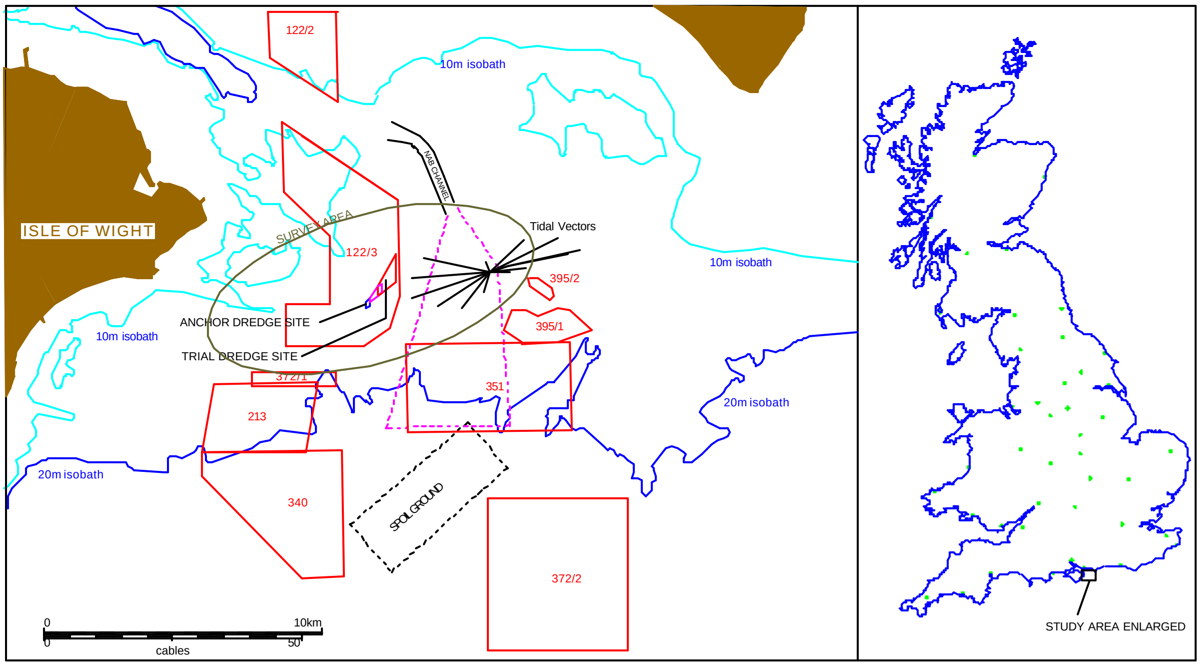
OCS STUDY
MMS 2002-054

# INTEGRATED REPORT ON THE IMPACT OF MARINE AGGREGATE DREDGING ON PHYSICAL AND BIOLOGICAL RESOURCES OF THE SEABED

**Final Report**

**October 2002**




U.S. Department of the Interior
Minerals Management Service

**COASTLINE SURVEYS LIMITED**

**MARINE ECOLOGICAL SURVEYS LTD**

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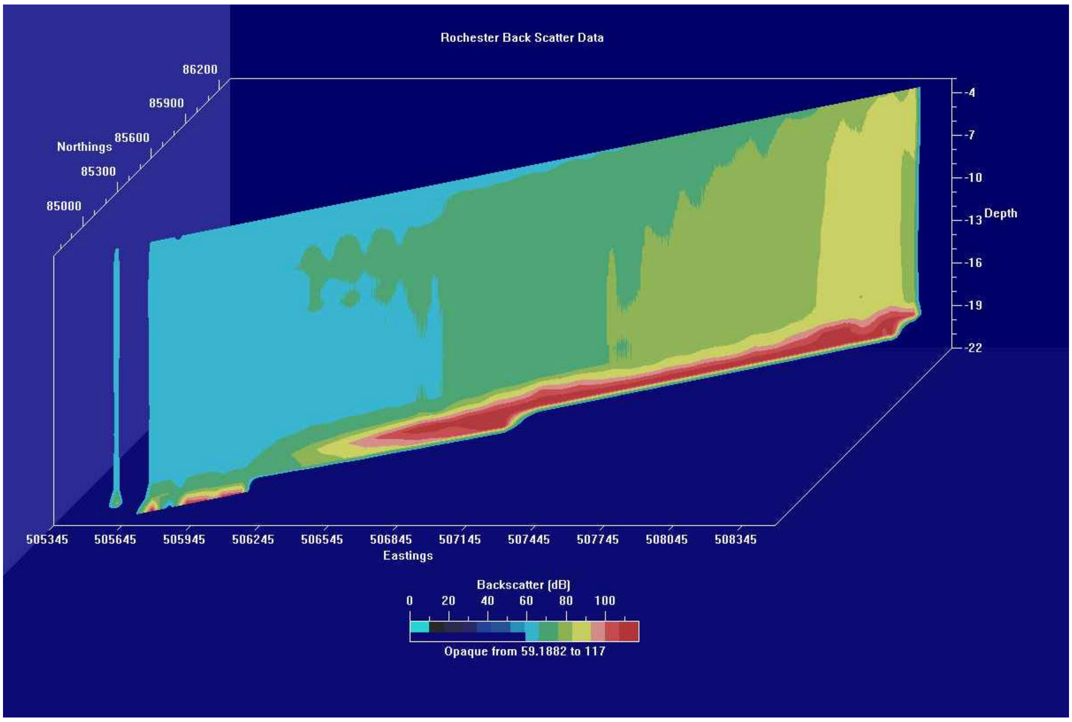



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## DISCLAIMER



## SPONSORSHIP

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## CITATION

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## ACKNOWLEDGEMENTS

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Dr. David Hitchcock served as Principal Investigator and Author of the report and I am indebted to the assistance of those above and others not mentioned.

## QUALITY STATEMENT.

Field surveys were carried out by Dr. D. R. Hitchcock B.Sc., Ph.D. (Wales), Dr. R.C. Newell B.Sc., Ph.D., D.Sc. (London), Dr. L.J. Seiderer B.Sc., Ph.D. (Cape Town), Mr. J.E. Robinson B.Sc. and Mr. S. Galliver B.Sc. Dr. Hitchcock holds United Kingdom status as a Chartered Surveyor. Separation and faunal identification was carried out by Mr. J.E. Robinson B.Sc., Ms. N.M. Stearn B.Sc., Ms. N. Simpson B.Sc., MSc. and Ms. S.C. Newell of Marine Ecological Surveys Limited. Ms. N.M. Stearn holds a Natural History Museum Id.Q. qualification in marine macrofaunal identification. Dr. L.J. Seiderer carried out community analysis.

Coastline Surveys Limited possesses corporate registration as a company of Chartered Hydrographic Surveyors according to the charter of the United Kingdom Royal Institute of Chartered Surveyors. Marine Ecological Surveys Limited is a member of the Environmental Law Foundation. Dr. R.C. Newell is an accredited Environmental Auditor certificated with the Institute of Environmental Assessment and Management for Environmental Impact Assessments to BS7750 under Eco-Audit Regulations (Registrant Number 9E).

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| | | | | |

**ABSTRACT**

An integrated study of the impacts of dredging on the physical and biological resources of a non-screened dredge area on the South Coast of Britain has been completed. This site has been dredged since 1991 by anchored suction dredgers and occasionally (since late 1998) by trailing suction dredgers, removing a total of nearly 2 million tonnes over that period. The gravelly resource has been extracted from a very small target area of roughly 400m x 400m, within a larger licence.

Over 350km of high-resolution sidescan sonar mapping has confirmed the areas that have been dredged by observing the extent of small pits formed on the seabed. 177 seabed samples have been obtained and the majority analysed for sedimentary and faunal analysis. The study area extended up to 10km either side of the dredge zone (one tidal excursion) in order to identify far-field effects on both physical and biological resources of the seabed.

The results clearly show that the physical impact of dredging on the seabed (without screening) is limited to a zone within approximately 300m downtide of the dredge area. There is no visible evidence of suspended sediments falling to the seabed beyond this zone, which may be manifested as infilling of small pits by fine sediments, siltation within crevices or development of migratory sand ripples. That is not to say that such events cannot happen, but probably merely represents a poor supply of fine material due to the lack of screening activities. However there is some statistical evidence that the surface sediment samples have a greater sand fraction within the excursion track of the plume than those samples either side.

The biological “footprint” of impact has been established. Species diversity, population density and biomass of benthic macrofauna of the study site is typical of that recorded in UK waters. Average benthic macrofauna biomass as a whole is equivalent to 4.06 grams Carbon per $m^2$.

The studies show that dredging at anchor using a small, modern 2300 tonne suction dredger is associated with a reduction of species diversity of 66%, population density (87%) and biomass (80-90%) of benthic invertebrates. Very importantly, the deposits are loaded as an ‘all-in’ cargo with no discharge of screened material at this site. In this case the suppression of invertebrate species variety, population density and biomass appears confined to the dredge sites themselves, with no evidence of impact outside the boundaries of the dredge pit.

Some distance outside the dredge site, there is evidence of an enhancement of benthic diversity and biomass in an elongated ‘halo’, which extends for a distance of up to 3 km from the dredge site. Average benthic macrofauna biomass is equivalent to 17 grams Carbon per $m^2$, some 4 times greater than the surrounding deposits.

Our monitoring aboard the dredge vessel determined some 17.36 tonnes ash-free dry weight of organic matter may be released per year in the outwash of dredgers operating within the restricted worked site of the much larger North Nab licence. This material is likely to be carried beyond the boundaries of the Licence Area along the axis of the tidal excursion. Whether this is sufficient to account for the enhanced values of biomass 1-3km from the dredge site is unknown.

In contrast with the intensively anchor dredged site, the trailer dredged site has been less exploited. Communities within this site are largely similar to those in the surrounding deposits. This suggests that the processes of recolonisation and recovery are sufficient to keep pace with the rate of removal of biomass when trailer dredging here. It must be noted that the key factor here may be *intensity* rather than *method* of dredging used.

Sites which have been left undredged for known times suggests that initial recolonisation by mobile components of the benthos can occur within weeks with some 70-80% of the species variety returning. This process is often accompanied by a similarly rapid increase in population density, although not as frequently, but with both of these stages in the recolonisation sequence being substantially completed within 3-6 months after cessation of dredging.

Restoration of biomass is achieved by growth of the small individuals that recolonise the deposits. This stage is incomplete even after 18 months compared with areas some distance away from the dredge site, and this finding is in keeping with anecdotal information available from the literature.

The results for trailer-dredged studies elsewhere indicate that species diversity may initially recover much quicker, as mentioned above. Population density is not dissimilar to anchor dredge sites, with biomass recovering to within 80% of the undredged sites within 3 months.

We conclude with the following general hypothesis based on this study and another partial study recently completed in the Southern North Sea on a trailer dredge study site (Newell *et al* 2002):-

(1) The degree of suppression of the fauna in the dredge site itself is clearly dependent on the intensity of dredging. In high intensity dredging (North Nab) the suppression of population density, species variety and biomass can be as high as 60-80%. In areas that are dredged less intensively by trailer techniques, the suppression is either less than at anchor dredge areas (North Nab), or undetectable (North Sea).

(2) There is no evidence of an impact outside the immediate dredge sites.

(3) Both sites show some evidence of an enhanced biomass and population density at some distance from the dredge site, possibly reflecting the deposition of organic components from fragmented invertebrates discharged in the outwash.

(4) Recovery of population density and species variety can be very rapid indeed. This depends on the degree of disturbance to which the area is subjected under natural conditions. In shallow water wave disturbed areas such as the North Sea, colonising species are mobile and well adapted to rapid recolonisation. In more stable (equilibrium) communities such as occur on coarse rocks and cobbles, recolonisation is slower.

(5) Recovery of biomass is achieved by growth of the recolonising individuals. In this case restoration of biomass generally requires at least several years. In some of the deeper water communities that we have recently analysed, individual species may be at least 20 years old. This implies that deep-water stable equilibrium communities may require a time of at least 20 years for recovery, compared with 2-3 years in shallow water coastal sands.

(6) Anchor dredging has a significant impact on the species variety, population density and biomass of benthic macrofauna, although without screening is largely limited to within a hundred metres of the active dredged zone. Trailer dredging, on the other hand, appears to have a much lesser impact on species variety, population density and biomass, although this may be limited to the lower intensity of trailer dredging activities in the study areas. However, species recovery data suggests that recovery is quicker for trailer dredge areas, due to the reduced distance of 'inwalk' for colonising species (only the widths of trailer tracks), compared with the larger disturbance of an anchor dredged area.

(7) On the available evidence collected herein, we propose that trailer dredging over a wide area at an intensity carefully matched to the potential times for species recovery (indicated by the response times to natural disturbances e.g. turbulent shallow water or less disturbed deeper waters) will be more sustainable than intensively dredging small areas of seabed.

(8) Re-analysis of ADCP backscatter data collected in 1995 on a screened dredge site some 20km east of the Nab study license supports recent evidence for development of a near-bed benthic boundary plume some 2-4 metres thick and a few tens of metres wide which extends beyond the limits of the dredge activity. On an extraction license undertaking cargo screening, this near bed plume may exceed 4.5 kilometres downtide. Such a phenomenon provides a potential mechanism for impacting physical and benthic resources well beyond the dredge licence boundary and requires further investigation.

Importantly, the detailed analyses of these and other data for this project have revealed the susceptibility of analysis methods to 'noise' within the datasets. This is caused by inter-sample variability due to significant under sampling of the diverse benthic macrofauna of sands and gravels by conventional methods.

We have shown that single samples of macrofauna obtained from a Standard $0.2m^2$ 'Hamon' type grab contain sufficient taxa to use non-parametric multivariate analytical techniques to define community composition. Values for individual variables, such as species variety are, however, heavily dependent on the number of replicate samples taken. At least 3 replicate samples are required to obtain a satisfactory assessment of the species composition of the macrobenthos of sands and muds, but that 13 or more replicates are required for gravels. The repercussions of this in terms of scale, frequency, density of sampling sites, numbers of replicate samples, alternative grab sizes and subsequent cost implications must be carefully considered when designing suitable monitoring protocols.

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## LIST OF ACRONYMS

| | |
|---|---|
| **ABP** | Acoustic Backscatter Profiling |
| **ADCP** | Acoustic Doppler Current Profiling |
| **AFDW** | Ash Free Dry Weight |
| **AGC** | Automatic Gain Control |
| **ARCS** | Admiralty Raster Chart Service |
| **BMAP** | Backscatter Mapping program (CSL in-house ADCP profiling software) |
| **BMAPA** | British Marine Aggregate Producers Association |
| **CBP** | Continuous Backscatter Profiling |
| **CEFAS** | The Centre for Environment, Fisheries and Aquaculture Science |
| **CSL** | Coastline Surveys Limited |
| **DGPS** | Differential Global Positioning System |
| **DRP** | Dredging Research Program |
| **GPS** | Global Positioning System |
| **IALA** | International Association of Lighthouse Authorities |
| **ICES** | International Council for the Exploration of the Sea |
| **INTERMAR** | Office of International Activities and Marine Minerals Division |
| **LAT** | Lowest Astronomical Tide |
| **MDS** | Multi-Dimensional Scaling |
| **MESL** | Marine Ecological Surveys Limited |
| **MMS** | Minerals Management Service |
| **MVBS** | Mean Volume Backscattering Strength |
| **OCS** | Outer Continental Shelf |
| **OSGB36** | Ordnance Survey of Great Britain 1936 (datum) |
| **PLUMES** | PLUme MEasurement System (USACE) |
| **SPM** | Suspended Particulate Matter |
| **SSC** | Suspended Solids Concentration |
| **UKHO** | United Kingdom Hydrographic Office |
| **UMD** | United Marine Dredging Ltd |
| **USACE** | United States Army Corps of Engineers |
| **VMADCP** | Vessel Mounted Acoustic Doppler Current Profiling |
| **VMAP** | Velocity Mapping (CSL in-house ADCP profiling software) |
| **WGS84** | World Geodetic Survey 1984 |

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**Appendix Table 1.** Listing of the benthic samples taken at the North Nab study site in 1999-2001, using a $0.2m^2$ Hamon Grab. Positions are shown reference to OSGB36 (in metres). Also listed is the percentage passing each particle size fraction used for the statistical and multi-dimensional scaling analysis.

**Appendix Table 2.** Listing of the benthic samples taken at the North Nab study site in 1999-2001, using a $0.2m^2$ Hamon Grab. Positions are shown reference to OSGB36 (in metres). Particle size distribution figures are % passing particular sieve sizes (125.0mm – 10.0mm this table).

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**Appendix Table 5.** Table summarising the biomass results for macrofauna (>1mm) extracted from the sediments of the North Nab Study site in 1999. Data have been calculated as Ash-Free Dry Weight (AFDW) from the blotted wet weight using conversion factors from Eleftheriou and Basford (1989). Values are expressed as grams AFDW per $0.2m^2$ Hamon Grab sample.

**Appendix Table 6.** Table summarising the shell length data for *Crepidula fornicata*. The numbers of specimens occurring in each size class are shown for each station in which the slipper limpet occurred, together with the total number in each station, and the percentage of the total in each size class.

**Appendix Table 7.** Table summarising the shell length (mm) for *Crepidula fornicata* as a function of age, assessed from growth bands

**Appendix Table 8.** Table summarising the total number of individuals of *Crepidula fornicata* at each of the survey stations at which the slipper limpet was found. Also shown are the number of year 1 (<20 mm) individuals, the equivalent biomass (g wet weight) and the ash free dry weight (g AFDW) calculated from wet weight x 0.085 (*from* Eleftheriou and Basford 1989).

**Appendix Table 9.** Table summarising the cumulative numbers of species discovered, the number of new species, the numbers of individuals and the total number of species recorded in a series of sand and mud samples of 0.2 $m^2$ taken in and adjacent to the North Nab Study site during March 1999. The species identification codes are shown in parentheses.

**Appendix Table 10.** Table summarising the cumulative numbers of species discovered, the number of new species, the numbers of individuals and the total number of species recorded in a series of coarse gravel samples of 0.2 $m^2$ taken in and adjacent to the North Nab Study site during March 1999. The species identification codes are shown in parentheses.

**Appendix Table 11.** Table summarising the cumulative numbers of species discovered, the number of new species, the numbers of individuals and the total number of species recorded in a series of gravel samples of 0.2 $m^2$ taken in and adjacent to the North Nab Study site during March 1999. The species identification codes are shown in parentheses.

# INTRODUCTION

## 1.1 Background to the Study.

The Office of International Activities and Marine Minerals Division (INTERMAR) of the Minerals Management Service (MMS), a Bureau within the United States Department of the Interior, has clear responsibilities for providing environmental analysis and assessment information facilitating the responsible management of all mineral resources within federal waters of the Outer Continental Shelf (OCS). This zone extends seaward from 3 miles offshore of the State Coastline Boundary to 200 miles offshore. Recent years have seen an increasing interest in the sand and gravel resources of this zone largely associated with increasing awareness of oceanographic, geomorphologic and environmental problems associated with aggregate extraction within nearshore State waters.

MMS has the authority under Public Law 102-426 (43 U.S.C. 1337(k)(2)) (31.10.1994) to negotiate, on a noncompetitive basis, the rights to OCS sand, gravel, and shell resources for shore protection, beach and wetlands restoration projects. Resources may also be used in construction projects funded in whole or part by or authorized by the Federal government. In 1999, this law was amended to prohibit charging State and local governments a fee for using OCS sand resources, although competitive leasing and fees remain for other uses, including commercial recovery of offshore sand and gravel for use as construction aggregate.

Recognising the technological, environmental and legislative management practices forged during the successful development of the United Kingdom marine aggregate industry, and continuing the valuable exchange of technical and environmental information between the U.S. and U.K., the MMS initiated a second project with Coastline Surveys Limited assisted by Marine Ecological Surveys Limited. This project would build not only on the conclusions of the first generic project carried out in the UK by the same contractors (Hitchcock *et al*, 1998), but also integrate subsequent research in the U.K. closely with other MMS coordinated projects in the U.S.

The project encompasses several key elements of interest to INTERMAR and the Marine Minerals Programme of MMS. Principally, the requirements for integrated information regarding the impact of benthic and surface sediment plumes, on physical and biological resources of the seabed, previously identified as a key requirement in several INTERMAR and State/Federal Task Force documents, are addressed by this project.

MMS maintains a full listing at www.mms.gov/intermar/environmentalstudiespage.htm of studies completed under the OCS Marine Studies Program:

**Completed Studies**

Marine Mining Literature Search Study (Generic)
Marine Mining Mitigation and Technology Study (Generic)
Marine Mining Placer Mining Test (Generic)
West Florida Shelf Benthic Repopulation Study (Generic)
Wave Climate Modeling and Evaluation Relative to Sand Mining on Ship Shoal, Offshore LA, for Coastal and Barrier Islands Restoration (Site-Specific)
Synthesis of Hard Mineral Resources on the Florida Panhandle Shelf (Site-Specific)
Environmental Surveys of OCS Sand Resources off Virginia (Site-Specific)
Investigation of Benthic and Surface Plumes Associated With Marine Aggregate Dredging Activities (Generic)
Environmental Surveys of OCS Sand Resources Offshore Alabama (Site-Specific)
Development of Criteria to Evaluate Wave Refraction Models (Generic)
Surveys of Sand Resource Areas Offshore Maryland/Delaware and the Environmental Implications of Sand Removal for Beach Restoration Projects (Site-specific)
Environmental Surveys of OCS Sand Resources Offshore New Jersey (Site-specific)
Wave Climate and Bottom Boundary Layer Dynamics with Implications for Offshore Sand Mining and Barrier Island Replenishment, South-Central Louisiana (Site-specific)
Study of the Cumulative Effects of Marine Aggregate Dredging (Generic)
Design of a Monitoring Protocol/Plan for Environmentally Sound Management and Development of Federal Offshore Sand Borrow Areas Along the United States East and Gulf of Mexico Coasts (Generic)
A Numerical Modeling Examination of the Cumulative Physical Effects of Offshore Sand Dredging for Beach Nourishment (Generic)

**Ongoing Studies**

Collection of Environmental Data Within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration (Site-specific; Draft report will be delivered late November 2002)
Integrated Study of the Biological and Physical Effects of Marine Aggregate Dredging (Generic; Final report will be delivered January 2003)
Environmental Surveys of Potential Borrow Areas on the East Florida Shelf and the Environmental Implications of Sand Removal for Coastal and Beach Restoration (Site-specific; Draft report expected lend of calendar year Summer 2002; Final Report February 2003)
Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration (Site-specific; Draft report due mid-February 2003; Final report due mid-April 2003)
Model Development or Modification for Analysis of Benthic and Surface Plume Generation and Extent During Offshore Dredging Operations (Generic; Final products due February 2003)
Winter Water Bird Survey of Offshore Shoals From Northern New Jersey to the Virginia/North Carolina Border (Interagency Agreement with Fish and Wildlife Service) (Final report due September 2003)
Field Testing of a Physical/ Biological Monitoring Methodology for Offshore Dredging and Mining Operations (Generic/Site-specific – being conducted at Sandbridge Shoal, offshore Virginia via Cooperative Agreement with VIMS) (Phase 1: $58,000; Phase 2: $564,469)(Final report due May 2004)
Environmental Investigation of the Use of Shoals Offshore Delaware and Maryland by Mobile Benthos and Finfish Species (Site-specific/Generic; Final Report due January 2005)
Worldwide Analysis of Shipwreck Damage Caused by Offshore Dredging: Recommendations for Pre-operational surveys/mitigation During Dredging to Avoid Adverse Impacts (Generic) (Final report due November 2003)
Wave-Bottom Interaction and Bottom Boundary Layer Dynamics in Evaluating Sand Mining at Sabine Bank for Coastal Restoration, Southwest Louisiana (GOM LSU CMI) (Final report due May 2005)

**Studies to be Procured FY 2003**

Investigation of Finfish Assemblages and Benthic Habitats Within Potential Borrow Areas in Federal Waters Offshore Southeastern Texas and Southwestern Louisiana
Review of Existing and Emerging Environmentally-Friendly Offshore Dredging Technologies (Budgeted Amount
Analysis of Potential Biological and Physical Dredging Impacts on Offshore Ridge and Shoal Features/Engineering Alternatives and Options to Avoid Adverse Environmental Impacts
Focused Analysis/Review of Benthic Assemblages on Ridge and Shoal Features of the U.S. East and Gulf of Mexico Coasts

**Table 1.1:** Completed and planned studies commissioned by the Environmental Studies Program, INTERMAR.

## 1.2 Purpose of the Study

Confirming the importance of generic research programs, USACE Technical Note DOER-E2 (December 1998) assessed the implications of environmental windows on operations and maintenance (OM) dredging in marine and freshwater environments, including removal of sands and gravels. Importantly, DOER-E2 identifies that 68% of USACE Districts cite turbidity, suspended sediments and/or sedimentation issues as a reason for enforcing environmental windows for operations. The authors observe that many restrictions are emplaced on the basis of 'limited, subjective or non-existent' data, possibly exceeding precautionary principles, and leading to controversial costs implications.

For the past decade or so, a good deal of concern has been expressed about the potential impact of marine aggregates extraction on coastal resources (International Council for the Exploration of the Sea, ICES, 1992a,b; 1993, 2001, 2002). This includes impacts on the physical composition and stability of coastline features, on fish and fisheries (*see,* for example, Wilber and Clarke, 2001), wildlife resources and on the marine food webs upon which they depend. Much of this concern in British waters centers on the possible impact of dispersed material rejected *via* the reject chute and spillways during the dredging process and which has been variously estimated to travel up to 15-km on each side from the point source of discharge by the ebb and flood tidal streams.

