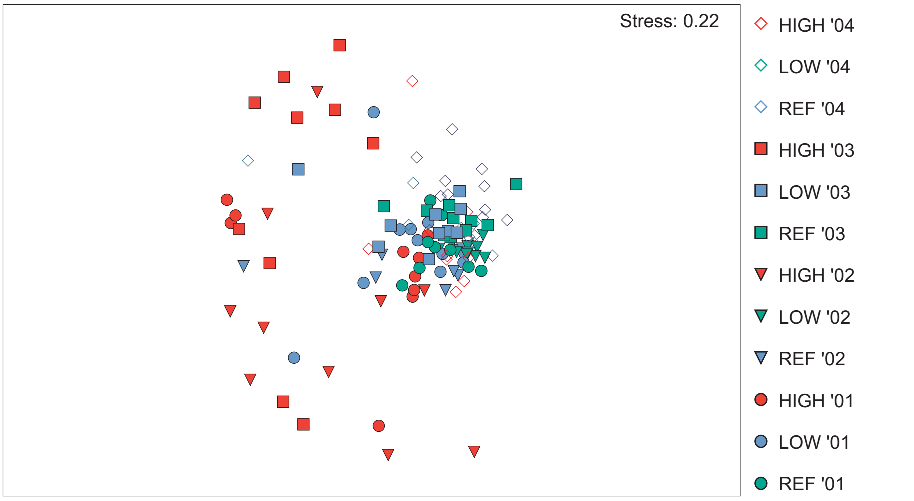


Table 5.2. R-values derived from the ANOSIM test for macrofaunal assemblages from locations of high and lower dredging intensity and from the reference sites at Area X in 2001-2004. * denotes significant difference at p‹ 0.01; ** denotes significant difference at p‹0.05.

Year	HIGH/REF	LOW/REF	HIGH/LOW
2001	0.178**	0.120**	0.091*
2002	0.637**	0.158**	0.459**
2003	0.602**	0.056	0.568**
2004	0.572**	0.222**	0.250**

Community groupings were explored further using the similarity percentages programme SIMPER. Table 5.3. shows the characterising species of the study sites in 2004. Generally, the fauna at all sites was characteristic of sandy gravel sediments. The lower dredging intensity and reference sites showed similar community structures across all years although the importance of the characterising species for each site was variable over time. The high dredging intensity site exhibited a decrease in the abundance of the opportunistic colonising species *Balanus crenatus* during 2002 and 2003 following the resumption of dredging within this area. In 2004, twelve months after dredging had ceased, *B. crenatus* had again become established within the high dredging intensity site along with the tube-dwelling polychaete, *S. spinulosa*.

Table 5.3. Results from SIMPER analysis of macrofauna data from Area X (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from samples subject to differing levels of dredging impact in 2004. Average abundance, average similarity and the % contribution to the similarity made by each characterising species is shown. Also listed is the cumulative percentage and the overall average similarity between replicate samples from within each group.

Group	Taxon	Average abundance	Average similarity	Similarity/ St.Dev.	% Contribution	Cumulative %	Overall average similarity
HIGH '04	*Sabellaria spinulosa*	133.70	2.74	1.61	7.03	7.03	39.03%
	Balanus crenatus	47.80	2.44	1.15	6.25	13.27	
	Poecilochaetus serpens	3.70	2.14	1.60	5.49	18.76	
	NEMERTEA	2.20	1.80	1.77	4.62	23.38	
	Galathea intermedia	2.70	1.78	1.79	4.56	27.94	
	Ampharete lindstroemi	2.50	1.51	1.17	3.88	31.82	
	Glycera tridactyla	1.50	1.36	1.15	3.48	35.30	
	Lumbrineris gracilis	3.30	1.33	1.23	3.42	38.72	
	Scalibregma inflatum	3.00	1.28	1.21	3.29	42.01	
LOW '04	*Lumbrineris gracilis*	9.00	1.89	1.77	4.79	4.79	39.55%
	Upogebia (juv.)	9.00	1.74	1.88	4.41	9.20	
	Pomatoceros lamarcki	8.10	1.62	1.82	4.09	13.29	
	Caulleriella alata	3.10	1.50	1.64	3.80	17.09	
	Mysella bidentata	8.90	1.45	1.15	3.67	20.76	
	Echinocyamus pusillus	3.90	1.32	1.04	3.35	24.10	
	Poecilochaetus serpens	9.60	1.24	1.20	3.15	27.25	
	Scalibregma inflatum	6.20	1.23	1.20	3.10	30.35	
	NEMERTEA	3.70	1.19	1.16	3.02	33.37	
	Mediomastus fragilis	4.70	1.12	1.21	2.83	36.20	
	Goniada maculata	1.50	1.11	1.07	2.81	39.01	
	Pholoe baltica	2.70	1.11	1.19	2.80	41.81	
REF '04	*Echinocyamus pusillus*	20.40	4.59	4.97	12.65	12.65	36.28%
	Praxillella affinis	3.20	2.69	5.69	7.41	20.06	
	Mysella bidentata	6.80	2.60	1.61	7.18	27.24	
	Lumbrineris gracilis	2.40	2.06	1.84	5.67	32.91	
	Notomastus	2.60	1.98	1.85	5.46	38.38	
	NEMERTEA	2.00	1.75	1.21	4.83	43.20	

5.3 Results (Hastings Area Y)

5.3.1 Sediment characteristics

Figures 5.15 allows inspection of the differences, in terms of mean particle size composition, between the high and lower dredging intensity and the reference sites in each year of the study (Figure 5.15a) and also within each site over the course of the investigation time (Figure 5.15b).

In terms of the mean particle size composition, sediments from the high dredging intensity and reference sites were similar and changed little over the period 2001-2003. Sediments from both sites were dominated by gravel although samples from the high dredging intensity site were more variable with a number of predominately sandy samples being found at this site. These sandy samples were not encountered at the reference sites.

In contrast,sediment samples collected from within the area of lower dredging intensity over the same period were much finer, containing proportionally less gravel and more medium sand. However in 2004, whilst the sediment composition at the lower dredging intensity and reference sites remained consistent with previous years, sediments at the high dredging intensity site became finer as a result of a decrease in the mean proportion of gravel and a corresponding increase in the proportion of medium sand.

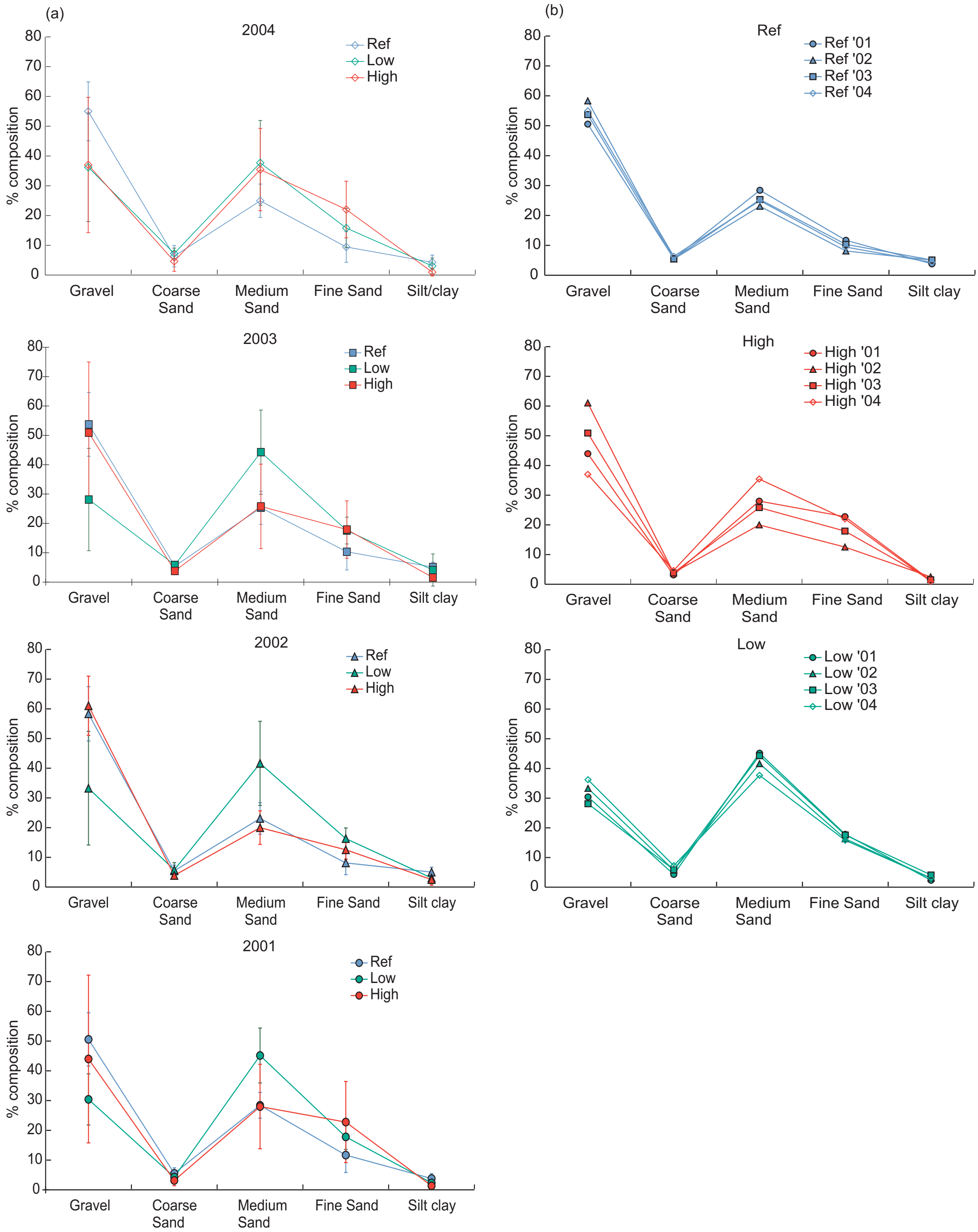


Figure 5.15. a) Annual comparisons of mean particle size composition of sediments taken from high and lower dredging intensity and reference sites (2001-2004). b) Annual records from each site are displayed together to allow inspection of the between year variation in average sediment composition (2001-2004).

5.3.2 Acoustic surveys

Figure 5.16 shows the sidescan sonar images of the sediments within and surrounding the high and lower dredging intensity sites at Hastings Area Y between 2001 and 2004. These images show the presence of weathered dredge tracks which are aligned in a NE - SW direction within both of the sites. The tracks are clearly present within the high dredging intensity site in all years and, to a lesser degree, within the lower dredging intensity site. Generally, where present, the tracks have weathered and infilled with sand to such an extent that they have agglomerated to form elongated sandy features and are difficult to distinguish as individual tracks. In all years, the sediments in the lower dredging intensity site appear to comprise of a distinct sandy (possibly agglomerated dredge tracks) and coarser facies. The sediments within the high dredging intensity site appear to be coarser in nature but are also characterised by dredged tracks which are infilled with sand to some degree.

Dredging commenced to the south of the high and lower dredging intensity sites in 2002 and evidence of this activity can be seen as intensive dredge tracks in the south eastern corner of the images that were collected in 2002 and 2003. Evidence of continued dredging in this area is evident from the 2004 sidescan sonar imagery. Given that the net sediment transport pathway in the area is to the north east (HR Wallingford, 1993; HR Wallingford, 1999; EMU, 1999 and Rees *et al.*, 2000) it might be expected that any fine sediment that had been mobilised as a result of this activity might contribute to a fining of the sediment within the high and, to a lesser extent, lower dredging intensity sites. However, the comparison of sidescan sonar imagery to determine evidence of subtle changes in substrate type can be difficult. This is due to a number of operational factors that affect the image quality and which can vary between surveys (e.g. weather conditions, system configuration, navigational inaccuracies). Nevertheless, a comparison between the 2001-2004 surveys suggests that there may have been some deposition of fine material immediately to the north of the northern margin of the recent dredging activity, and also to the east of the high dredging intensity site.

The multibeam bathymetry data collected in 2003 shows the location of the high and lower dredging intensity sites in relation to the topographic features present at the seabed (Figure 5.17). The weathered dredged furrows caused by suction trailer dredging activity can be clearly seen within the high and, to a much lesser extent, lower dredging intensity sites. The physical effects of the recent dredging activity to the south west of the sites is also apparent and provides a comparison between the topographical manifestation of weathered and fresh dredging impacts.

Using multibeam bathymetric data from 2003, a series of 200 m long profiles of the seabed through each of the sites have been generated and are shown in Figure 5.18. The profile across the reference site shows a smooth seabed with topographic variations less than 20 cm. The lower dredging intensity site shows a smooth undulating seabed with a topographic variation around 30 cm. The profile across the high dredging intensity site shows a strong, but smoothed topographic relief with a difference around 1.20 m. Just south of the high dredging intensity site aggregate extraction has taken place since 2001 (Lane 9B). To illustrate the difference between recent extraction activities and relinquished extraction sites a profile across the recent extraction area is shown in Figure 5.18 (Lane 9B). This profile shows very rough seabed topography with many narrow incisions and a change in topography around 1.50 m. Compared to the seabed within the relinquished high dredging intensity site the seabed topography within this current actively dredged zone is much more variable. A widening and shallowing of dredging related features was suggested from comparison of individual furrows at Hastings Area X and this also appears to be occurring at Area Y.

Profiles across the same section of the seabed within the high dredging intensity site, measured using multibeam bathymetric datasets from 2003 and 2004, are presented in Figure 5.19. Changes over the one-year period were small and did not reveal any evidence of physical ‘recovery’. Due to the limited amount of temporal multibeam bathymetric datasets, it is not possible, at present, to quantify the rate of erosion of dredge tracks at this site. However, this technique and resulting data analyses offer great potential for monitoring the persistence and erosion of dredge tracks at these and other sites over time.

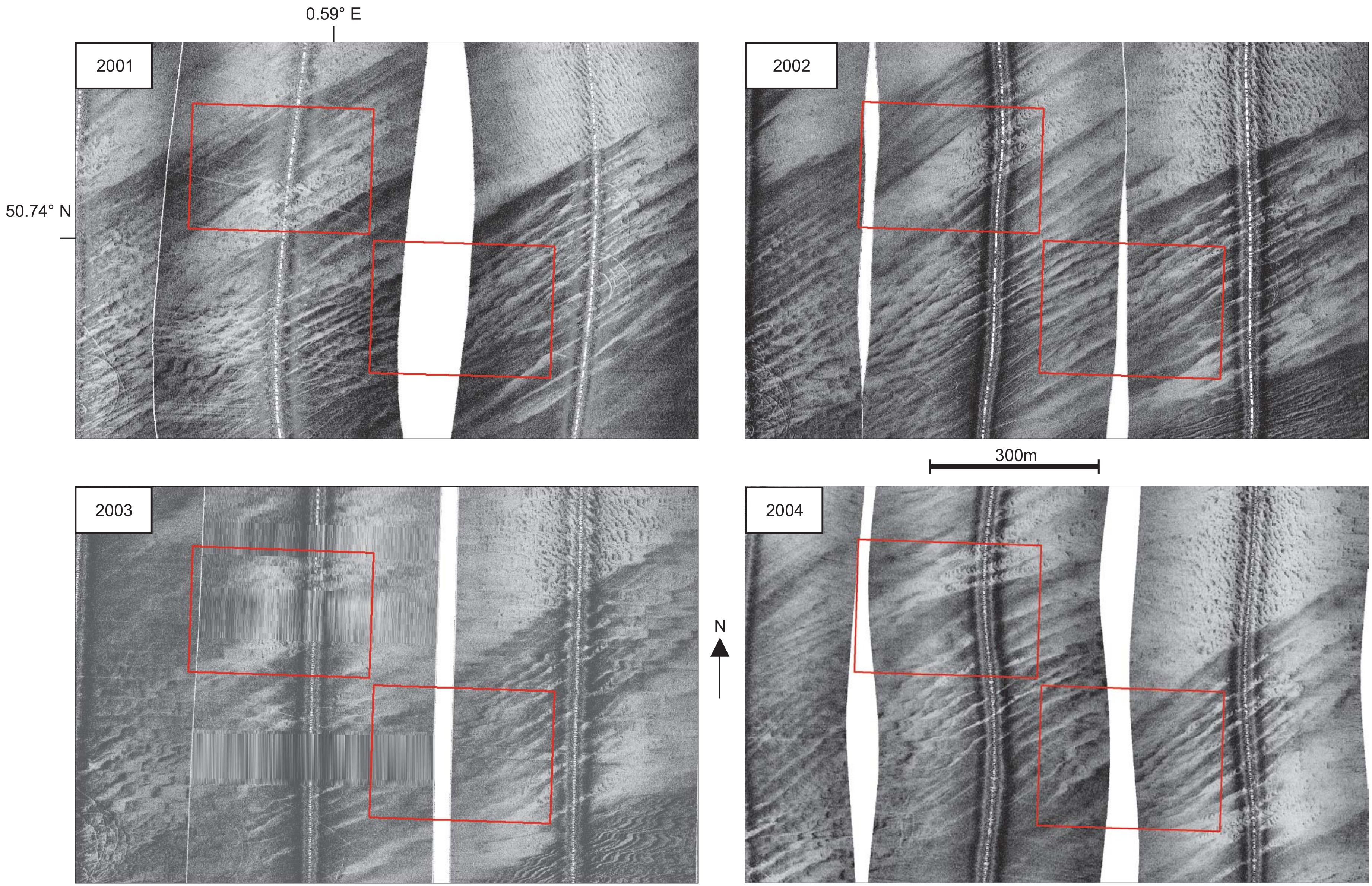
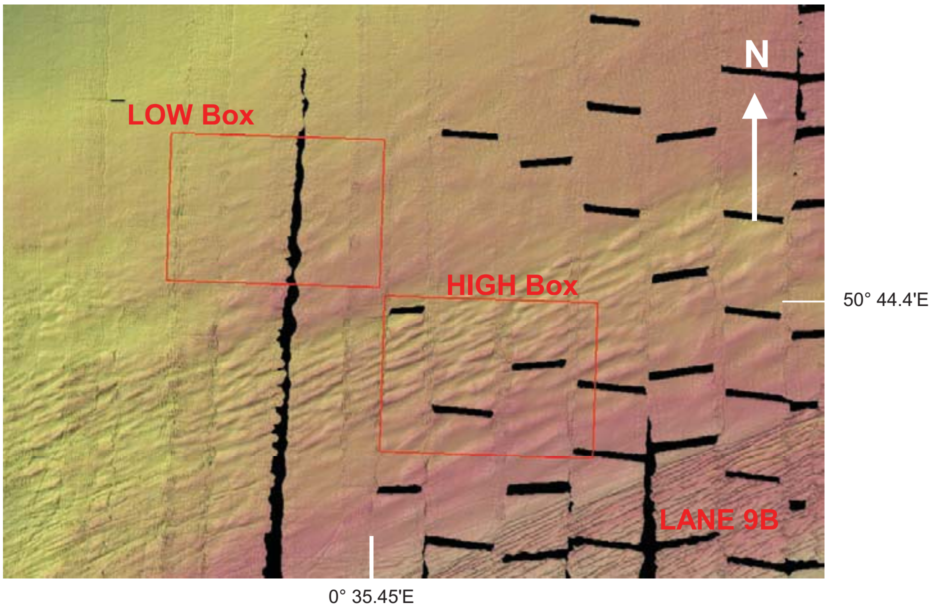


Figure 5.16. Sidescan sonar images of the high and low dredging intensity boxes at Area Y (2001-2004).

