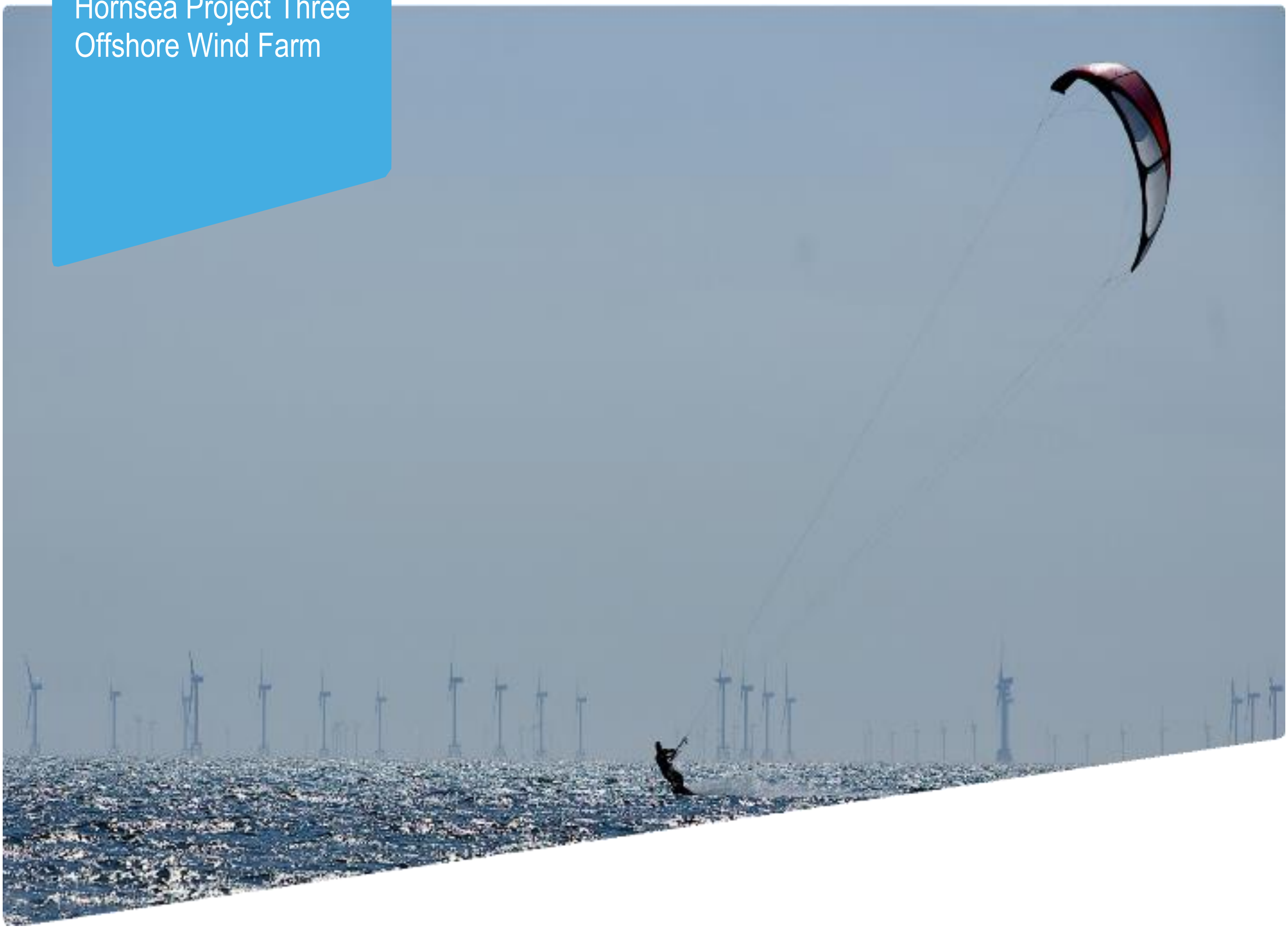

Hornsea Project Three

Offshore Wind Farm

Appendix 16 to Deadline 7 submission – Newell et al., 2004

Date: 14th March 2019

Hornsea 3
Offshore Wind Farm

Ørsted

Document Control			
Document Properties			
Organisation	Ørsted Hornsea Project Three		
Author	Newell et al., 2004		
Checked by	n/a		
Approved by	n/a		
Title	Appendix 16 to Deadline 7 submission – Newell et al., 2004		
PINS Document Number	n/a		
Version History			
Date	Version	Status	Description / Changes
14/03/2019	A	Final	Submitted at Deadline 7 (14th Mar 2019)

Ørsted

5 Howick Place,

London, SW1P 1WG

Front cover picture: Kite surfer near a UK offshore wind farm © Ørsted Hornsea Project Three (UK) Ltd., 2019.

Journal of Coastal Research	20	1	115–125	West Palm Beach, Florida	Winter 2004

Impacts of Marine Aggregate Dredging on Benthic Macrofauna off the South Coast of the United Kingdom

R.C. Newell†, L.J. Seiderer†, N.M. Simpson†, and J.E. Robinson†‡

†Marine Ecological Surveys Limited
Trewood Cottage
Steeple Lane
St. IVES
Cornwall TR26 2PF. U.K.

‡Benthic Ecology Research Group
Department of Biological Sciences
University of Plymouth
Drake Circus, Plymouth
Devon PL4 8AA. U.K.

ABSTRACT

NEWELL, R.C.; SEIDERER, L.J.; SIMPSON, N.M., and ROBINSON, J.E., 2004. Impacts of marine aggregate dredging on benthic macrofauna off the south coast of the United Kingdom. *Journal of Coastal Research,* 20(1), 115–125. West Palm Beach (Florida), ISSN 0749-0208.

A survey of benthic macrofauna in the vicinity of a coastal marine aggregate dredging site off the south coast of UK was carried out in 1999. The object of the survey was to determine impact of marine aggregate dredging on community composition, the extent of impact outside the boundaries of the dredge site, and the rate of recolonization and recovery of the fauna following cessation of dredging. Part of the site was intensively dredged by vessels at anchor whilst other parts were less intensively exploited by trailer dredger. The impact of dredging within the intensively exploited anchor dredge site was limited to the dredged area. Impacts included a suppression of species variety, population density and biomass, as well as differences in species composition compared with the surrounding deposits. In contrast, trailer dredging had no impact on community composition of macrofauna within the dredge site.

No suppression of benthic community structure was recorded beyond 100 m from the dredge site. Species variety, population density, biomass and body size of macrofauna was enhanced for as much as 2 kilometers in each direction along the axis of the tidal streams. Whether this reflects organic enrichment derived from the dredge site warrants further investigation.

The rate of restoration of biomass following dredging was slower than that recorded for species diversity and population density. The data for the North Nab study site allow a generalised recolonization sequence to be constructed for coastal deposits.

ADDITIONAL INDEX WORDS: *Environmental impact, recovery time and sequence.*

INTRODUCTION

Most studies on the impact of dredging on marine benthos show that dredging can result in a 30–70% reduction in species variety, a 40–95% reduction in the number of individuals, and a similar reduction in biomass in dredged areas (NEWELL *et al.,* 1998). Studies by KENNY and REES (1994, 1996) and KENNY *et al.* (1998) showed that initial colonization occurred within months of the cessation of dredging at an experimentally-dredged site off the coast of Norfolk, UK, but that restoration of biomass took several years.