Studies from the early to mid 1990s off the Dutch coast (van Moorsel and Waardenburg, 1990, 1991; van Moorsel, 1993, 1994) and off the Norfolk coast (Kenny and Rees 1994, 1996) have concentrated mainly on the impact of dredging operations on the variety and abundance of bottom-dwelling (benthic) species within dredged areas, and on the subsequent recovery of diversity and biomass following cessation of dredging. The possible scale of impact of sediment deposition outside the immediate dredged area is, however, largely unknown. It remains a key factor in assessing the likely impact of marine aggregate mining on other uses of the marine environment including recreation, commercial fisheries and aquaculture, and conservation of biological and other resources including historic wreck sites.

Partly to address the question of the scale of physical impact outside the immediate dredged area, Acoustic Doppler Current Profiling (ADCP) techniques have recently been used in studies of plume dispersion from both commercial aggregate dredgers (Hitchcock and Drucker, 1996) and in relation to spoils disposal from capital dredging works (Whiteside, Ooms and Postma, 1995). These studies essentially confirm that the initial sedimentation of material discharged during spoils disposal or from outwash from dredgers does not, as had been widely assumed, disperse according to the Gaussian diffusion principles used in most simulation models, but behaves more like a density current where particles are held together by cohesion during the initial phase of the sedimentation process.

In an earlier study carried out by Hitchcock *et al.* (1998) and funded primarily by the Minerals Management Service, U.S Department of the Interior, Washington (Contract No 14-35-001-30763), evidence was presented which showed that the fate of material rejected by screening during marine aggregate dredging can be defined by Acoustic Backscatter Profiling (ABP) techniques combined with conventional water sampling methods (Thevenot and Johnson, 1994; Weiergang, 1995; Hitchcock and Dearnaley, 1995; Hitchcock and Drucker, 1996; Hitchcock *et al.,* 1998).

The results of that study, obtained mainly from the Owers Bank on the south coast of U.K. and the work of others (*see* Land *et al.,* 1994; Whiteside *et al.,* 1995) suggested that the settlement of material from the water column is controlled by the velocity of entry and the complex cohesion properties of the reject material *en masse*, rather than by the density and dispersion rates of individual particles in the discharge.

As a result, the zone of initial deposition of reject material from commercial aggregate dredgers is much less than that predicted from some simple dispersion models based on Gaussian diffusion principles. Direct measurement of the rate of settlement of inorganic components of the screened material show that deposition is mainly confined to distances of up to 1 km from the point of discharge, a result which is confirmed by direct measurements of deposition rates on the sea bed (*see* also Gajewski and Uscinowicz, 1993).

Hitchcock *et al.* (1998) summarised the impact of marine aggregate dredging on benthic biological resources, and rates of recovery reported following the cessation of dredging in varying types of deposits, based on reports in the literature worldwide. These studies showed a 60-80% reduction in population density, species diversity and biomass within dredged areas. Recolonisation and recovery of biomass was reported to vary from a few months to up to 15 years. Review of the literature suggested that the rate of recovery was fastest in unconsolidated deposits such as muds and sands; these are colonised by 'opportunistic' species that are well adapted to rapid recolonisation and growth following episodic mortality.

In contrast, more consolidated and coarser deposits are colonised by a wide variety of slow growing 'equilibrium' species that may take several years for recolonisation following disturbance. In general, a period of 2-3 years has been commonly recorded for restoration of species composition and benthic biomass in sands and gravels that are exploited by the marine aggregates industry in the U.K. (Hitchcock *et al.*, 1998; Newell *et al.*, 1998).

Despite the information that is available on the impact of dredging on biological communities on the sea bed, there have been surprisingly few comprehensive studies on the impact of dredging and the nature of the recolonisation and recovery processes within commercially-exploited areas. The studies by Kenny and Rees (1994, 1996) and by Kenny *et al.* (1998) on an experimentally-dredged site off the coast of Norfolk, U.K., suggest that initial colonisation may occur within months of the cessation of dredging, but that the process of stabilisation of community structure and restoration of biomass may take several years.

Recent studies by van Dalfsen and Essink (1997), Essink (1997), van Dalfsen *et al.* (1999), Désprez (2000) and Sardá *et al.* (2000) support the view that the process of recolonisation and recovery in commercially-exploited sand borrow sites is a complex one involving initial colonisation by fast-growing 'opportunistic' species that are replaced and supplemented by a wider species diversity of slow-growing 'equilibrium' species after cessation of dredging. Such work has been confined to the dredge sites themselves. No data have hitherto been available on the impact of discharge of material by screening and outwash from the dredger beyond the immediate boundaries of the dredged site.

The quantities of material rejected by screening are significant, and have a potential for impact on biological communities outside the boundaries of the dredged area. Estimates by Hitchcock and Drucker (1996) showed that for a trailer-dredger of 4,500 tonnes hopper capacity operating on the Owers Bank, off the south coast of U.K., approximately 750 tonnes of solids were discharged through overspill and as much as 7,223 tonnes from the screening reject chute, per cargo.

In a more recent study of a newly exploited deposit off Southwold, Suffolk, U.K. in April 1998, it was shown that for a cargo of 5,630 tonnes, 8,713 tonnes of material were rejected through the screening chute and 360 tonnes through outwash from hopper discharge (Newell *et al.*, 1999). That is, estimates to date suggest that 1.6-1.7 times the cargo load is discharged into the surrounding water column during normal loading of a screened cargo of gravel in U.K coastal waters. This figure may be higher for particular cargoes, reaching 3-4 times the cargo load (Hitchcock and Drucker, 1996).

This material comprises not only a large inorganic particulate load, but also contains significant quantities of organic matter. Values recorded in dredger outwash for newly exploited deposits off Southwold, Suffolk, were as high as 1.454 g per litre ash-free dry weight (AFDW) of which 0.007 g per litre (0.48%) comprised lipids (Newell *et al.*, 1999). This organic matter appears to be derived from fragmented benthic invertebrates ‘processed’ during dredging. Such material has a much lower specific gravity than the inorganic components of the dredger outwash and may be associated with ‘far field’ acoustic backscatter which is detectable at distances of as much as 3,335 m 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).

Newell *et al.* (1999) suggested that the organic enrichment from fragmented invertebrates in the dredger outwash may account for the enhanced benthic species diversity and population density of benthic invertebrates commonly recorded beyond the boundaries of dredged areas (*see* Poiner and Kennedy, 1984). There have, however, been no direct studies of organic content of the outwash of dredgers in heavily exploited areas, nor of the impact of either this material or the particulate components on biological communities outside the boundaries of dredged areas.

## 1.3 Study Objectives.

Overspill and, more importantly, screened and rejected material will disperse downstream and cause an impact. It is important that this is quantified. There have been many predictions of dispersion by modeling techniques and many of these have subsequently been modified, sometime substantially, in the light of our fieldwork programmes. Assessment of the actual impact on the seabed (physical and biological) will enable correlation with the predicted dispersion of material, actual dispersion of material (footprint) and impact of settled material (footprint of significant impact, rather than any impact no matter how small).

The evidence from the ADCP studies referred to above firmly suggests that the biological impact of sediment deposition surrounding a dredged area is likely to be much smaller than has been predicted from conventional sediment deposition simulation models in the past, and there is a good deal of scattered information in the literature supporting this view. The principal theme of this project is therefore to carry out an *integrated* Physical and Biological Resource Impact study on a *worked* site with a view to establishing the nature and extent of impact contours on the seabed surrounding the dredged site. The scope and methodology for the project follows from the research requirements identified from a comprehensive review of the impact of marine aggregates dredging on the physical and biological resources of the seabed (Newell, Seiderer and Hitchcock, 1998).

With the above in mind and taking note of ongoing developments in this and other projects, the study necessarily adapted to best resolve the following key questions in relation to marine aggregate mining in a commercially-worked Licence Area:-

- Does the use of ADCP techniques supported by traditional water sample characterisation still provide a best value approach to defining the gross morphology of the dispersing plume and any sub-divisions attributable to different sources and processes?

- Is there a detectable impact on the sedimentary provinces that may be caused by marine aggregate mining?

- Can high-resolution sidescan sonar mosaic imagery provide broad scale mapping at sufficient resolution to identify any impacts due to mining operations either due to changing sedimentary or biological community?

- Is there a detectable 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*)?

- Is there a detectable impact on community structure as assessed by non-parametric multivariate techniques?

- How far beyond the immediate limits of the dredged area do such impacts extend?

- Can any impact on community structure beyond the boundaries of the dredged area be related to 'far-field' deposition of material in the outwash?

- Are there differences in impact of anchor dredging where material is essentially exploited at one site, and trailer-dredging over a wider area?

- What is the nature and rate of the recolonisation and recovery processes in a commercially dredged area?

- Can any recommendations be made on the scale, frequency and number of samples required for cost-effective monitoring of the impact of sand and gravel mining on sea bed resources?

## 1.4 Project Structure

The project team structure is shown below (Figure 1.4). The integration of physical and biological components within the same project is fundamental to providing coherent results and recommendations that are applicable and acceptable to the industry and regulatory authorities.

Within the organisations we hold all personnel, equipment and experiences necessary to complete the works. This has been used to maximum benefit for the project with some of the adverse weather problems encountered during fieldwork at the site being overcome by team members, resources and facilities being able to be diverted from other neighbouring projects to collect data at reduced re-mobilisation costs. Experience shows clearly that dredge plume monitoring must be conducted during calm, clear conditions in order to precisely co-locate the ADCP, water samples, and other monitoring devices with reduced geographical error.

The research platform for all survey work was the multi-purpose research and survey vessel M.V. FlatHolm. This 300-dwt vessel provided a stable research base for the work with accommodation and endurance enabling intensive field campaigns to maximise the short weather windows that were available. Dedicated survey accommodation enabled the complete spread of equipment to be mobilised at once, with enough room for sample storage (nearly 3000kg of sediment samples were obtained).

Faunal identification for biological community analysis is also carried out within the team structure at the premises of Marine Ecological Surveys Ltd (MESL). MESL staff hold British Natural History Museum Id.Q. qualifications in marine macrofaunal identification. The responsiveness of the laboratory has further enabled samples obtained at opportune times to be analysed quickly.

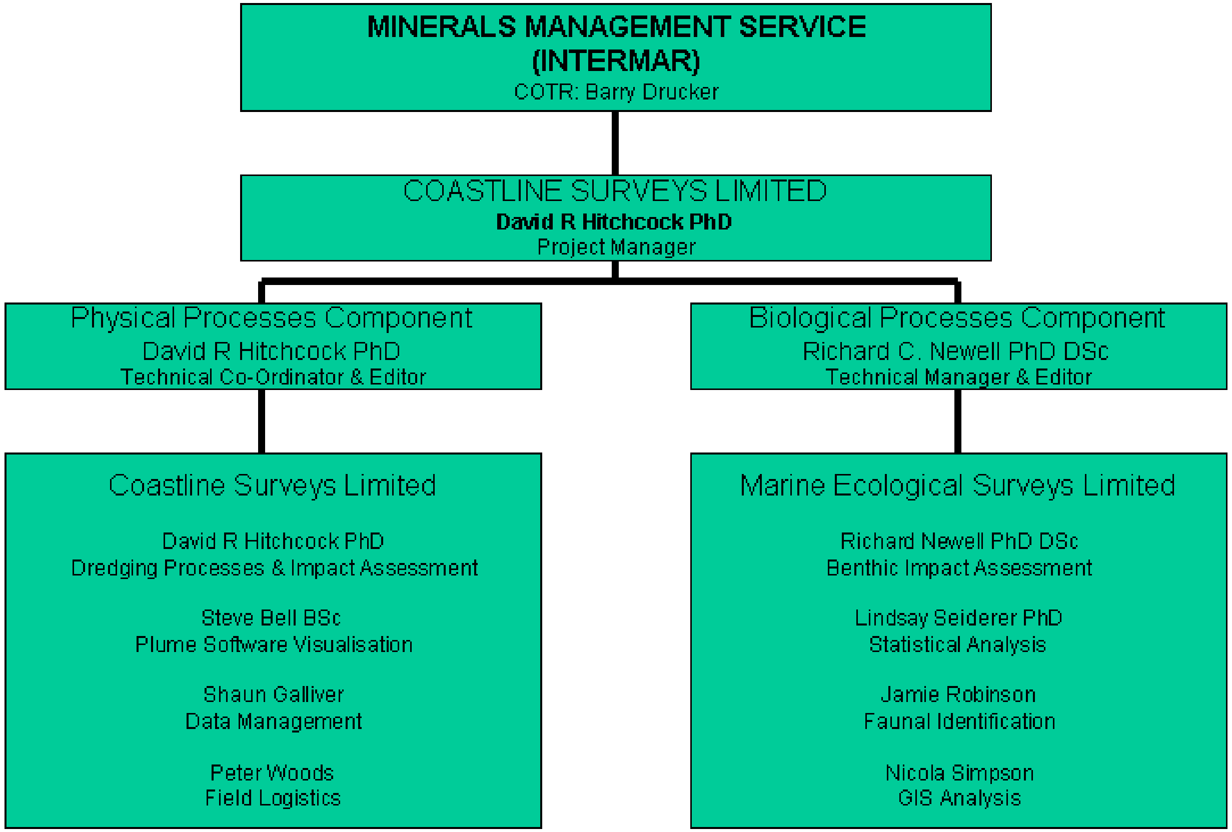


**Figure 1.4** Management diagram showing key personnel, affiliations and primary responsibilities.


**Plate 1.4.** 24m Research and survey vessel M.V. Flat Holm used for the surveys at Licence Area 122/3

## 1.5 Study Site North Nab 122/3

Choice of a suitable study site presented some difficulties because the effects of the dredging process itself, important for the U.S. industry case, needed to be distinguished from secondary impacts of discharge of overboard screened material. A complicating factor is that in many dredged sites, trailer dredging occurs over a relatively wide area so that impacts may be dissipated in space and time.

A small heavily-exploited aggregate area to the east of the Isle of Wight, off the south coast of U.K. known as the North Nab Production Licence Area 122/3 was selected as study site for a number of clear cut reasons. This site is licensed to and managed by United Marine Dredging Ltd (UMD). Firstly, although the amount of aggregates removed from the area is quite low, up to 150,000 tonnes per annum, material is extracted from very localised 'sweet spots', each of the order of a few hundred metres square. This makes the operation one of the most intensively dredged sites per unit area. Secondly, the area was licensed in 1989 and has a comprehensive historical record of dredging activities, locations and volumes. Any impacts that may be created by the operations could reasonably be expected to be established by the time of the investigation. Finally, although material is not screened (common in many U.K. operations, especially in the North Sea), 'all-in' loading without screening is a feature of 75% of South Coast licences (A. Bellamy, *pers. comm.*). It is also the predominant technique of loading cargoes in the U.S., although recent signs are that screening of cargoes (rejection of unwanted particle size fractions at sea, or *beneficiation*) may become prevalent in the U.S. as well.

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, usually to remove unwanted sand-sized fractions. Smaller dredgers, *circa* 2300 tonnes capacity, mainly operate on the North Nab licence Plate 1.5a).

The location of the study site and boundaries of the Licence Area are shown in Figures 1.5a and 1.5b, together with the strength and direction of the tidal streams and broad boundaries of the area surveyed. Figure 1.5c records the sampling stations. Within the boundaries of Licence Area 122/3, also shown are the sub-areas that have been exploited for gravel by different techniques (trailer suction dredging or anchor suction dredging), and the time since dredging started.

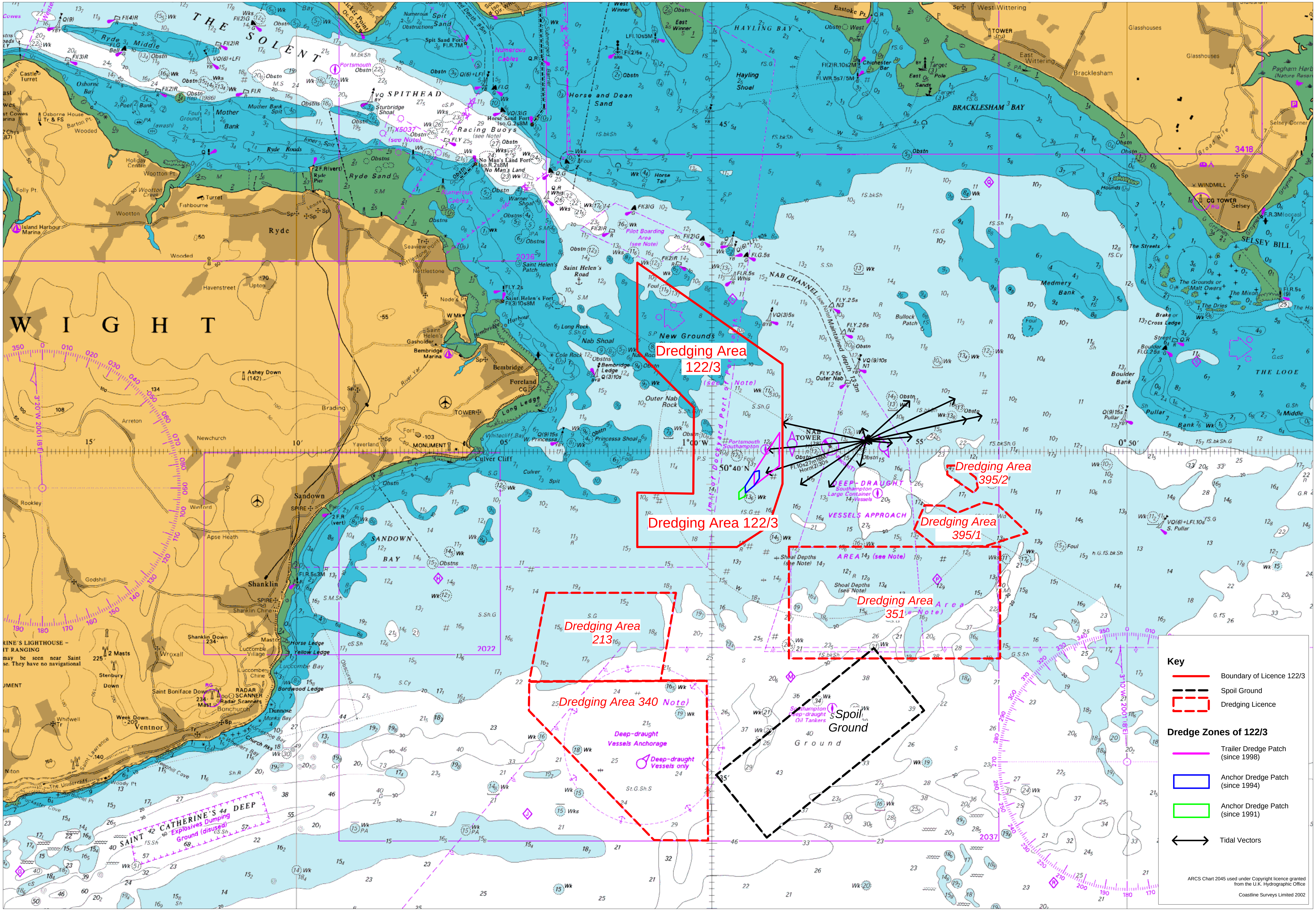


Figure 1.5a: Map of the Survey Area & Licence 122/3 in relationship to the Isle of Wight, bathymetry and adjacent dredging licences

**Plate 1.5a.** *City of Chichester* 2300 tonne capacity dredger operated by UMA working on the North Nab licence.

The variety of loading techniques at North Nab is important for several reasons. Firstly, the presence of the two techniques in two distinct zones can be used to make a first comparison to assess the individual impact of the two principal methods of aggregate exploitation on benthic biological communities, although it should be pointed out that less material is removed by trailer dredging than from the anchor-dredged site. Differences between the two dredging sites may therefore reflect dredging intensity, rather than the type of dredging method used.

Secondly, the results also allow some comparisons of the nature of the recolonisation processes and rates of recovery in relation to anchor-dredging and trailer-dredging, as well as an assessment of the impact of the relatively small quantities of material discharged in the outwash for unscreened ('all-in') cargo loads.

Third, on a practical point, measurements of plume generation and decay originating from an anchored vessel are more straightforward to interpret on the basis of time-distance plots, due to the single source location. A trailing vessel will have a moving discharge zone that will compound the interpretation of the stage of plume development at any given point and hence time. Similarly, the variable distance from the moving discharge point will compound impacts observed at any point on the seabed. This is important for determining not only the source terms for development of predictive models and assessments of impact for new extraction licences, but very important for field validation of the outputs from models.

It is important to emphasise, however, that what is not included in this study is an assessment of the impact of the large quantities of material discharged through reject chutes as part of the screening process, common in other licence areas (Plate 1.5b), as mentioned earlier. Similarly it is not known to what extent this quantity of material would affect physical impacts on sediment distribution, transport and sedimentation, bedforms etc, nor the biological impacts and rates of recolonisation reported in this project for North Nab Licence Area 122/3.

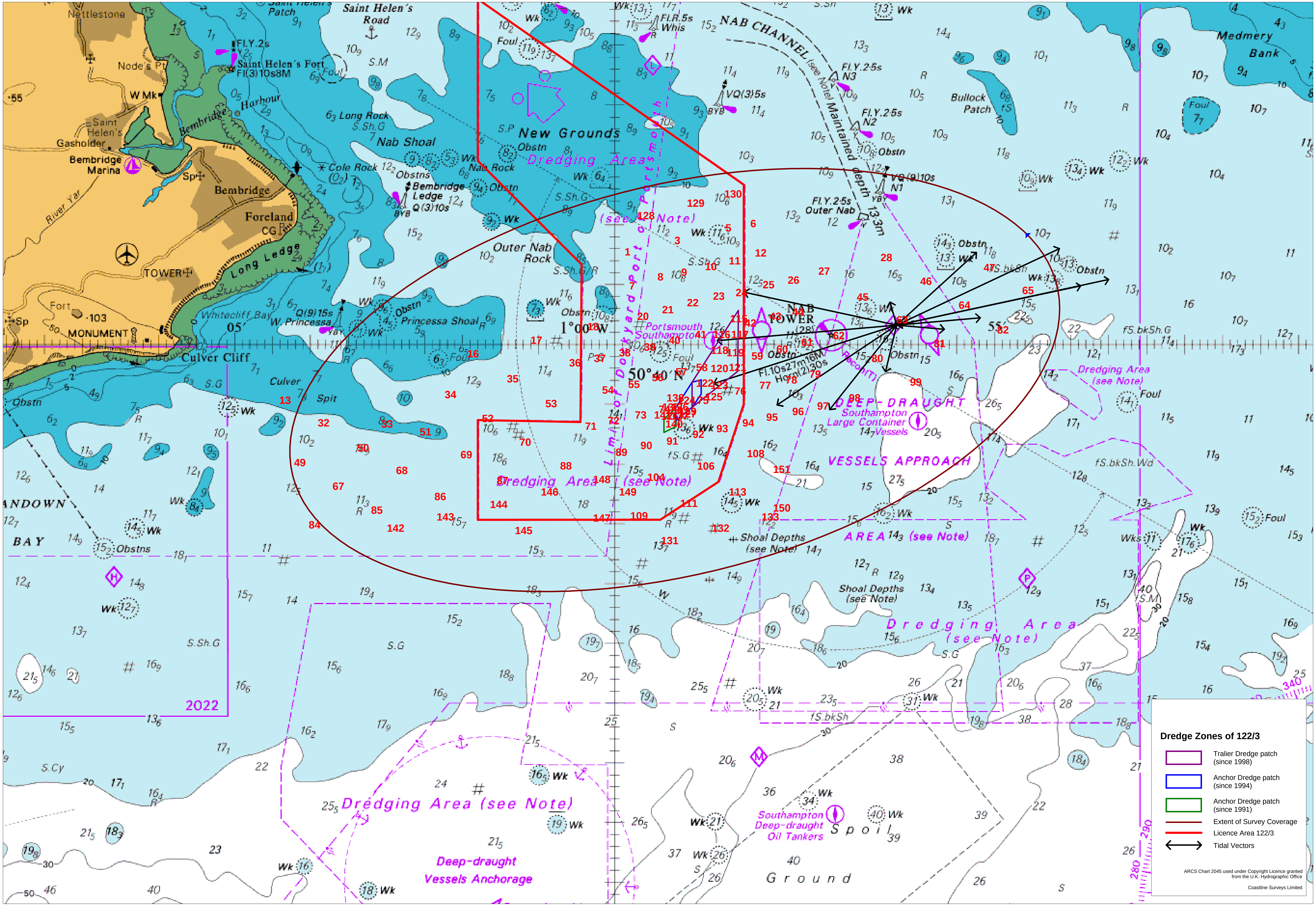


Figure 1.5b: map of the Survey Area in detail showing grab sample positions and extent of survey coverage

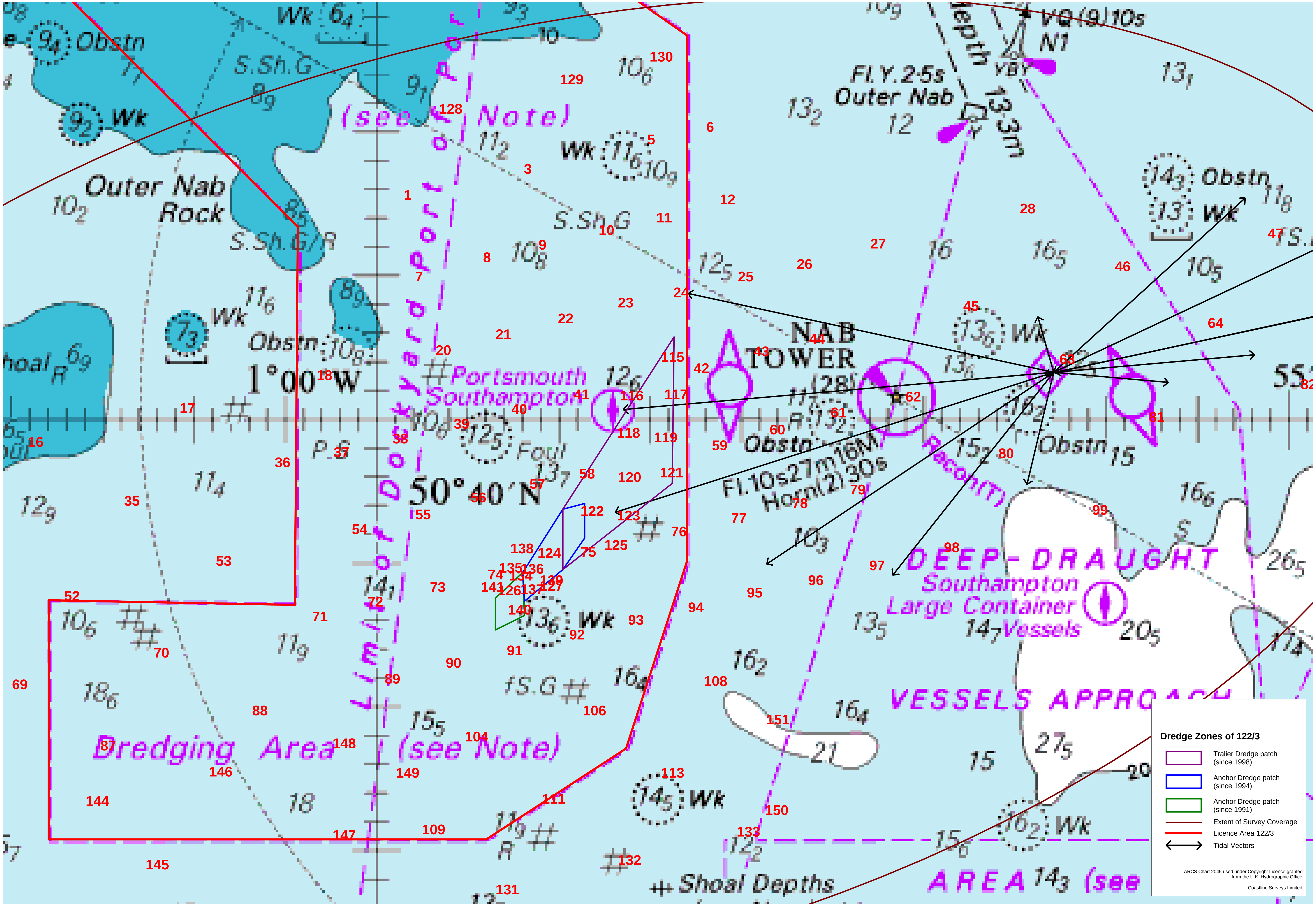


Figure 1.5c: Detail locations of the sampling strategy used to assess impacts within the intensively dredged areas

Quite simply, analysis of the impact of dredging of fully-screened cargoes requires a comparative study at another site using similar techniques to those used in this project which have been proven in their principle and execution and which can be further refined in light of the observations made. The nature and rate of the recolonisation processes also require a specifically designed and systematic study that is co-ordinated with differing dredge techniques in a worked Licence Area. Some of the biological components of such a study have recently been completed for a screened, trailer dredged area in the central North Sea off the Humber estuary at Production Licence Area 408 (Newell *et al* 2002). Rather unfortunately this work was undertaken during routine monitoring operations and the physical aspects of the site were not addressed in a combined study.