Figure 5.17. Overview of the 2003 multibeam bathymetry results in Hastings Area Y. Differences in physical impacts between historic high and low intensity dredged areas are noticeable, as well as the difference with recent extraction activities in Lane 9B.



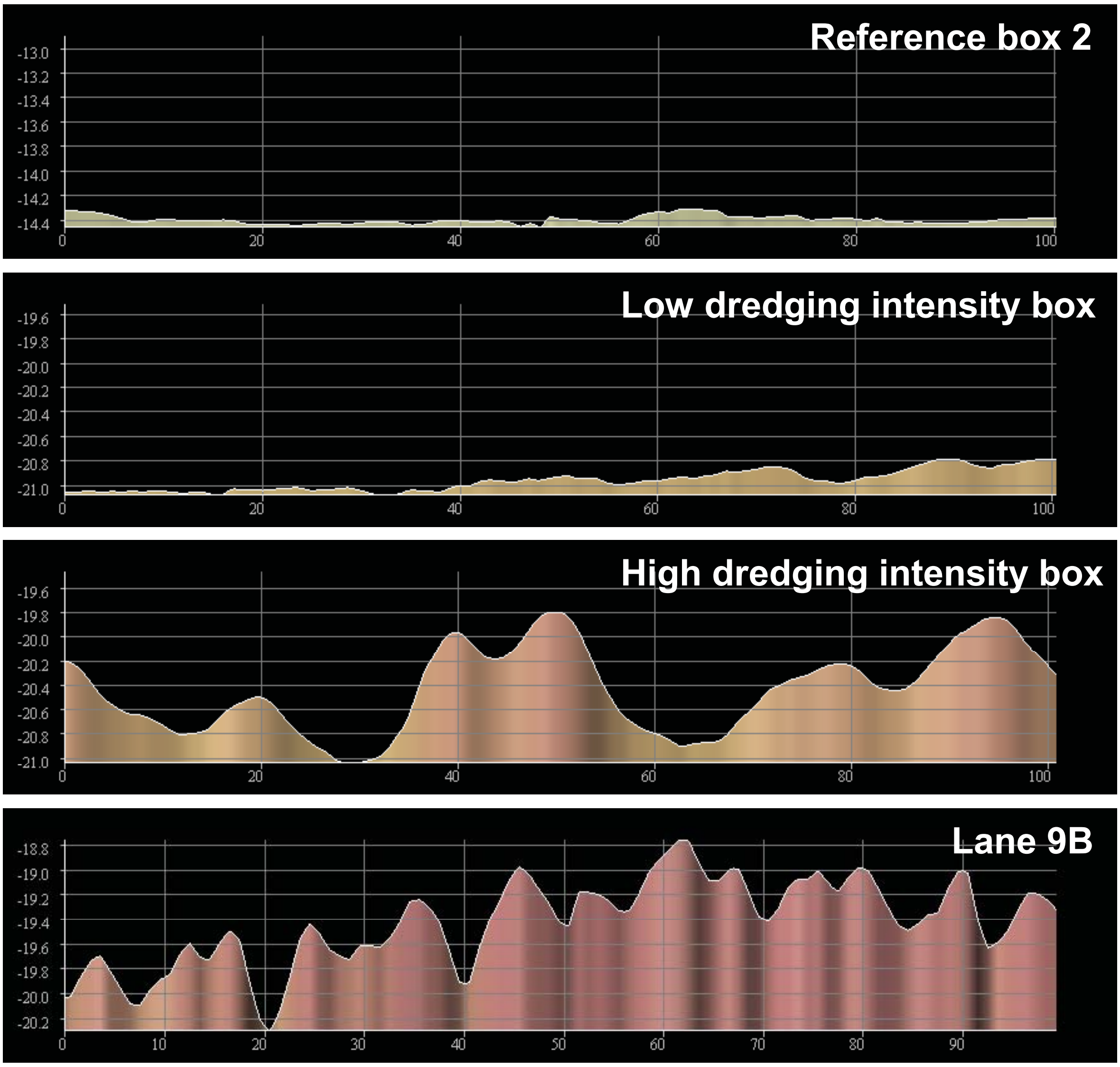
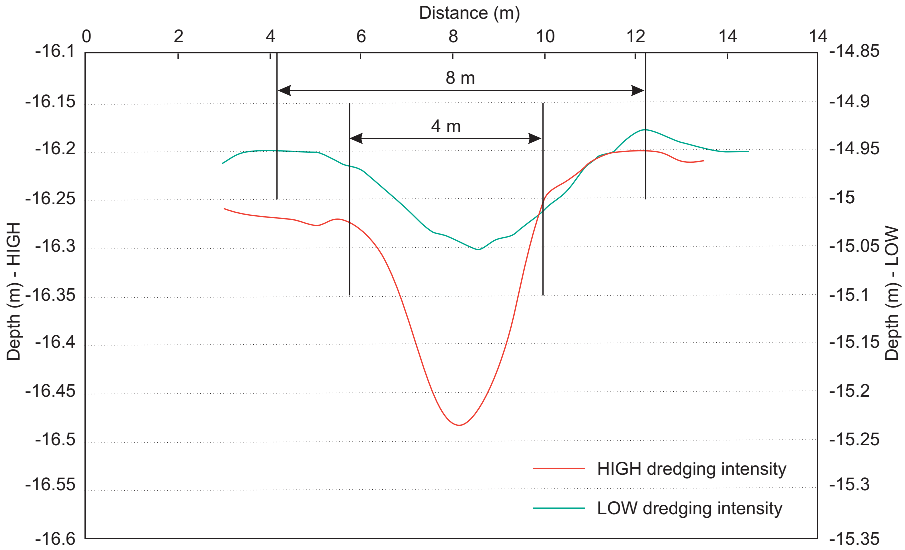


Figure 5.18. Seabed profiles from the 2003 multibeam bathymetric survey carried out at Hastings Area Y. The profile from lane 9B shows the impact of recent dredging activities.

Figure 5.19. Difference in seabed profile from the same area between the 2003 and 2004 multibeam bathymetry surveys in Hastings Area Y high dredging intensity site.



5.3.3 Macrofaunal assemblage structure

Univariate Analyses

In 2004, ANOVA results showed that there were no significant differences in terms of numbers of species, abundance and biomass between any of the sites (see Figure 5.20). However, this lack of difference can be largely attributed to declines in univariate indices at the reference sites as opposed to 'recovery' at dredged sites. This illustrates the importance of a proper understanding of natural variability, without which false conclusions can easily be drawn.

Figure 5.21 shows the change in abundance of selected individual species within each site from 2001 to 2004. For many species fewer individuals were found at the lower intensity site. Examples include the crustaceans *Balanus crenatus* and *Galathea intermedia* and the polychaete *Pomatoceros lamarcki*. A number of species, including the polychaete *Sabellaria spinulosa* and the bivalve *Mysella bidentata*, also had reduced densities at both high and lower dredging intensity sites. However, one or two species such as the burrowing amphipod *Bathyporeia elegans*, were found in higher numbers at the dredged sites, possibly due to the sandier sediments.

Multivariate analyses

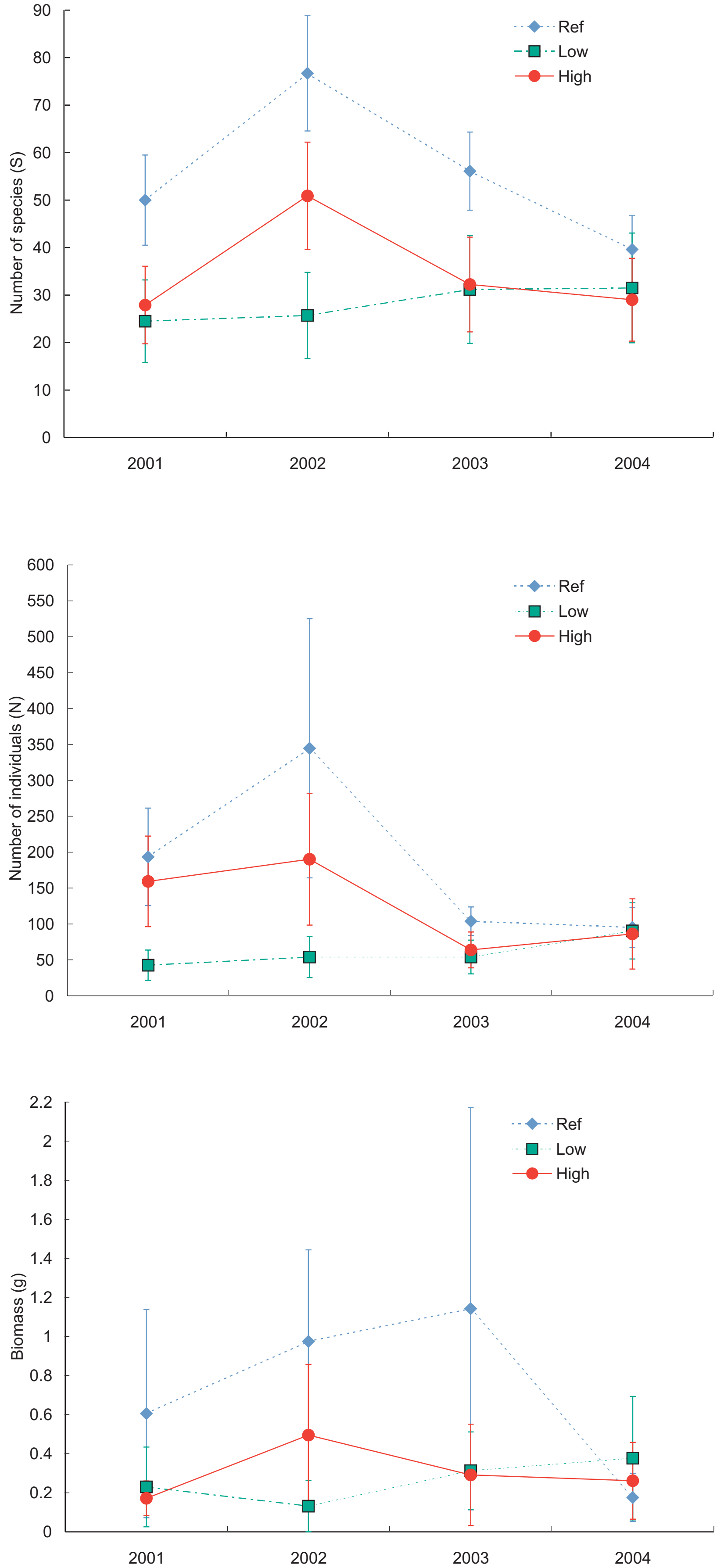
Figure 5.22 shows the output from the non-metric multi-dimensional scaling ordinations of macrofaunal abundance data from the Hamon grab surveys carried out at Area Y. Still evident in 2004 is the much higher degree of variability between replicate samples derived from the dredged locations, compared with the reference samples, as depicted by the much wider spread of samples from the dredged sites in the MDS ordination.

The results of an ANOSIM test (Table 5.4) confirm that significant differences still exist between dredged and reference sites. There is also no evidence that the difference between high and reference sites is becoming smaller over time. This is perhaps not surprising given that 'recovery' appeared to take 6 years at the nearby Area X lower dredging intensity site. However, the situation is less certain between the lower dredging intensity and reference sites where ANOSIM values have declined over the last 3 years of study. This assessment is made very difficult as a result of the variability at the reference site and serves to illustrate the importance of properly understanding natural variability, which can only be established through an extended period of monitoring.

However, in 2004, no significant difference was detected between high and lower dredging intensity sites. This indicates that these two sites have become increasingly similar in this year.

The community groupings were explored further using the similarity percentages programme SIMPER and the results revealed characterising species from each of the treatment groups in 2004 (Table 5.5). From 2001-2003, the area of high dredging intensity supported a mix of epifaunal and infaunal species, particularly in 2001, whereas many more epifaunal species associated with coarser sediments typified the reference samples. In contrast, characterising species from the area of lower dredging intensity were mainly infaunal and more typical of sandy substrata (e.g. burrowing amphipods such as *Bathyporeia elegans* and *Gastrosaccus spinifer* were present at this site, as were the polychaetes *Spiophanes bombyx* and *Ophelia borealis*). Interestingly the characterising fauna found at the high dredging intensity site in 2004 became much more similar to the fauna found at the lower dredging intensity site. As with the Hastings Area X data, the barnacle *Balanus crenatus* dominated samples from both the area of high dredging intensity and reference sites in 2001. Again, the relative importance of this species in terms of its percentage contribution to the overall similarity was less in reference samples compared with those obtained from the area of high dredging intensity. Furthermore, the dominance of this species diminished at both of these sites in 2002, 2003 and 2004 resulting in a more equitable distribution of densities among the species.

Figure 5.20. Summary of means and 95% confidence intervals for numbers of species (S), number of individuals (N) and biomass (AFDW (g)) from sites of high and lower levels of dredging intensity and two nearby reference sites at Area Y in 2001-2004.



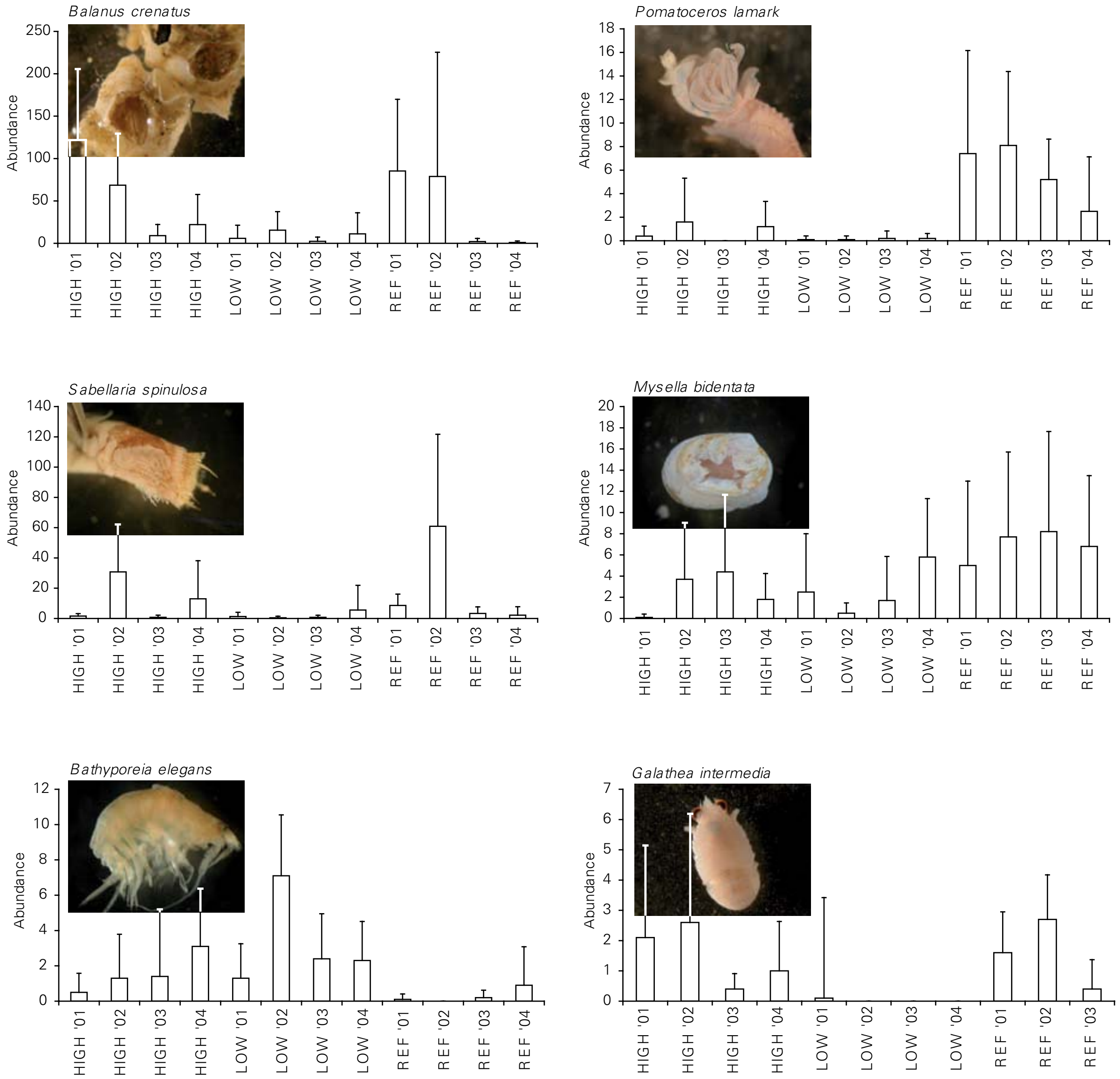


Figure 5.21. Means (± SD) of abundances of selected macrofaunal species sampled in 2001-2004 at sites of high and lower levels of dredging intensity and at two reference sites (codes as in Table 5.1).