Recent studies by VAN DALFSEN and ESSINK (1997), VAN DALFSEN *et al.* (2000), DESPREZ (2000) and SARDÁ *et al.* (2000) show that the process of recolonization and recovery in commercially-exploited sand borrow sites is a complex one involving initial colonization by fast-growing (‘*opportunistic*’) species. In stable environments these are replaced and supplemented by a wider species diversity of slow-growing (‘*equilibrium*’) species after cessation of dredging. In more disturbed habitats the community is dominated by opportunistic species which do not move towards an equilibrium community because of repeated environmental disturbance.

Previous studies have been mainly confined to impacts within dredge sites. The dredging process has, however, important potential impacts outside the boundaries of the dredge site. In some sites *in situ* gravel deposits are transferred in bulk into the hold for subsequent use as beach feed or for landfill (see HESS, 1971). In other areas the proportion of sand:gravel in the cargo is adjusted to suit customer requirements by a process of screening. This can involve return of significant quantities of sand overboard at sites of dredging (HITCHCOCK and DRUCKER, 1996; NEWELL *et al.,* 1999).

This material comprises a large inorganic particulate load and also contains significant quantities of organic matter (NEWELL *et al.,* 1999). Such material has a lower specific gravity than inorganic components of the dredger outwash and is detectable at distances of as much as 3.3 km downstream of a dredger during normal loading of a screened cargo off the Owers Bank, U.K. (HITCHCOCK and DRUCKER, 1996; HITCHCOCK *et al.,* 1998).

Material derived from the dredging process may also be

9 received and accepted in revision 6 June 2003.

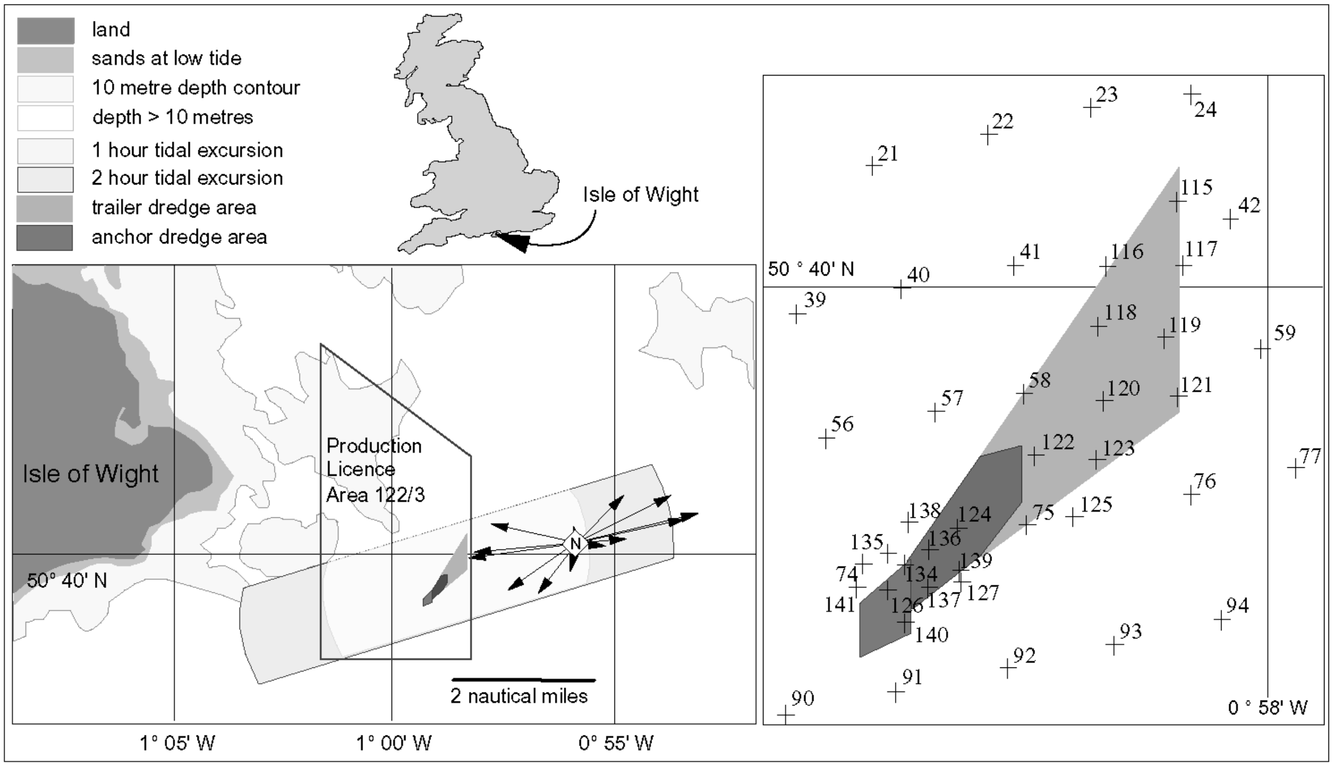

Figure 1. Map of the survey area showing the limits of the area surveyed (up to 2 hour tidal excursions) and the dredged site within the boundaries of the Production Licence Area. The enlarged map shows the anchor-dredge and trailer-dredge areas, together with the distribution of sampling stations within and adjacent to the dredged sites.

carried as a benthic plume for significant distances along the sea bed. DICKSON and REES (1998) reported the presence of a sediment plume at the sediment-water interface over 8 kilometers from a dredge site on the east coast of the U.K. Similar benthic boundary plumes have been reported even for unscreened cargoes at the Owers Bank off the south coast of U.K (HITCHCOCK *et al.,* 2002).

Study Objectives

Our study was undertaken to determine the following key questions in relation to marine aggregate mining in a commercially-worked Licence Area:

- Is there an impact of marine aggregate mining on key features of benthic biological community structure including species diversity (S), population density (N), biomass (B) or body size (B/N)?
- How far beyond the immediate limits of the dredged area do such impacts extend?
- What is the nature and rate of the recolonization and recovery processes in a commercially-dredged area?

Study Site

A small heavily-exploited aggregate area to the east of the Isle of Wight, off the south coast of the U.K., known as the North Nab Production Licence Area 122/3 was selected as a study area. The boundaries of the Licence Area are shown in Figure 1, together with the strength and direction of the tidal streams and the broad boundaries of the area surveyed. Areas which have been exploited for gravel within the boundaries of Licence Area 122/3 are also shown in Figure 1.

The total amount of marine aggregates dredged from this small area is quite low at 150,000 tonnes per year, but the amount removed per unit area is probably amongst the highest on the south coast of the U.K. The area had been exploited for almost 10 years prior to the survey, so any impact of intensive dredging on the benthos at this site should be apparent.

The material is not significantly screened, but of the approximately eleven Licence Areas on the south coast of the U.K., nine involve non-screened cargoes.

The North Nab study area is therefore representative of the majority of the Licence Areas on the south coast of the United Kingdom, in contrast with those of the southern North Sea which are generally heavily-screened.

The North Nab site has the further advantage that both anchor-dredging from a stationary dredger and trailer-dredging have been used to exploit the sea bed deposits in adjacent locations within the boundaries of the Licence Area (see Figure 1). The survey could therefore be used to assess the impact of the two principal methods of aggregate exploitation on macrofaunal communities. The results also allow some comparisons of the nature of the recolonization processes and rates of recovery in relation to anchor-dredging and trailer-dredging.