**Plate 1.5b**. Intense dredging with screening on a southern North Sea aggregates licence.

## 2.0 STUDY SITE ENVIRONMENT

### 2.1 Geological Setting

The Eastern Solent comprises solid chalk overlain by Tertiary clays and sands with a veneer of recent sediments. The Eastern Solent represents a drowned valley and flood plains of the proto Solent that flowed southward into the origins of the present English Channel during the late Devensian when sea levels were roughly 120m below present level.

Rising sea levels of the Holocene Transgression from 15,000 years BP to 5000 years BP caused the river valley to flood and deposit fluvial gravels and sands throughout the flood plains. These nearshore sand deposits form the resources for the local beaches, whilst the gravel deposits form the basis of the regional dredging industry activities.

### 2.2 Seabed Morphology

The study site is in a relatively flat region of the seabed in the 15-18m water depth (*refer* Figure 1.5a) gently inclining to the south and southwest. The southern boundary of the study site reaches 20m water depth LAT with the shallowest waters to the north in 12-14m. There are no significant bedforms recorded or major topographic features. Tidal currents flow generally along the contours.

### 2.3 Seabed Surficial Sediments

Surficial sediments of the area comprise Holocene sands and gravels deposited during the transgressions of the period, together with reworked Recent sediments. The licence area in particular is characterised by a high proportion of gravels, with some gravelly sands and very little silt content, typically less than 2%. A more detailed assessment of the sediment characteristics is discussed in the results section.

## 2.4 Hydrodynamic Conditions

East Solent tidal currents have been investigated and reported extensively in connection with the aggregate dredging applications and with development of shoreline management plans (SMP) by the local district authorities.

The tidal dispersion curve for tidal diamond **N** (UKHO Chart No. BA 2045 latitude 50° 40.1' N; 000° 56.4' W) indicates 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 flood and 1.6 knots at 252 ° on the ebb. The sum of movement during one tidal phase (excursion) is a maximum of 6-7 nautical miles during the Spring tides. The direction of flow is fairly uniform with the ebb tide flowing generally to the west-southwest and the flood to the east-northeast. Figure 2.4 demonstrates the flow pattern and tidal residual. The mean spring tide range is 3.7m and neap range only 1.7m.

| HW | Direction | Spring (m/s) | Neap (m/s) |
|---|---|---|---|
| -6 | 085 | 1.30 | 0.56 |
| -5 | 078 | 2.96 | 1.48 |
| -4 | 078 | 3.33 | 1.67 |
| -3 | 065 | 2.78 | 1.48 |
| -2 | 048 | 1.67 | 0.74 |
| -1 | 345 | 0.37 | 0.19 |
| 0 | 282 | 2.41 | 1.30 |
| 1 | 265 | 2.78 | 1.30 |
| 2 | 252 | 2.96 | 1.48 |
| 3 | 236 | 2.22 | 1.11 |
| 4 | 218 | 1.67 | 0.74 |
| 5 | 193 | 0.74 | 0.37 |
| 6 | 095 | 0.74 | 0.37 |

**Table 2.4** Tidal components at Nab Tower for Spring and Neap tides at hourly tidal states.

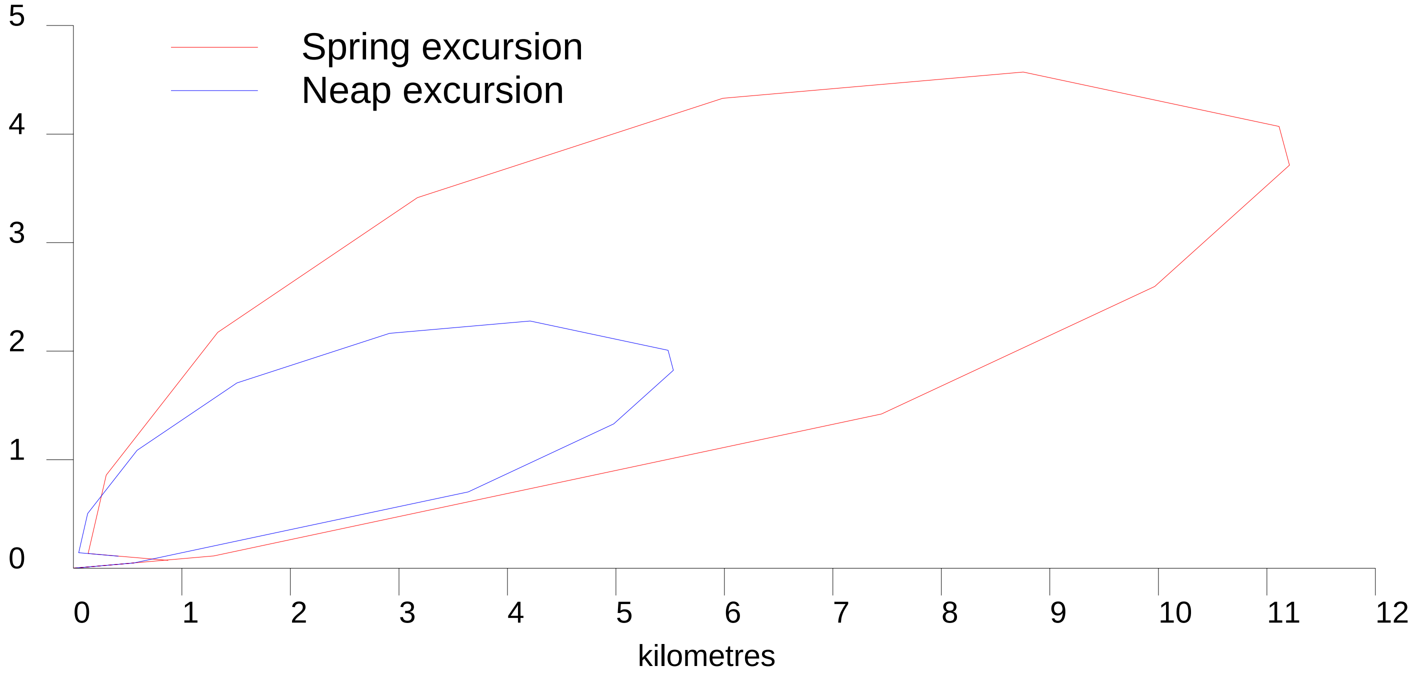


**Figure 2.4.** Tidal excursion for Nab Tower Tidal Diamond 'E'. Low water at 0,0. Note the residual water displacement of the spring tide to the east (almost 900m) and for the neap tide (less than 500m). Also, a particular time based package of water (at t=0, low water) will return to within 200m of its starting position after t=11 hours, and, on a spring tide, will replicate its position after 12 ¾ hours.

It is important to consider the tidal excursion carefully. From Table 2.4 and Figure 2.4 for the Nab site, it is clear that sediments emanating from an anchor dredge operation lasting some 3 hours may impact a body of water varying between 1.5km length (neap tide, 2.5 hours before low water to 0.5 hours after low water) to 9km length (spring tide, 0.5 hours after low water to 3.5 hours after low water). On a spring tide the impact will therefore have greater areal extent, but on a neap tide the intensity of the impact may be greater due to less dilution of the returned sediments. Neap tides result in a residual movement to the east of some 400m, but spring tides result in a residual movement of nearly 900m to the east per tidal cycle.

Extreme offshore waves come from the south-to-south west sector, which has the longest fetch, into the open channel and thence Atlantic Ocean. The highest waves from this direction range in magnitude between 3.7m for a return period of 0.1 years to 5.7m for a return of 100 years (HR Wallingford, 1997).

## 3.0 MATERIALS AND METHODS - SITE CHARACTERISATION

Six field campaigns were undertaken during the course of the project. During March and June 1999 141 seabed samples were obtained over the entire area, including some repeat stations. In September 1999, a further 10 samples were obtained close into the dredge site, as it became apparent that the effects of the dredging activity were much more limited in proximity to the dredging activity and, more than likely, located primarily within a few hundred metres of the active zone. In August 2000, a further 10 samples were obtained from within the active zone again, during an opportune effort to make a preliminary assessment of the expected rate of recovery.

| | |
|---|---|
| March 13th – 14th 1999 | First field campaign, 95 sites grabbed. |
| June 8th 1999 | Further 46 grab sites sampled |
| June 9th – 10th 1999 | Whole area sidescan sonar and mosaic at 250m range and bathymetry at 400m linespacing |
| September 7th 1999 | Additional 10 grabs taken close to dredge area for biological nearfield information |
| January 17th 2000 | Dredge area surveyed by sidescan sonar and mosaic at 75m range and bathymetry at 100m linespacing |
| February 1st 2000 | Overspill and organic measurements from 2300 tonne capacity dredger *City of Chichester* working North Nab Are 122/3 |
| August 15th 2000 | Dredge area surveyed by sidescan sonar at 50m range and bathymetry at 50m linespacing over central area. |
| August 16th 2000 | Underwater video work, plus 10 grabs taken in preparation of dredger arrival (poor conditions) |
| June 2001 | ADCP of *City of Chichester*, Multibeam bathymetry / sidescan sonar Underwater video |

**Table 3**. Summary of successful fieldwork operations. Unsuccessful mobilisation and abandonment due to weather or other factors excluded.

The primary navigation system used for these surveys was a Trimble 4000SSi 18-channel GPS unit. This survey grade receiver is of the dual-frequency type with 18 parallel channels accessing the L1/L2 carrier phase, L1/L2 P code and L1 C/A code. Differential corrections were provided by an SBA-1 IALA Beacon receiver in RTCM 1.04v2 format or a FUGRO SeaSTAR/OmniSTAR combined GPS and SPOT beam differential receiver. Stated accuracies are better than 5m and 1m respectively. Secondary receivers were in place, and comprised a Trimble 7400 RSi GPS unit with differential corrections.

Output from the shipborne receiver, after receiving real-time corrections, is via RS232 protocol communications to the Coastline Surveys Ltd PC-based Integrated Navigational Positioning System (INPS). Differential position data was output from the primary receiver through RS232C communications configured as NMEA0183 Lat/Long output for input to the PC computer and logged using the navigation survey program, Trimble HydroPRO v1.3 and v1.5. The GPS antennae were mounted vertically above the echosounder transducer to obviate the need to apply offsets. Offset errors for other sensors were reduced by accurately detailing the offsets and applying heading in real-time, generated by a digital fluxgate compass and a TSS Meridian gyrocompass.

The control and planning of the survey was based on the Airy Spheroid with grid co-ordinates expressed in metres and decimetres on the Ordnance Survey of Great Britain 1936 (OSGB) National Grid. The dGPS unit was configured to output serial information in the International Standard WGS84 co-ordinate system to the INPS, which then converts the co-ordinates to the OSGB datum using the national parameters for translation, modified for local variance, based on information available from the Ordnance Survey of Great Britain.

The INPS computer recorded the location of the survey vessel. The co-ordinates are graphically presented on a helmsman’s monitor along with the survey line plan to enable steering of the vessel along the predetermined track. A vessel cross track error image enables the helmsman to remain on line, generally within 10m.

Navigational data, time and water depths were recorded ("fixed") at a nominal track time interval of 3 or 6 seconds, corresponds to a horizontal fix interval of approximately 5-10m depending on speed, determined by the survey operations underway. At each "fix" a "fix pulse" is generated by the INPS and is transmitted to the echosounder and thermal printers. Every fix generates a pulse, which prints simultaneous annotation on the echosounder, sonar and geophysical records. The INPS records the instantaneous, minima, maxima and average readings of depths generated by the echosounder digitiser. The records presented here are based on instantaneous calculations.

For quality assurance, prior to and after the survey, the dGPS position solution was checked against known positions to establish any gross errors. The calibration data indicated no need for an offset to be applied to the survey data recorded. During the survey, the solutions of all positioning systems were constantly monitored against each other to indicate any instability in one or other of the systems.

During the resolving of the positional information, a 'quality factor' is generated for each observation. This number, GDOP (Geometric Dilution Of Precision) is based on the number of satellites available, their geometry in space and their heights above the horizon. A GDOP figure greater than 8 indicates an unsatisfactory solution to the position information and is tagged to enable simple recognition. There were no difficulties with satellite signal and differential correction reception.

### 3.1 Bathymetry

An Odom 'Hydrotrac' survey grade digital thermal echosounder with 200T5HAD $8^o$ 208kHz transducer was used to digitally obtain the bathymetric data. The echosounder transducer is permanently mounted in the hull of the survey vessel well forward and on the centreline. This is 2.5m below the water line during normal survey speeds with normal trim attitude, and immediately below the GPS antenna horizontal reference position. A Seatex MRU-5 multi-axis motion sensor removed vessel motions from the survey record. Standard calibration checks were carried out at the beginning, during and end of each survey period.

Accuracies of bathymetric systems in shallow water are primarily a function of echosounder installation, performance and digitising, tidal recording and translation, co-tidal correction factors (if applied) and meteorological and atmospheric conditions. Additional errors in successive surveys can be caused by, amongst others, lateral differences in vessel track (horizontal accuracy) not precisely repeating previous sounding points. In zones of active sediment movement, changes in seabed topography (especially migratory sand waves) can appear as net changes in seabed levels, whereas the data actually represents a mere shift in sediments. In areas of steep relief, small horizontal position differences can cause seemingly larger vertical inaccuracies.

It is essential to use a motion sensor for any type of bathymetric surveys where the data may be used for subsequent volumetric analysis, or data accuracy will degrade beyond the level of assessment and 'noise' in the dataset will exceed the volumes of change.

Tidal data was recorded at 15-minute intervals on an automatic tidegauge reduced to Chart Datum. Using co-range and co-tidal corrections, the readings are translated to the survey area. During the processing algorithms, tidal heights are subtracted from the heave-corrected and spike-smoothed raw water depths.

It has been assumed, in the absence of other information, that the tidal readings obtained are sufficiently representative across the whole of the site not to require a network of tidegauges across the site or adjustment of the tidal heights at the extremity of the survey area for hydraulic gradient and tidal delay.

Tidal reduction techniques follow the approved UK Hydrographic Office and British Admiralty methods for tidal records and reduction of data to datum. Sources referred to include Admiralty Tide Tables N.P. 201-00 (Hydrographer of the Navy, 1999), Admiralty Tidal Handbook No.2 "Datums for Hydrographic Surveys", N.P. 122(2) (Hydrographer of the Navy, 1975) and "Hydrographic Surveying", EM 1110-2-1003 (USACE, 1994). Using the Simple Harmonic Method A (ATT, NP201-00), Admiralty Tide Predictions for tidal heights during the survey have been compared to the observed data. There is generally good agreement between the sets of data, and this confirms the accuracy of the tidal monitoring and reduction procedure adopted.

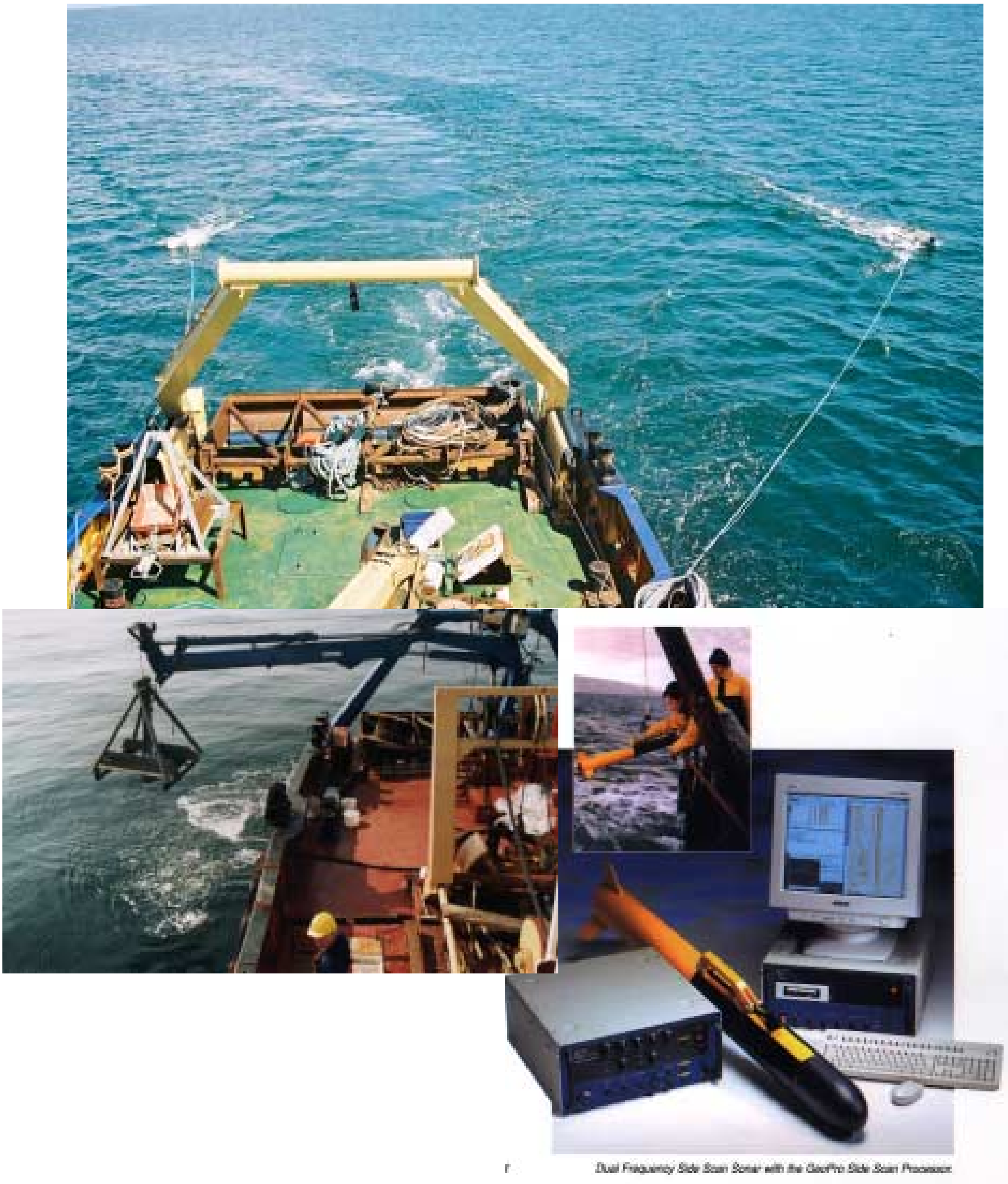


**Plate 3.1.** Fieldwork aboard the MV Flat Holm – showing sidescan sonar and Hamon Grab.

### 3.2 Sidescan sonar digital mosaicing

A GeoAcoustics 159D Dual Frequency 125kHz/410kHz side-scan sonar towfish was deployed from the centre of the stern of the vessel on an 8mm co-axial armoured tow such that the towfish 'flies' at the optimum height equivalent to 10% of the sonar range. The towfish was interfaced to a GeoAcoustics SS941 Transceiver Unit to control gain and record quality, and to a GeoPRO digital sonar mosaicing system. High quality greyscale images were also printed using an Ultra 200 3 channel Thermal Recorder. The recorder was interfaced to the INPS for fiducial event marking and the layback of the towfish from the tow point entered into the INPS and mosaicing system for good positional accuracy.

The survey progressed at a speed of approximately 1.0-1.5m/s (2-3 knots). Faster speeds will degrade record quality and object resolution and identification.

The recorder sweep speed was set such that the records were presented at a slant range of 100m per side. A swath of seabed some 200m wide was isonified with each pass with these settings in suitable water depths. The side-scan sonar transceiver was set to operate at 125kHz frequency for the duration of the survey with the higher frequencies available for target search and identification, if needed.

The side-scan sonar image, which may be considered as an 'oblique facsimile' of the seabed, was inspected and features identified during the survey in real-time. During post-processing, seabed surface topography and sedimentary characteristics are transferred to a seabed features plan. Correcting for the antenna offset and layback of the towfish from the GPS antenna, and the vessel heading, the position of individual features and targets can be plotted.

The characteristics of seabed features and seabed materials can be assessed on the basis of their appearance on the side-scan sonar records. In broad terms, the criteria for discriminating between rock, gravel, sand, silts/clays and manmade features are as shown in Table 3.2

Against a background of a sandy seabed, debris can be located and identified reliably, since there will be a reasonable contrast between the moderate reflectivity of sand and high reflectivity of objects. This contrast is reduced in areas of higher background seabed reflectivity, such as gravelly or rocky terrain. This is more so for the latter seabed, since shadows cast by rocks may obscure the location of any debris. When passing close to navigation buoys, the system is of sufficient resolution to be able to discern anchor chains and scour patterns caused by the moorings.

| | |
|---|---|
| **Rock**: | high acoustic reflectivity, textural variation |
| **Gravel**: | high acoustic reflectivity, little textural variation |
| **Sand**: | moderate acoustic reflectivity, textural variation showing megaripples and/or sand waves |
| **Silts/Clays**: | low acoustic reflectivity, no textural features |
| **Manmade**: | high acoustic reflectivity, limited areal extent, regular shape, non-conformity with other features |

**Table 3.2.** Summary of principle sidescan sonar textural interpretations. Secondary information such as attitude, sonar-grazing angle, order of shadows and returns etc are equally important in quantifying the above.

The characteristics of the seabed materials can be assessed on the basis of their appearance on the side-scan records and 'ground-truthed' using grab sample and/ or diver data.

The GeoAcoustics SS941 transceiver system is particularly useful for geological surveys in that the gain of the system is not continually adjusted as the strength of the received signal varies with geology, as is common with some other systems. In this way, the Automatic or Adaptive Gain Controls does not obliterate changes in the acoustic reflectivity of the changing substrate and different geological provinces can be readily identified.

During normal conditions of towage in shallow water, i.e. along straight lines, the possible error in position for the sonar towfish is estimated to be +/- 0.5m. When steering a course with deviations from the straight line and when steering across the current direction, positional errors of the fish can be slightly greater, although the restricted length of the tow will limit this.

When positioning targets from the side-scan records, the single major factor in determining the location of a target is the variation of the towfish heading relative to the course over the ground of the survey vessel, due to degrees of motion- freedom of the towfish. Rigidly mounting the sonar fish to the vessel, or reducing the length of the layback, reduces this effect, since the heading of the vessel is constantly recorded by the INPS. Where features are identified on more than one survey line the position of the feature is more reliably determined. Positional errors due to towfish heading will be larger at greater ranges from the towfish. By simple trigonometry, a five-degree heading error at 50m range will produce a positional error of +/-2.2m whilst at 200m range it would be +/- 8.6m.