Figure 5.22. MDS of Bray-Curtis similarities from 4th root transformed species abundance data at the high and lower dredging intensity sites and at two reference sites.

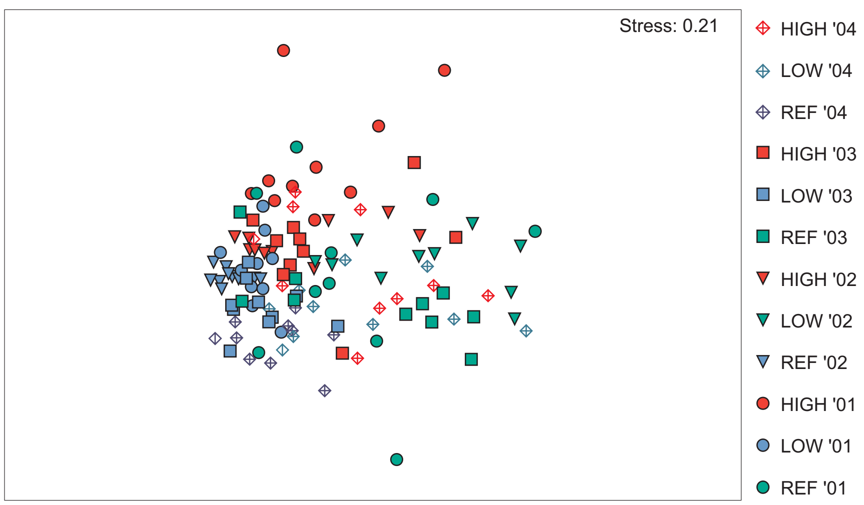


Table 5.4. R-values derived from the ANOSIM test for macrofaunal assemblages from locations of high and lower dredging intensity and from the reference sites in 2001-2004 at Area Y. ** denotes significant difference at p<0.05.

Year	HIGH/REF	LOW/REF	HIGH/LOW
2001	0.411**	0.337**	0.289**
2002	0.283**	0.752**	0.436**
2003	0.413**	0.322**	0.243**
2004	0.466**	0.128**	0.036

Table 5.5. Results from SIMPER analysis of macrofauna data from Area Y (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from samples subject to differing levels of dredging impact in 2004. Average abundance, average similarity and the % contribution to the similarity made by each characterising species is shown. Also listed is the cumulative percentage and the overall average similarity between replicate samples from within each group.

Group	Taxon	Average abundance	Average similarity	Similarity/ St. Dev.	% Contribution	Cumulative %	Overall average similarity
HIGH '04	NEMERTEA	1.50	3.60	3.54	11.90	11.90	30.26%
	Echinocyamus pusillus	8.40	3.19	1.21	10.56	22.46	
	Bathyporeia elegans	3.10	2.47	0.83	8.17	30.62	
	Spiophanes bombyx	1.60	2.04	0.84	6.75	37.38	
	Phoronis	1.20	1.55	0.88	5.13	42.50	
LOW '04	*Echinocyamus pusillus*	9.10	3.40	1.60	11.28	11.28	30.16%
	Bathyporeia elegans	2.30	2.64	0.93	8.77	20.05	
	NEMERTEA	2.00	2.53	1.50	8.39	28.44	
	Nephtys (juv.)	1.00	2.29	0.98	7.61	36.05	
	Lagis koreni	2.80	1.83	1.17	6.08	42.12	
REF '04	*Echinocyamus pusillus*	20.40	4.59	4.97	12.65	12.65	36.28%
	Praxillella affinis	3.20	2.69	5.69	7.41	20.06	
	Mysella bidentata	6.80	2.60	1.61	7.18	27.24	
	Lumbrineris gracilis	2.40	2.06	1.84	5.67	32.91	
	Notomastus	2.60	1.98	1.85	5.46	38.38	
	NEMERTEA	2.00	1.75	1.21	4.83	43.20	
	Glycera lapidum (agg.)	1.50	1.52	1.22	4.19	47.39	

6. Temporal investigations of the physical and biological status of Area 408

6.1 Methods

6.1.1 Study Site

The study site, Area 408, is located in an area known as the Coal Pit, 100 km east of the Humber estuary in the southern North Sea (Figure 6.1). Water depths at Area 408 range between 22 and 33 m LAT and the tidal ellipse is orientated in a NW-SE direction. Maximum spring tidal velocity reaches 1.0 ms^{-1} and the residual tidal direction and subsequent sediment transport is predominately to the south-east. However, a series of bedforms located in the west of Area 408 suggest a reversal in transport direction (Coastline Surveys Europe Ltd, 2002).

The site was licensed for sand and gravel extraction in 1995 and dredging commenced in 1996. As a condition of the extraction licence, the site was subdivided into a number of discrete zones in order to limit the active operational area within the licence. This was instituted in order to limit the geographical scale of environmental impact during any one period and minimise disruption to fishing or other activities. Dredging in one of these zones (Zone 2) ceased in 2000 following the removal of 1,459,131 tonnes over a period of four years between 1996 and 1999. Zone 2 occupies an area of 2.56 km^2. Screening of dredged cargoes was carried out at this site in order to achieve the required ratio of sand and gravel. This screening resulted in the return of 38% of the material removed from the seabed in 1998 across the licensed area. The cessation of dredging operations in this zone allowed an investigation of the status of the seabed fauna and sediments in a 'fallow' area of a currently zoned marine aggregate extraction licence.

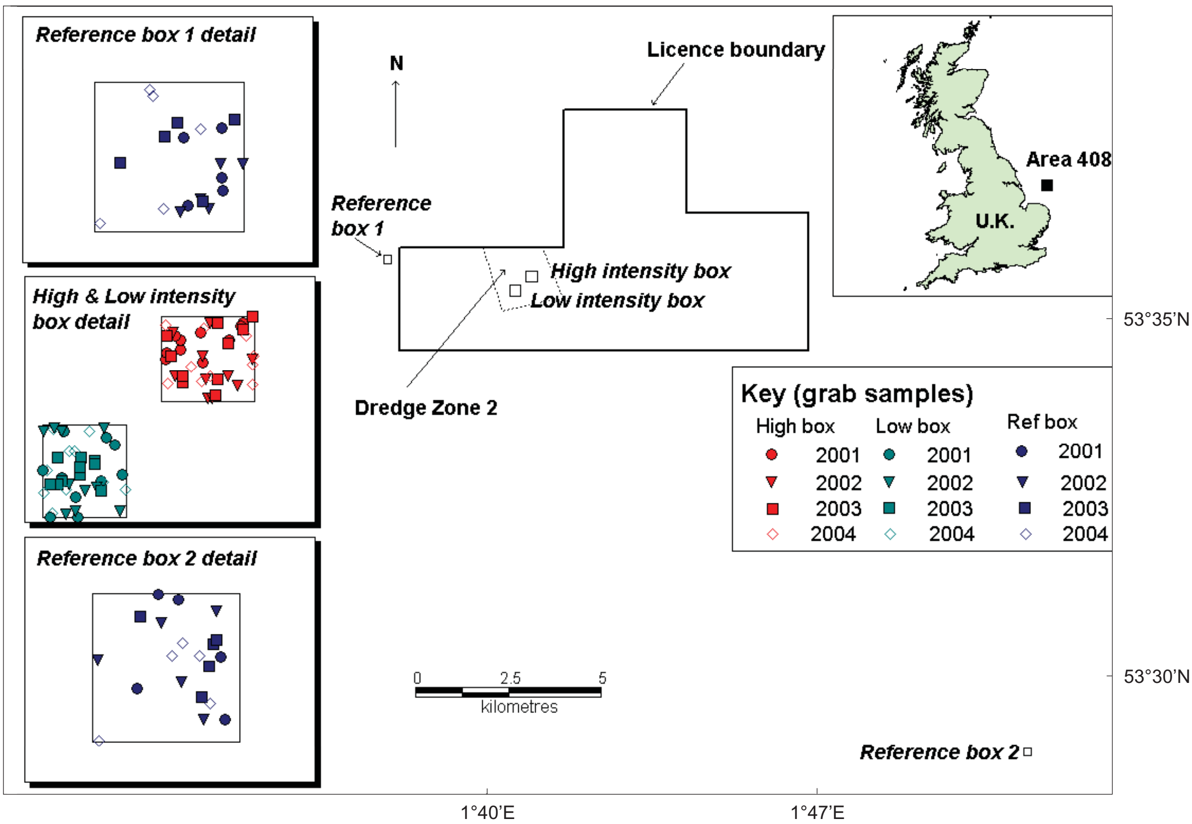


Figure 6.1. Map showing the location of Area 408 aggregate extraction licence and sampled stations from surveys carried out in 2001 – 2004.

Table 6.1. Co-ordinates of the sampling boxes and numbers of samples collected from 2001-2004 at Area 408.

Treatment	Code	Box co-ordinates		Area (m^2)	Number of samples collected			
		Latitude	Longitude		2001	2002	2003	2004
High intensity box	HIGH ‘01 to ‘04	53° 35.670’ N 53° 35.514’ N	01° 40.956’ E 01° 41.244’ E	~90,000	10	10	10	10
Low intensity box	LOW ‘01 to ‘04	53° 35.472’ N 53° 35.304’ N	01° 40.590’ E 01° 40.848’ E	~90,000	10	10	10	10
Reference box 1	REF 1 ‘01 to ‘04	53° 35.899’ N 53° 35.785’ N	01° 37.491’ E 01° 37.683’ E	~45,000	5	5	5	5
Reference box 2	REF 2 ‘01 to ‘04	53° 28.737’ N 53° 28.623’ N	01° 53.126’ E 01° 53.316’ E	~45,000	5	5	5	5

6.1.2 Sampling design

EMS data was used in order to locate areas of seabed subjected to different levels of dredging intensity within Zone 2. Based on data from 1998, the last year of any significant dredging activity, areas of high and lower levels of dredging intensity were identified. The area of high dredging intensity represents >5 hours of dredging within each 100 m by 100 m block whereas the area of lower dredging intensity is equivalent to <1 hour of dredging within each 100 m by 100 m block. Based on this information, treatment boxes, measuring 300 m by 300 m, were assigned to these two areas of the seabed. Within each treatment box, 10 randomly positioned 0.1 m^2 Hamon grab samples were collected from 2001 to 2004 that is 2 - 5 years after the cessation of dredging. In addition, two reference sites (Reference Box 1 and 2) were also sampled over the same period. The dimensions of each reference site are half those of the high and lower dredging intensity sites. In order to achieve the same sampling density as the dredged sites, five replicate samples were collected from each of the reference sites. When combined, the data from these two reference sites provide a similar density of samples per unit area as those collected from the dredged sites. Details of the locations sampled as part of the Area 408 time-series investigations are presented in Table 6.1.

6.2 Results

6.2.1 Sediment characteristics

Figures 6.2 allows inspection of the differences, in terms of mean particle size composition, between the high and lower dredging intensity and the reference sites in each year of the study (Figure 6.2a) and also within each site over the course of the investigation (Figure 6.2b). Throughout the period of investigation, the high dredging intensity and reference sites remained relatively similar with regards to their sediment characteristics, although the high intensity dredging site showed greater variability and contained proportionally more coarse sand and less fine sand. Since 2001 the sediments at the lower dredging intensity site have become coarser i.e. an increase in the proportion of gravel and decrease in medium sand. The high and lower dredging intensity sites showed greater variability in the composition of sediment samples 2001-2004 compared to the reference sites.

6.2.2 Acoustic surveys

Sidescan sonar data, collected over the period 2001-2004, reveal differences in the distribution of sediments across Zone 2 (Figures 6.3). Moving from east to west, the amount of exposed gravel decreases and this is increasingly overlain by a veneer of mobile sand. The 2004 sidescan sonar images show a more homogeneous seabed compared to previous years. This may be a result of further eastward progression of the mobile sand layer. This sand veneer increases in thickness from east to west and appears to form megaripples in the extreme west of the zone. These changes may account for the differences in sediment composition of the high and lower dredging intensity sites. In the high dredging intensity site, underwater video footage revealed gravel sediments are frequently exposed at the surface, although there are occasional patches of what appears to be a sand veneer. Underwater TV surveys from previous years have shown attached colonial epifaunal species such as the cnidarian *Alcyonidium diaphanum*, the bryozoan *Flustra foliacea* and hydroids were common within the area of high dredging intensity. In contrast, sandy sediments dominated the lower dredging intensity site and the sand veneer appeared to be thicker, forming sand ripples and sand waves. Colonial epifaunal species were much less frequent in this area than in the area of high dredging intensity.

Weathered dredge tracks from suction hopper dredging can still be seen in the area of high dredging intensity in 2004, although becoming less distinct than in earlier surveys. The reference sites appear to be dominated by exposed gravels with conspicuous epifaunal taxa including *Alcyonium digitatum* and *Flustra foliacea*. The sidescan sonar images show a homogeneous gravelly seabed from 2000-2004 (Figures 6.4-6.5).