MATERIALS AND METHODS

Positions of the Sampling Stations

A survey of benthic macrofauna at a total of 131 sampling stations in the vicinity of the North Nab Production Licence Area 122/3 was carried out between 13th and 16th March 1999. Additional samples were collected on 7th September 1999. Positions were fixed with a Trimble 4000 SSI with a 300 DCI Differential Global Positioning System (dGPS) using Trimble Hydro Version 6.05 receiving in WGS 84 and converting to OSGB 36. The position of the grab on the vessel was offset and the accuracy of the positions was calibrated in port to within 2 meters.

The sampling stations were chosen to quantify the benthos both within the dredging areas and in zones potentially affected by deposition, as well as in control zones well outside any area of potential impact of dredging activity. The dredge history of sites within the survey area was obtained from records held by United Marine Dredging Ltd. who operate North Nab Production Licence Area 122/3.

The tidal excursion for tidal diamond N at latitude 50°40.1′N; 00°56.3′W on British Admiralty Chart No 2045 shows that tidal streams close to the eastern boundaries of the dredging area comprise a main tidal stream of up to 1.8-knots at 078° on the Spring flood and 1.6-knots at 252° on the ebb (see Figure 1). The positions of the sampling stations extend approximately 3 nautical miles to the east of the eastern boundary of Area 122/3, and a similar distance to the west of the western boundary of the Licence Area.

These sampling stations cover a potential zone of impact associated with deposition of material from dredging activities in the extraction area. They allow comparison with *control* sites outside any likely impact of dredging activity, as well as with areas directly impacted by extraction of marine aggregates from within the boundaries of the dredging area.

Collection and Extraction Procedures

Samples were taken with a 0.2 meter² Hamon Grab. Use of this grab has the advantage that loss of material by *wash-out* from the jaws experienced with conventional grabs is reduced (see HOLME and MCINTYRE, 1984; SIPS and WARDENBURG, 1989; KENNY and REES, 1994; VAN MOORSEL, 1994). The samples also allow strict comparison with the results of surveys elsewhere using a similar grab.

The samples were released from the grab onto a 1 millimeter mesh sorting tray, the contents of which were transferred to 10 litre buckets and preserved in formalin for subsequent separation and identification. The biological material collected includes both infauna and sessile epifauna. Separation of this macrofauna was carried out in the laboratory by elution with a large volume of tap water through a 1 millimeter mesh sieve, and by careful manual separation of the residual fauna from the remaining sediment. The macrofauna was then preserved in methanol for subsequent identification and enumeration. A reference collection of key taxa was retained for future reference.

Biomass Determination

The blotted wet weight of the main faunal groups was measured. These data were then used to estimate total biomass as ash-free dry weight (AFDW) in grams using conventional conversion factors for each of the faunal groups. These were Polychaeta = wet weight × 0.155, Crustacea = wet weight × 0.225, Mollusca = wet weight × 0.085, Echinodermata × 0.08; Miscellaneous Groups including Porifera and Bryozoa = wet weight × 0.155 (ELEFTHERIOU and BASFORD, 1989).

Particle Size Analysis

One factor which affects community composition of the benthos is sediment type (see PEARSON and ROSENBERG, 1978; WESTON, 1988; CLARKE and MILLER-WAY, 1992), although other factors including the consolidation of the deposits is also important (see SEIDERER and NEWELL, 1999; NEWELL *et al.,* 2001).

Sub-samples of sediment were taken for particle size analysis. The material was sieved over the range 125 millimeters down to 0.075 millimeters. Results were expressed using conventional Wentworth Classification to give percentage composition of each particle size. These data were then used as an input to similarity analysis of sediment composition in the survey area using multi-variate techniques. The results of analysis of sediment composition are reported separately (see HITCHCOCK *et al.,* 2002).

Analysis of Invertebrate Community Structure

The statistical methods used to analyse the structure of the invertebrate communities of the coastal sediments follow those of FIELD *et al.* (1982; see also CLARKE and WARWICK, 1994). The Plymouth Routines in Multivariate Research (PRIMER) version v5 software (CLARKE and GORLEY, 2001) was used for analyses of community structure.

Comparisons between faunal groups were made using the ANOSIM sub-routine within the PRIMER software. The test used resembles a standard ANOVA test. A significance level of $<1\%$ was used to distinguish the groups from one another. The degree of separation of the groups was distinguished as a scale of $R = 0$ (groups indistinguishable from one another) to $R = 1$ (no similarity between the groups). The species that account for the similarity and differences between the faunal groups were identified using the SIMPER sub-routine within the PRIMER software.

RESULTS

Abundance and Variety of Benthos

In all, a total of 316 taxa were recorded. The assemblage as a whole was dominated by Polychaeta and Crustacea, although hydroids, Mollusca and Bryozoa were also important at some sampling sites.

Table 1. *Comparison of survey data recorded for the vicinity of a worked site at North Nab Production Licence Area 122/3 with the results of surveys of the macrofauna of unexploited deposits in U.K. coastal waters.*

Site	Total Taxa	Mean Species Per 0.2 m²	Mean Individuals Per 0.2 m²	Biomass gAFDW Per 0.2 m²	N	Source
St. Catherine's Isle of Wight	270	37 ± 22	918 ± 1166	5.59 ± 8.97	52	MESL, 1996a
Folkestone, Kent	343	37 ± 25	595 ± 777	4.95 ± 23.6	70	MESL, 1996b
Orford Ness, Suffolk	223	30 ± 20	949 ± 4056	3.18 ± 9.7	60	MESL, 1997b
North Norfolk	—	36	1488	5.66	–	Recalculated from Kenny *et al* 1998
Lowestoft, Norfolk	112	9 ± 5	134 ± 272	1.49 ± 3.49	60	MESL, 1997a
West Channel	229	20.78 ± 14.79	77.97 ± 89.09	1.47 ± 2.45	91	MESL, 1999a
West Bassurelle	294	44.04 ± 18.84	186.44 ± 109.95	2.41 ± 2.85	100	MESL, 1999b
North NAB	316	26.77 ± 14.96	199.52 ± 244.08	2.11 ± 4.36	131	This study

MESL = Marine Ecological Survey Limited
gAFDW = grams ash-free dry weight according to (ELEFTHERIOU and BASFORD, 1989)

Table 1 shows the total number of taxa, mean number of species, mean number of individuals and mean biomass recorded in the North Nab survey site compared with values recorded from non-dredged coastal deposits in U.K. waters. Values recorded for the North Nab survey area are generally similar to those recorded for non-dredged deposits elsewhere in U.K. coastal waters. In general, biomass values of 1.5–5.0 grams AFDW per 0.2 meter² have been recorded for unexploited deposits. This compares with an average value for the biomass in the vicinity of the North Nab Production Licence Area 122/3 of 2.11 grams AFDW per 0.2 meter². Dredging within the Production Licence Area does not appear to have had a marked effect on species variety, population density or biomass of benthic organisms in the survey area as a whole.

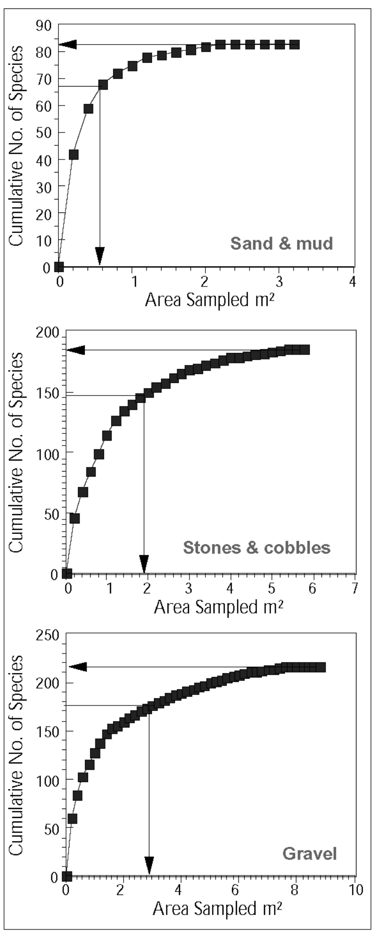

Figure 2. Species area curves for the macrofauna in the three main types of sediments that were identified in the survey area.