Some 350 kilometres of high resolution sidescan sonar and bathymetry has been processed. These have allowed us to create high quality fully orthorectified digital mosaics of the seabed, over which discriminators of the footprints of impact of the dredging operation can be laid for further analysis.

### 3.3 Positions of Biological Sampling Stations

The positions of the sampling stations were chosen to assess biological resources 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 Aggregates who operate North Nab Production Licence Area 122/3.

The survey zone was determined by pre-analysis of the dredge history of the site and assessment of tidal movements within the region. Tidal streams reach up to 1.0ms$^{-1}$ on the flood (078$^{o}$) but only 0.8ms$^{-1}$ on the ebb (252$^{o}$). Maximum tidal excursion is slightly less than 12km to the east and west. All information available from other survey areas suggests than any impact of deposition of material rejected during the dredging process is confined well within one tidal dispersion and is likely to be confined to a distance of less than 3 km (*see* Poiner and Kennedy, 1984; Whiteside *et al*., 1995; Hitchcock and Drucker, 1996; reviewed in Newell *et al*., 1998).

Based on the information obtained in previous studies on an area some 20km to the east, we therefore designed the survey and sampling regime to extend up to 6km in each direction, with the axis of the investigation aligned with the tidal excursion. Further, and also based on previous research, the width of the survey area was delimited to 1000m.

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. The positions of the sampling stations are shown in Appendix Table 1 and Figure 1.5b.

Additional samples were taken on 7th September 1999 to define the impact of dredging within the boundaries of the intensively dredged part of the Licence Area, and to give some information on the relation between past dredging within the site and recovery of biological resources. The positions of stations, which were used to assess the impact of dredging within the intensively dredged part of Licence Area 122/3, are shown in the enlargement of the survey site map in Figure 1.5c.

Samples of deposits were also taken for subsequent particle size analysis. Notes on the position of each sample, the volume of sample taken with the 0.2m$^2$ Hamon grab, and the percentage stones, gravel and sand in the deposits are included in Appendix Table 1.

### 3.4 Collection and Extraction Procedures

A standard 0.2m$^2$ Hamon Grab was deployed from the 23.3m survey vessel MV Flat Holm operated by Coastline Surveys Ltd to collect the samples. Use of this grab has the advantage that loss of material by "washout" from the jaws experienced with conventional grabs is reduced (*see* Holme and McIntyre, 1984; Sips and Waardenburg, 1989; Kenny and Rees, 1994; van Moorsel, 1994). The samples also allow strict comparison with the results of surveys elsewhere using a similar grab. Some stages in the deployment of the Hamon grab and the subsequent separation and preservation of the fauna are shown in Plate 3a.

The samples were released from the grab onto a 1mm mesh-sorting tray, the contents of which were transferred to 10 litre buckets and preserved in formalin for subsequent separation and identification. Separation of the biological material was carried out in the laboratory by elution with a large volume of tap water through a 1mm mesh sieve, and by careful manual separation of the residual fauna from the remaining sediment (Plate 3b). The biological material was then preserved in methanol for subsequent identification and enumeration. A reference collection of key taxa was retained for future reference. Some examples of the macrofauna from the North Nab survey site are shown in Plate 3c.

**Plate 3.4a.** Some stages in the deployment of the Hamon Grab and the subsequent separation and preservation of the fauna on board the survey vessel MV Flat Holm. The dredger *City of Cardiff* and the Isle of Wight are shown in the background.

**Plate 3.4b.** Separation of biological material from the sediments was carried out by elution over a 1mm mesh sieve. This was followed by careful sorting of the residual macrofauna, which were identified under a stereomicroscope.

**Plate 3.4c.** Some examples of the macrofauna from the North Nab Research Area. Taxa included *Sabellaria*, sponges, serpulids (*Pomatoceros*) upper photographs; bryozoa (*Flustra*), numerous amphipods (*Ampelisca*) middle photograph; hydroids (*Tubularia*) and the American slipper limpet (*Crepidula*) lower photographs.

### 3.5 Analysis of Outwash Samples

Aliquots of well-shaken samples of outwash water were filtered through a pre-weighed Watman GF/C filter, washed with distilled water, dried at 105°C and re-weighed to determine total suspended solids. Each filter was then carefully folded, placed in a crucible, weighed and ashed at 650°C in a muffle furnace. After cooling, the filter + crucible were re-weighed to determine the weight of volatile solids. The ashed solids were then calculated from the difference between the total suspended solids and volatile solids. All results were expressed as mg per litre.

### 3.6 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 in grams using conventional conversion factors for each of the faunal groups. These were *Polychaeta* = wet weight x 0.155, *Crustacea* = wet weight x 0.225, *Mollusca* = wet weight x 0.085, *Echinodermata* x 0.08; Miscellaneous Groups including *Porifera* and *Bryozoa* = wet weight x 0.155 (Eleftheriou and Basford, 1989).

### 3.7 Particle Size Analysis

One factor that has been thought to affect benthic community composition in seabed deposits is sediment type (*see* Pearson and Rosenberg, 1978; Weston, 1988; Clarke and Miller-Way, 1992), although much recent evidence suggests that sediment granulometry itself may be less important than the consolidation of the deposits (*see* Seiderer and Newell, 1999, Newell *et al*., 2001).

In total, some 177 grab samples were obtained over 4 phases of the work using the Standard 0.2m$^2$ Hamon-type grab, deployed from the MV Flat Holm. Sub-samples of up to 5 litres of sediment were taken for particle size analysis. This material was sealed in strong plastic bags with a label on both the inside and on the outside of the bag. Most of these samples were analysed for benthic community (*see* Hitchcock *et al*. 2002b).

Grain size analysis of the fractions 0.075mm – 125mm by sieving (according to BS1377 and BS812: Part 102) determined the principal components of the seabed sediments and the results were expressed using conventional Wentworth Classification to give percentage composition of each particle size.

Similarity analysis of the sediment size distributions was performed using non-parametric multivariate analysis methods similar to those outlined in Section 3.10 for biological community composition. The data input to the multivariate analysis of sediment composition is summarised in Appendix Table 2.

### 3.8 Thematic Maps GIS

All of the GIS maps used in this report were generated using MapInfo Professional Version 6.0 and/or AutoCAD 2000. These are both comprehensive desktop-mapping tools that enable multiple layers of data to be viewed geospatially.

Thematic mapping is a powerful method for analysing and visualising univariate data. The data are given graphic form by scaling or shading so that they are visible on a map and therefore readily comparable with other data already located on the map. Patterns and trends that are difficult to detect in tabular form can be easily visualised. In addition to this, thematic scaling or shading does not entail interpolation between the stations at which samples were taken and thus problems associated with interpolation of results between spatially distinct stations are avoided.

### 3.9 Dominance & Diversity

One measure of the uniformity of species composition in natural communities is to plot so-called “k-dominance” curves which show the percentage of a population which is represented by each of the species within the community (*see* Lambshead *et al*., 1983; Clarke, 1990; Warwick, 1993).

Communities with a wide range of species generally have a k-dominance curve which shows no evidence of a major dominance by one or a few species. In contrast, where there is an environmental stress imposed on a community, sensitive species are replaced by large numbers of those (resistant) species that are capable of survival. This leads to a reduction in species variety and a numerical dominance by one or a few resistant species. In these cases the community may show as much as 80-90% dominance by one or two (resistant) species.

### 3.10 Analysis of Invertebrate Community Structure

The statistical methods which we have used to analyse the structure of the invertebrate communities of the coastal sediments to the east of the Isle of Wight follow the methods of Field *et al*. (1982; *see* also Walker *et al*., 1979; Warwick and Clarke, 1991; Clarke and Green 1988; Clarke, 1993; Clarke and Warwick, 1994a; Kenny and Rees, 1994; Somerfield *et al*., 1994). We have used these methods in our previous surveys of benthic communities in proposed marine aggregates licence areas off St Catherine's, Isle of Wight, in the West Varne Area 432 off Folkestone, in the vicinity of Area 454 off Lowestoft, Norfolk, in the vicinity of Area 452 off Southwold, Suffolk (Marine Ecological Surveys, 1996a,b; 1997a,b), and in the central mid English Channel (Marine Ecological Surveys, 1999a,b).

The procedure comprises five stages:-

*(a) Transformation of the data.*
*(b) Construction of a Similarity Matrix.*
*(c) Classification to form a dendrogram from the similarity matrix*
(d) *Ordination to check and confirm the relationships indicated by the Group*
(e) *Average Sorting dendrogram in stage (c).*

*(a). Stage 1. Transformation of the Raw Data.*

One of the problems commonly encountered in an analysis of community structure is that some species are dominant.

There are several ways in which the statistical weighting of such dominant species can be reduced in the analysis. We have used the `Root-Root` transformation of Stephenson and Burgess (1980) in our studies of benthic communities in the deposits to the east of the Isle of Wight.

$$Y_{ij} = \sqrt{\sqrt{X_{ij}}} = X_{ij}^{0.25} \quad \text{..........................................(1)}$$

Where $X_{ij}$ is the raw data score of the *i*-th species in the *j*-th sample, and $Y_{ij}$ is the corresponding transformed score. It has the important practical advantage that the absolute values for the counts of dominant species is less important than in an index based on untransformed data.

*(b). Stage 2. Similarity Matrix.*

Comparison of each sample with every other sample using a measure of similarity leads to the formation of a triangular similarity matrix. A wide range of similarity indices has been reviewed by Washington (1984). Good accounts can also be found in Heip *et al*. (1988) and Magurran (1991). Field *et al*. (1982) used the well-known measure of Bray and Curtis (1957) and this is the index that we have used in our analyses. It is algebraically equivalent to the Czanowski coefficient used by Field and McFarlane (1968) and by Day *et al*. (1971). The Bray-Curtis measure is not affected by joint absences, but gives more weight to abundant species than to rare ones when comparing samples.

A measure of the dissimilarity between samples is often used for the construction of a similarity matrix *viz*:-

$$\delta_{jk} = \frac{\sum_{i=1}^{N} (Y_{ij} - Y_{jk})}{\sum_{i=1}^{N} (Y_{ij} + Y_{jk})} \quad \text{.....................................(2)}$$

Where $\delta_{jk}$ is the dissimilarity between the *j*-th and *k*-th samples summed over all *N*-species, $Y_{ij}$ is the score for the *i*-th species in the *j*-th sample, and $Y_{ik}$ is the score for the *i*-th species in the *k*-th sample. $\delta_{jk}$ ranges from zero (identical scores for all species) to 1.0 (no species in common). In practice, it is convenient to use the Similarity ($S_{jk}$) in its percentage form:-

$$S_{jk} = 100(1 - \delta_{jk}) \quad \text{..................................(3)}$$

The application of a measure of similarity results in a triangular matrix whose entries compare each of the *N*-samples with every other sample. This matrix can be arranged as a trellis diagram (*see* Sanders, 1958), but is more conveniently summarised in diagrammatic form as a dendrogram or ordination. The latter method is being increasingly used in the analysis of multispecies community structure, and has been used in our surveys of spatial variations in the benthic communities in coastal waters.

*(c). Stage 3. Classification.*

Methods available to produce a dendrogram from the similarity matrix have been described by Clifford and Stephenson (1975). The most successful and widely used procedure is `Group Average Sorting` which joins groups of samples together at the average level of similarity between all members of one group and all members of another.

Although this method of classification is simple, and is becoming widely used in ecological studies, Field *et al*. (1982) caution that there are several disadvantages in the use of dendrograms as a sole method of classification of the samples. They recommend that an additional method of presentation is used to investigate the relationships between the samples.

If the results of the two methods agree, then assumptions inherent in the dendrogram method evidently do not lead to artificial similarities and relationships between samples. They recommend `Multidimensional Scaling` (MDS) as a method of ordination. We have used both methods in our analyses of benthic communities in coastal deposits, and have found that in general there is good agreement between the two.

*(d). Stage 4. Ordination.*

Multidimensional Scaling (*see* Kruskal and Wish, 1978) produces an ordination of the *N*-stations in a specified number of dimensions. Field *et al*. (1982) used non-metric MDS, for which there are two widely available computer programs, namely M-D-SCAL and KYST (*see* Kruskal, 1977) and more recently PRIMER (Clarke and Warwick, 1994b). Field *et al*. (1982) used the version M-D-SCAL 5 MS in their analysis of spatial variations in the meiofauna of the Exe estuary, U.K. We have used the PRIMER version in a series of studies of invertebrate community structure in relation to potential perturbation from dredging activities (Marine Ecological Surveys, 1996a,b; 1997a,b, 1999a,b). The groups that were identified as different communities have been colour coded and the corresponding colours superimposed onto a map of the survey area.

# 4.0 MONITORING OF AGGREGATE MINING OPERATIONS

## 4.1 Background

Comprehension of plume morphology formed by dredging activity at each site is fundamental in assessing any impacts of dredging beyond the limits of physical disturbance by the dredge head. It is primarily by this mechanism that any impacts will be extended beyond the active dredge zone. Over the past decade, we have developed novel techniques for tracking development and decay of marine mining plumes using a combination of the latest ADCP systems and traditional water sampling techniques. New advances in software analysis and presentation enable hitherto unknown representation of plume structure.

The form and magnitude of the plume is governed by three principal components;

(1) the dredging technique, including type of dredging plant in operation, method of overboard returns, and operational conditions such as speed over the ground;

(2) sensitivity to suspension and resuspension of the bed material i.e. the ease with which the bed material will be disturbed and will remain in suspension, largely determined by the characteristics of the sediment (geotechnical, rheological and micro-biological); and

(3) condition of the overlying waters i.e. water depth, current velocity and shear, turbulence, temperature, wave climate, salinity etc.

A full description of ADCP systems procedures is outwith the scope of this report, but *see* Thevenot and Johnson (1994), Land *et al*. (1994) and Hitchcock *et al*. (1998). A brief overview is included in section 4.2. The utility of ADCP techniques as interdisciplinary instruments are now well established and accepted.

## 4.2 Theory of Approach

Acoustic Doppler Current Profiling techniques utilise the transmission of a beam of sound into the water column by 3 or 4 highly directional 2.5 degree beam width transducers arranged in a ‘Janus’ configuration, inclined at 30 degrees to the vertical. The transducers for the RDI 1200kHz BroadBand system used in this project are driven by a common power amplifier, but with four independent receiver channels. Data is acquired from the ADCP Deck Box using a PC running the mission planning, acquisition and post-processing software ‘Transect’ supplied by RD Instruments. Backscattered sound from plankton, small particles, air bubbles and small-scale inhomogenities in the water (‘scatterers’) are received by the transducer.

The received signal differs by a Doppler frequency shift proportional to the relative velocity difference between transducer and scatterers. A rapid and continuous series of time based ‘range-gated’ transmissions enables a profile of the water column, divided into ‘bins’ which may be as small as 0.25m, to be computed knowing the precise geometry of the beams and a measured or assumed value for the speed of sound in water. Each cell or ‘bin’ of data is allocated velocity components in x, y and z directions. Bins are grouped into ‘ensembles’, which are recorded instantaneously (during the plume tracking exercise) or can be averaged over time or distance (as for current metering or wide scale oceanographic investigations). These data can then be manipulated either in real-time or post-processed to provide detailed representation of the water velocity movements through the water column.

The fundamental assumption is made that the ‘scatterers’ will be moving at the same rate as the cell of water they are in. The transducer may be stationary, or velocity and heading can be input from external sources e.g. from a Global Positioning System (GPS) sensor and gyrocompass. Alternatively velocity can be determined using bottom tracking of the seabed by the 4th beam.

Collecting such density of data by impellor or electro-magnetic current meter (EMCM) methods would be prohibitively costly. The primary function of Doppler current profiling techniques is to record continuous current velocities through depth and, depending on the equipment, dynamically using a moving boat.

A secondary function of some systems enables the operator to display the acoustic strength of the returned signals for each bin. This will be affected by the suspended particulate matter (SPM). When used in Vessel Mounted (VM) (Figure 4.2a) mode this provides a graphic illustration of relative differences in acoustic backscatter, and hence represents relative variations in suspended solids concentration (Figure 4.2b).

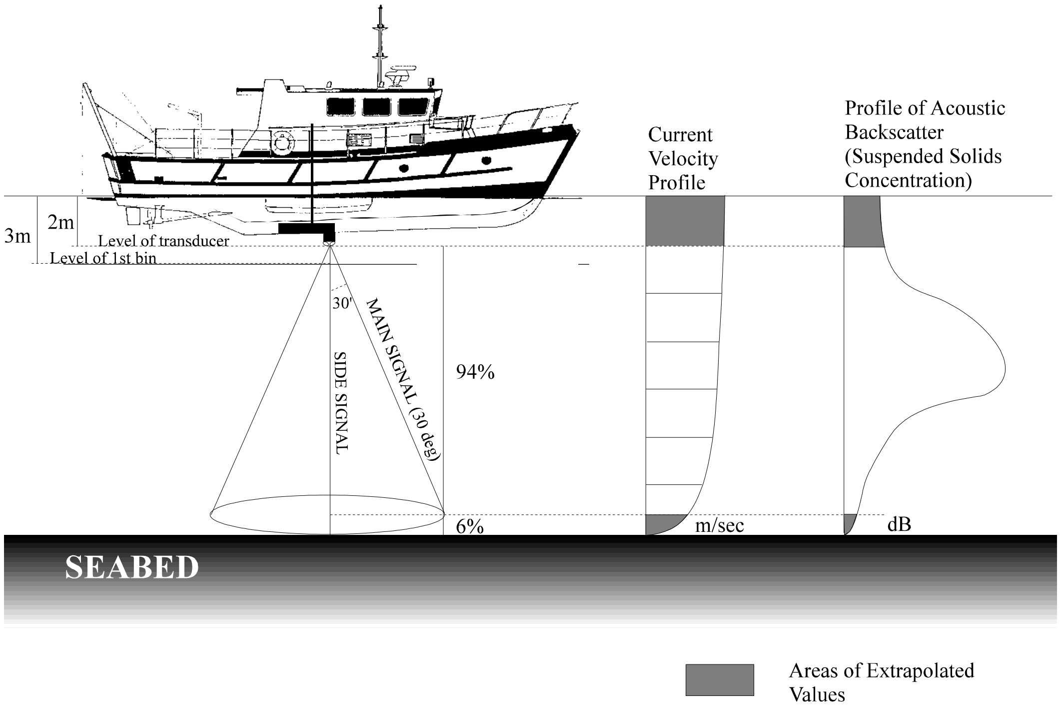


**Figure 4.2a.** Deployment arrangement for Vessel Mounted Acoustic Doppler Current Profiler (VMADCP) as developed during this study for Continuous Backscatter Profiling. Upper and lower part of current and suspended sediment profiles are calculated by extrapolation based on values within measurable range

Since the early 1980s, Acoustic Doppler Current Profilers have become routine instruments for physical oceanographers and they are now fitted to many oceanographic research vessels. Doppler current profiling and acoustic backscatter measurements have been used since the late 1980s for observing distributions of suspended particulate matter, particularly zooplankton following the work of Flagg and Smith (1989). Recently, its' use has been extended for observing sediments suspended by dredging and dredged material disposal operations, particularly cohesive sediments in the U.S.A., (*see*, for example, Thevenot and Kraus, 1993; Ogushwitz, 1994) and studying wastewater outfalls (Dammann *et al*, 1991).

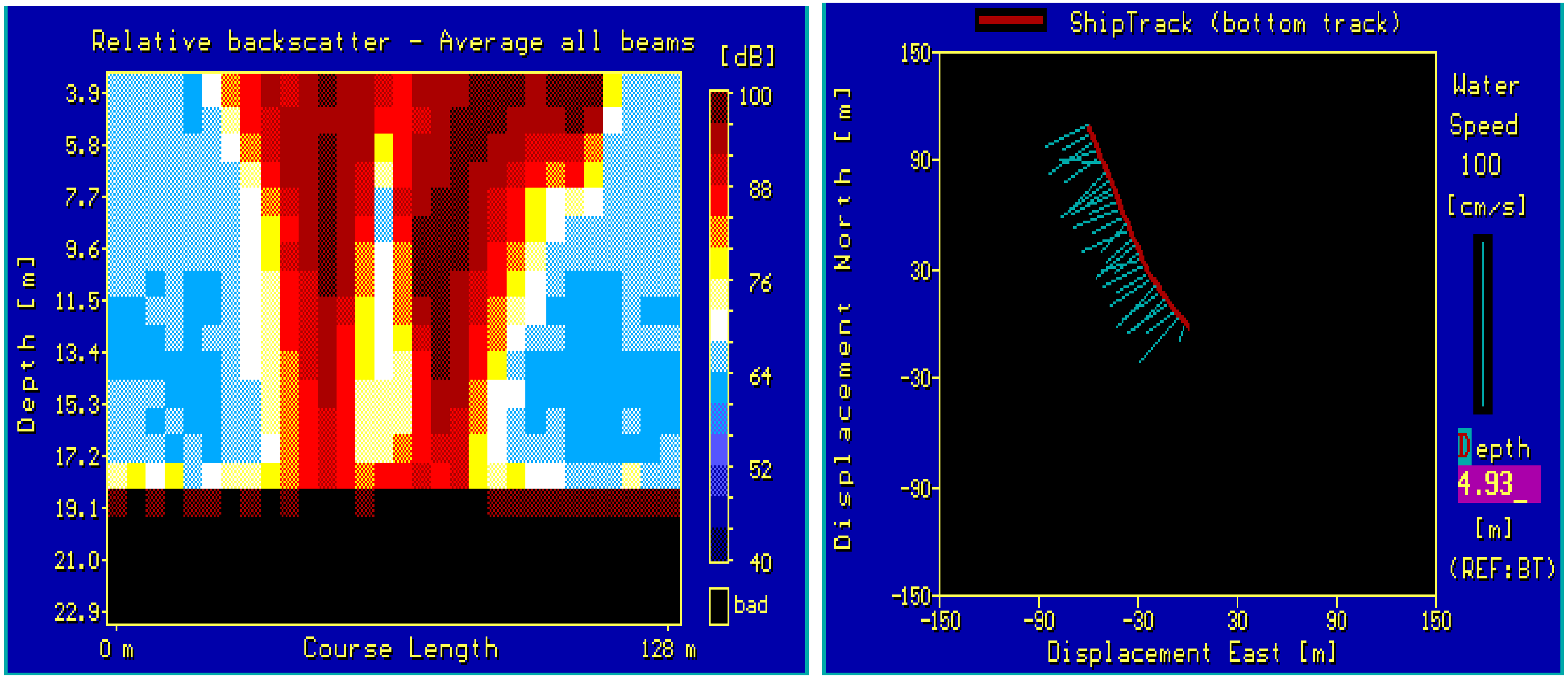


**Figure 4.2b LEFT SIDE:** the Acoustic Doppler Current Profiler™ screen dump showing plume of suspended sediment either side of dredge vessel, immediately astern. Higher suspended solids concentrations are shown in darker colours, the seabed appears black. Clear waters appear in light blue. The darker returns on the starboard side of the ship (right hand side of the figure) reflect the combined overspill and reject plume, whereas the port side of the ship contains only material overspilled. The independent plumes formed either side of the vessel are separated at this distance astern, and are just joining together at depth. **RIGHT SIDE:** shows current velocities (proportional to 'stick' length) and direction, recorded simultaneously, whilst traversing along the transect at left.

There are some significant limitations when using Doppler current profiling techniques for plume monitoring. The most critical is the presence of air bubbles in the water column. Air bubbles transmit the sound signal at a significantly different speed to that of the surrounding waters (due to compression) and will induce considerable noise into the displayed results. It is not possible to circumvent them. When monitoring the passage of a vessel, the wake will appear similar to that of a plume, requiring detailed field notes to explain the apparent 'plume'. Further fieldwork with gravimetric analysis of suspended matter from the monitoring location enables site-specific correlation tables to be generated and thus provide conversion to SSC.

The transect shown in Figure 4.2b must be viewed bearing in mind the presence of air bubbles and their acoustic signature, caused not only by the motion of the vessel, and the action of the propellers, but also by the 'plunging effect' (initial entry velocity due to gravity and pumping) of the overboard discharge.

It is presently generally considered for bio-oceanographic monitoring that acoustic backscatter from ADCP cannot be practically calibrated at sea by users (*see* Roe and Griffiths, 1996). Calibration difficulties have meant that virtually all measurements presented have been based on relative backscatter measurements. These relative data are useful for providing semi-quantitative distribution patterns, but they are not comparable over different hydrographic regimes because of the variation in sound absorption with temperature and salinity. Furthermore they cannot be used to compare backscatter at different depths, and they will inevitably provide generalised backscatter/biomass relationships (Roe *et al*, 1996).

Working on oceanographic-scale plankton investigations, recent work by Roe *et al* (1996) improves these relative data by comparing the mean volume backscattering strength (MVBS) within each depth cell of the ADCP using the manufacturers calibration data together with the *in situ* temperature and salinity conditions and the internal electronics temperature and noise levels. This is then compared to concurrent temperature and salinity data from a towed undulating hydrographic sensor platform (SeaSoar) in order to accurately calculate the sound absorption coefficient a, a principle component in determining absolute values for measured backscatter.

The following section outlines techniques for determining suspended solids concentrations and also outlines recent investigations into the use of ADCP equipment for measuring the suspended solids concentrations of plumes generated by various types of dredging activities.

### 4.3 ADCP Monitoring

The ADCP Deck Box maintains a feedback voltage to the transducers at a constant signal voltage level. The feedback control voltage (Automatic Gain Control - AGC) required varies according to the intensity of the received echo at the transducer, i.e. is proportional to the level of acoustic backscatter. The AGC values are the average of the four individual beam values. The AGC value is converted to relative backscatter (dB) depending on several environmental factors including the electronics temperature, factory calibration of the transmitter and receiver and the beam pattern and sensitivity of the transducers. At a typical electronics temperature of 28$^{o}$C, the relative backscatter conversion equates to 0.42dB/AGC count.