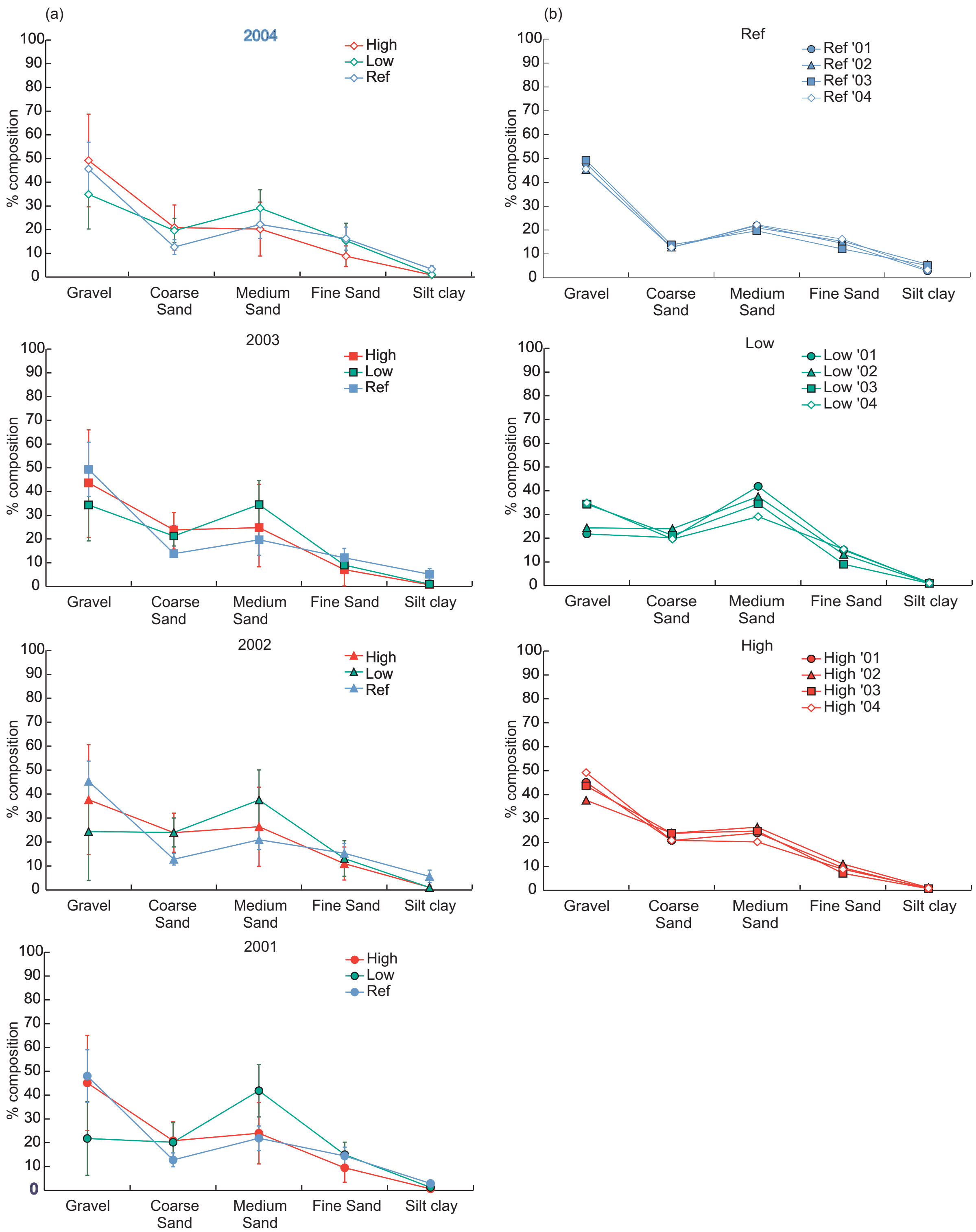
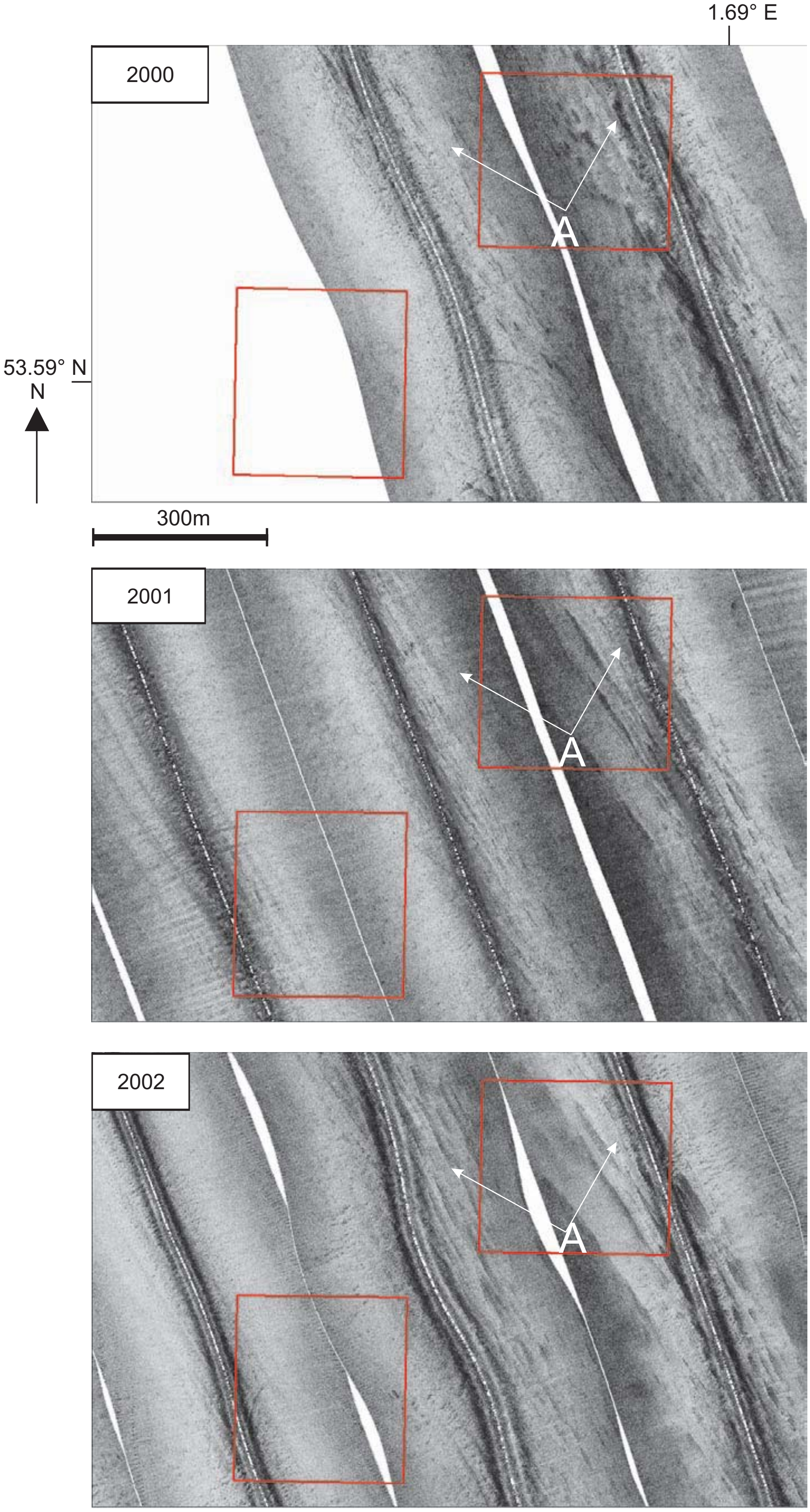
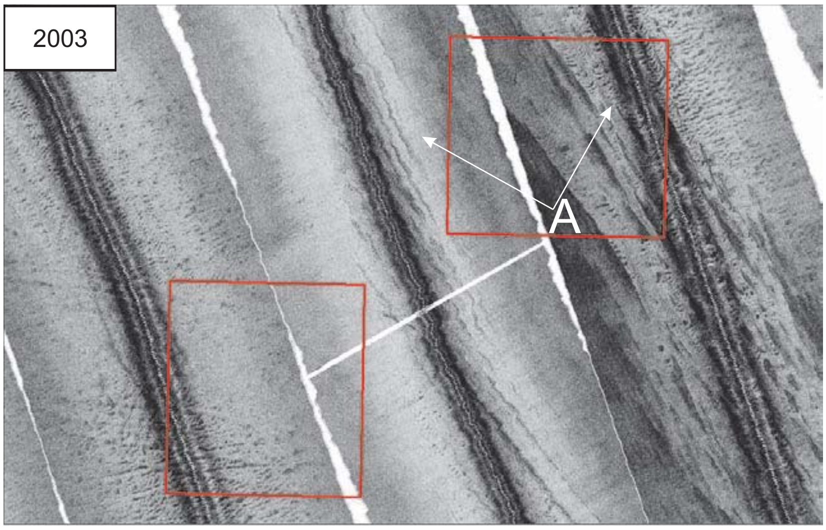


Figure 6.2. a) Annual comparisons of mean particle size composition of sediments taken from sites of high and lower dredging intensity and reference sites (2001-2004). b) Annual records from each site are displayed together to allow inspection of the between year variation in average sediment composition (2001-2004).

Figure 6.3. Sidescan sonar images of high (top right red box in each image) and low (bottom left red box in each image) dredging intensity sites at Area 408 (2000 – 2004). A) Area of weathered trailer suction hopper dredge tracks 2000 - 2003.





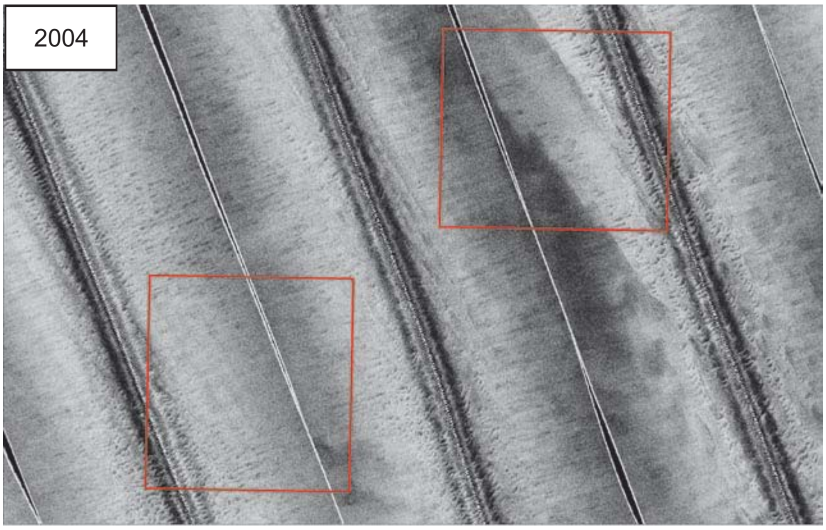


Figure 6.3. continued: Sidescan sonar images of high (top right red box in each image) and low (bottom left red box in each image) dredging intensity sites at Area 408 (2000 – 2004). A) Area of weathered trailer suction hopper dredge tracks 2000 - 2003.

Figure 6.4. Sidescan sonar images of reference site 1 at Area 408 (2002 – 2004).

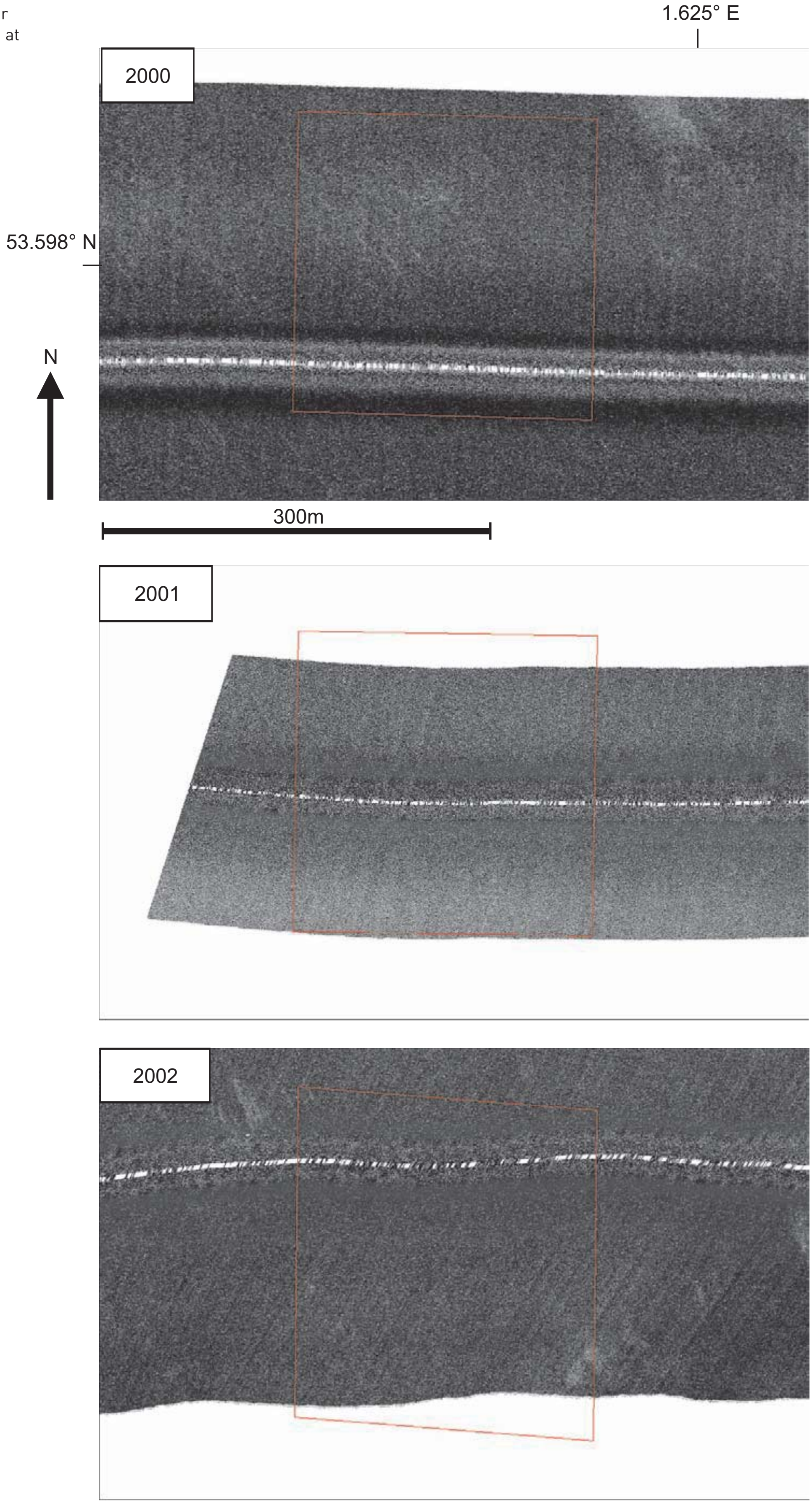
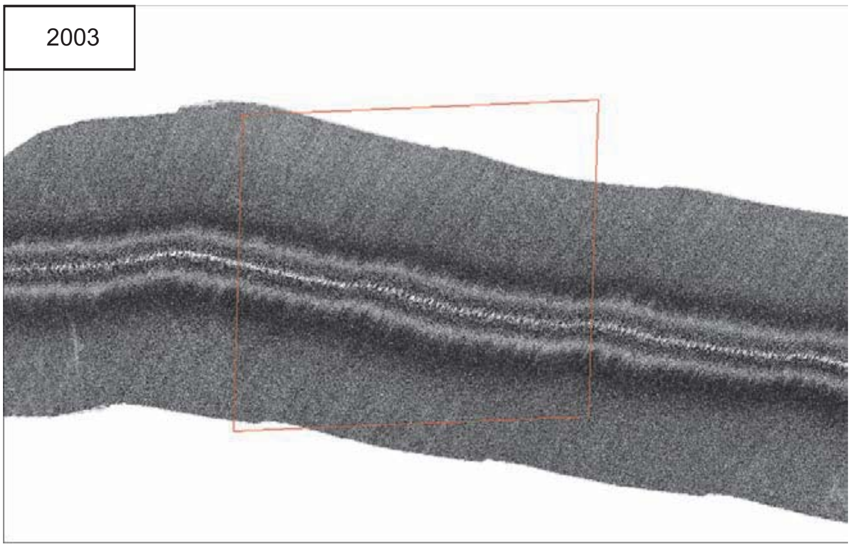
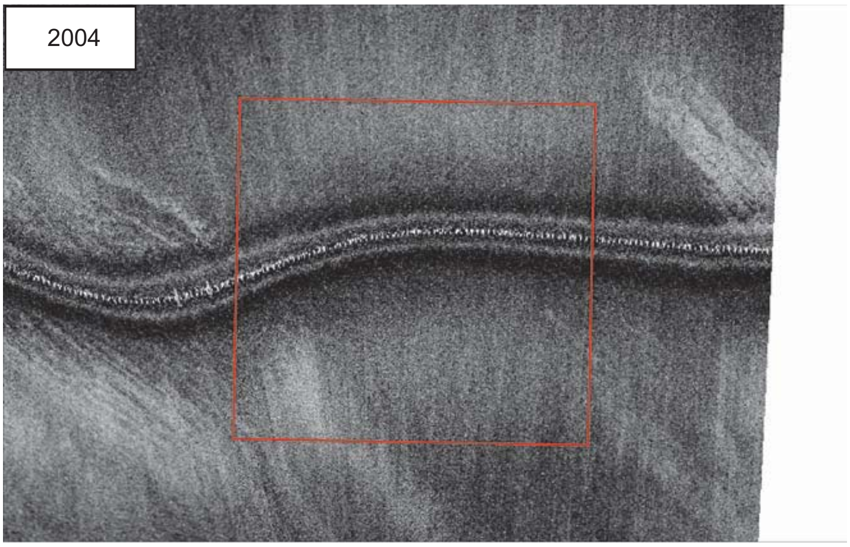


Figure 6.4. continued:
Sidescan sonar images of reference site 1 at Area 408 (2002 – 2004).





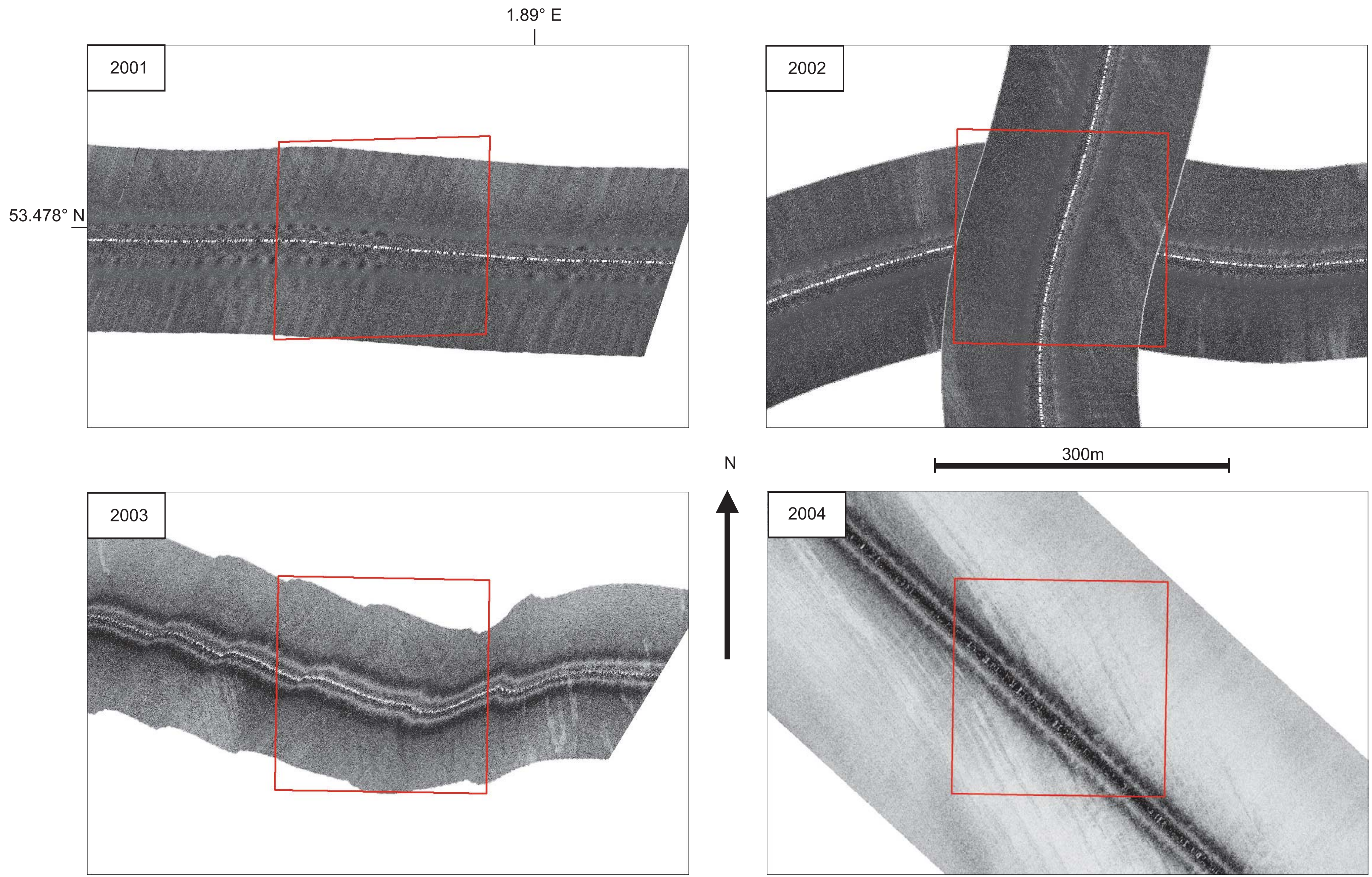


Figure 6.5. Sidescan sonar images of reference site 2 at Area 408 (2001 – 2004).