Impacts on Community Structure

One of the difficulties in the analysis of benthic communities is that there is a wide variability between replicate samples taken close together in the survey area. This reflects the patchiness of many components of marine communities and the fact that the 0.2 meter² sample of the sea bed deposits is small compared with the spatial separation of the macrofauna.

Figure 2 shows a series of *species area curves* for the macrofauna in the three main types of sediments that were identified in the survey area. The species recorded in each of a series of samples of 0.2 meter² have been plotted as a cumulative curve showing additional taxa recorded as a function of area sampled (meters²) in repeated replicates for each of the three types of sediment.

Figure 2 shows that the total number of species, as judged from the point at which no further taxa were discovered despite further replicate sampling of 0.2 meter², was 82 in sands and muds of the survey area. The corresponding value for coarse gravel was 185 taxa and that for the other gravel deposits was as high as 215 taxa. This increase in biodiversity probably reflects the habitat heterogeneity of gravels compared with sands and muds. These results are of importance because they suggest that removal of the coarse fraction, and rejection of sands by overboard screening may result in a reduction of species diversity in sea bed deposits.

A second feature of interest is that the *area sampled* required to identify at least 80% of the taxa that actually occur in the deposits is clearly related to sediment type. In the case of sands and muds that are dominated by one or a few taxa, only 0.4–0.6 meter² of sea bed (*i.e.* 2–3 replicate samples of 0.2 meter²) are required to discover at least 80% of the species

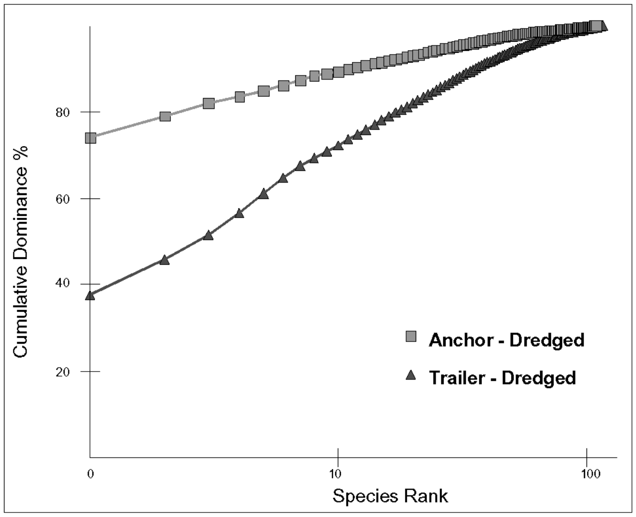

Figure 3. *K*-dominance curves for the macrofauna in combined anchor-dredged sites (squares) and trailer-dredged sites (triangles).

present in the deposits, even when as many as 82 taxa are present. Similar results have been obtained for sands and muddy deposits of the eastern English Channel by NEWELL *et al.* (2001).

Where the deposits comprise a larger species variety such as occurs in coarse gravel, an area of sea bed of up to 2.0 meter^2 (*i.e.* 10 replicate samples of 0.2 meter^2) are required to define 80% of the species present. Finally, in mixed sandy gravels of the survey area, an area of sea bed of at least 2.6 meter^2 (*i.e.* 13 replicate samples of 0.2 meter^2) are required to satisfactorily identify 80% of the taxonomic diversity of the sediments.

When sufficient samples are pooled to give a reliable estimate of species diversity, the data show that dredging for marine aggregates at North Nab Area 122/3 has an impact on the relative contribution of different species comprising the benthic macrofauna community. Figure 3 shows *k*-dominance curves plotted for combined trailer-dredged sites and for combined anchor-dredged sites within the Production Licence Area. *K*-dominance curves show the relative contribution of each component species to the total complement in the community (see LAMBSHEAD *et al.,* 1983).

Anchor dredged sites were heavily dominated by one species. In contrast, the sediments within the trailer dredged site had a relatively low dominance by one or a few species, and a more uniform species composition typical of undisturbed environments. This suggests that within the heavily exploited anchor-dredged site typical benthic macrofauna had been replaced by large numbers of mobile opportunistic species that are able to rapidly recolonise sediments following episodic disturbance.

Multi-variate Analysis of Community Composition

Figure 4 shows a group average sorting dendrogram and the corresponding two-dimensional multidimensional scaling (MDS) ordination for the infauna of deposits in the immediate vicinity of the dredge site. This shows a graded change in fauna which may comprise three groups or communities. These evidently have some common characteristics, indicated by the lack of clear separation in the MDS ordination. The groups have been designated Group A, Group B and Group C in Figure 4.

Analysis of similarity shows that faunal groups A, B and C are all significantly different from one another at the 1% level. However, whereas Groups A and B are very dissimilar ($R = 0.956$), as are Groups A and C ($R = 0.933$), Groups B and C are less dissimilar to one another ($R = 0.491$).

The species that account for the similarity within each of the three faunal groups identified above may be summarised as follows:

Group A: Characterised by polychaetes including *Notomastus* sp (22.9% of the similarity), *Cirratulus filiformis* (15.4%) and *Capitella* sp (13.7%).

Group B: Characterised by a wide range of species each making a small contribution to the percentage similarity of the group. They include *Pomatoceros* sp (7.4%), *Sabellaria spinulosa* (6.3%), *Distomus variolosus* (5.5%), *Ampelisca brevicornis* (5%), *Crepidula fornicata* (4.8%), *Cirriformia tentaculata* (3.9%), *Typosyllis prolifera* (3.9%), *Nucula nucleus* (3.7%), *Unicola crenatipalma* (3%), *Lumbrinereis latreilli* (2.9%), *Notomastus* sp (2.8%) and *Euclymene* sp (2.5%).

Group C: Characterised by *Distomus variolosus* (19.9%), *Crepidula fornicata* (13.8%), *Pomatoceros* sp (9.3%) and *Sabellaria spinulosa* (8.5%).

There is also a relatively large group of stations where the macrofauna communities have a relatively low level of similarity with one another and with faunal groups that occur elsewhere in the survey area. This may reflect disturbance of the benthos in dredged deposits. A similar disruption of community structure and low similarity levels of the macrofauna following dredging has been recorded for an experimentally-dredged site in the southern North Sea by KENNY and REES (1994, 1996).

Other groups of sites in the North Nab study site where the fauna was poorly-classified corresponded with deposits bordering mixed sands and reefs. The distribution of the main faunal communities close to the dredge site identified by multi-variate analysis of community composition of macrofauna is shown in a map of the survey area in Figure 5.

The concentration of poorly-classified communities within the dredge sites suggests that there is an impact of dredging on community composition close to the site of anchor dredging. The relatively uniform distribution of faunal Group C, both within the trailer-dredged site and in the surrounding deposits suggests, however, that any impacts on the community composition based on an analysis of species variety and population density, are confined to the intensively-exploited anchor dredge site.