Absolute backscatter has been calculated (*see*, for example, Roe *et al*, 1996) for each depth layer (removing the effects of spherical spreading of the beam, attenuation and changes in the isonified volume) according to the RD Instruments' Technical Note (1990) and following the concept of determining the mean volume backscattering strength (MVBS).

A number of investigators have further attempted to correlate the backscatter sound strength (dB) of a returned signal with suspended solids concentration (mg/l) with varying degrees of success (Thevenot and Kraus, 1993; Tubman *et al*, 1994; Ogushwitz, 1994). Land *et al* (1994) report statistically acceptable correlation with optical silt meters and water samples for sediment in the range 5 - 75mm with a mean particle diameter 10mm and concentrations up to 1000mg/l.

Lohrmann and Huhta (*In:* Tubman *et al*, 1994) calibrated a 2.4MHz BroadBand ADCP in a purpose-built laboratory calibration tank using material obtained by grab from the seabed of the site to be studied. Although suspended solids concentrations determined by the ADCP were considered to agree 'reasonably well' with the water sample analyses, the maximum error was considered to be ± 60% at 50mg/l. This is largely explained by the theory of Rayleigh backscattering used by the ADCP, which itself can only be accurate to ± 50%. Thevenot and Kraus (1993) hypothesised that flocculation of the material could be a contributing factor to the differences between laboratory and field calibrations.

The techniques involve very careful and rigorous calibration by field sampling that must be repeated at frequent intervals, especially when particle characteristics such as mineralogy and refractive index are expected to change. Within this project, the use of Doppler current profiling techniques, in particular in Vessel Mounted configurations, has concentrated on accurately representing the gross morphology of the plume in real-time. This enhances the positioning of other sampling equipment such as water bottles or pump sampling apparatus (Plate 4.3a) within the plume for acquiring the suspended solids concentrations.

**Plate 4.3a**. Deployment of water sampling equipment in the plume generated by the *City of Chichester*

During post-processing the concentration of solids within a water sample can be confidently placed into perspective within the plume and so apply that concentration to immediate regions of equal acoustic strength to facilitate building graphic representations of the plume behaviour. Correlation of the acoustic strength of the return with suspended solids concentrations has not been attempted.

The U.S. Army Corps of Engineers (USACE) Dredging Research Program (DRP) undertaken between 1988 and 1995 at a cost of $35 million has investigated many facets of applied research and development to dredging operations. A significant study by this project was the development of the PLUme MEasurement System (PLUMES) (Kraus and Thevenot, 1992) which also utilised commercially available broadband acoustic Doppler current profiling equipment.

The results have been successfully used to document the actual movement of the sediment plume for resource agencies, who were concerned that the plume did not impinge on nearby environmentally sensitive biological regions (Hales, 1995). At least $5 million were saved in not having to conduct extensive environmental studies related to designation of new disposal sites at these locations.

The results obtained both through this research and also reported recently worldwide demonstrate the enormous potential for ADCP operations providing real-time data acquisition and representation of hydrographic and oceanographic conditions. Conventional sampling programmes are enhanced through efficient targeting of resources and confidence in the resultant data. However, analysis of backscatter data for correlation with suspended solids concentrations must take account of the fact that ADCP observations may represent concurrent changes in particle concentration and particle morphology without discrimination.

The sediment plume generated by a small suction dredger, the City of Chichester, was monitored by ADCP techniques during the loading of an ‘all-in’ cargo. An RDI 1200kHz BroadBand unit was deployed over the bow of the survey vessel (Plate 4.3) and the equipment and software configured for moving vessel mode. ADCP transects across the plume were conducted at differing ranges from the anchored dredge vessel, to determine the plume shape and morphology. Two distinct monitoring strategies were followed. In the first, the survey vessel conducted transverse profiles perpendicular to the plume axis at set distances downstream of the dredge vessel, and produced a series of profiles indicative of the status of the plume and its dispersing morphology. Water samples taken at varying points along each transect and at different depths give sediment mass per litre of seawater (suspended sediment concentration). Each of these profiles represents a time-dependent status of the plume, and the rate of dispersion and settlement of the sediments can be determined.


**Plate 4.3b.** ADCP unit deployed from bow of the survey vessel MV Flat Holm

Secondly, the survey vessel deployed a mid-water drogue with a surface buoy in the plume just downstream of the dredge vessel. The survey vessel then conducted vertical and transverse profiling away from the dredger, always passing through the same parcel of water as indicated by the drogue surface buoy. This technique gives a time-based status of the plume but also removes some of the variability of the loading process and the ‘pulsing’ of overboard spilling of sediments from the dredge vessel. Specifically, within this study, we have not attempted to calibrate the ADCP backscatter signals with particular suspended sediment concentrations.

### 4.4 Data Processing

The RD Instruments' data acquisition software 'Transect' is used to generate many of the graphics of relative backscatter and current velocity that are shown within this report. However, in order to assess the with-depth variations of relative acoustic backscatter, current velocity and current direction, two programs have been written to further analyse the ASCII output from the Transect software.

Velocity MAP (VMAP) enables the user to select the specific bin depths of interest (or all depths) and extracts relevant data from the Transect ASCII file on an iterative basis. Each bin is ascribed with respective values for x (easting), y (northing) and z (depth) components, with the corresponding value for current direction and magnitude. Sub-routines convert this data into AutoCAD Drawing Interchange Format (.DXF) for plotting as fully annotated drawings. Data for each depth is assigned an individual layer name. Within AutoCAD, the user can select the depths required for presentation, and produce a straightforward plot of the tidal conditions throughout each circuit. VMAP allows the user to change the averaging period over which measurements may be plotted, either by time or distance basis.

BMAP (Backscatter MAP) is a program similar to VMAP in that is was written to post-process the output ASCII files from the Transect software. However, BMAP concerns itself with investigating the with-depth variation of the relative backscatter recorded by the ADCP™. Processing of the Transect files involves generating an ASCII file that contains, in tabular format, all the easting, northing, depth and relative backscatter values, as well as all other system and observed variables. These are presently modelled using a simple contouring package to produce pixelated images of the contoured, relative backscatter levels at the required depths for comparison. Figure 5.4c shows the example of the plume as monitored at three depths as an output from BMAP. From this figure it is clear what the extent of the high backscatter levels are, and the rapidity with which they decrease to levels slightly elevated above background.

The representation of the plume has been undergoing continual refinement, and in late 2001 we upgraded to *Slicer v.3* which provides us with much enhanced capabilities for visual three-dimensional representation (easting, northing and depth) of the plume with a fourth component (relative backscatter) indicated by colour. Figures 5.4a and 5.4b were produced using this technique and some routines developed in-house for manipulating the data from BMAP format to *Slicer.*

## 5.0 RESULTS - PHYSICAL RESOURCES

Surface plots of the bathymetry of the study site are shown in Figure 5a for 1999 and Figure 5b for 2001. The survey area can be seen to straddle a weak scarp (note the elevation differences have been graphically enhanced). Nonetheless the active area of the dredge site is seen to be clearly located in the facing edge of that scarp, and it is possible that this represents a paleobeach environment. There are no apparent significant correlations between the sedimentary and biological communities and the bathymetry of the study area.

The licence itself appears to be geologically controlled in relation to the bathymetry and further work may be able to determine additional resource zones on the basis of the bathymetry.

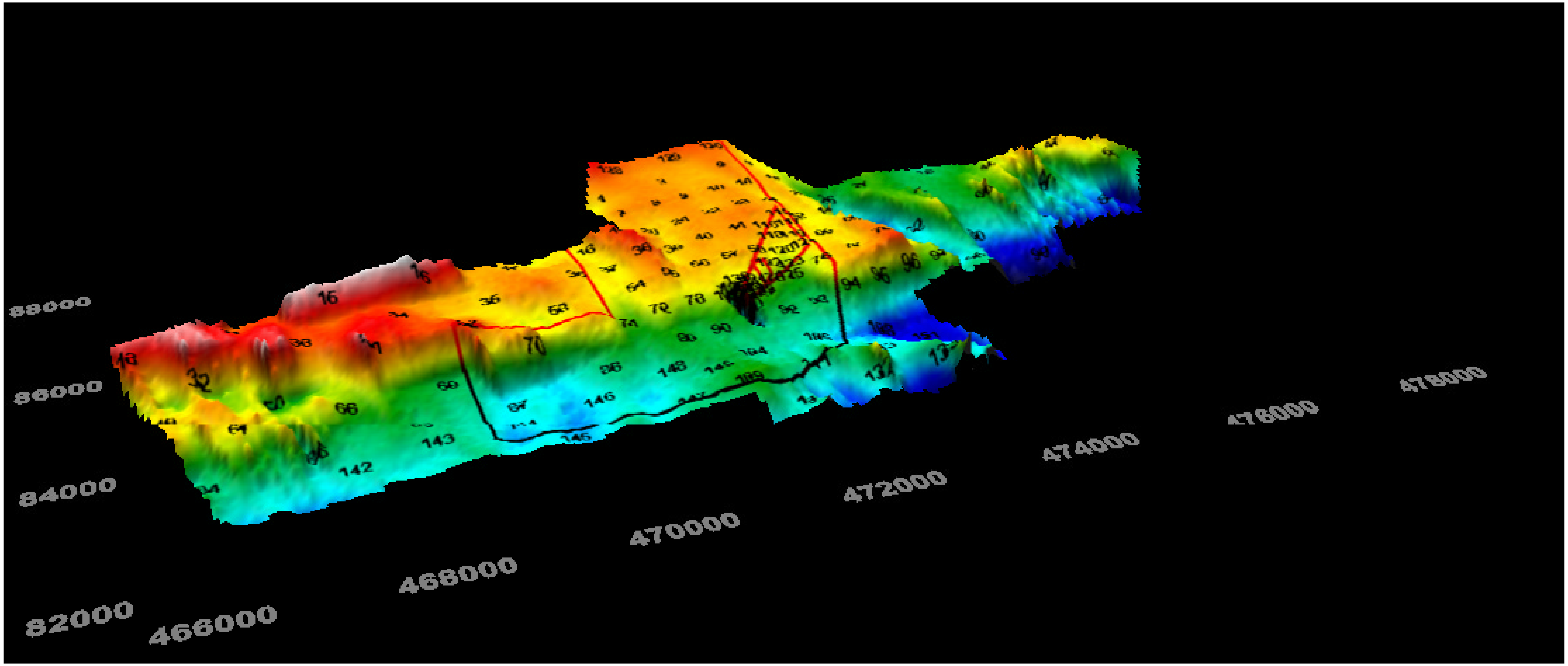


**Figure 5a** Surface plot of bathymetry for 1999 with grab sample positions superimposed. The survey area can be seen to straddle a weak scarp, the elevation differences have been enhanced. Nonetheless the active area of the dredge site is seen to be clearly located in the facing edge of that scarp, and it is possible that this represents a paleobeach environment.

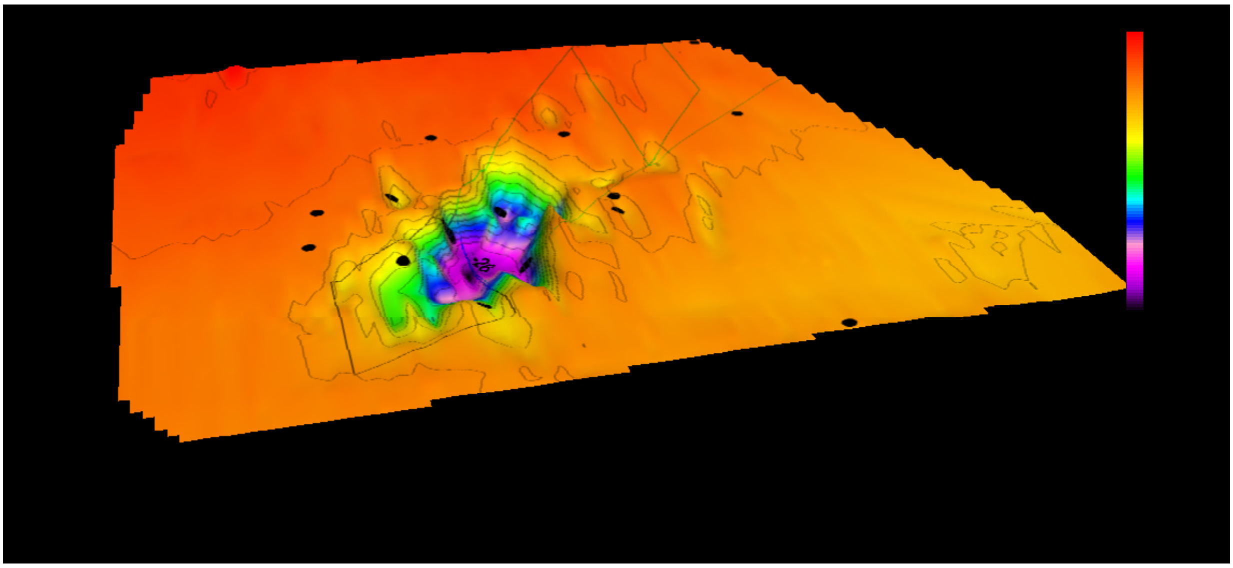

**Figure 5b** Surface plot of bathymetry of the active dredge area in June 2001 with grab sample positions superimposed. The location of the dredge pits, especially within the management boundaries can be clearly seen.

### 5.1 Nature of the Deposits in the Survey Area

The deposits in the survey area comprise mostly sands and gravels in a depth of 10-20 metres of water. The central part of the survey zone is dominated by gravels, which have been exploited by anchor dredging since 1991 in a small part of the Licence Area shown in Figures 1.5a and 1.5c. The anchor-dredging zone was extended northeast in 1994 and subsequently further to the northeast using trailer-dredging techniques (see Figure 1.5c). Elsewhere in the east of the survey area the deposits are dominated by sands with relatively low gravel content to the east of the Nab Tower.

Deposits in the west of the survey area comprised gravels with variable quantities of sand and mud, with reefs in the shallower waters off Bembridge in the southeast of the Isle of Wight. Good samples were obtained at most of the stations sampled with the Hamon grab, with the exception of outcrops of reefs. The percentage stones (>37.5 mm particle diameter), gravel (>3.35 mm particle diameter) and sand (>0.075 mm particle diameter) is summarised in Appendix Table 1.

The volume of sediment obtained at each of the sampling stations is summarised in Appendix Table 1. An average volume of 10.6 litres of sediment was obtained for 130 samples of 0.2 $m^2$ used for biological analysis. A specific gravity of seabed deposits may be approximated as 1.8kg/$m^3$, thus the average weight of seabed material from which the fauna was extracted can be calculated as 19.1 kg per sample. This value was used to estimate the quantity of benthic invertebrate material that is likely to be ‘processed’ by a dredger during the normal loading operation.

Figure 5.1a shows the representative particle size of 151 grab samples that were analysed for full particle size distribution. This information was then used to investigate both the possibility that there was tendency for samples downstream of the dredge site to show a fining of size (due to the plume) and test the relationship of particle size to benthic community relationships.

Analysis of the particle size distribution in the deposits of the survey area is best carried out by non-parametric multivariate techniques. These identify differences and similarities between the sediments that could not be identified by mere inspection of the data. Similar methods have been used to analyse the particle size composition of coastal sediments in the southern North Sea off Orford Ness by Seiderer and Newell (1999), in the eastern English Channel off Hastings, Kent by Kenny (1998) and off Folkestone, Kent by Newell *et al*. (2001).

Both the percentage similarity of the sediments and the corresponding two-dimensional multidimensional scaling (MDS) ordination based on the percentage particle size distribution at each of the stations sampled are shown in Figure 5.1c.

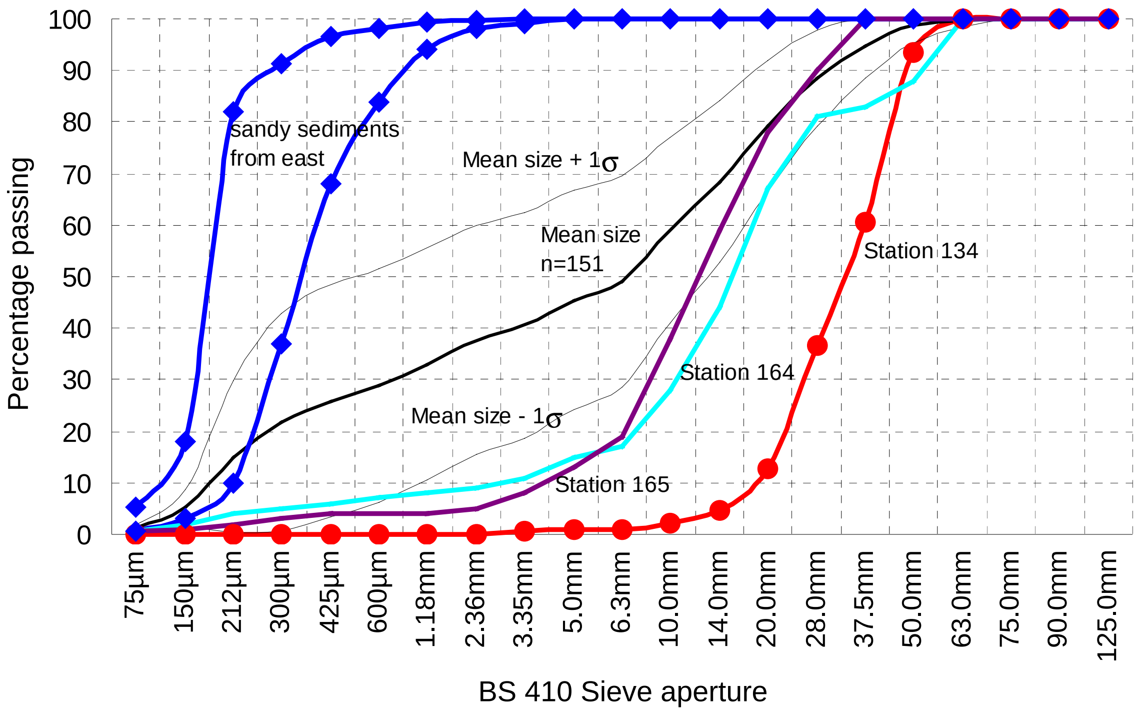


**Figure 5.1a** Representative particle size distribution of 151 grab samples from the North Nab study site with specific samples selected that are referred to in the text.

Figure 5.1b shows the percentage composition of the deposits in the North Nab survey area, graphically, based on the data shown in Appendix Tables 1 and 2 and summarised in size curves of Figure 5.1a.

It is clear that the deposits in the central part of the survey area comprise >60% gravel. At the east of the survey area, the percentage gravel falls to less than 10% where sands dominate the seabed deposits. At the western end of the survey area, the percentage gravel falls to below 40% mainly due to the increased proportion of sands and muds noted in our site survey records.

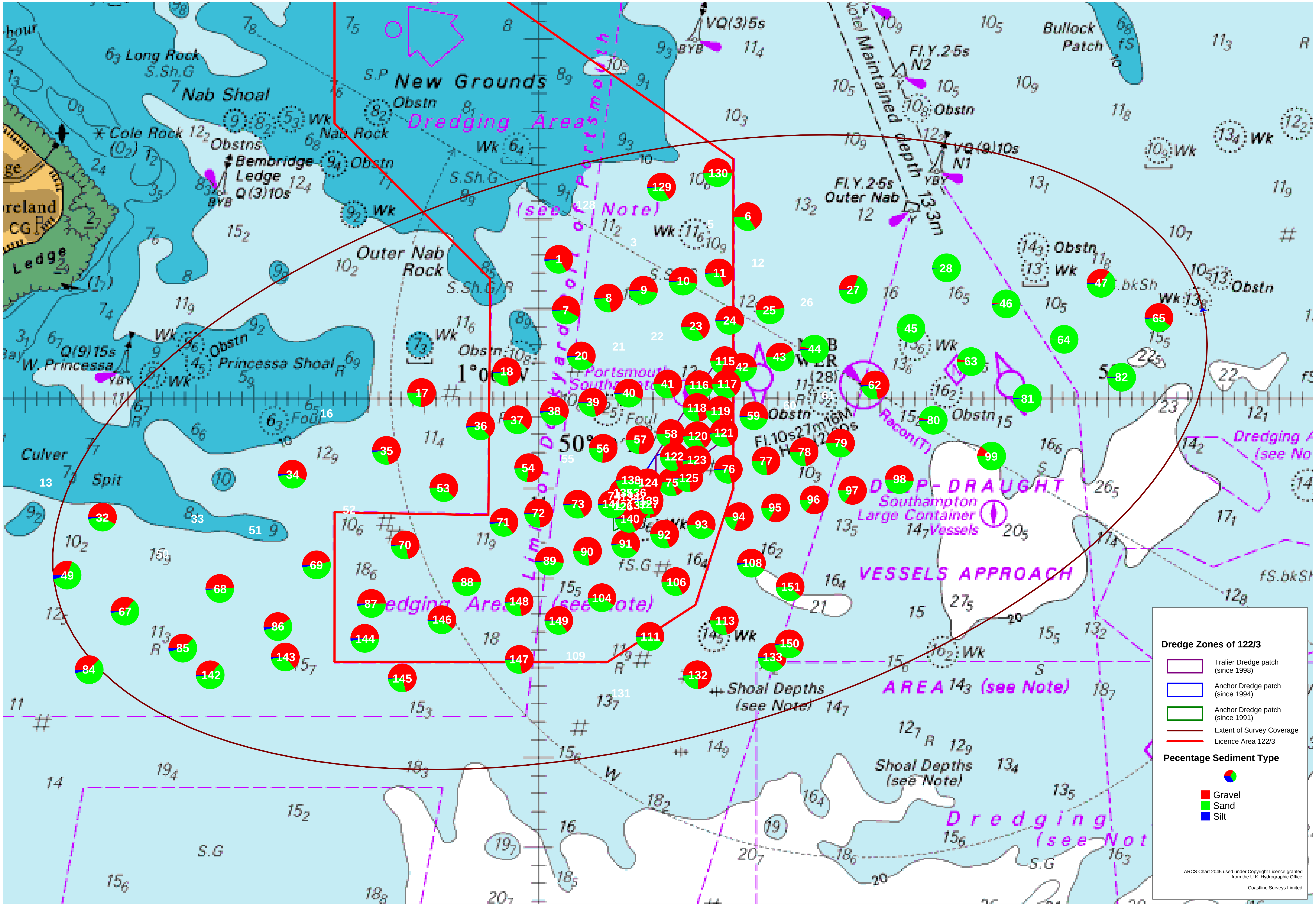


Figure 5.1b: Map of the North Nab survey area showing the relative proportions of silt (<0.063mm), sand (0.063mm - 3.35mm) and gravel (>3.35mm)

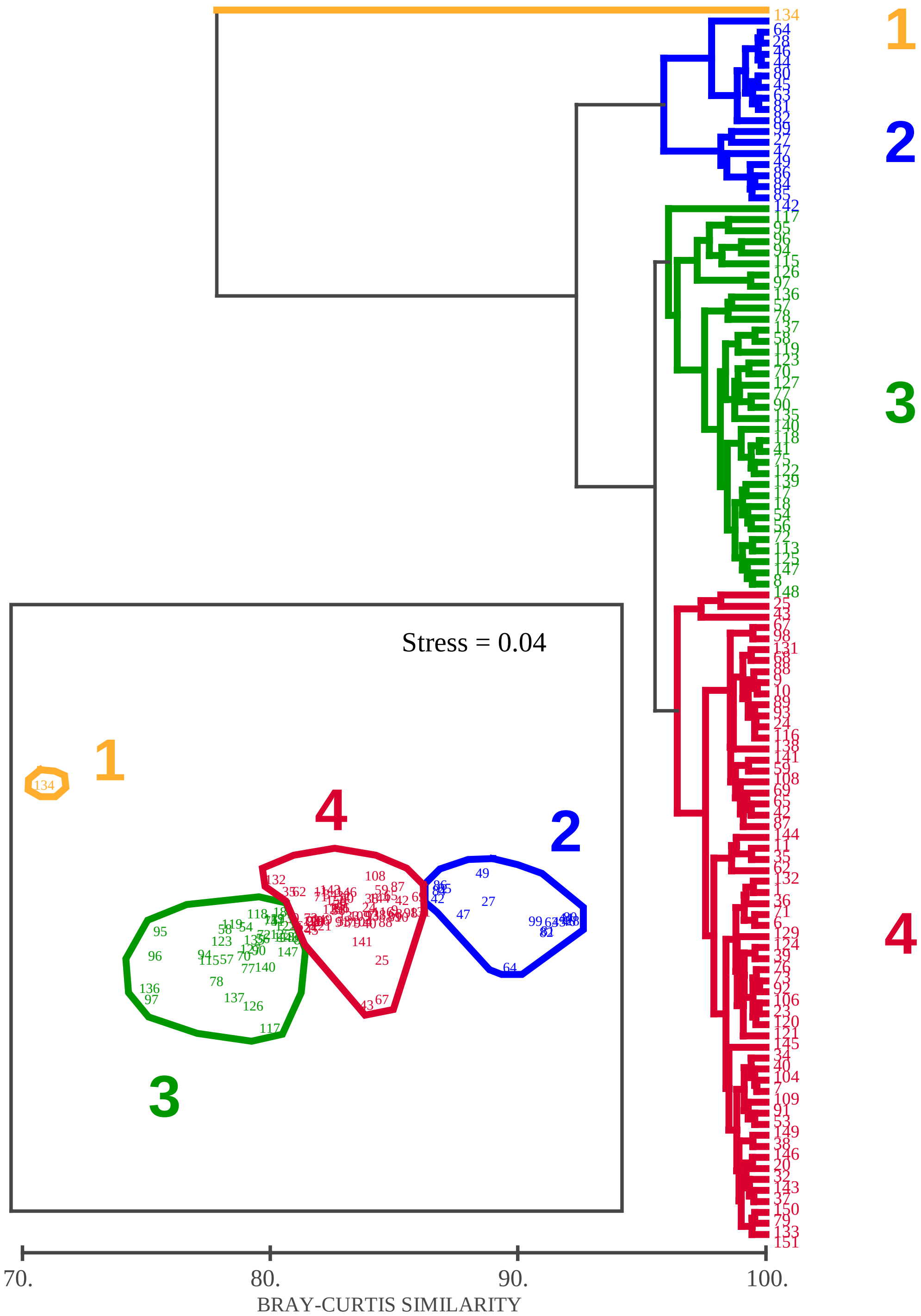


**Figure 5.1c**. Group average sorting dendrogram and corresponding two-dimensional multidimensional scaling (MDS) ordination based on the particle size composition of sediments from the North Nab survey area in March 1999.