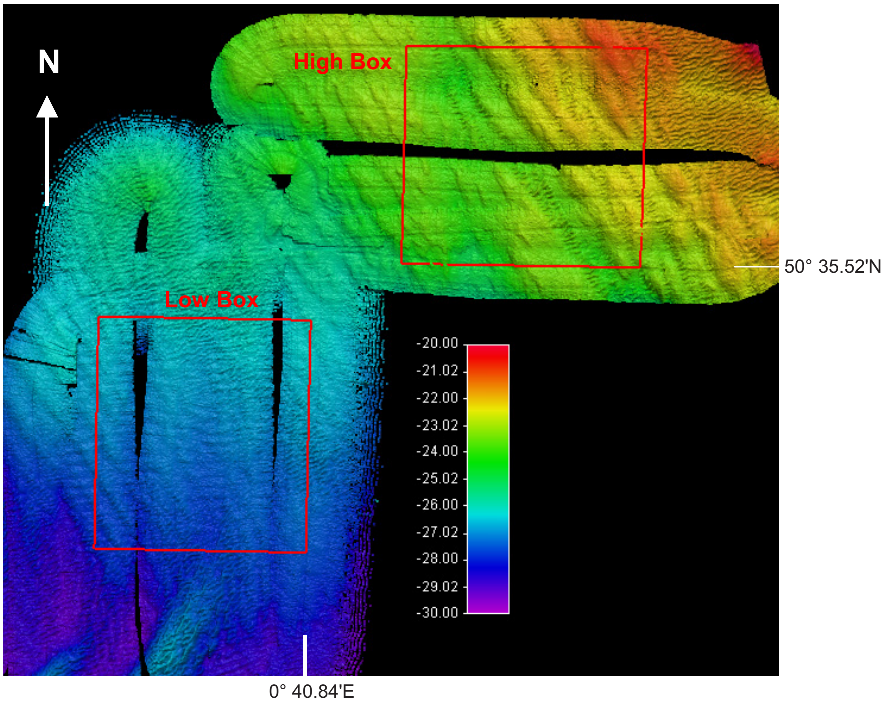


Figure 6.6. Overview of the 2004 multibeam survey result at Area 408.

Results from a multibeam bathymetric survey carried out in 2004 around the high and lower dredging intensity sites are shown in Figure 6.6. Water depths in the area vary from 30 m (in between the sandwaves in the southwest of the area) up to 20 m (in the megaripples fields in the northeast of the area). The seabed in most of the area is occupied by megaripples, particularly to the east of the high dredging intensity site and to the north of the low dredging intensity site. In the southern part of the area sandwaves superimposed with megaripples dominate the seabed morphology.

Figure 6.7 shows that the seabed topography in the high dredging intensity site is characterised by NNW-SSE running features. These coincide with the main direction of dredging activities and are therefore thought to be a result of aggregate extraction activities. Similar features can be seen in the lower dredging intensity site, although they are less pronounced because of the lower dredging intensities in the area. Individual furrows, which can be recognised in areas of recent dredging activities, were not detected in the area. This suggests that physical 'recovery' of the seabed has taken place in the area. It is thought that the absence of topographic impacts on the seabed in this area may have been facilitated by the mobile sediments. The megaripple field to the east of the high dredging intensity site confirms this presence of mobile sands in the area.

6.2.3 Macrofaunal assemblage structure

Univariate Analyses

Figure 6.8 shows a comparison of various univariate measures at each sampling site between 2001-2004. A one-way ANOVA detected no significant difference between the high and lower dredging intensity sites in any of the univariate measures over the period of the investigation. Between 2001-2004, both dredged sites had significantly lower values of all univariate measures compared to the reference sites. Some of the macrofaunal species that contributed to the differences between the dredged and reference sites were *ACTINARIA* and *NEMERTEA*, the amphipods *Urothoe elegans* and *U. marina*, the polychaete *Notomastus* sp. and the bivalve *Mysella bidentata*. These were lower in abundance at the dredged sites than at the reference sites (see Figure 6.9).

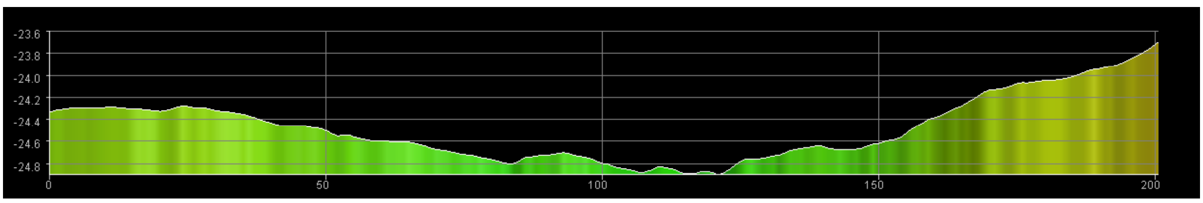
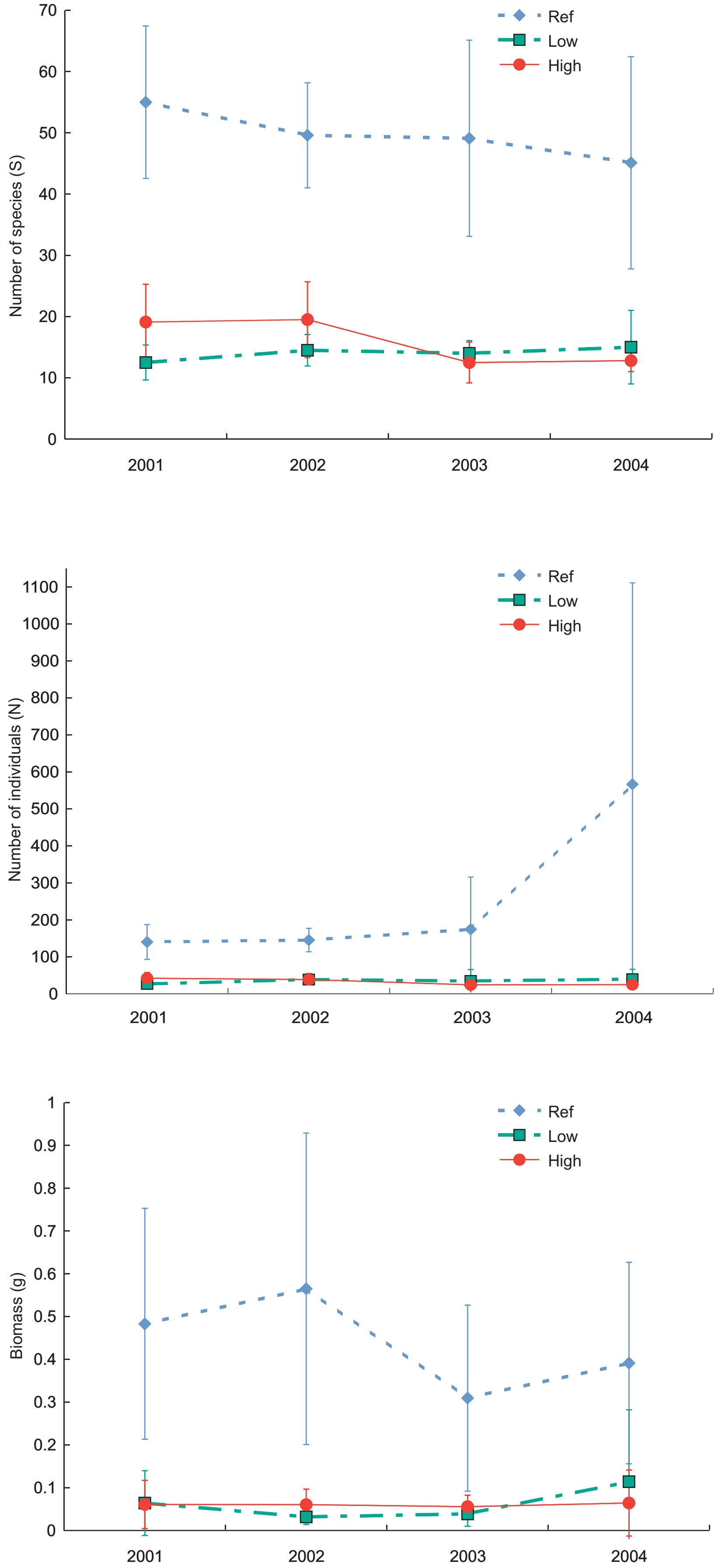


Figure 6.7. Seabed profile across the high dredging intensity site at Area 408 showing a smooth seabed.

Figure 6.8. Summary of means and 95% confidence intervals for number of species (S), number of individuals (N) and biomass (AFDW) from sites of high and lower levels of dredging intensity and two nearby reference sites at Area 408 in 2001-2004.



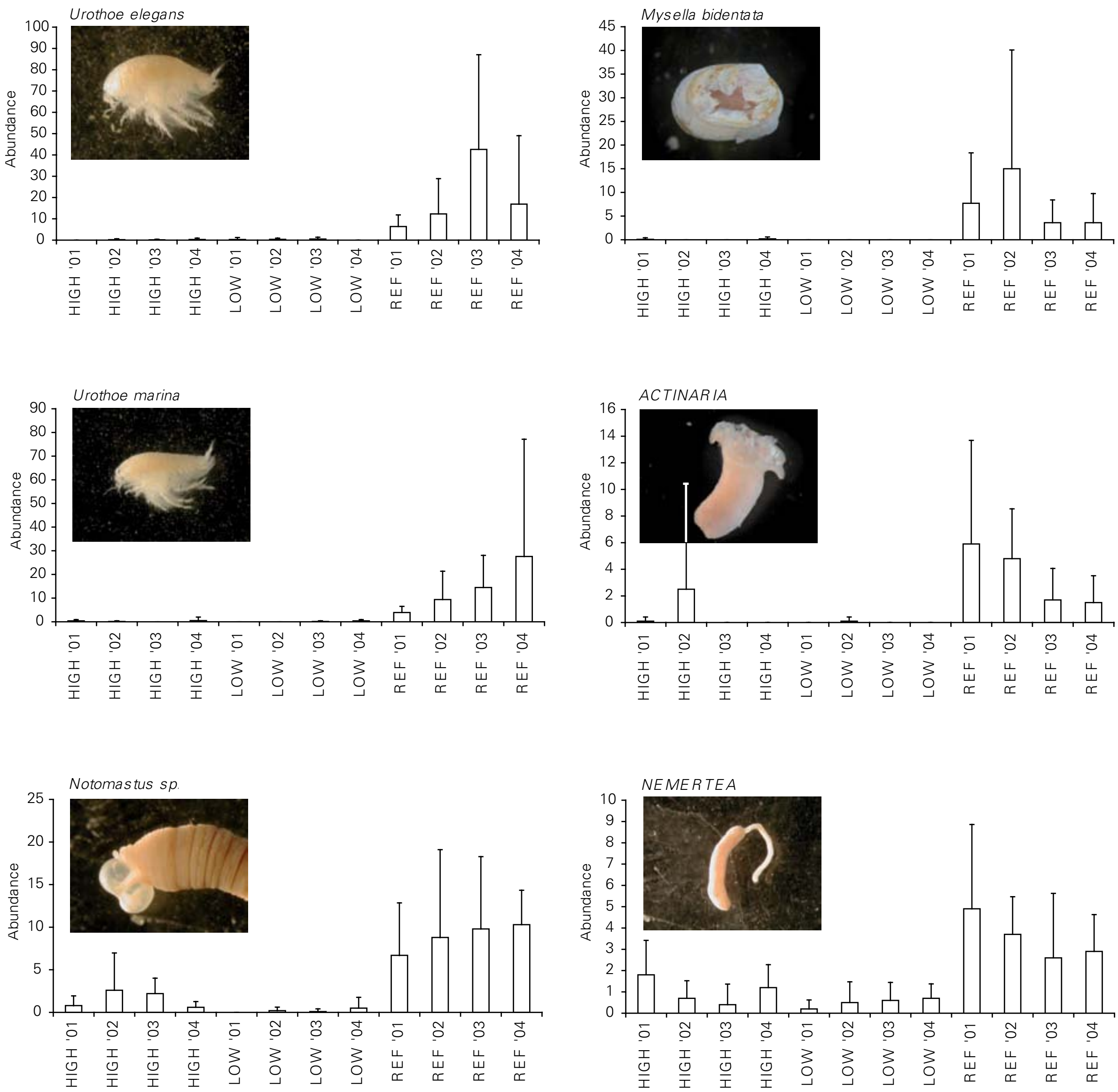


Figure 6.9. Means (±SD) of abundances of selected macrofaunal species sampled in 2001-2004 at sites of high and lower levels of dredging intensity and at two reference sites (codes as in Table 6.1).

Multivariate Analyses

The MDS ordination for macrofaunal assemblages collected at sites of high and lower dredging intensity and at the two reference sites between 2001-2004 is presented in Figure 6.10. The samples from the high dredging intensity site were more diffusely separated compared to the reference samples, with some overlap with the samples from the lower dredging intensity site.

Comparison of the R-values derived from the ANOSIM test (Table 6.2) shows a large significant difference between the lower dredging intensity site and the reference sites in the first few years of the investigation, which decreases slightly in 2004. The differences between the lower dredging intensity site and the reference sites are greater than between the high dredging intensity site and the reference sites. No obvious trend in the R-values was observed during the investigation that would indicate increasing similarity between sites over time.

The SIMPER results revealed characterising species from each of the treatment groups in 2004 (Table 6.3). As in previous years, the dredging sites were dominated by relatively few, tolerant, sand-dwelling polychaetes such as *Ophelia borealis*. In contrast, a greater range of characterising species was found at the reference sites.

Figure 6.10. MDS of Bray-Curtis similarities from 4th root transformed species abundance data 2, 3, 4 and 5 years (2001-2004) after the cessation of dredging at high and low levels of dredging intensity and at the reference sites.

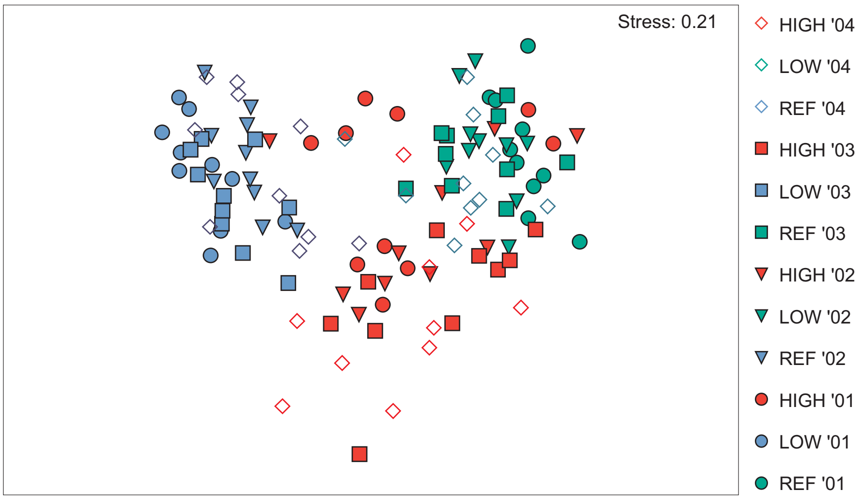


Table 6.2. R-values derived from the ANOSIM test for macrofaunal assemblages from locations of high and lower dredging intensity and from the reference sites in 2001-2004 at Area 408. * denotes significant difference at p‹ 0.01; ** denotes significant difference at p‹0.05.

Year	HIGH/REF	LOW/REF	HIGH/LOW
2001	0.745**	0.999**	0.398**
2002	0.669**	0.994**	0.285**
2003	0.828**	0.946**	0.445**
2004	0.631**	0.73**	0.245**

Table 6.3. Results from SIMPER analysis of macrofauna data from Area 408 (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from samples subject to differing levels of dredging impact from 2001–2004. Average abundance, average similarity and the % contribution to the similarity made by each characterising species are shown. Also listed are the cumulative percentage and the overall average similarity between replicate samples from within each group.

Group	Taxon	Average abundance	Average similarity	Similarity/ St. Dev.	% Contribution	Cumulative %	Overall average similarity
HIGH '04	*Echinocyamus pusillus*	5.00	6.43	1.85	22.71	22.71	28.32%
	NEMERTEA	1.20	3.29	0.90	11.63	34.34	
	Pisione remota	1.20	2.72	0.69	9.60	43.93	
	Spio armata (agg.)	1.20	1.78	0.53	6.27	50.20	
LOW '04	*Ophelia borealis*	8.40	8.39	3.65	20.92	20.92	40.09%
	Spio armata (agg.)	2.90	5.80	1.77	14.46	35.38	
	Polycirrus	1.90	4.43	1.17	11.04	46.43	
REF '04	*Notomastus*	10.30	3.57	2.59	10.40	10.40	34.32%
	Polycirrus	7.90	2.76	3.37	8.04	18.44	
	Ophelia borealis	8.80	2.45	1.08	7.13	25.58	
	Echinocyamus pusillus	3.80	2.26	1.32	6.59	32.17	
	NEMERTEA	2.90	2.01	1.48	5.86	38.03	
	Urothoe marina	27.60	1.28	0.84	3.72	41.75	

7. Discussion

As a result of the absence of baseline data the approach adopted in this research programme to assess the 'recovery' of the seabed following cessation of aggregate dredging has been to compare the physical and biological status of dredged sites in relation to local reference conditions. The analyses carried out are thus designed to investigate whether there are differences between dredged and reference localities, and where differences exist, to assess whether there is any indication of progress towards increasing similarity. As such, each of the high and lower dredging intensity sites from the four study areas can be categorised into one of three broad groups. These include:

1. sites which are largely indistinguishable from reference conditions and which are therefore considered to have **recovered**.
2. sites where conditions are still significantly different from reference sites, but where there is a trend towards increasing similarity. These sites are considered to be **recovering**.
3. sites where there is, as yet, **no obvious trend** towards increasing similarity with reference conditions.