Impacts Outside the Boundaries of Dredged Areas

The results show that there was no suppression of species diversity, population density or biomass of benthic macrofauna outside the immediate boundaries of the dredged sites in

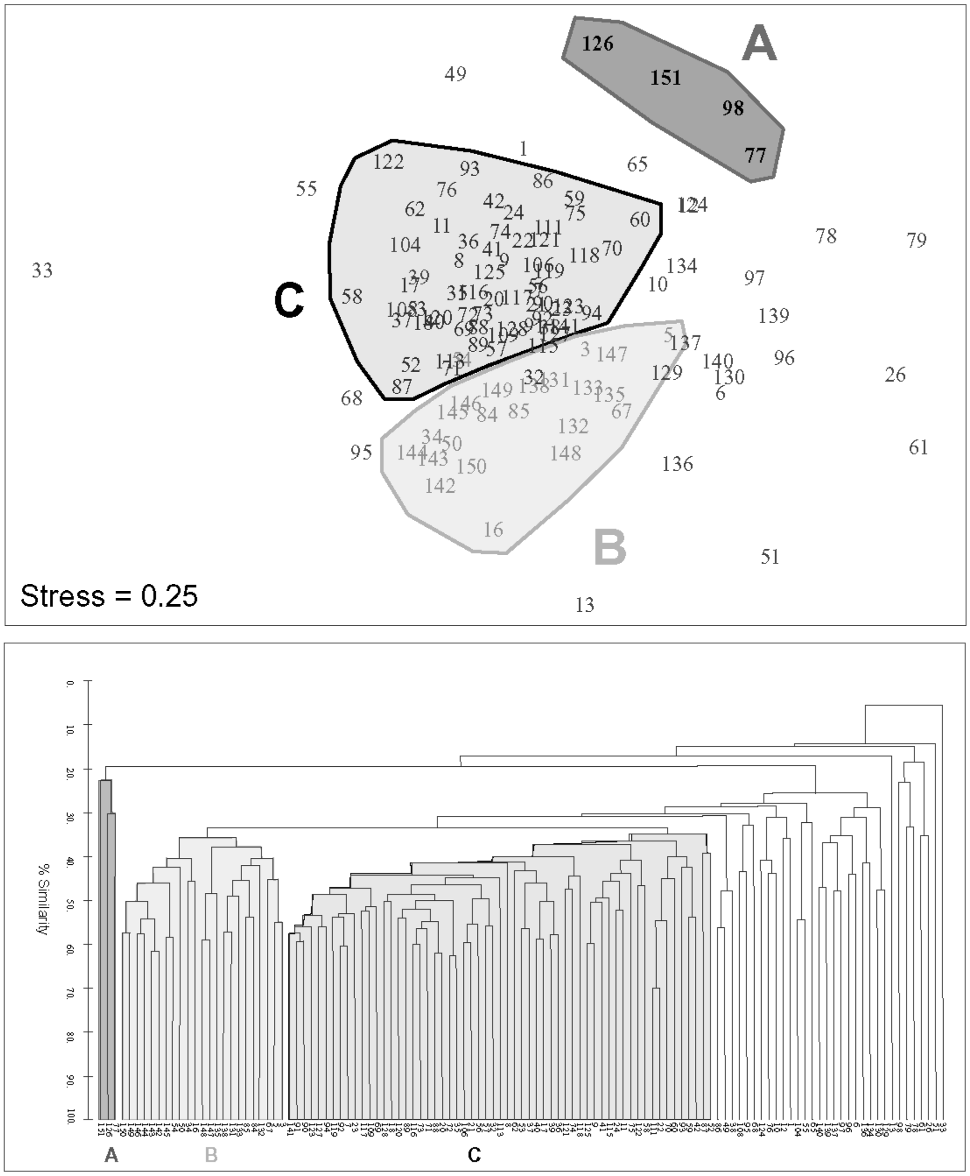

Figure 4. Group average sorting dendrogram and two-dimensional MDS-ordination for the macrofaunal communities at each of the stations in the survey area. The boundaries of the three main groups, or communities of macrofauna identified by multi-variate analysis are indicated. The high stress reflects the heterogeneous macrofauna recorded from the deposits.

the North Nab survey area. There is, however, clear evidence of a zone of enhanced biomass outside the boundaries of the dredge site extending along the axis of the tidal stream for a distance of up to 2 kilometers.

Table 2 shows mean values for number of species (S), population density (N), biomass (B) (grams AFDW) and body size (B/N) (grams AFDW) of benthos recorded from a total of 131 samples of 0.2 meter^2 in the North Nab survey area (from Table 1). Also shown are mean values for stations occurring within a zone extending for 600 meters across, and for 2 kilometers along the axis of tidal streams from the North Nab dredge site.

This shows that the stations within a zone of probable transport of material from the dredge site (near-site stations) had a higher species richness of 39.8 species compared with 26.8 species per 0.2 meter^2 for the survey area as a whole. The population density of macrobenthos in the near-site stations was 523.3 individuals per 0.2 meter^2 compared with 199.5 for the survey area as a whole. Biomass was 8.84 grams AFDW per 0.2 meter^2 compared with 2.11 grams AFDW for the survey area as a whole. Finally the mean body size was 0.0220 grams AFDW for the near site stations compared with 0.0103 grams AFDW for the macrobenthos of the whole survey area.