Sediments in the survey area are evidently best regarded as comprising four main types. These are an isolated Group 1 sediment type that occurs only at Station 134; this may reflect an impact of dredging at that site. A second Group 2 (coded blue in Figure 5.1c) comprises mainly sands and muddy sands with a low proportion of gravel. A third Group 3 (coded green in Figure 5.1c) comprises mainly gravels. A final Group 4 (coded red in Figure 5.1c) comprises gravels with varying proportions of sand and mud.

The results for Station 134 are of particular interest. This site corresponds with the centre of an anchor-dredge pit recorded in May 1999. Inspection of Figures 5.1a and 5.1c shows that the sediments at Station 134 are quite distinct from all others in the survey area. The deposits at this site are exceptionally coarse (see Appendix Tables 1 and 2) and may reflect a removal of fine material during the dredging process. Elsewhere the deposits closely resemble those outside the boundaries of the exploited area, so any impact of dredging on particle size composition appears to be confined to the immediate vicinity of a dredge site currently under exploitation. The distribution of these groups of sediments is shown in Figures 5.1d and 5.1e.

The Group 1 sediment type occurs only at Station 134, close within the zone of intensive anchor dredging. The Group 2 sediments (coded blue in Figure 5.1d) represent the sands and muddy deposits that occur at the eastern and western extremities of the survey area. The Group 3 sediments (coded green) are mainly confined to the high-grade gravel deposits close to the intensively worked area within the boundaries of the main Production Licence Area 122/3 (see Figure 5.1e). Finally the Group 4 sediments (coded red) represent the sandy gravels that occur over much of the central part of the survey area.

The sediments within each Group are evidently related to one another with a high degree of internal similarity and are relatively uniform over much of the central part of the survey area. A similar high level of internal similarity has been recorded for other coastal sediments both in the southern North Sea (Seiderer and Newell, 1999) and in the eastern English Channel (Kenny, 1998, Newell *et al*., 2001).

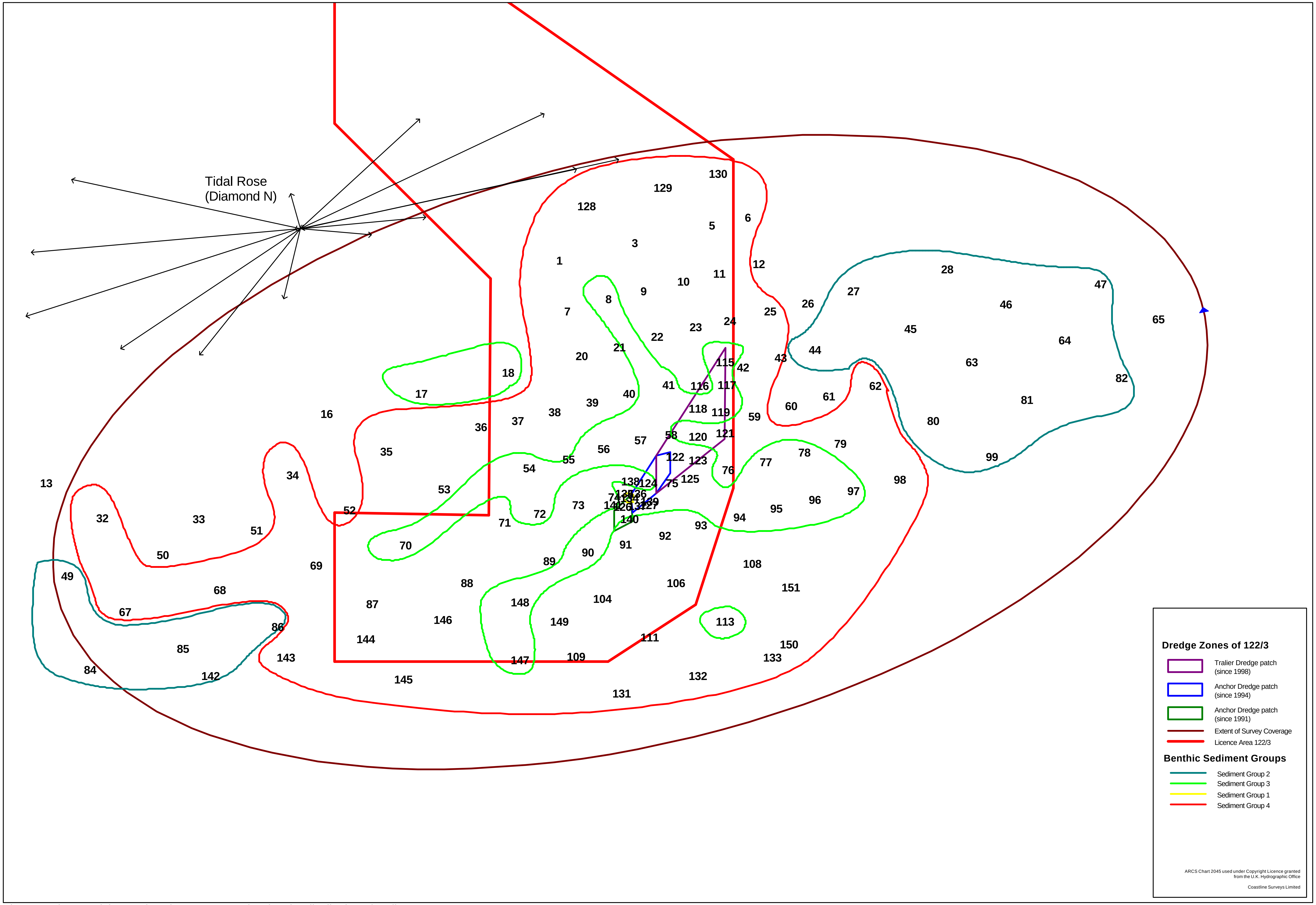


Figure 5.1d: Map of the North Nab survey area showing the distribution of sediment types identified by non-parametric multivariate analysis

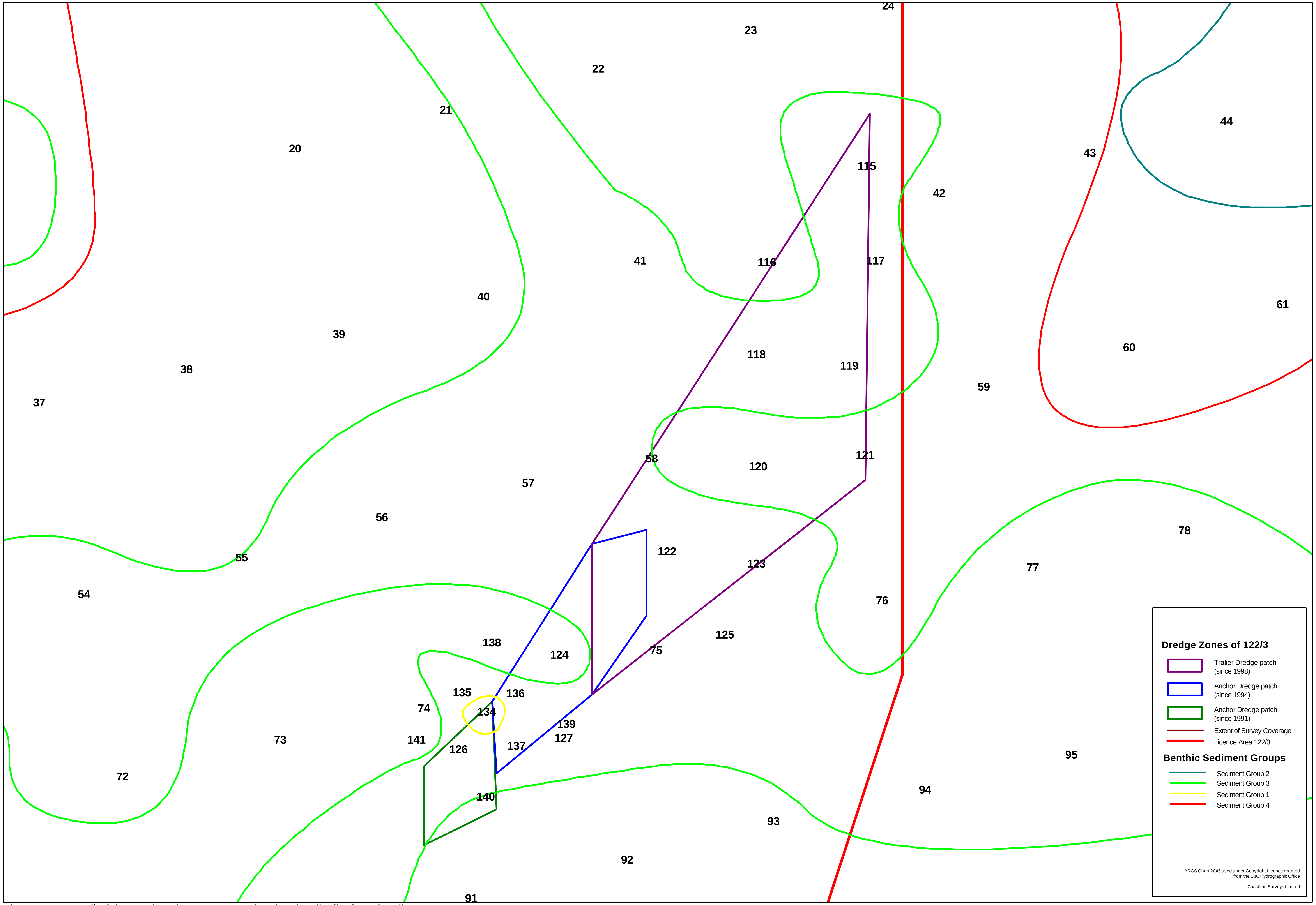


Figure 5.1e: Detail of the North Nab survey area showing the distribution of sediment types identified by non-parametric multivariate analysis in previous figure

Although the sediments at Station 134 are quite distinct from those in the surrounding deposits and may reflect a local impact of dredging on sediment composition, the similarity of sediment composition at other sites within the exploited area that are known to have been worked in the months prior to the survey shows that neither anchor dredging nor trailer dredging at the North Nab site has resulted in a detectable alteration in sediment composition compared with the surrounding deposits. This is to be expected in a Production Licence area where there is no discharge of screened material.

## 5.2 Sidescan Sonar Mosaics of the Survey Area

The principal sidescan sonar mosaic that has provided most information is generated from the data collected in 1999. Subsequent surveys collected data very close into the dredging operation, within the actively dredged pits area, but this seabed is so uneven the sidescan sonar can reveal little information.

Inspection of the sidescan sonar mosaic presented in Figure 5.2a clearly shows the differing acoustic contrasts of the seabed in the principal sediment provinces. To the east, the lighter tone reflects the distribution of predominantly sandy size sediments. The remainder of the survey area is typically a uniform dark grey, characteristic of even, coarser sediments. The distribution of coarse sediments on the sonargraphs is again quite clearly depicted by the licence boundaries. Other than a very small zone, some 500$m^2$, on the extreme northwest boundary of the survey zone, there are no bedforms such as ripples or megaripples. This localised development is near a small shelf of local solid rock control. Around the actively dredged area there is no evidence of development of sand ripples or other microtopographical features indicative of a localised sand transport path, as may be expected to develop during overboard release of sediments. We know that screening does not occur on this licence, so the potential quantity of remobilised fine sediments is small.

Also shown on Figure 5.2a are the boundaries of the principal sediment provinces based on multivariate analysis of the sediment classes, overlain onto the regional sidescan sonar mosaic of the region collected in 1999. The major sediment provinces are well indicated by the production licence area that closely follows the distribution of gravelly sediments. This supports the resource management Code of Practice to restrict licensed areas of the seabed to the minimum required. These techniques enable a detailed assessment of the sediment distribution, and importantly reveal small groups of gravelly sediments that show an elevated sand content, distributed around the actively dredged area, not discernible by other geostatistical techniques. The ribbons of sandier gravels extend some 1500-2000m away from the dredge location and correspond well with the predominant tidal axes away from the active dredge zone.

From Figure 5.1a, the distinct sample stations 134, 164 and 165 are located within the dredge pit, and reflect a very well sorted coarse gravelly deposit, which is the target resource.

Anchor dredge activity can clearly be located on the sidescan sonar. Single dredge pits caused during isolated dredging operations are also clear around the main dredge area. There is also isolated evidence of trailer dredging activities in the designated zone, but these trails are poorly distinguished. Loading whilst trailing is not commonly undertaken. Anecdotal evidence from the vessels suggest that the method performs poorly in this locale, due possibly to presence of a lag gravel deposit through which the dredge head does not penetrate easily. Measurements from the sonargraphs indicate that the trailer dredge tracks are shallow, some 10-20 centimetres deep. Width is poorly distinguished.

Figure 5.2c clearly show the distribution of sediments (as discussed above) and faunal communities. For a detailed analysis of the benthic resources and the implications of the community distributions, see the following chapter. Importantly, however, we may briefly consider the lack of correlation between the change in sediment type downstream of the dredging activity (the enhanced ‘sandiness’ of the gravels) (from Figure 5.2a) and the faunal community.

This suggests that either the type of community structure present is unaffected by the change in sediment composition or, more likely, is tolerant of the level of change that the community has been exposed to. However, an increased or prolonged exposure may cause a negative impact, or the existing exposure may cause a level of stress to the community that reduces its tolerance to other impacts.

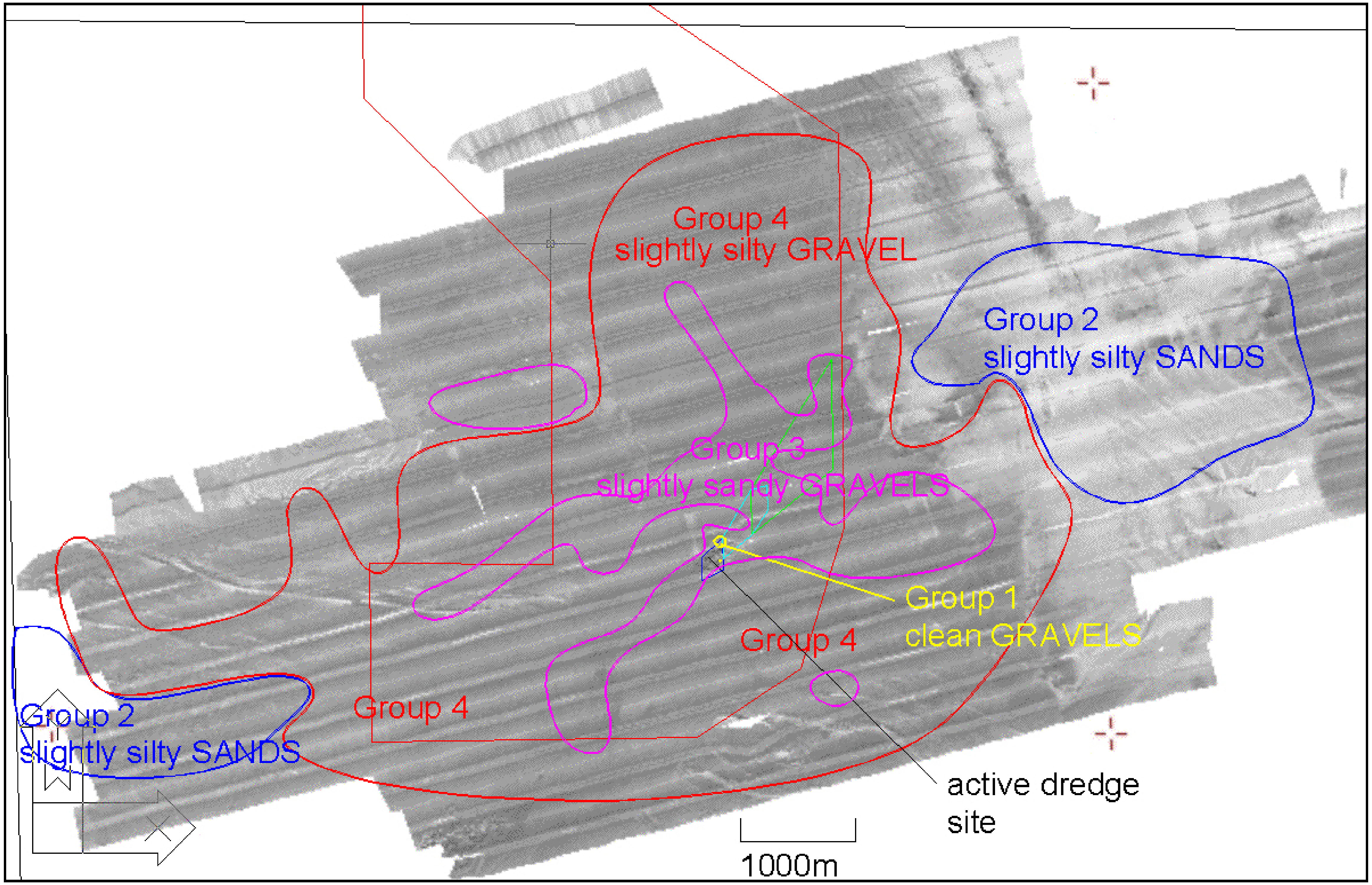


**Figure 5.2a** Sidescan sonar mosaic formed from the 1999 data collection. The principal sedimentary provinces determined by the statistical analysis of the grab samples has been superimposed on the sonargraph. The correlation between sandy sediments and low reflectivity is clear to the east of the mosaic. Other than the exposed sub-bottom sediments of Group 1 (clean gravels), almost the entire licence area is of slightly silty gravels. Note the elongated changes in sedimentary composition (Group 3) adjacent to the dredge zone aligned with the principal tidal vectors, to the South West, West, North and East.

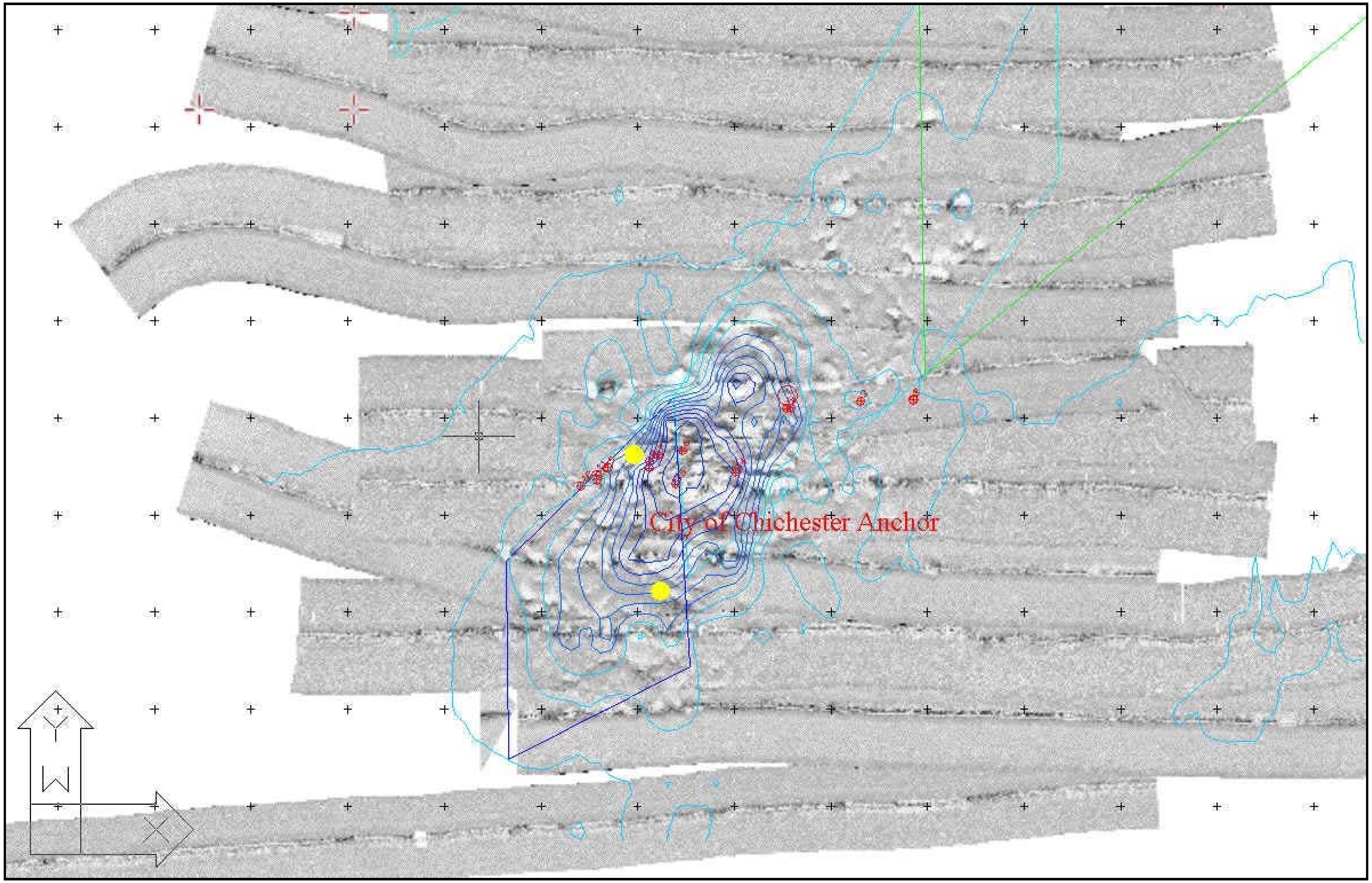


**Figure 5.2b** Sidescan sonar mosaic formed from the 2000 data collection. The bathymetry is superimposed, reduced to chart datum.
The dredging activity can be seen to be slowly working towards the north, when compared with data collected in 1999.
There is a good correlation between the location of the pits from the sidescan and the hollows recorded on the bathymetry.

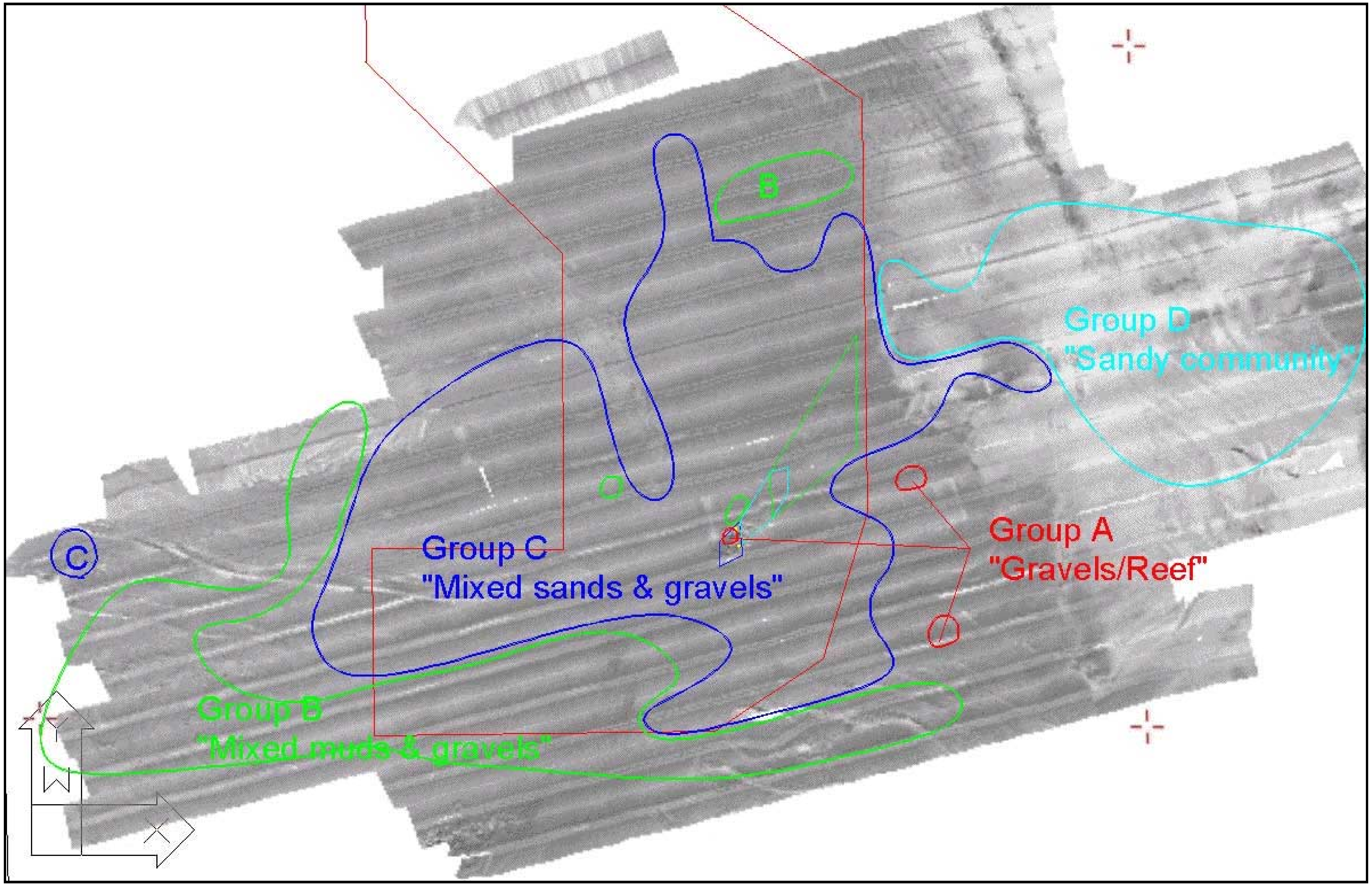


**Figure 5.2c**. Superimposing the benthic community types on the sidescan mosaic and comparing with Figure 5.2a, we can see that there is no correlating change in community type similar to the recorded changes in sediment province. Community Groups B and C pass over the tongues of sandy material downstream of the dredge zone (this does not appear to be an artefact caused by data density). See Section 6 for full analysis of the community types and implications of these observations.