Results from 2004 surveys show substantive 'recovery' appears evident within areas of lower dredging intensity at Area 222 and Area X, while all other sites remain, to varying extents, disturbed. There are a number of factors that may explain why only these sites have recovered and why the 'recovery' appears to have occurred at a similar rate. Firstly, of all the study sites, Area 222 and Area X have had the longest period for 'recovery' with both sites being last dredged in 1996. In contrast, dredging finished at Area 408 and Area Y in 1999 and 2000 respectively. Secondly, the lower dredging intensity sites at both Area 222 and Area X appear to have been subjected to similar (<1 hour per 100 m x 100 m block) lower levels of dredging intensity. Thirdly, the sediment composition at both these sites, although more variable, was very similar to reference conditions. In contrast, sediments within lower dredging intensity sites at Area 408 and Area Y have shown large differences in comparison with reference conditions.

At Area X, the lack of 'recovery' within the site of high dredging intensity can be explained by recent dredging activity during 2002 and 2003. However, although topographic evidence of dredging is clearly evident in 2004 the composition of sediments is very similar to reference conditions, thus promoting the potential for 'recovery' within this area. Indeed there was a substantial and largely unexpected rise in all univariate measures at this site in 2004. Particularly surprising were the large numbers of juvenile *Sabellaria spinulosa* found within this site in 2004. Further monitoring would be needed to determine whether these individuals are able to establish themselves in this area over the longer term.

In contrast to the lower dredging intensity site at Area 222, the high dredging intensity site continues to show significant differences, in terms of the communities present, compared to reference conditions. This is most likely a result of the clear differences in sediment composition. The high dredging intensity site is much finer than both the lower dredging intensity and reference sites and evidence of dredge tracks are more persistent in this area. However, results from 2004 suggest a trend towards coarsening of sediments at this site and an increase in similarity, in terms of the macrofaunal communities present, with the reference sites. Continued monitoring would be needed to confirm this trend.

The sequence of 'recovery', in terms of univariate measures, seen at Area 222 and Area X shows an emerging pattern which contrasts with an existing model of macrobenthic community response to the effects of dredging (ICES, 2001). This model was based on a number of case studies available in 2001 and suggests that the most common sequence of 'recovery', in terms of univariate measures, would be abundance followed by number of species and finally biomass. However, at the Area 222 lower dredging intensity site the sequence of 'recovery' was biomass in 2001, abundance in 2002 and numbers of species in 2003. In 2001 two species, *Lanice conchilega* and *Psammechinus miliaris* accounted for over half the total biomass within low dredging intensity samples. Both these species are thought to have a high recoverability potential (Ager, 2002; Jackson, 2004). In subsequent years biomass became increasingly distributed among a greater number of species, such that the 3 dominant species in each year account for 63%, 59%, 45%, 41% of total annual biomass in 2001, 2002, 2003 and 2004 respectively. In 2004 the Area 222 high dredging intensity site remained significantly different to reference conditions and yet total biomass in this year was not significantly different from the reference sites. In common with the lower dredging intensity site in 2001 much of the biomass is accounted for by a small number of opportunistic species including *Harmothoe impar* and *Psammechinus miliaris*. For example 77% of the total biomass is accounted for by only 3 species and only 1 species accounts for 62%. This contrasts with the reference site where the total biomass is more evenly distributed across a greater number of species.

At the Area X lower dredging intensity site biomass and abundance values were both found to be not significantly different ($p<0.05$) from the reference sites in 2001, whereas numbers of species remained significantly different ($p<0.05$) until 2002. In common with Area 222 much of the biomass was accounted for by a small number of species, three of which accounted for 82% of the total biomass. One of these species was *Crepidula fornicata*, an opportunistic species which, as a result of its mode of reproduction (adults spawn at least once a year, large numbers of eggs are produced, there is a long planktotrophic larval stage giving the species high dispersal potential and adults reach maturity within a year) has strong powers of recoverability (Rayment, 2003). The occurrence of this species within this disturbed site accords with the results of de Montaudouin *et al*. (2001) who suggested that physical disturbance is a factor that could stimulate the presence of this species, having observed preferential settlement in the trails of trawl fishing gear. Interestingly, this species was not found at either reference site in this year. In 2003 and 2004 biomass was more evenly distributed across a greater number of species. Again at the Area X high dredging intensity site biomass values and the number of species were not significantly different ($p<0.05$) from reference conditions in 2004, following only one year after the cessation of dredging. Once again, far from being the last facet of community structure to 'recover', biomass appears to return to reference values relatively quickly.

At Area Y, apart from some weathering of dredge tracks, there is, as yet, little indication of progress towards 'recovery'. However, given that Area X took 7 years to recover it is perhaps not unexpected that this site remains perturbed 4 years after cessation of dredging. Also, sediments within Area Y appear more variable, spatially and temporally, compared with those of Area X. Some of this variability appears to result from the position of the Area Y lower dredging intensity site on the boundary between the gravelly sediments within the licence area and a more sandy area to the north-east (Boyd *et al*., 2004). Also, sand mobilised from current dredging to the south in lane 9B may be transported into Area Y. This may be responsible for the increase in the proportion of sand within the high dredging intensity site in 2004.

In contrast to the other extraction sites both the sediments and biota within the sites of high and lower dredging intensity at Area 408 remain significantly different from reference conditions and show little evidence of any progress towards increasing similarity. The primary reason for the difference between dredged and reference sites appears to be due to differences in the nature of sediments within the dredged sites, where sands exist at the seabed surface. Work carried out by Evans (2002) suggests that some of this material may have resulted from dredging activities, particularly screening. In contrast the reference sites are more dominated by surface gravel. However, sediments may be coarsening within the lower dredging intensity site and this is accompanied by slight upward trends in the biota. However, any progress towards 'recovery' at this site would appear to be happening slowly. Results from this work appear to conflict with those reported by Robinson *et al*. (2005) who suggest that aggregate dredging has little obvious impact on the structure of the macrofauna at Area 408. However a possible cause of their result, at least within zone 2, may be the position of their stations outside the most intensively dredged areas.

In conclusion, the data collected during 2004 has contributed to this programme of research in a number of ways. Firstly it has confirmed the suspected 'recovery' identified at Area 222 and Area X during 2003 (Boyd *et al*., 2004). In addition it has identified possible progress towards 'recovery', not seen in 2003, within the Area 222 and Area X high dredging intensity sites and also within the Area 408 lower dredging intensity site. However, evidence from the continuation of this study suggests the fauna remain in a perturbed state in areas previously subjected to high levels of dredging intensity, at least 8 years at Area 222, 5 years at Area 408, 1 year at Area X and 4 years at Area Y. These findings, particularly those obtained at Area 222 and 408, appear to conflict with a body of case studies which together suggest that substantial progress towards restoration of the fauna could be expected within 2-3 years following cessation of marine sand and gravel extraction (Millner *et al*., 1977; Kenny *et al*., 1998; Sardá *et al*., 2000; van Dalfsen *et al*., 2000; ICES, 2001; Newell *et al*., 2002).

This study has also demonstrated the importance of consistent time-series data. Such datasets are vital for determining natural variability, and thus establishing meaningful trends. This appears particularly important at Area Y where, taken in isolation, the lack of difference in univariate measures between sites seen in 2004 may have led to a conclusion that 'recovery' was well under way. However the data from previous years shows the lack of difference is probably the result of declines at the reference site. This also illustrates the importance of continued monitoring beyond the time when 'recovery' was first suspected to ensure robust conclusions.

Work using the multibeam bathymetric systems have also shown utility in allowing quantification of rates of infill of dredge tracks where temporal data are available.

This study has investigated a variety of sites subject to different conditions and therefore different responses and rates of 'recovery'. As such this work offers valuable insights into 'recovery' at other extraction sites. However, in order that maximum benefit is derived from this programme time-series work needs to continue. This will enable us to satisfactorily answer the fundamental questions of how long each site takes to recover and how this process takes place. This information is essential to validate more theoretical models of 'recovery'.

Lessons For Policy

1. The rate and nature of recolonization following dredging is dependant on site specific factors.
2. Assumptions of a relatively speedy 'recovery' rate (i.e. within 2 to 3 years) for gravelly areas are not always applicable.
3. There is evidence that dredging intensity is an important factor in determining the nature and rate of recolonization.
4. There is a requirement to determine what is an 'acceptable' level of dredging intensity in different areas.
5. Minimizing the size of dredging sites (cf. MMG1) is likely to increase dredging intensity per unit area.
6. Electronic Monitoring System (EMS) data should be used to inform survey design in the assessment of the impacts of aggregate dredging.
7. This research programme provides evidence that aggregate dredging has the potential, in some areas, to lead to long-term changes in the nature of the seabed. As such there is a need for scientific evidence regarding what's feasible in terms of restoration.

8. Future work

Continuation of this research programme

Recommendations for the continuation of the research programme include:

1. Continuation of the time-series investigations

This programme of research offers the potential to provide invaluable insights into the 'recovery' process at other marine aggregate extraction sites. However this relies on the research being able to answer the question of how long study sites take to recover. At this stage, while significant progress has been made, the question remains unanswered. However a modest amount of continued monitoring could reveal the answers and this information will be of significant value for the development of models designed to predict 'recovery' times. Recommendations for the extension of the existing time-series investigations are given in Table 8.1, together with a site-specific supporting rationale below. These suggestions offer a cost effective means of answering the fundamental question of 'How long do the chosen study sites take to recover?' Any requirement for further work, beyond 2008, would need to be based on the results from monitoring carried out between 2006-2008.

Future sampling rationale

Area 408
Little change, in terms of progress towards 'recovery', is evident at this site and so further monitoring is not recommended until 2008.

Area 222
Future monitoring is recommended at Area 222 in 2007. This will allow an assessment of whether the Area 222 low dredging intensity site has truly 'recovered', or, as suggested by the univariate biological results, the site is undergoing successional changes in line with the model of 'recovery' proposed in Boyd et al., (2004). There is also a need to monitor the suggested trend towards 'recovery' at the high dredging intensity site.

Area X
Assuming no further dredging takes place within the Area X high dredging intensity site in 2005/06, continued monitoring of this site offers an opportunity to investigate early phases of recolonization. This is of particular interest in relation to the presence of *Sabellaria spinoulosa* identified in 2004.

Area Y
The two Hasting's sites offer the potential to establish the link between dredging intensity and the period of time required for 'recovery' of the seabed at this location. Given that the Area X low dredging intensity site took seven years to 'recover' it would be necessary to return to Area Y in 2007, seven years after cessation of dredging in this area.

2. Assessing Ecosystem Health

The traditional concept of biological 'recovery' assumes the return of a community, given time, to a state similar, or identical to that which existed prior to disturbance, or in

Table 8.1. Recommendations for the continuation of the time-series investigations at the four sampling sites. Figures indicate the number of years since dredging ceased.

	2001	2002	2003	2004	2005	2006	2007	2008
Area X	5 ■	6 ■	7 ■	8 ■	9	10 ▒	11	12
Area Y	1 ■	2 ■	3 ■	4 ■	5	6	7 ▒	8
Area 222	5 ■	6 ■	7 ■	8 ■	9	10	11 ▒	12
Area 408	2 ■	3 ■	4 ■	5 ■	6	7	8	9 ▒

Key: ■ *Sampling undertaken* ▒ *Proposed sampling* comparison with a suitable reference site (i.e. a return of the same species and in similar numbers).

Research has shown that this form of 'recovery' may not always be a realistic prospect. For example, where dredging produces a significant change to the sediment composition, a healthy "natural" assemblage will then be different from the initial one, possibly without overall detriment to the environment. Therefore, it may be theoretically more sensible to consider the functional capacity (or health) of the ecosystem rather than the range of species present. The return of a region to "functional health" can be judged as a separate metric of system 'recovery' since new communities may perform similar functional roles as the original assemblages. In this functional sense, a seabed may have recovered and the new community provide the required ecosystem services (such as food, shelter, and productivity) although the assemblage has changed. This concept allows for a system to be altered without the immediate conclusion that it has been damaged. The concept of ecosystem functionality and health allows managers to determine the acceptability of changes in different circumstances. Currently the precautionary principle dictates that the seabed should be left in a similar condition to that which existed prior to dredging. This maximises the potential for a similar community to re-establish itself after cessation of dredging.

9. References

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10. ANNEX I – The effects of dredging activity on epifaunal communities – surveys following cessation of dredging

Introduction

The effect of dredging activity on macroinfauna has been widely studied and well documented (Kenny and Rees, 1996; Newell *et al.*, 1998; Seiderer and Newell, 1999; Van der Veer, 1985) but the effects on epifaunal communities are less well known, although a limited number of investigations have been carried out (Kenny *et al.*, 1991; Shelton and Rolfe, 1972).

There are several attributes of the epifauna of coarse substrates which make this group an important target in environmental assessments (see Rees and Service, 1993; Rees *et al.*, 1999). These include their ability to support a relatively high diversity or biomass of other species e.g. in association with subtidal mussel beds.

Assessment of the epifauna may be particularly effective in rocky areas or where the environment is so physically disturbed as a result of tidal and wave action that infaunal species composition is very impoverished. Furthermore, many epifaunal species are preyed upon by fish hence an assessment of the impact of anthropogenic perturbations on the epifauna in areas where juvenile fish are present would seem to be highly appropriate. In addition, sedentary benthic species provide a direct route for carbon from the water column via filter feeding. Finally, complementary surveys of the epifauna may provide additional information beyond that obtained from infaunal investigations. Thus, a comparison of the responses of the two components of benthos sampled simultaneously in the field may provide insights into the underlying mechanisms by which different aspects of the perturbations could affect community structure.

A number of factors will influence the effect of dredging on macrobenthic populations and their ensuing restoration. These include the types of organisms which remain in the vicinity (Thrush *et al.*, 1991,1992) following sediment extraction, the life histories and mechanisms of dispersal of different fauna (Levin, 1984), the patchiness of the environment (Hall, 1994), the spatial and temporal variability of dredging disturbance (Hall, 1994) and the effects of existing or new recruits on the substratum (Dean and Hurd, 1980).

In the case of epifaunal populations, physical disturbance and the de-stabilisation of the sediments as a result of aggregate extraction is also likely to be a significant factor in terms of the potential for recolonisation of this component following cessation of dredging. This is because it has been shown that there is an inverse relationship between average number of epifaunal species and the amount of sediment disturbance caused by peak spring tidal currents (Greening and Kenny, 1996). It therefore appears that stability of the sediment and transport of sand by tidal (and wind) induced currents may control the relative abundance and diversity of epifauna associated with marine gravels in the UK.

Four aggregate extraction sites considered representative of dredging practices and habitats around the UK were utilised for the purposes of this study. Two of these sites are located at Hastings Shingle Bank on the South Coast (Areas X and Y), and the other two are located on the east coast, one offshore of Felixstowe in the region of the Thames (Area 222) and the other, offshore from the Humber estuary (Area 408).

Each of these extraction areas represents differing scenarios. Whilst inherent variability associated with the dredging history of each site inevitably confounds the geographical comparison of effects, the selected sites account for current dredging practices employed in the UK and are representative of several habitats where dredging is occurring. In addition, all the sites vary in the time-interval since cessation of dredging and therefore have the potential to represent different stages in the ‘recovery’ process.

The aim of this study was to assess the status of epifaunal communities within and outside areas where dredging had ceased and to investigate whether different levels of historical dredging intensity affect the subsequent rate of epifaunal re-colonisation. It is part of an ongoing field survey programme designed to enhance the understanding of processes leading to physical and biological ‘recovery’ of the seabed following dredging, thereby aiding the identification of practices to minimise environmental harm at licensed sites, and to promote rehabilitation on cessation. Work carried out during 2001-2003 has already been reported by *Boyd et al.*, (2004). This report focuses on the results of additional survey work carried out in the summer of 2004.

Methods

Survey sites

During August 2004 epifauna samples were taken at four extraction areas on the east and south coasts of England aboard the research vessel *RV Cefas Endeavour*. Area 222 is located approximately 20 miles east of Harwich in the southern North Sea, whereas Area 408 is located 60 miles east of the Humber estuary, also in the southern North Sea. The remaining two sites, Areas X and Y, are located in the eastern English Channel on the Hastings Shingle bank, 7 miles south of Hastings (see Figure 2.1 of the main report). Section 2.2 of the main report gives an account of the environmental conditions and dredging histories at each extraction area.

Survey design

At each extraction area, sites which had been exposed to historically high and lower dredging intensities were identified with the use of data derived from an Electronic Monitoring System (EMS). This system is fitted to all dredging vessels operating under a Crown Estate licence within the UK and allows an accurate record of where dredging activity occurs. A reference site was also selected which was considered representative of the wider environment. Sampling boxes were then designed in order to provide the boundaries within which sampling at each of the treatments and reference locations took place. The dimensions of the boxes were the same for the treatments within each extraction site but differed between extraction areas and are shown in Table 10.1. With this design, the area of high dredging intensity represents conditions following the repeated removal of commercial aggregate from most of the total surface area of a 100 m by 100 m block, many times over the course of 1 year. In contrast, the area of lower dredging intensity represents conditions after the removal of up to about 90% of the total surface area in a similar 100 m by 100 m block in a single year. The numbers of hours of dredging and hence the relative number of hours assigned to the high and lower dredging intensity sites differed between each extraction area and the average number of hours of dredging are shown in Table 10.2.

Table 10.1. Dimensions of sample boxes at each of the extraction licenses.