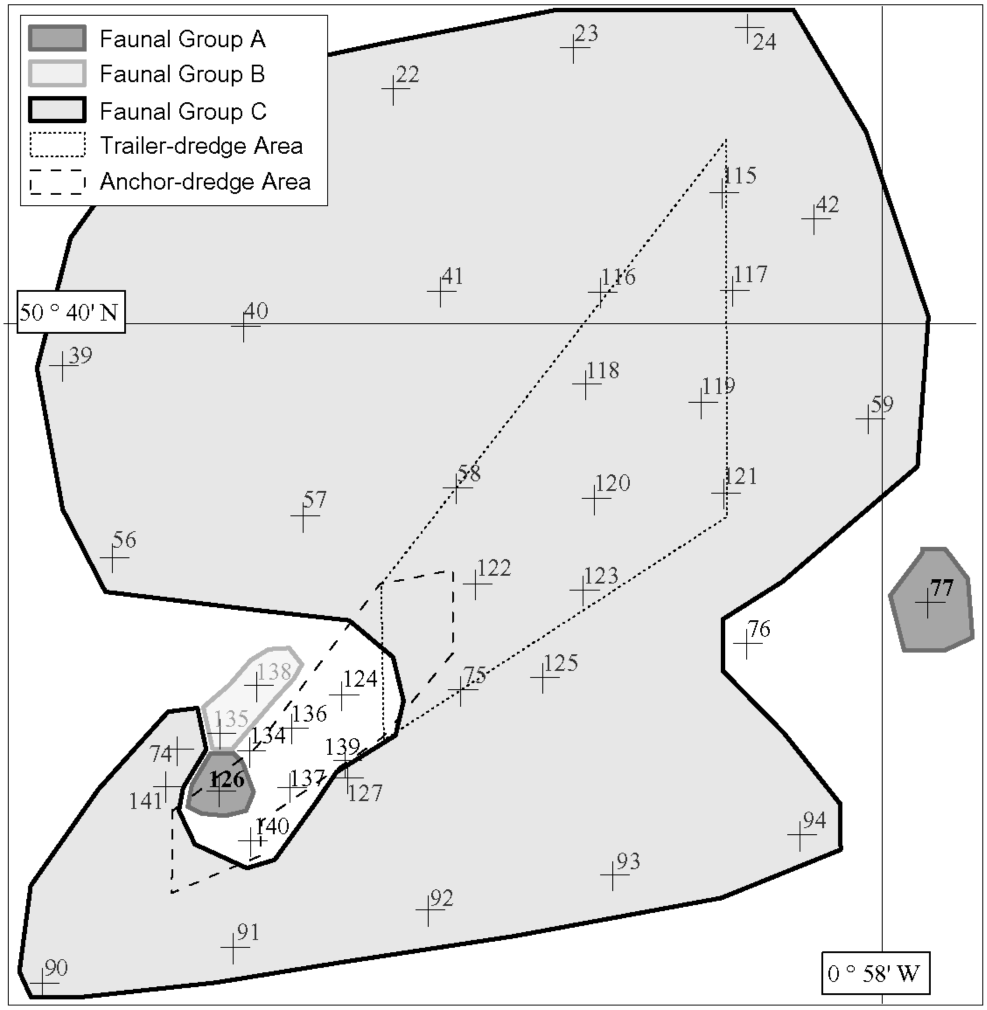

Figure 5. Map of the survey area showing the distribution of macrofaunal types in the deposits within and immediately adjacent to the dredged areas. Note the poorly classified (heterogeneous) communities within the anchor-dredged area, and the similarity of the communities within the trailer-dredged area compared with those in the surrounding deposits.

That is, the near site stations had a macrofaunal assemblage which was approximately 148% higher in species variety, 262.3% higher in population density, 419% higher in biomass and 213% higher in average body size of the individuals. These results are similar to the enhancement in benthos reported by POINER and KENNEDY (1984) close to a site of dredging in Queensland, Australia. They attributed this to release of organic matter from sediments disturbed by dredging. The possibility that this zone of enhanced species richness, population density and biomass of benthic macrofauna surrounding the dredge site may reflect organic enrichment from the dredge site warrants further investigation.

Impacts of Dredging within the Dredged Site

Impacts on Population Density, Species Variety & Biomass

Anchor-Dredged Site: Impacts of dredging on species variety, population density and biomass of macrofauna within anchor-dredged and trailer dredged sites are of interest because the data can be related to the known dates at which dredging had taken place at particular sampling sites. This gives information on the immediate impact of dredging on the benthic macrofauna and can also be used to estimate the rates of restoration of species diversity and population density within deposits following cessation of dredging.

Table 3 shows that the population density at Station 126 was reduced by 87% compared with average values for the survey as a whole. This site was close to an area being dredged at the time of our survey on 13.03.99. An 88% reduction in population density was recorded at Station 139, despite the fact that this site was last dredged 178 days prior to our survey. In contrast, a reduction of only 16% in the population density was recorded at Station 134, despite the fact that records show that this station was dredged only 7 days previously.

In general the results show that anchor dredging has a

Table 2. *Showing the values for the species variety* (S)*, population density* (N)*, biomass* (B)*, and body size* (B/N) *of the benthic macrofauna. Values are shown for all stations in the survey area and for near-site stations in a zone extending up to 2 Km along the axis of dispersion of material within the tidal stream for the North Nab dredge site.*

	No. of Species (*S*) Per 0.2 m²	No. of Individuals (*N*) Per 0.2 m²	Biomass (*B*) gAFDW Per 0.2 m²	Body Size (*B/N*) gAFDW Per 0.2 m²
All Stations				
Mean	26.8	199.5	2.11	0.0103
S.D.	15	244.1	4.36	0.0148
N	131	131	131	131
Near Site Stations				
Mean	39.8	523.3	8.84	0.022
S.D.	15.6	389.2	7.26	0.0196
N	23	23	23	23
% Increase	148	262.3	419	213.5

gAFDW = grams ash-free dry weight according to (ELEFTHERIOU and BASFORD, 1989)

significant impact on population density of the benthos, although the exact level of suppression recorded depends on whether the samples coincided with the middle of a dredge pit, and the number of days elapsed since dredging took place.

These data showing a reduction of the population density of macrobenthos in dredged areas agree with results reported in the literature for various sediment types (see NEWELL *et al.,* 1998). A reduction of 70–80% in the number of individuals has been reported for commercially exploited sands and gravels (DESPREZ, 1992, 2000; VAN MOORSEL, 1994). A smaller reduction of 46% was reported for sands in Moreton Bay, Queensland, by POINER and KENNEDY (1984) and a value of 60% for sands in Hong Kong waters (MORTON, 1996).

The data for the North Nab site also show high population densities of benthos within approximately 100 meters from the dredge sites. This suggests that where the cargo is loaded without significant losses overboard, impacts on the macrobenthic population density is confined to the immediate area of the dredge site.

Impacts on species variety in general parallelled those described for population density with a reduction of 11–66% in dredged areas (Table 3). Table 3 also shows that a major suppression of biomass of 80–90% occurred in previously dredged sites. Further, it is clear that this suppression persisted for periods in excess of 18 months after cessation of dredging.

Trailer-Dredged Site: Table 3 shows that recovery of the population density to within 30–60% of that in the surrounding deposits is achieved within 80 days. The time required for restoration of population density is not dissimilar to that for anchor-dredge sites.

Recovery of species diversity may occur somewhat faster within the narrow trailer-dredge tracks compared with the larger pits in the sea bed associated with anchor-dredging. A recovery of 86% of the species diversity can occur within 20 days after trailer dredging, and full recovery is achieved within approximately 80 days. Finally the biomass in trailer-dredged areas shows some recovery after 80 days, but is still suppressed by at least 80% compared with that in the surrounding deposits 80 days after cessation of dredging.

DISCUSSION

Inspection of records from operating dredgers allows some estimates of the time course and sequence of recovery in the initial phases of the recolonization process at the North Nab dredge site. Restoration of the species variety to within 70–80% of that which occurs in the surrounding deposits generally occurs within 100 days although at Station 134 restoration apparently occurred within only 7 days. This may reflect a sampling inaccuracy in that the grab sample may not have coincided with the centre of the dredge pit at that site.

The data summarised in Table 3 suggest that in general,

Table 3. *Table showing the date at which a series of stations in the North Nab Production Licence Area 122/3 were sampled for macrofauna, when the stations were last dredged and the elapsed time in days. The number of species* (S)*, number of individuals* (N)*, and the biomass* (B)*, the body size* (B/N) *at each station is shown, together with the % reduction compared with average background values for all stations outside the dredge area.*

Station	Date Sampled	Date Last Dredged	Days Elapsed	Species (*S*) Per 0.2 m²		Individuals (*N*) Per 0.2 m²		Biomass (*B*) gAFDW per 0.2 m²		Size (*B/N*) mg	
				No.	%	No.	%	g	%	mg	%
Anchor-Dredge											
126	13.03.99.	—	—	11	−62	26	−87	0.257	−83	1	−86
134	08.06.99.	01.06.99.	7	21	−28	166	−16	0.606	−61	3.6	−49
141	08.06.99.	21.02.99.	107	22	−24	130	−44	0.149	−90	1.1	−84
139	08.06.99.	18.12.98.	178	21	−28	44	−88	0.04	−98	0.8	−89
124	13.03.99.	06.04.98.	312	10	−66	114	−42	0.964	−38	8.5	21
137	08.06.99.	15.07.98.	355	26	−11	330	69	2.106	36	6.4	−9
136	08.06.99.	09.05.99.	395	33	13	357	82	0.17	−89	1.5	−79
140	08.06.99.	25.11.97.	560	20	−31	153	−22	0.258	−83	1.7	−86
Trailer-Dredge											
118	13.03.99.	21.02.99.	20	25	−14	84	−57	0.594	−62	7.1	1
122	13.03.99.	23.12.98.	80	31	7	60	−69	0.235	−85	3.9	−44
123	13.03.99.	23.12.98.	80	30	3	105	−46	0.301	−80	2.9	−59
121	13.03.99.	21.12.98.	82	18	−38	124	−37	0.196	−87	1.6	−87
120	13.03.99.	19.12.98.	84	25	−14	358	83	2.1	36	5.9	−16