### 5.3 Plume Morphology

A composite image of the continuous backscatter profiling (CBP) of the plume developed by the 2300 tonne capacity *City of Chichester* during loading of an all-in cargo is shown in Figure 5.3a. The screen-dump images show a series of transects downstream of the dredger at varying distances. Data collection at the far-field extremes of the survey, necessary to prove return distances to background levels, was curtailed by the presence of numerous small vessels at anchor. Nevertheless, the transects and samples obtained give a good indication of the near-field density current dynamic phase plume morphology. High intensity backscatter values are coloured red, reducing through yellow, white and to pale blue approaching background levels of backscatter. Close to the dredger, the plume can be visualised falling immediately below the vessel (45 metre image). The sequence 45 metres to 200 metres shows the dense plume falling to the seabed, and spreading laterally downstream of the operation. Scale of the transects changes such that the 45 metre transect is some 200 metres long, whilst the 200 metre transect is some 500 metres long.

Suspended sediment samples obtained by subsurface pumps immediately astern of the dredger are presented in Table 5.3a along with corresponding depths and distances downstream of the dredger. Pre-dredging background levels are 5-10 mg/l in settled conditions. Maximum values reached are approximately 5.5 g/l reducing to 450 mg/l further away from the vessel at the limit of the survey. Considerably more samples are needed for future works to resolve the fine scale eddies and internal structures that are developed during the overspill process. Included in Table 5.3a are corresponding results of a previous study on an adjacent site, using a similar methodology. In this instance, generally much lower concentrations of suspended sediments were recorded. Although the vessels are similar in size and operation, this may be due to different tidal conditions in the earlier study leading to much quicker dispersion of the plume. Van der Veer *et al*. (1985) measured overflow concentrations of suspended sediment from a small dredger to be 6300 mg/l, within range of the results obtained here. Background concentrations were found to average 60 mg/l.

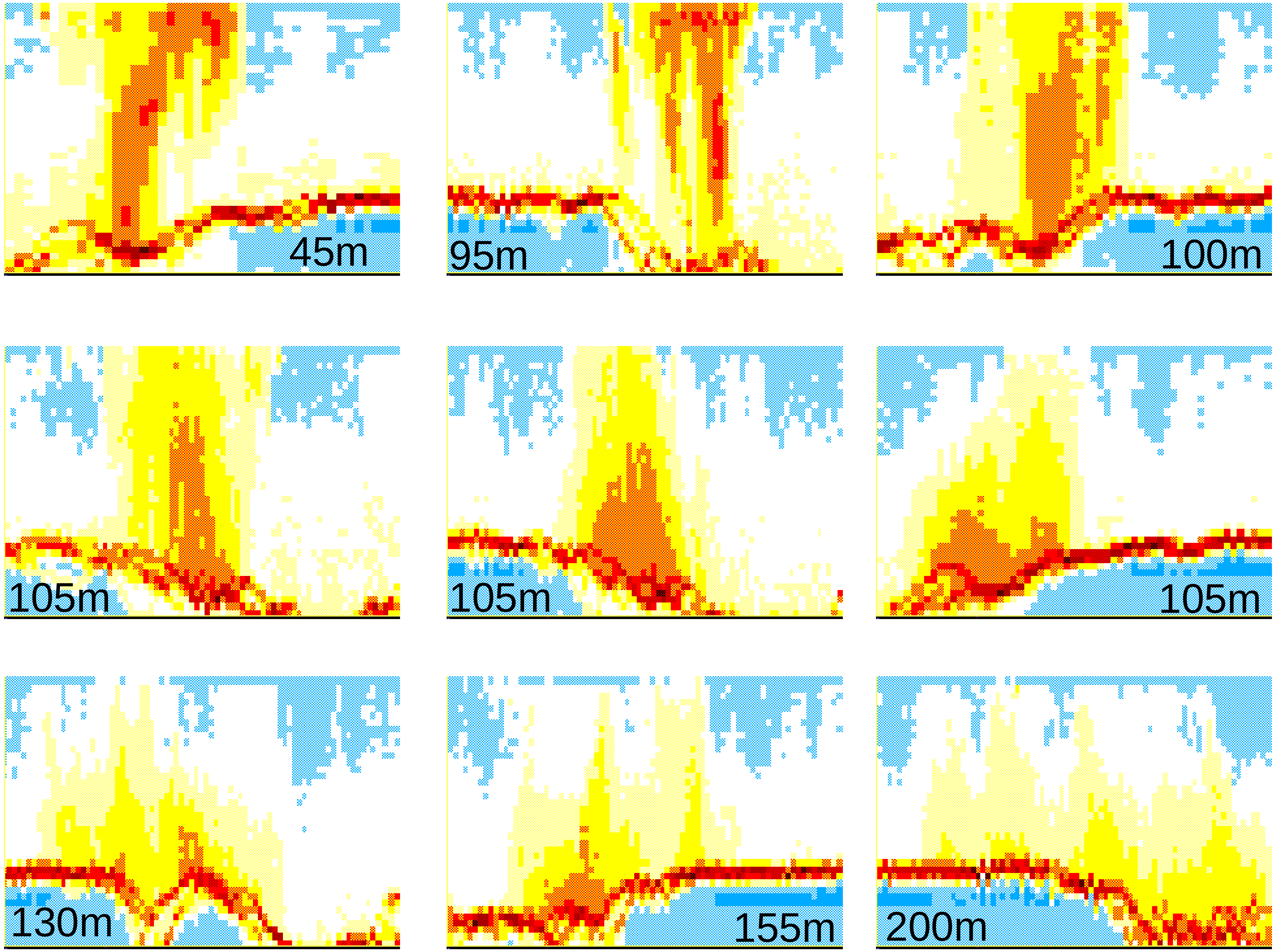


**Figure 5.3a.** Series of Acoustic Doppler Current Profiles obtained with a 1200kHz RDI BroadBand system astern of the small 2300 tonne capacity suction dredger *City of Chichester* whilst loading at anchor without screening. Profiles show high intensity backscatter (red) close to and immediately astern of the dredger (range 45m), reducing quickly to levels approaching background away from the dredger (range 200m). Transect lengths range from 200m close to dredger, slowly increasing to 500m at maximum range from dredger. Water depth 25m.

Sampling data from the 1995 research (Hitchcock and Dearnaley, 1995) indicated that at distances less than 100 metres from the dredger, total suspended solids concentrations ranged 480-611 mg/l in the lower water column, and 80-340 mg/l in the upper water column. Most of the sand had settled out reaching background levels within 250 metres, implying a forced settling rate of 32 mm/s in the water depths and current speed encountered, whilst the silt content reached background within 480 metres implying a settling velocity of 17 mm/s. This study provides suspended solids concentrations an order of magnitude higher, in the range 0.5-5.5 g/l.

Figure 5.3b records two longitudinal profiles downstream of the dredging operation to the limits that were possible on the day. The first profile (45 metres to 820 metres) shows a reduction in backscatter with two distinct phases. At about 300 metres, there is a rapid reduction in suspended solids backscatter. It is not clear whether this is a phenomenon of irregular loading and hence discharge rates (the dredge density and rate varies by the minute), or may represent observations similar to previous work, with a major reduction in the plume density roughly 300 metres to 500 metres from the dredge site (Newell *et al*. 1998, Hitchcock and Drucker 1996).

| Sample Number | Distance (metres) | Depth (metres) | Volume (litres) | Suspended Solids (mg/l) |
|---|---|---|---|---|
| Nab14 | 84 | 18 | 9.049 | 1259.808 |
| Nab15 | 152 | 15 | 8.926 | 728.2097 |
| Nab16 | 210 | 10 | 8.651 | 947.8673 |
| Nab17 | 337 | 2 | 4.965 | 2819.738 |
| Nab18 | 65 | 2 | 8.54 | 1030.445 |
| Nab19 | 133 | 5 | 9.298 | 1312.11 |
| Nab20 | 192 | 10 | 8.595 | 1407.795 |
| Nab21 | 258 | 15 | 8.694 | 1702.323 |
| Nab22 | 331 | 18 | 8.363 | 442.425 |
| Nab23 | 66 | 5 | 7.594 | 5517.514 |
| Nab24 | 98 | 2 | 7.367 | 1615.312 |
| Nab25 | 195 | 10 | 7.724 | 1993.786 |
| Nab26 | 262 | 18 | 7.785 | 3301.22 |
| Nab27 | 474 | 5 | 7.899 | 696.2907 |
| Nab28 | 612 | 10 | 7.277 | 3091.933 |
| Nab29 | 674 | 15 | 8.288 | 711.8726 |
| Nab30 | 776 | 2 | 8.126 | 615.3089 |
| Nab31 | 109 | 2 | 6.9 | 695.6522 |
| Nab32 | 183 | 5 | 7.439 | 927.544 |
| Nab33 | 272 | 10 | 8.021 | 411.42 |
| Nab34 | 350 | 15 | 9.171 | 621.5244 |
| OWERS01 | 138 | 12 | | 1170 |
| OWERS02 | 156 | 16 | | 1171 |
| OWERS03 | 178 | 18 | | 1346 |
| OWERS04 | 194 | 18 | | 1225 |
| OWERS05 | 585 | 8 | | 26 |
| OWERS06 | 573 | 12 | | 18 |
| OWERS07 | 561 | 16 | | 18 |
| OWERS08 | 534 | 18 | | 18 |
| OWERS09 | 549 | 18 | | 22 |
| OWERS10 | 491 | 1 | | 46 |
| OWERS11 | 675 | 4 | | 10 |
| OWERS12 | 691 | 8 | | 13 |
| OWERS13 | 707 | 12 | | 13 |
| OWERS14 | 724 | 18 | | 25 |
| OWERS15 | 740 | 18 | | 38 |
| OWERS16 | 201 | 4 | | 47 |
| OWERS17 | 227 | 8 | | 304 |
| OWERS18 | 248 | 12 | | 582 |
| OWERS19 | 259 | 18 | | 613 |
| OWERS20 | 94 | 4 | | 723 |
| OWERS21 | 111 | 8 | | 103 |

**Table 5.3a** Table showing the total suspended sediment concentrations in waters downstream of aggregate dredging operations on two adjacent sites (Nab and OWERS). Ten litre samples obtained using sub-surface pumps.

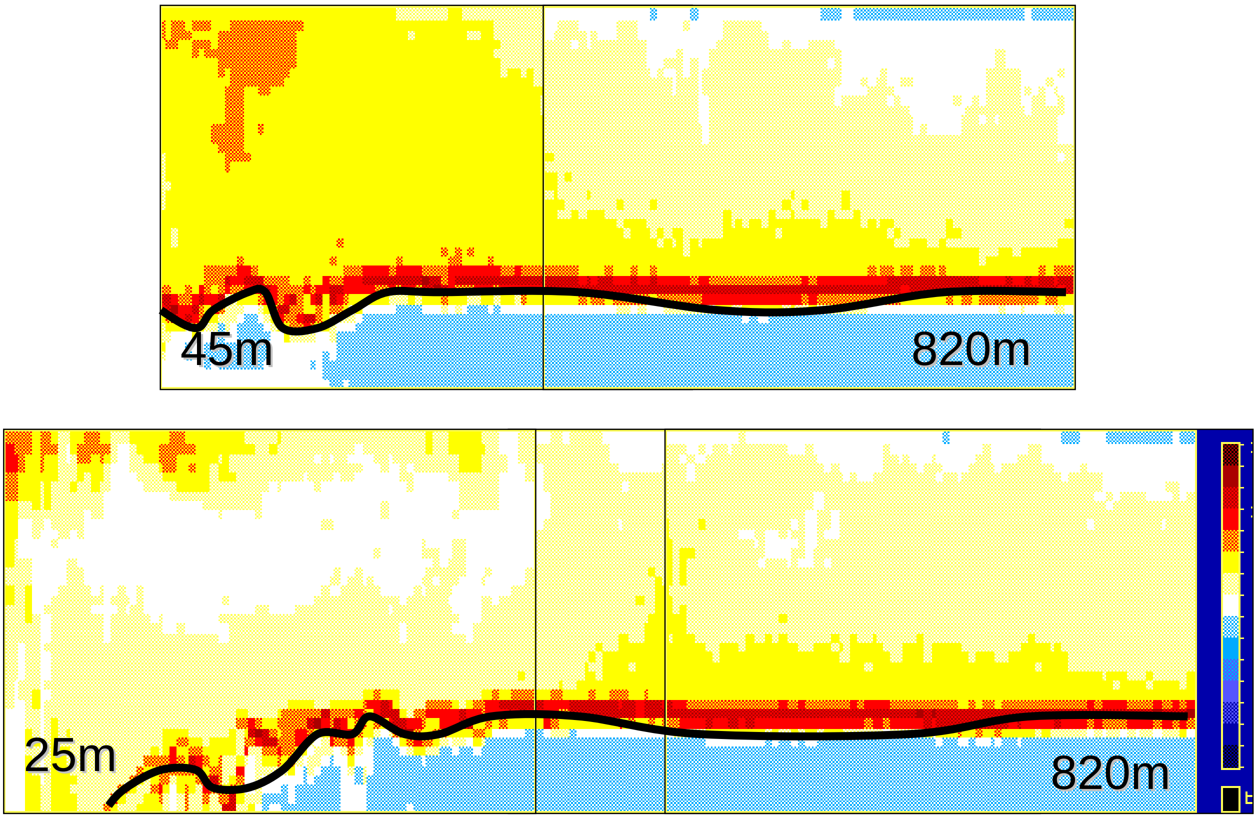


**Figure 5.3b** Longitudinal Backscatter profiles obtained downstream of the 2300 tonne capacity suction dredger *City of Chichester* showing the persistence of a nearbed sediment plume to the end of the monitoring area. Water depth 25m. Figures are ranges astern and downtide of the dredger.

Interestingly the second profile shows a near bed extension to the dense plume, extending beyond 800 metres, some 3-4 metres high in the water column off the seabed. This is important because it gives us, for the first time, some indication of a near bed extension to the benthic plume that has been observed by others (Dickson and Rees, 1998) and is discussed further in the following sections.

### 5.4 Impacts Outside The Dredge Boundary on Physical Resources

New software has enabled us to re-process data collected in previous research and presented elsewhere (Hitchcock and Drucker, 1996). Figures 5.4a and 5.4b present a 3D image of the same plume data as 5.4c. This re-processing has enabled us to identify a near bed extension to the dense dynamic phase of the plume that extends beyond the zone of monitoring, and hence well beyond the zone of previous detected impacts outside the dredge boundary. In water depths of 21 metres and currents of up $1.5ms^{-1}$, extraction of sand and gravels with screening would appear to generate a near-bed plume, some 2-4 metres thick, that extends downstream beyond 4.5 kilometres from the dredge site. The fate of the material is presently unknown since data does not exist beyond this zone.

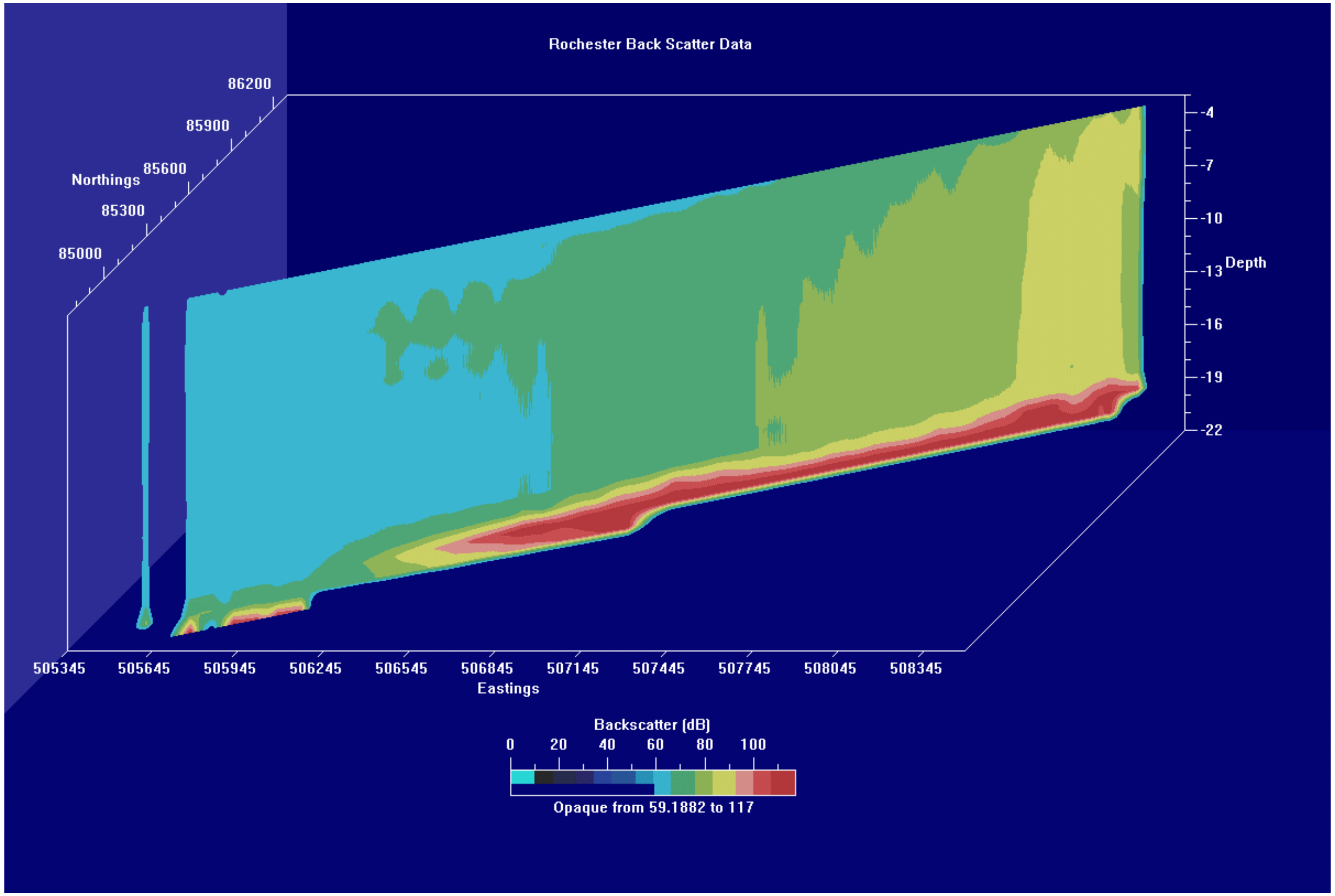


**Figure 5.4a**. Backscatter profiles obtained in 1995 on a similar aggregate dredging site located nearby have been reprocessed with newly developed software and reveal the presence of a well developed nearbed sediment plume extending well beyond the initial zones of impact.

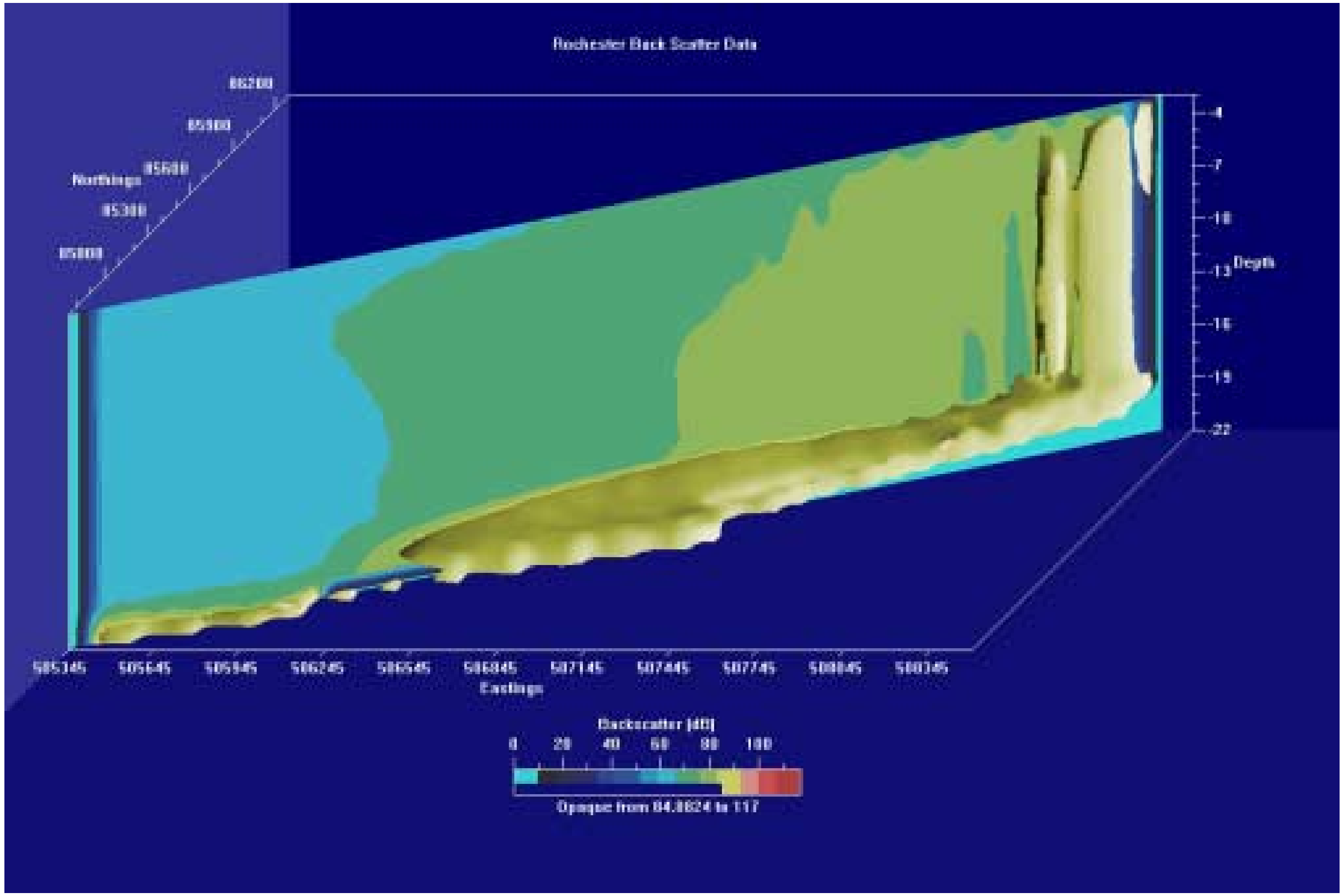


**Figure 5.4b**. The thickness of the nearbed plume can be gauged from this image of well-developed nearbed sediment plume. This extends well beyond the initial zones of impact.

However, the recent study by Dickson and Rees (1998) does suggest that ‘benthic landers’ (seabed monitoring apparatus designed by CEFAS) have monitored the progress of a near bed plume of sediments some 8 kilometres from a dredge site in the southern North Sea. This is important for two reasons: (i) using different technologies, independent studies have corroborated the presence of a near bed plume extending some way beyond the dredge site; and (ii) the extension of the near bed plume beyond the dredge zones gives credence to a mechanism for faunal community enhancement that has been observed in various studies (Newell *et al*. 1998, Poiner and Kennedy, 1984).

Following figure 5.4c, sequences of figures illustrate the new processing technique and clearly show the common presence of a near bed plume of sediments travelling beyond our zones of measurements.  Others have recorded this phenomenon in the southern North Sea.