Extraction area	High, low and reference sites dimensions
Area 222	200 m x 200 m
Area 408	300 m x 300 m
Hastings X	300 m x 200 m
Hastings Y	300 m x 200 m

Sampling method

Epifaunal samples were collected using a modified 2 m Jennings beam trawl with a heavy-duty steel beam, chain mat and a 4 mm mesh liner fitted inside the net (see Jennings *et al.*, 1999 for design specifications). The beam was deployed with a 3:1 ratio of warp length to depth and towed at a speed of ≅0.5 ms^{-1} for a fixed period of five minutes with the co-ordinates of the start and finish time of the tow being recorded. Tow length altered across each area due to the effect of variation in local current and wind condition. At each of the three treatments (high, low and reference), the 2 m Jennings beam trawl was deployed four times to give four replicate samples. A total of 44 beam trawl samples were collected in 2004 across all sites. On retrieval of the trawl an estimate of the volume of sample was recorded and the samples were then processed on board the ship.

Table 10.2. Dredging history and intensity of dredging in hours at high and low sites since the inception of EMS data collection system in 1993.

Year	Area 222 HIGH	Area 222 LOW	Area 408 HIGH	Area 408 LOW	Hastings Y HIGH	Hastings Y LOW	Hastings X HIGH	Hastings X LOW
1993	6.87±6.37	0.75±0.75	0	0	1.00± 0.75	0.50±0.50	0	0
1994	20.25±19.25	1.75±1.75	0	0	3.60 ± 2.40	1.25±1.25	0	0
1995	9.99±9.25	<0.25*	0	0	0.50 ± 0.25	0.37±0.37	0	0
1996	5.87±5.87	<0.25*	0.50±0.25	0	8.00 ± 2.00	1.00±0.75	16.87±11.62	0.37±0.37
1997	0	0	2.25±0.50	<0.25*	8.75 ± 1.50	1.25±1.25	0	0
1998	0	0	10.49±3.74	0.50±0.50	8.75 ± 1.50	0.37±0.37	0	0
1999	0	0	<0.25*	<0.25*	8.87 ± 1.63	0.37±0.37	0	0
2000	0	0	0	0	0.75 ± 0.50	<0.25*	0	0
2001	0	0	0	0	0.50±0.25	<0.25*	0	0

* EMS data is collected at intervals of 15 minutes so any dredging occurring for less than 15 minutes is counted as ‹0.25 hours

Figure 10.1. Showing type of heavy duty beam used during this study.

Sample processing

Each beam trawl sample was washed over a 5 mm sieve. Most macrofaunal species were identified and enumerated at sea. Specimens which could not be identified whilst at sea were preserved in formalin for later identification in the laboratory. All specimens were identified to species level, as far as possible, using a range of standard taxonomic keys. In samples where taxa were present in large densities a sub-sample was taken. In these cases, an appropriate proportion of the sample (usually a quarter or a third) was taken after it was evenly distributed over the 5 mm mesh and all taxa were recorded. The remainder of the sample was then sorted for all other taxa excluding the high density specimens. All animals were enumerated with the exception of colonial taxa, which were recorded on a presence/absence basis. A representative of each specimen encountered was fixed in 4-6% formaldehyde solution and identification was confirmed in the laboratory. In the following account, the epifaunal data are reported as numbers per tow i.e. their densities are not adjusted for tow length.

Data analysis

Univariate analysis

The statistical package PRIMER v6. (Clarke and Gorley, 2004) was used to calculate univariate and multivariate statistics. The following univariate measures were calculated: total abundance (A), numbers of species (S), Shannon-Wiener diversity index ($H'log_2$), and Margalef's species richness (d).

The significance of differences between each of the dredging intensities was tested using one-way ANOVA. Fishers least significance difference (LSD) multiple comparisons procedure was used to determine whether there were significant differences in the numbers of species and individuals between samples obtained from the areas of high and lower dredging intensity and reference sites. This analysis was carried out using the software package STATGRAPHICS plus, Version 4.1.

Multivariate analysis

For all multivariate analyses, colonial taxa were removed from the data matrix. This approach was used in order to test whether there were any significant differences in community composition between samples collected from areas subjected to different levels of dredging intensity. All non-colonial community data was standardised and a 4th root transformation was applied. This transformation reduces the effect of dominant taxa and takes account of rarer taxa. Standardisation was applied, as data arising from beam trawl samples are considered at best semi-quantitative samples due to differing volumes of material retained by the trawl (Brown *et al.*, 2001).

A non-metric Multi Dimensional Scaling (MDS) ordination was carried out to assess the sample and species associations in relation to the recorded dredging intensity (Kruskal and Wish, 1978). This method provides a map of the samples using information of the form "sample a is closer to sample b (in species composition) than it is to sample c or d (etc)". In the resulting two-dimensional ordination the relative distance apart of any pair of samples reflects their relative dissimilarity. The ordination was based on a lower triangular similarity matrix of 4th root transformed abundance data using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957).

ANOSIM analysis (Clarke,1993) was applied in order to test for significant differences in species assemblages between different levels of dredging intensity. SIMPER analysis was then employed to establish the contribution of individual species to the differences between treatments (Clarke, 1993).

Table 10.3. The average length of beam trawl tows at aggregate extraction site.

	Area 222	Area 408	Hastings X	Hastings Y
HIGH	152.5 ± 27.5m	220 ± 40m	157 ± 30m	167.5 ± 27.5m
LOW	147.5 ± 22.5m	222.5 ± 22.5m	182.5 ± 32.5m	255 ± 65m
REF	167.5 ± 17.5m	220 ± 20m	170 ± 30m	170 ± 30m

Results

Univariate measures

The average trawl tow lengths over the 4 years are shown for each study site (Table 10.3). A total of 207 taxa were recorded from the survey of the four extraction areas of which 65 were colonial species (largely hydroids and bryozoans). The results from both univariate and multivariate statistical analyses of data collected in 2004 establishes that differences remain between epifaunal communities subjected to dredging activity (both high and lower dredging intensity sites) and the reference sites, but at some extraction areas these differences are less pronounced than in previous years.

At Area 222, for the first time since the study commenced in 2001, there are no significant differences in numbers of species between any sites in 2004. This is due to an increase in numbers of species at the high dredging intensity site and a reduction at the lower dredging intensity site and reference sites (Figure 10.2a). The same is true for the numbers of individuals at each site (Figure 10.2b) where an increase was seen at the dredged sites in 2004 but this was not significantly different to the numbers of individuals at the reference sites. It is worth noting that the high dredging intensity site at Area 222 has seen a year-on-year increase in numbers of individuals.

At Area 408, numbers of species at the reference sites remain significantly higher than at either dredged sites in 2004 (Figure 10.3a), whilst the dredged sites were not

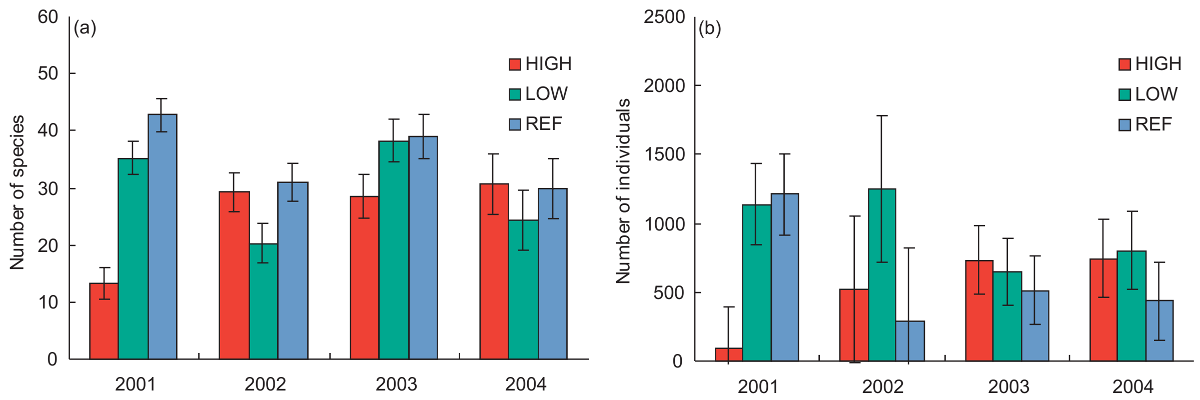

Figure 10.2. Means and 95% LSDs for numbers of epifaunal species (a) and individuals (b) at high and lower dredging intensity sites and reference sites 2001-2004 at Area 222.

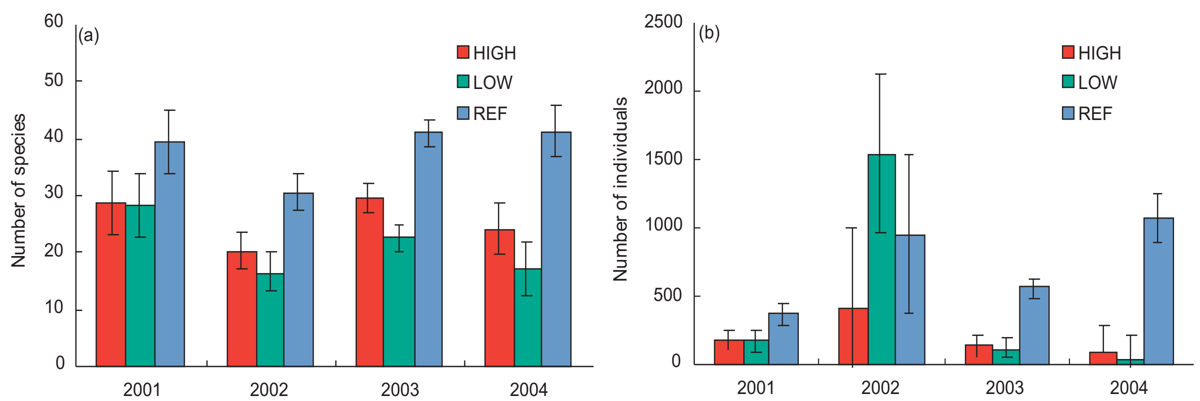

Figure 10.3. Means and 95% LSDs for numbers of epifaunal species (a) and individuals (b) at high and lower dredging intensity sites and reference sites 2001-2004 at Area 408.

significantly different from one another. This is consistent with results for the entire study period. Similarly, numbers of individuals in 2004 (Figure 10.3b) were significantly greater at the reference than the dredged sites. The presence of large numbers of individuals of the shrimp *Pandalus montagui*, the swimming crab *Liocarcinus depurator*, the starfish *Asterias rubens*, and the ascidian species *Ascidiella* at the reference sites, but not at the dredged sites is responsible for this difference.

At the Hastings X extraction area, numbers of species and individuals at the lower dredging intensity site and reference sites (high not sampled due to renewed dredging) were not significantly different to each other in 2004 (Figure 10.4a and b). It is worth noting that numbers of species present at both sites in 2004 was the lowest seen during the study period 2001-2004. Numbers of individuals were also not significantly different (Figure 10.4b). The large confidence intervals associated with numbers of individuals is related to the mollusc *Crepidula fornicata* that were present in high numbers in one of the replicate samples, hence skewing the mean values and subsequent confidence limits.

At Hastings Y, numbers of species encountered at the reference site were significantly lower than those at the site of lower dredging intensity (Figure 10.5a). However, numbers of species at the high dredging intensity site were not significantly different (p>0.05) from those at the reference site or lower dredging intensity site. Numbers of individuals remained similar to each other (Figure 10.5b) as in 2003.

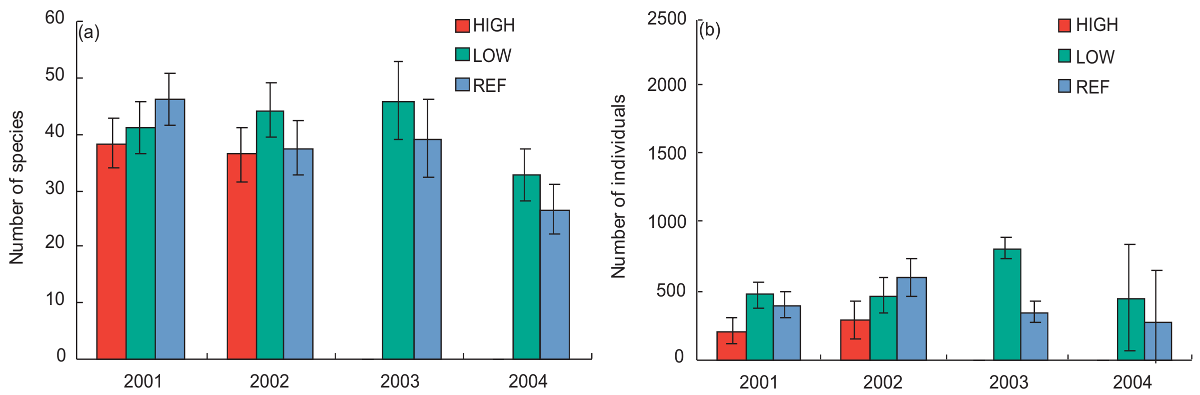

Figure 10.4. Means and 95% LSDs for numbers of epifaunal species (a) and individuals (b) at high and lower dredging intensity sites and reference sites 2001-2004 at Hastings X.

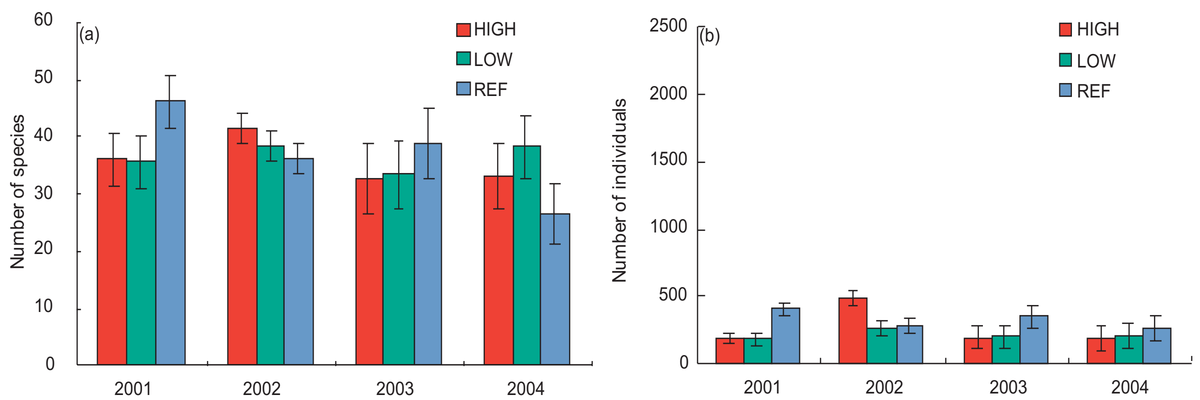

Figure 10.5. Means and 95% LSDs for numbers of epifaunal species (a) and individuals (b) at high and lower dredging intensity sites and reference sites 2001-2004 at Hastings Y.

Multivariate analyses

The MDS ordinations of epifaunal assemblages collected at high and lower dredging intensity sites and reference sites over the four years study (Figure 10.6a-d) indicate that at all extraction areas, samples from each of the sites tend to cluster distinctly from each other. There is also evidence of greater similarity within the year of survey at some of the extraction areas, indicating that differences between sites may be becoming less over time.

The samples collected at Area 222 in 2004 (Figure 10.6a) cluster closely within sites except one sample from each of the lower dredging intensity sites and reference sites. Their position on the plot relative to previous years appears to demonstrate a trend of increasing similarity between sites over time.

Conversely, at Area 408 (Figure 10.6b) the reference samples from all years remain removed from the high and lower dredging intensity samples throughout the survey period, indicating little change over time.

At Hastings X (Figure 10.6c), the 2004 samples collected from the lower dredging intensity site are widely separated indicating dissimilarity between replicates and along with the reference samples from 2004, distinctly cluster away from samples collected in previous years. At Hastings Y (Figure 10.6d) samples collected in 2004 from the lower dredging intensity site and reference sites cluster closely within sites, whilst those from the high dredging intensity site are seen to be widely separated, indicating a high degree of dissimilarity.

A further MDS ordination of all samples from all years (Figure 10.6e) shows that there is generally good discrimination between samples collected from different geographical areas, which may reflect biogeographical differences in the fauna.

Analysis using the ANOSIM procedure (Clarke and Warwick, 1994) confirms that there is a statistically significant difference ($p<0.1$) between the assemblage structure of samples collected from dredged sites compared with those obtained from reference sites for all combinations with the exception of the lower dredging intensity site at Area 408 in 2003 and 2004, and at Hastings Y, between the high and lower dredging intensity sites in 2004 (Tables 10.3-6). These tables also show that there is greater dissimilarity between dredged and reference sites than between dredged sites. Closer inspection of the percentage dissimilarities reveals that there is an obvious reduction in dissimilarity over time at Area 222, which is also reflected in Figure 10.6a. There was no similar obvious reduction at the remaining three extraction areas.

The species responsible for the observed differences between treatments were determined using the SIMPER routine in PRIMER. The results for 2004 only are shown. Earlier results are published in Boyd *et al.* (2004).

Compared to earlier SIMPER analyses for 2001-2003 data, differences between sites in 2004 at Area 222 (Table 10.7) are due to reductions in numbers of individuals rather than absences of species. Whilst the same species are present at each of the sites, they appear to be present in greater numbers than seen in previous years. High numbers of *Crangon allmanni* at the high dredging intensity site distinguish this from the lower dredging intensity site and reference sites, whilst *Psammechinus miliaris* is the main species which accounts for differences between the reference sites and lower dredging intensity site.

At Area 408 (Table 10.8) the main difference between dredged sites and the reference sites is due to large numbers of *Pandalus montagui* and *Ascidiella* sp. at the reference site, which are absent, or present in much smaller numbers, at the dredged sites. Overall, individuals at the dredged sites appear depressed compared to the reference site.