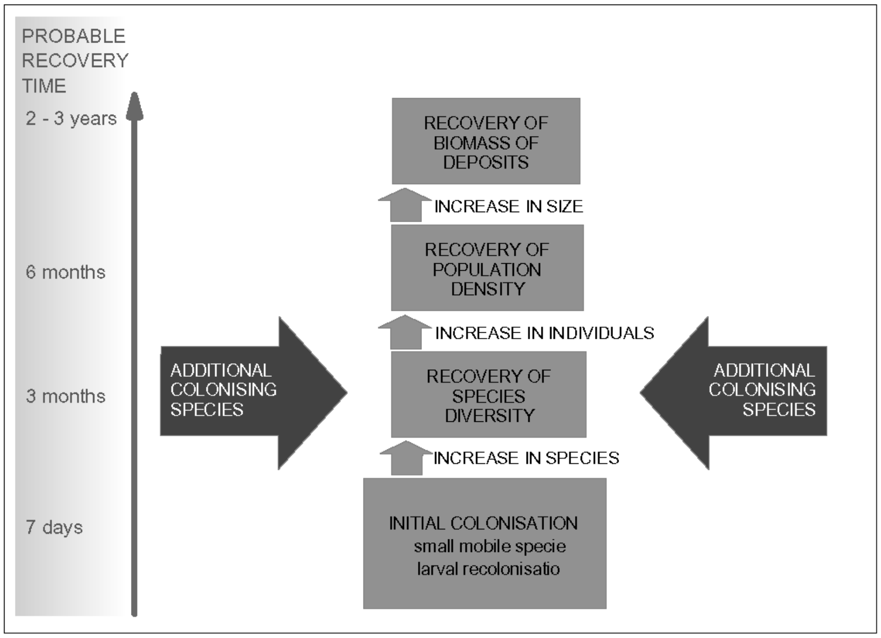

Figure 6. Generalised flow diagram showing the sequence of recovery of the macrofauna in coastal marine deposits in a *high energy* disturbed area following cessation of dredging.

population density is restored to within 60–80% of that in the surrounding deposits within 175 days after cessation of dredging. Station 134 again appears to be anomalous in that restoration of the population density to within 86% of that in the surrounding deposits evidently occurred within 7 days.

Finally, restoration of biomass by growth of individuals is far from complete even after 18 months. These data for the time taken for restoration of the biomass agree with those in the literature where recovery of biomass after initial recolonization by the macrofauna of sands and gravels has been reported to take 2–3 years (DESPREZ, 1992, 2000; KENNY and REES, 1994, 1996; NEWELL *et al.,* 1998; NEWELL *et al.,* 2002).

A generalised flow diagram showing the sequence of recovery of the macrofauna in coastal marine deposits following cessation of dredging is shown in Figure 6. It should be emphasised that whilst the sequence is likely to be similar in a wide range of deposit types, the absolute rates are likely to vary from the relatively rapid restoration of community structure noted above.

Where the deposits are stable, as in low-energy environments, or where the deposits are coarse, the biological community is represented by a higher proportion of long-lived and slow-growing species which have a slow rate of reproduction (for review, see NEWELL *et al.,* 1998). These components may take longer to recover both species variety and population density and for the biomass to be restored by growth of the individuals (see also VAN DALFSEN *et al.,* 2000).

CONCLUSIONS

This study has shown that aggregate dredging has an impact on community composition of the benthic macrofauna within the boundaries of an intensively-dredged site in coastal deposits off the south coast of U.K. Dredging at this site was associated with a significant suppression of population density, species diversity and biomass of benthic macrofauna. The community was dominated by one species within the boundaries of the intensively dredged site.

In contrast, there was little evidence of an impact on community structure outside the immediate boundaries of the intensively dredged site, including areas that had been lightly exploited by trailer-dredger. Macrofaunal communities outside the boundaries of the intensively dredged site had a relatively low dominance by one or a few species, and a more uniform species composition typical of undisturbed environments. This suggests that within the heavily exploited site, local infauna had been replaced by large numbers of mobile opportunistic species that were able to colonise sediments following episodic disturbance.

Although community structure of benthic infauna was apparently unaffected by dredging outside the immediate boundaries of the intensively dredged site, there was an enhancement of species diversity, population density, biomass and mean body size of the macrofauna in deposits surrounding the dredge site. The possibility that this reflects organic enrichment from the dredge site warrants further investigation.

The data also allow some estimates of the nature and rate of recolonisation processes in marine deposits following cessation of dredging. Recovery of species diversity to within 70–80% of that in the surrounding deposits was generally achieved within 100 days. Recovery of population density was achieved within 175 days. In contrast, restoration of biomass following growth of the individual colonising species was incomplete even 18 months after cessation of dredging.

ACKNOWLEDGMENTS

This study was supported by the United States Department of the Interior, Minerals Management Service Contract Number 14-35-01-99-CT-30980 to Coastline Surveys Ltd. U.K. and is reported in full in HITCHCOCK *et al.* (2002). We are grateful to Dr Andrew Bellamy of United Marine Dredging Limited for kindly providing us with information on dredging within the North Nab study site and for his assistance and co-operation during the course of this study.

LITERATURE CITED

CLARKE, D. and MILLER-WAY, T., 1992. An environmental assessment of the effects of open-water disposal of maintenance dredged material on benthic resources in Mobile Bay, Alabama. U.S. Army Engineer District, Mobile. *Misc Paper D-92-1.* 40p.

CLARKE, K.R. and GORLEY, R.N., 2001. *PRIMER v5: User Manual/Tutorial.* Primer-E-Ltd., Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH. U.K. 91p.

CLARKE, K.R. and WARWICK, R.M., 1994. *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation.* Natural Environment Research Council U.K. 144p.

DESPREZ, M., 1992. Bilan de dix années de suivi de l'impact biosédimentaire de l'estraction de graves marins au large de Dieppe. Comparaison avec d'autres sites. Rapport Groupe d'etude des Milieux Estuariens et Littoraux GEMEL, St Valery/Somme. Cited in: *Report of the Working Group on the Effects of Extraction of Marine Sediments on Fisheries.* ICES Report No CM 1993/E:7 Marine Environmental Quality Committee. pp. 51–67.

DESPREZ, M., 2000. Physical and biological impact of marine aggregate extraction along the French coast of the eastern English Channel. Short and long-term post-dredging restoration. *ICES Journal of Marine Science.* 57, 1428–1438.

DICKSON, R.R. and REES, J.M., 1998. Impact of dredging plumes on Race Bank and surrounding areas (A908). CEFAS Lowestoft. Unpublished Final Report to MAFF, U.K. 15p.

ELEFTHERIOU, A. and BASFORD, D.J., 1989. The macrofauna of the offshore northern North Sea. *Journal of the Marine Biological Association of the UK.,* 69, 123–143.

FIELD, J.G.; CLARKE, K.R., and WARICK, R.M., 1982. A practical strategy for analyzing multispecies distribution patterns. *Marine Ecology Progress Series,* 8,37–52.

HESS, H.D., 1971. *Marine sand and gravel mining industry in the United Kingdom.* NOAA Tech. Rep. ERL 213-MMTCI. U.S. Dept. of Commerce, Boulder, Colorado 176p.

HITCHCOCK, D.R. and DRUCKER, B.R., 1996. Investigation of benthic and surface plumes associated with marine aggregates mining in the United Kingdom. *In: The Global Ocean-Towards Operational Oceanography. Oceanology International* Vol 2. ISBN 0-900254-12-2. pp. 220–234.

HITCHCOCK, D.R.; NEWELL, R.C., and SEIDERER, L.J., 1998. *Investigation of benthic and surface plumes associated with marine aggregate mining in the United Kingdom—Final Report.* Contract Report for the U.S. Department of the Interior, Minerals Management Service. Contract Number 14-35-0001-30763. Coastline Surveys Ltd. Ref. 98-555-03 (Final), 168p.

HITCHCOCK, D.R.; NEWELL, R.C., and SEIDERER, L.J., 2002. *Integrated report on the impact of marine aggregate dredging on physical and biological resources of the sea bed.* US Department of the Interior, Minerals Management Service, International Activities and Marine Minerals Division (INTERMAR), Washington DC. (Contract No. 14-35-01-CT-30980).

HOLME, N.A. and MCINTYRE, A.D., (eds.), 1984. *Methods for the Study of Marine Benthos.* International Biological Programme Handbook. 2nd Edition. Blackwell, Oxford.

KENNY, A.J. and REES, H.L., 1994. The effects of marine gravel extraction on the macrobenthos: Early post-dredging recolonisation. *Marine Pollution Bulletin,* 28 (7), 442–447.

KENNY, A.J. and REES, H.L., 1996. The effects of marine gravel extraction on the macrobenthos: results 2 years post-dredging. *Marine Pollution Bulletin,* 32 (8/9), 615–622.

KENNY, A.J.; REES, H.L.; GREENING, J., and CAMPBELL, S., 1998. The effects of gravel extraction on the macrobenthos at an experimental dredge site off north Norfolk. UK. (Results 3 years post-dredging). *ICES CM 1998/V: 14,* 1–8.

LAMBSHEAD, P.J.D.; PLATT, H.M., and SHAW, K.M., 1983. The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity. *Journal of Natural History,* 17, 859–874.

MESL (MARINE ECOLOGICAL SURVEYS LTD.), 1996a. *Benthic Ecology of St Catherine's Licenced Dredging Area 407.* Report prepared for Oakwood Environmental, Wormley, Surrey. 62 pp.

MESL (MARINE ECOLOGICAL SURVEYS LTD.), 1996b. *Benthic Ecology of West Varne Licenced Dredging Areas 432/1 & 432/2.* Report prepared for Oakwood Environmental, Wormley, Surrey. No SCS/432/1. 45 pp.

MESL (MARINE ECOLOGICAL SURVEYS LTD.), 1997a. *Benthic Ecology off Lowestoft Dredging Application Area 454.* Report prepared for Oakwood Environmental, Wormley, Surrey. No. SCS/454/1. 48 pp.

MESL (MARINE ECOLOGICAL SURVEYS LTD.), 1997b. *Benthic Ecology off Suffolk (Shipwash Gabbard) Dredging Application Area 452.* Report prepared for Oakwood Environmental, Wormley, Surrey. No SCS/452/1. 47 pp.

MESL (MARINE ECOLOGICAL SURVEYS LTD.), 1999a. *Benthic Ecology south west of the Isle of Wight. Area 465/1 & 465/2 (West Channel).* Report prepared for Coastline Surveys Limited, Stonehouse, Gloucestershire. 39 pp.

MESL (MARINE ECOLOGICAL SURVEYS LTD.), 1999b. *Benthic Ecology: Areas 458 & 464 (West Bassurelle).* Report prepared for Oakwood Environmental, Wormley, Surrey. 39 pp.

MORTON, B., 1996. The subsidiary impacts of dredging (and trawling) on a sublittoral benthic molluscan community in the southern waters of Hong Kong. *Marine Pollution Bulletin,* 32(10), 701–710.

NEWELL, R.C.; SEIDERER, L.J., and HITCHCOCK, D.R., 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources in the sea bed. *Oceanography and Marine Biology: Annual Review,* 36, 127–178.

NEWELL, R.C.; HITCHCOCK, D.R., and SEIDERER, L.J., 1999. Organic enrichment associated with outwash from marine aggregates dredging: a probable explanation for surface sheens and enhanced benthic production in the vicinity of dredging operations. *Marine Pollution Bulletin,* 38(9), 809–818.

NEWELL, R.C.; SEIDERER, L.J., and ROBINSON, J.E., 2001. Animal: sediment relationships in coastal sediments of the English Channel off Folkestone, Kent. *Journal of the Marine Biological Association of the UK.,* 81, 1–9.

NEWELL, R.C.; SEIDERER, L.J.; SIMPSON, N.M., and ROBINSON, J.E., 2002. *Impact of marine aggregate dredging and overboard screening on benthic biological resources in the central North Sea: Production Licence Area 408, Coal Pit.* Marine Ecological Surveys Limited. Technical Report No ER1/4/02 to the British Marine Aggregate Producers Association (BMAPA). 72 pp.

PEARSON, T.H. and ROSENBERG, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: Annual Review,* 16, 229–311.

POINER, I.R. and KENNEDY, R., 1984. Complex patterns of change in the macrobenthos of a large sandbank following dredging. *Marine Biology,* 78, 335–352.

SARDÁ, R.; PINEDO, S.; GREMARE, A., and TABOADA, S., 2000. Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea. *ICES Journal of Marine Science,* 57, 1446–1453.

SEIDERER, L.J. and NEWELL, R.C., 1999. Analysis of the relationship between sediment composition and benthic community structure in coastal deposits: implications for marine aggregate dredging. *ICES Journal of Marine Science,* 56, 757–765.

SIPS, H.J.J. and WARDENBURG, H.W., 1989. *The macrobenthic community of gravel deposits in the Dutch part of the North Sea (Klaverbank): Ecological impact of gravel extraction.* Bureau Waardenburg bv, Culemborg, Netherlands, 34p.

VAN DALFSEN, J.A. and ESSINK, K., 1997. *Risk analysis of coastal nourishment techniques in The Netherlands.* Ministry of Transport, Public Works and Water Management, National Institute for Coastal and Marine Management/RIKZ. Haren, The Netherlands. Report RIKZ-97.022, 98p.

VAN DALFSEN, J.A.; ESSINK, K.; TOXVIG MADSEN, H.; BIRKLUND, J.; ROMERO, J., and MANZANERA, M., 2000. Differential response of macrozoobenthos to marine sand extraction in the North Sea and Western Mediterranean. *ICES Journal of Marine Science,* 57,1439–1445.

VAN-MOORSEL, G.W.N.M., 1994. *The Klaver Bank (North Sea), Geomorphology, Macrobenthic Ecology and the effect of gravel extraction.* Rapport Bureau Waardenburg and North Sea Directorate (DNZ), Ministry of Transport, Public Works & Water Management, The Netherlands, 65p.

WESTON, D.P., 1988. Macrobenthos-sediment relationships on the continental shelf off Cape Hatteras, North Carolina. *Continental Shelf Research,* 8(3), 267–286.