Differences between the reference sites and lower dredging intensity sites at Hastings X in 2004 (Table 10.9) are characterised by a high abundance of *Psammechinus miliaris* at the reference site, versus a high abundance of *Crepidula fornicata* at the lower dredging intensity site. Overall, the sites appear to contain the same species but in varying densities.

At Hastings Y, as with Area 222, differences between the sites in 2004 are due to reductions in densities rather than absences of species, which was a feature of differences in earlier years of survey (Table 10.10). High numbers of *Psammechinus miliaris* at the reference site is the dominant cause for differences between this site and the dredged sites.

BIOENV analysis indicated a relatively strong correlation between species composition in 2004 and the 'hydrodynamic indices' of peak tidal current and potential mobility of fine sand ($\rho w=0.574$ for both variables). This relationship appears to be slightly weaker than that shown for the 2001-2003 data (see Boyd *et al.*, 2004 for previous results).

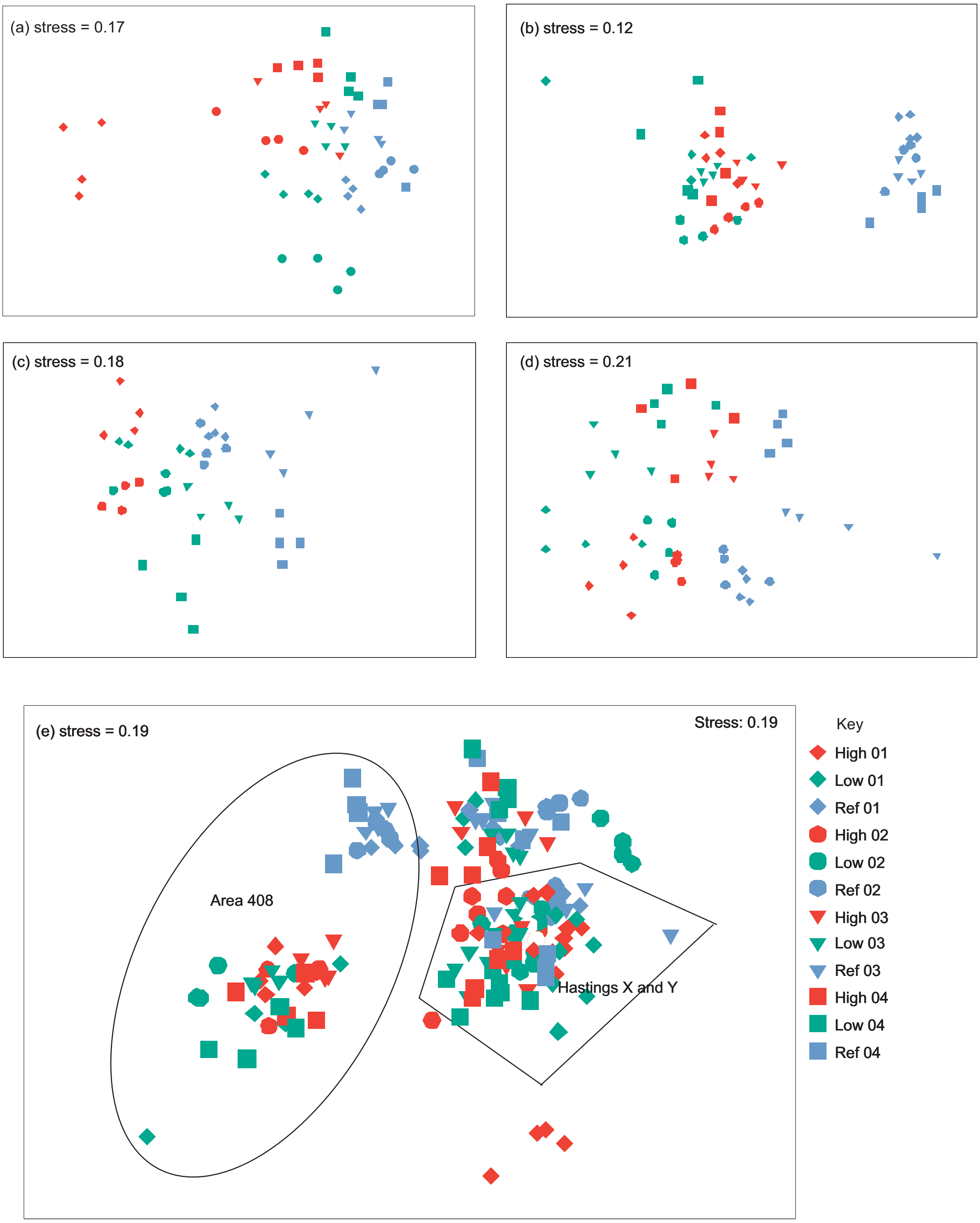

Figure 10.6. Multi-Dimensional Scaling ordinations of: (a) All samples collected from Area 222 2001-2004 (b) All samples collected from Area 408 2001-2004 (c) All samples collected from Hastings X 2001-2004 (d) All samples collected from Hastings Y 2001-2004 (e) All samples collected from all extraction areas 2001-2004. Area 408 samples circled, Hastings X and Y samples boxed, Area 222 samples all remaining samples.

Table 10.3. Table of % dissimilarities between high and lower dredging intensity sites and reference sites over all years at Area 222 based on 4th root transformed non-colonial species abundance data. All are significant at p<0.05 except *(significant at p<0.10).

	HIGH 01	LOW 01	REF 01	HIGH 02	LOW 02	REF 02	HIGH 03	LOW 03	REF 03	HIGH 04	LOW 04
LOW 01	67										
REF 01	75	38									
HIGH 02	66	53	52								
LOW 02	75	52	53	56							
REF 02	76	53	45	51	54						
HIGH 03	73	49	51	49	61	51					
LOW 03	77	45	44	47	52	48	*35				
REF 03	77	50	42	51	61	42	41	37			
HIGH 04	69	54	56	48	68	59	*42	46	47		
LOW 04	75	54	55	52	65	52	47	39	49	43	
REF 04	75	56	48	54	62	44	53	50	43	47	43

Table 10.4. Table of % dissimilarities between high and lower dredging intensity sites and reference sites over all years at Area 408 based on 4th root transformed non-colonial species abundance data. All are significant at p<0.05 except * (significant at p<0.10) and ** (non significant).

	HIGH 01	LOW 01	REF 01	HIGH 02	LOW 02	REF 02	HIGH 03	LOW 03	REF 03	HIGH 04	LOW 04
LOW 01	**43										
REF 01	67	75									
HIGH 02	43	52	68								
LOW 02	47	52	78	34							
REF 02	67	77	37	61	74						
HIGH 03	40	49	61	41	47	58					
LOW 03	35	44	73	42	41	72	33				
REF 03	68	77	40	67	76	42	58	68			
HIGH 04	43	54	72	43	49	70	40	37	70		
LOW 04	48	54	80	52	54	78	50	*40	76	46	
REF 04	70	79	47	65	75	43	63	73	42	68	79

Table 10.5. Table of % dissimilarities between high and lower dredging intensity sites and reference sites over all years at Area X based on 4th root transformed non-colonial species abundance data.
All are significant at p<0.05 except * (significant at p<0.10).

	HIGH 01	LOW 01	REF 01	HIGH 02	LOW 02	REF 02	LOW 03	REF 03	LOW 04
LOW 01	36								
REF 01	46	38							
HIGH 02	44	42	46						
LOW 02	44	36	41	*34					
REF 02	46	41	34	41	36				
LOW 03	50	43	43	44	40	43			
REF 03	59	53	46	58	56	47	45		
LOW 04	53	49	54	49	45	50	47	60	
REF 04	56	52	48	57	53	47	48	52	46

Table 10.6. Table of % dissimilarities between high and lower dredging intensity sites and reference sites over all years at Area Y based on 4th root transformed non-colonial species abundance data. All are significant at p<0.05 except * (significant at p<0.10) and ** (non significant).

	HIGH 01	LOW 01	REF 01	HIGH 02	LOW 02	REF 02	HIGH 03	LOW 03	REF 03	HIGH 04	LOW 04
LOW 01	*39										
REF 01	44	49									
HIGH 02	42	45	41								
LOW 02	41	42	43	26							
REF 02	47	49	34	35	36						
HIGH 03	47	51	49	47	45	46					
LOW 03	46	49	56	44	43	53	38				
REF 03	57	62	47	55	58	47	45	55			
HIGH 04	52	50	52	47	45	49	42	46	57		
LOW 04	52	49	54	50	47	53	46	48	55	**37	
REF 04	56	57	48	53	51	47	43	53	51	46	42

Table 10.7. The average abundance of the top 10 ranked non-colonial species contributing to the dissimilarity between high and lower dredging intensity sites and reference sites at Area 222, derived from SIMPER analysis of untransformed data from 2004; species are ordered in decreasing contribution.

Species	LOW 04	HIGH 04	Species	REF 04	HIGH 04	Species	REF 04	LOW 04
Crangon allmani	34.75	337.50	*Crangon allmani*	3.25	337.50	*Psammechinus miliaris*	194.50	314.25
Pandalina brevirostris	270.50	62.25	*Psammechinus miliaris*	194.50	166.25	*Pandalina brevirostris*	129.00	270.50
Psammechinus miliaris	314.25	166.25	*Pandalina brevirostris*	129.00	62.25	*Pandalus montagui*	0.50	57.75
Pandalus montagui	57.75	61.50	*Pandalus montagui*	0.50	61.50	*Crangon allmani*	3.25	34.75
Pagurus bernhardus	6.00	32.50	*Pagurus bernhardus*	6.25	32.50	*Chlamys spp.*	11.75	34.00
Chlamys spp.	34.00	3.25	*Pisidia longicornis*	22.75	1.75	*Pisidia longicornis*	22.75	10.75
Anapagurus laevis	3.25	15.00	*Anapagurus laevis*	1.75	15.00	*Pilumnus hirtellus*	10.25	0.25
Liocarcinus holsatus	7.50	18.00	*Liocarcinus holsatus*	9.50	18.00	*Asterias rubens*	8.00	11.50
Ophiura albida	11.25	1.50	*Pilumnus hirtellus*	10.25	-	*Ophiura albida*	-	11.25
Pisidia longicornis	10.75	1.75	*Chlamys spp.*	11.75	3.25	*Liocarcinus holsatus*	9.50	7.50

Table 10.8. The average abundance of the top 10 ranked non-colonial species contributing to the dissimilarity between high and lower dredging intensity sites and reference sites at Area 408, derived from SIMPER analysis of untransformed data from 2004; species are ordered in decreasing contribution.

Species	LOW 04	HIGH 04	Species	REF 04	HIGH 04	Species	REF 04	LOW 04
Asterias rubens	1.75	27.00	*Pandalus montagui*	379.50	-	*Pandalus montagui*	379.50	-
Ammodytes	2.50	8.00	*Ascidiella* sp.	321.75	0.50	*Ascidiella* sp.	321.75	-
Callionymus lyra	6.75	12.00	*Asterias rubens*	139.25	27.00	*Asterias rubens*	139.25	1.75
Limanda limanda	2.50	4.75	*Liocarcinus depurator*	59.75	3.00	*Liocarcinus depurator*	59.75	0.25
Liocarcinus depurator	0.25	3.00	*Macropodia*	32.25	2.25	*Macropodia*	32.25	0.25
Liocarcinus holsatus	1.75	3.25	*Philocheras trispinosus*	16.25	1.50	*Philocheras trispinosus*	16.25	0.25
Buglossidium luteum	4.50	4.25	Gobiidae	20.25	1.00	Gobiidae	20.25	1.25
Arnoglossus laterna	2.50	1.50	*Callionymus lyra*	24.25	12.00	*Callionymus lyra*	24.25	6.75
Pagurus bernhardus	3.50	4.50	*Taurulus bubalis*	11.00	0.25	*Taurulus bubalis*	11.00	-
Pleuronectes platessa	0.50	2.25	*Agonus cataphractus*	10.75	0.25	*Agonus cataphractus*	10.75	1.75

Table 10.9. The average abundance of the top 10 ranked non-colonial species contributing to the dissimilarity between high and lower dredging intensity sites and reference sites at Hastings X, derived from SIMPER analysis of 4th root transformed data from 2004; species are ordered in decreasing contribution.

Species	LOW 04	HIGH 04	Species	REF 04	HIGH 04	Species	REF 04	LOW 04
						Psammechinus miliaris	160.00	3.25
						Crepidula fornicata	3.25	321.00
No samples collected			No samples collected			Gobiidae	3.50	31.75
From high treatment			From high treatment			*Ophiura albida*	17.00	2.25
						Asterias rubens	7.00	20.00
						Buccinum undatum	9.75	2.50
						Macropodia	12.00	7.50
						Pagurus bernhardus	21.75	24.00
						Callionymus lyra	1.25	3.25
						Hinia spp.	2.00	3.75

Table 10.10. The average abundance of the top 10 ranked non-colonial species contributing to the dissimilarity between high and lower dredging intensity sites and reference sites at Hastings Y, derived from SIMPER analysis of untransformed data from 2004; species are ordered in decreasing contribution

Species	LOW 04	HIGH 04	Species	REF 04	HIGH 04	Species	REF 04	LOW 04
Pagurus bernhardus	49.00	27.00	*Psammechinus miliaris*	160.00	20.75	*Psammechinus miliaris*	160.00	10.50
Macropodia	23.50	24.50	Gobiidae	3.50	19.25	*Pagurus bernhardus*	21.75	49.00
Ophiura albida	28.25	12.50	*Macropodia*	12.00	24.50	*Macropodia*	12.00	23.50
Hinia spp.	18.25	3.75	*Pagurus bernhardus*	21.75	27.00	*Hinia* spp.	2.00	18.25
Psammechinus miliaris	10.50	20.75	*Asterias rubens*	7.00	14.75	*Ophiura albida*	17.00	28.25
Gobiidae	9.00	19.25	*Buccinum undatum*	9.75	0.25	*Anapagurus laevis*	2.50	10.50
Asterias rubens	7.00	14.75	*Ophiura albida*	17.00	12.50	*Buccinum undatum*	9.75	4.50
Anapagurus laevis	10.50	4.25	*Pagurus prideaux*	3.75	6.50	Gobiidae	3.50	9.00
Pagurus prideaux	5.50	6.50	*Crepidula fornicata*	3.25	3.75	*Pagurus prideaux*	3.75	5.50
Buccinum undatum	4.50	0.25	*Philocheras trispinosus*	-	3.75	*Asterias rubens*	7.00	7.00

Discussion

Whilst the absence of comprehensive 'pre-dredging' data introduces some uncertainty into assessments of progress towards 'recovery' of these epifaunal communities in the dredged sites, the reference sites are considered to be representative of unimpacted sediments around the extraction areas and therefore provide a sound alternative means for an evaluation of the effects of aggregate extraction. Previous examination of the epifaunal communities at each extraction area in the period 2001-2003 suggests that at the study sites investigated, the numbers and densities of epifaunal taxa within the dredged treatments were typically reduced compared with the nearby reference sites. Statistical analysis of data collected in 2004 confirms that this is still the case at Area 408. However, at the three remaining extraction areas, Area 222, and Hastings X and Y, there is an apparent subtle trend towards 'recovery' at the dredged treatments, through an increasing similarity of the epifaunal communities at the dredged sites to the epifaunal community seen at the reference sites.

The report of previous data collected in 2001, 2002 and 2003 (Boyd *et al.*, 2004) inferred that a combination of dredging histories and environmental conditions (the newly developed hydrodynamic indices peak tidal flow and mobility of sand) were responsible for differences between the speed at which the dredged sites were seen to move towards 'recovery' at each extraction area. Results also suggested that screening of cargoes from Area 222 and Area 408 had a more persistent and acute impact on the epifauna than removal of the sediment as an 'all-in' cargo from the Hastings licences. This could be a function of alteration of the sediment from gravel to a sandier substratum as discussed for Area 222 by Boyd *et al.* (2004). The differences between high and lower dredging intensity sites and reference sites at the two Hastings study sites were less pronounced, but this was likely to have been confounded by the response to renewed dredging activity.

The fact that some form of 'recovery' of epifaunal communities now appears to be occurring at Area 222 eight years after cessation of dredging is a positive outcome. It remains to be seen whether this trend will persist and it is therefore important that further time-series investigations are carried out to determine this. Whether Area 408 epifaunal communities will also start to show some form of 'recovery' in future years remains to be seen. Dredging ceased at this extraction area 4 years ago, and so it may be the case that the epifaunal community will become more alike at all sites over a similar timescale to Area 222.

The renewed dredging activity at Hastings X does confound our ability to ascertain whether the reduction in differences between sites are in response to this activity, or due to other natural factors. Again, further time-series investigations will help to develop our understanding and establish whether the apparent 'recovery' is indeed the start of an upward trend or a symptom of natural variation in numbers of species and individuals which is universally acknowledged to occur in biological communities.

It is important to note that there appears to be some correlation between time required for 'recovery' of the epifaunal and infaunal communities at each extraction site. For Area 222 specifically, the apparent trend towards 'recovery' of epifaunal communities was also evident for infaunal communities. At Area 408, there remains a difference between the dredged and reference sites for both infaunal and epifaunal communities. Results for Hastings are less comparable, possibly due to differing responses to renewed dredging activity as previously discussed.

It is apparent from the fourth year of this study, that timescales for progress towards 'recovery' are not the same for all extraction areas. Any changes in the status of benthic assemblages in areas that have been subjected to commercial aggregate extraction will need to be referenced both against variations in particle size and the hydrodynamic regime. It is likely that a combination of direct and indirect effects will be responsible, but these will vary in importance depending upon location, and hence any generic models of cause/effect relationships will require 'ground-truthing', and in all probability some modification, in order to satisfy site-specific needs.

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