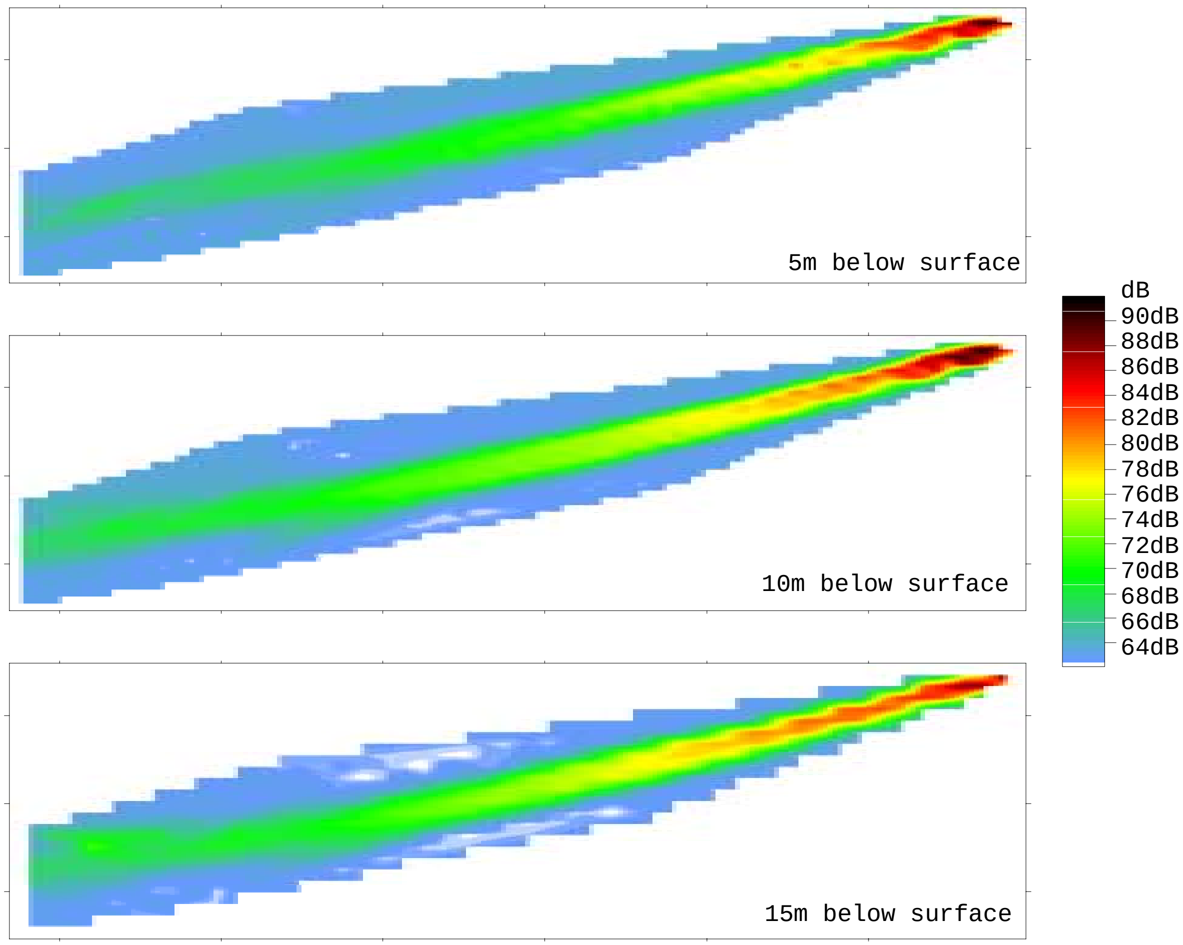


**Figure 5.4c**. Representation of the plume from the City of Rochester in 1995. This can be compared with Figures 5.4a and 5.4b, which were produced using new image processing techniques. The raw data has not been altered. The near bed plume is not visible from these types of image, even at the near bed sections.

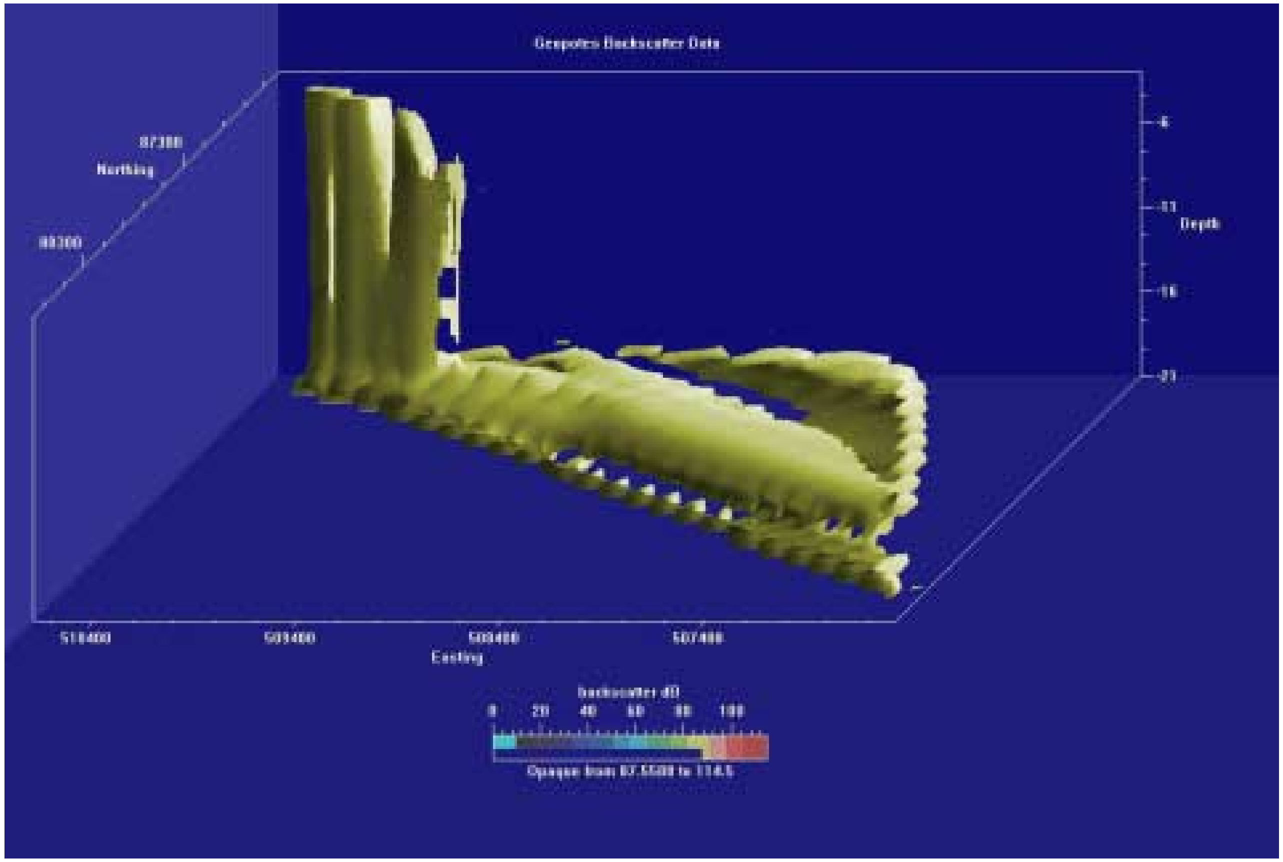


**Figure 5.4d.** Reprocessed representation of the 1995 data collection for the Geopotes, a large Dutch dredger temporarily working in the UK for beach recharge purposes. The near bed plume extends for some 5km to the end of the survey zone, although is much thinner. This may be due to the highly dense overspill formed by the Geopotes, which has a single central spillway discharging below the vessel.

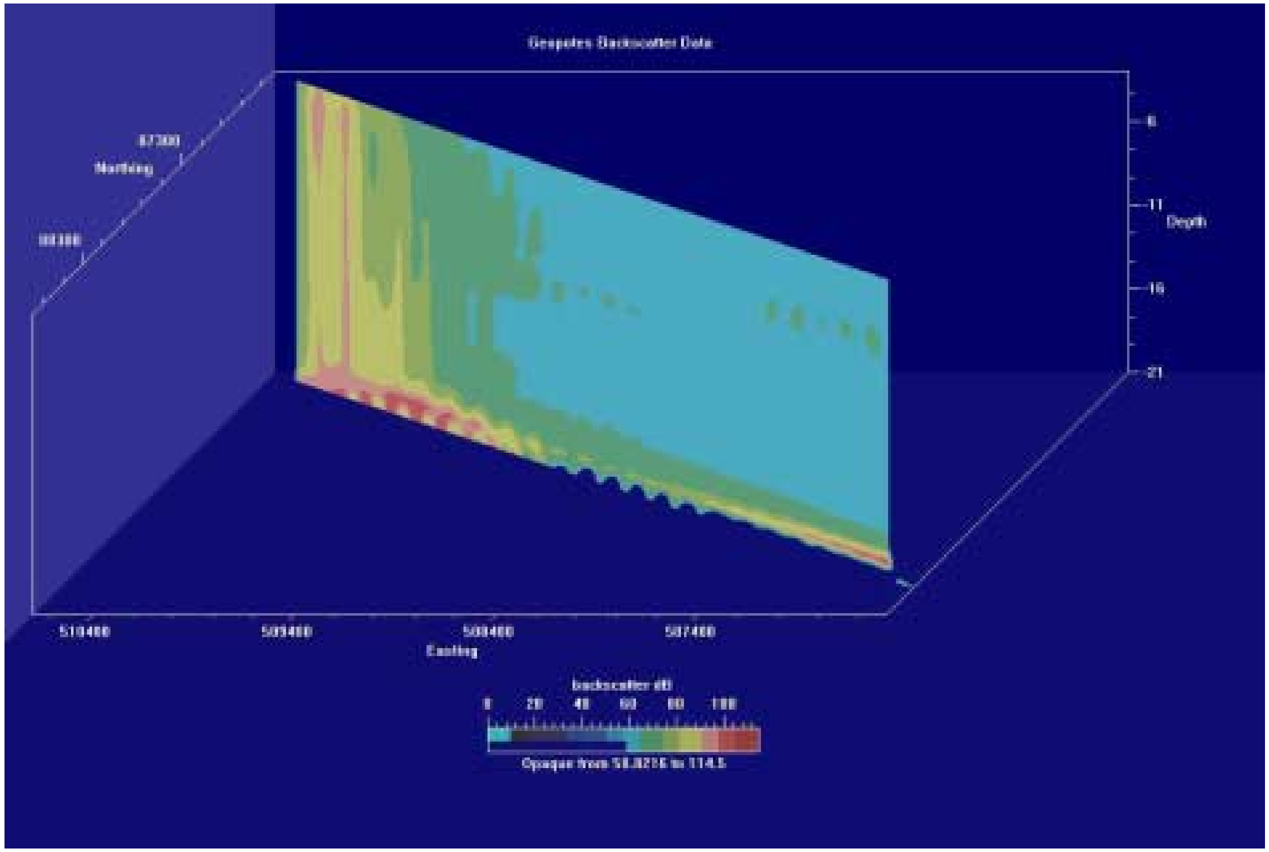


**Figure 5.4e.** Reprocessed representation of the 1995 data collection for the Geopotes, a large Dutch dredger temporarily working in the UK for beach recharge purposes. The near bed plume extends for some 5km to the end of the survey zone, although is much thinner. This may be due to the highly dense overspill formed by the Geopotes, which has a single central spillway discharging below the vessel.

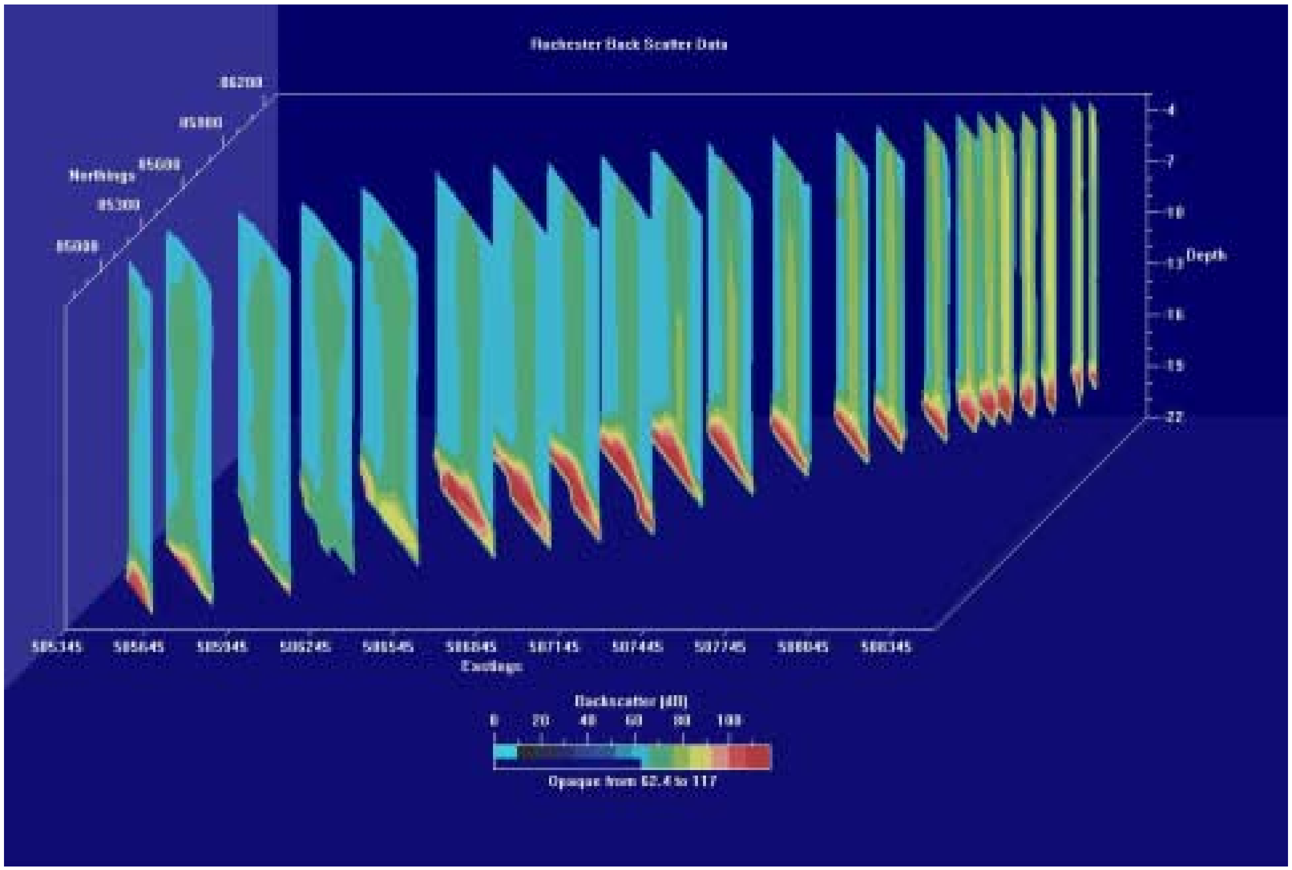


**Figure 5.4f.** Reprocessed representation of the 1995 data collection for the Rochester, a small English anchor dredger. The near bed plume extends for some 3km to the end of the survey zone. Note the thickness of the plume in the near bed zone. The width is approximately 700m at its maximum.

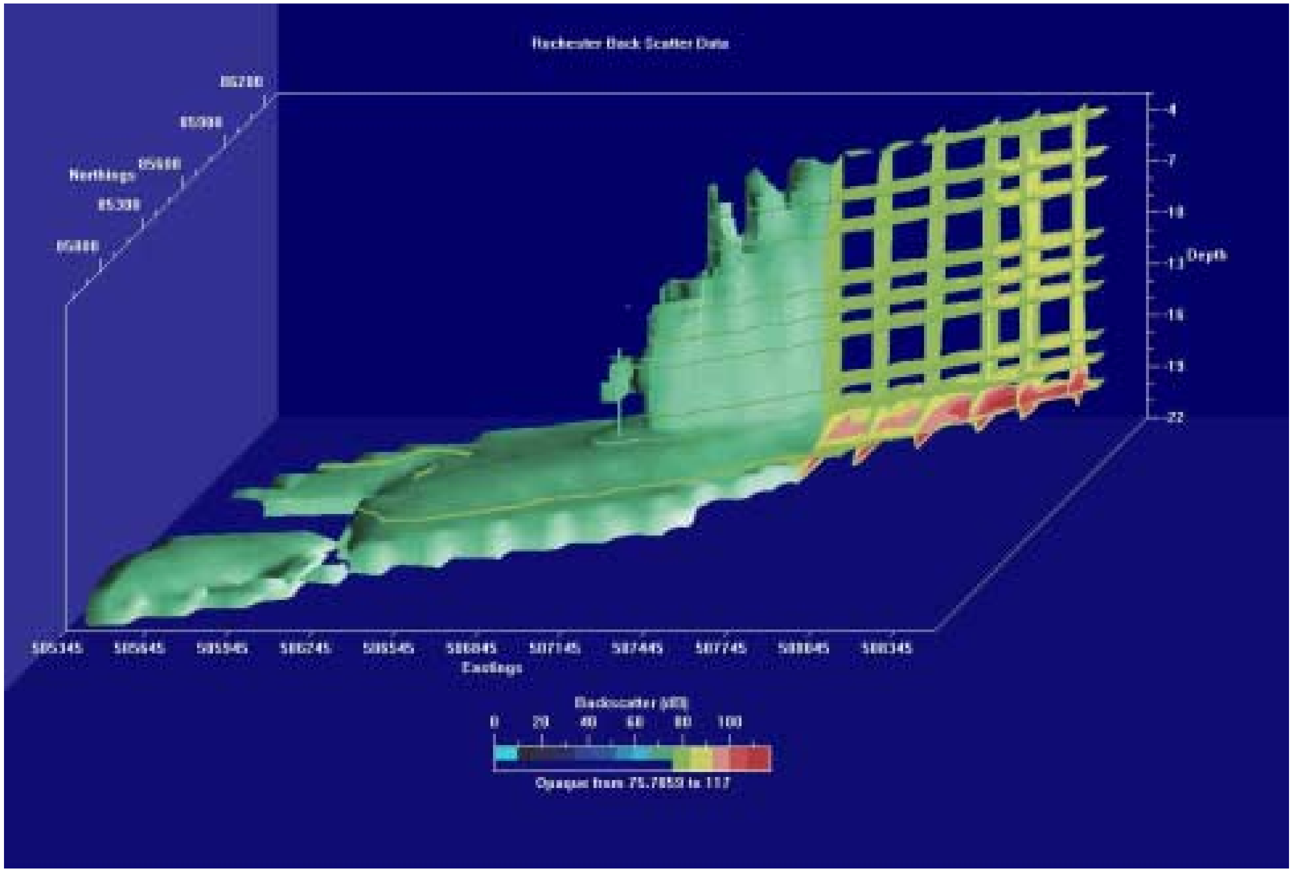


**Figure 5.4g.** Reprocessed representation of the 1995 data collection for the Rochester, a small English anchor dredger. The near bed plume extends for some 3km to the end of the survey zone. Note the thickness of the plume in the near bed zone. The width is approximately 700m at its maximum.

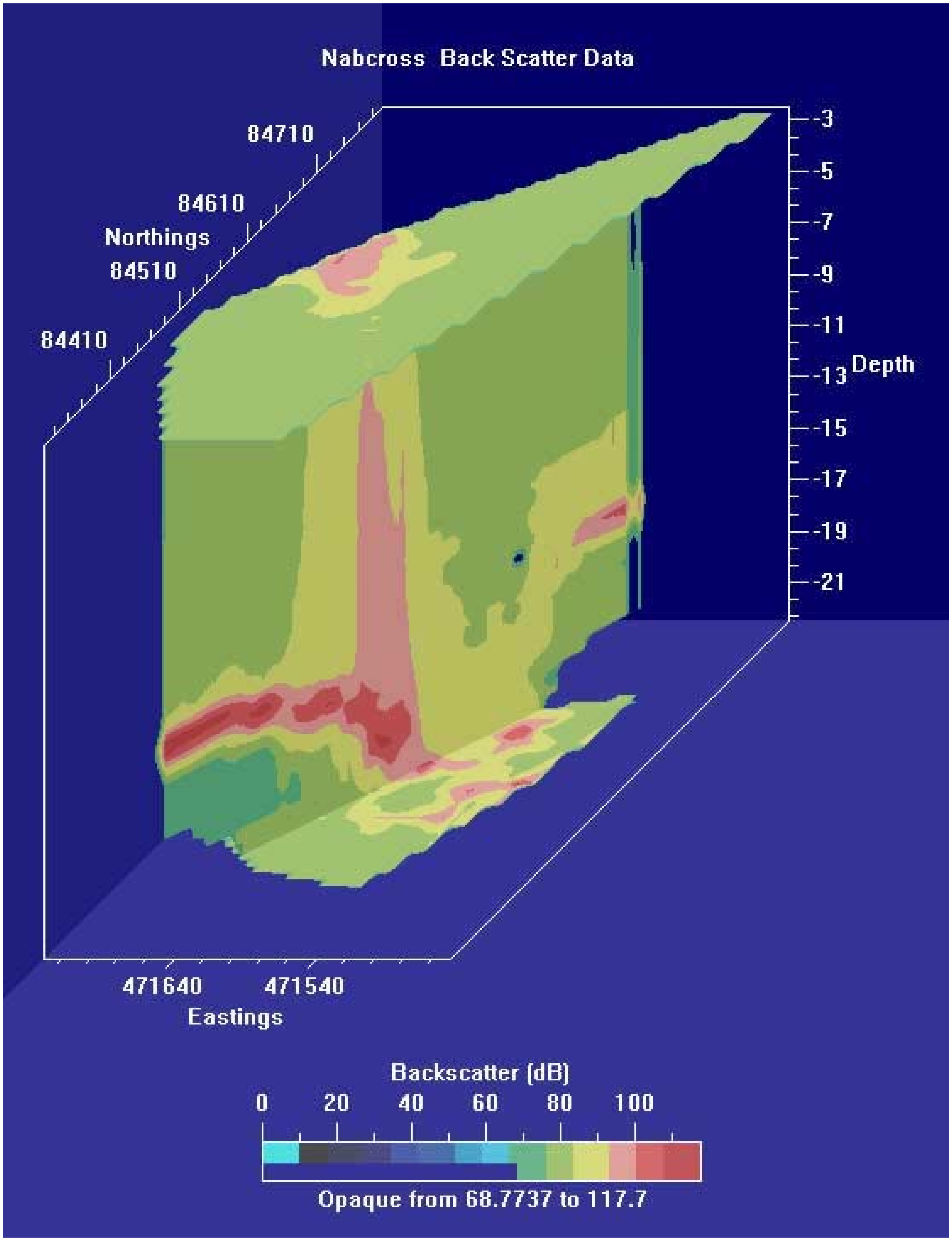


**Figure 5.4h:** 2001 data collected at the Nab study site. AVI video data has been prepared from these shots showing the generation and 3D representation.

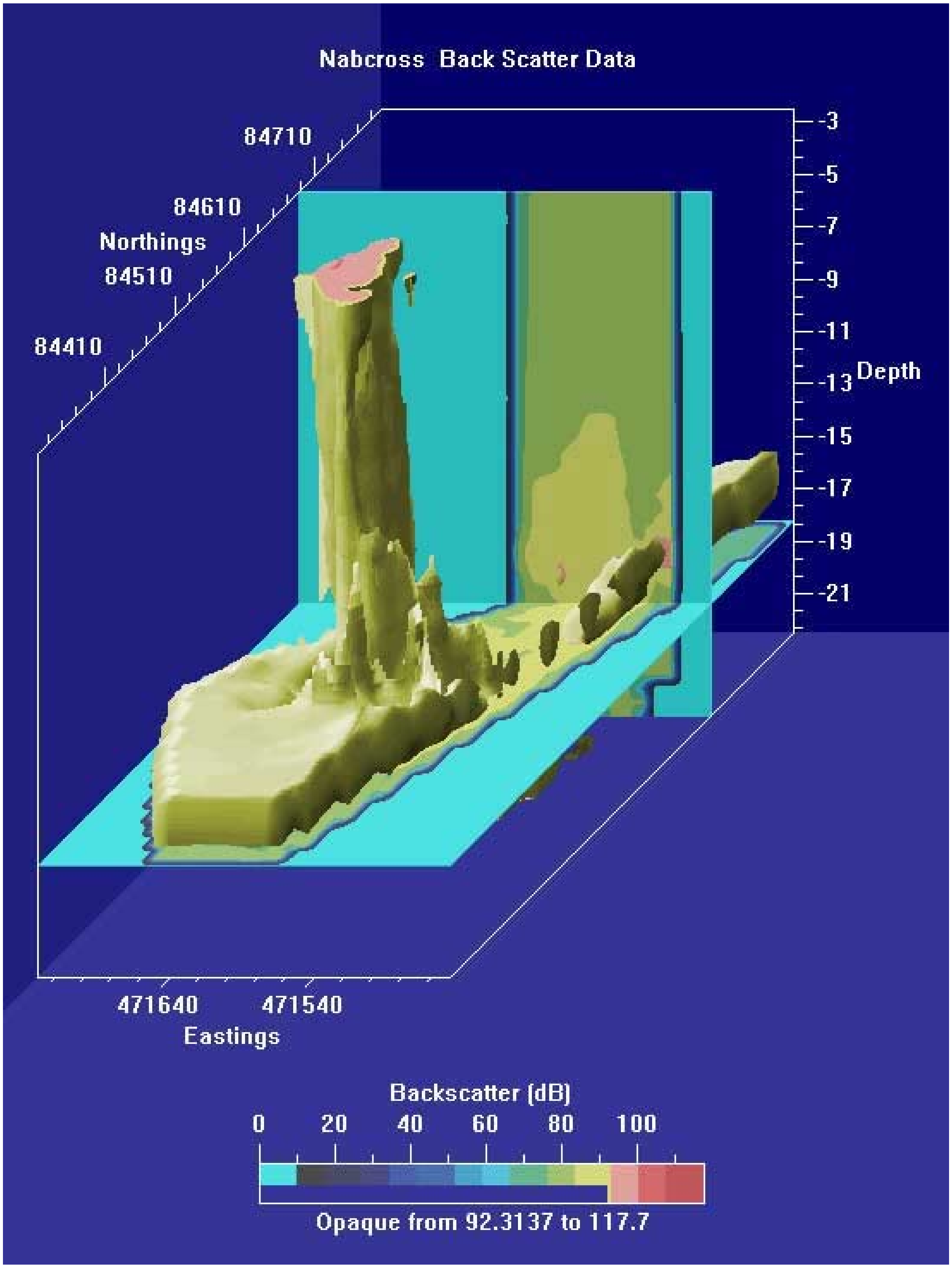


**Figure 5.4i:** 2001 data collected at the Nab study site. AVI video data has been prepared from these shots showing the generation and 3D representation.

It has often been assumed for the purposes of simulation models for British coastal waters that the dispersion of material rejected via the reject chute and spillways during the dredging process is controlled by Gaussian diffusion principles. Consequently, tidal currents could carry suspended material as much as 20 kilometres each side from a point source of discharge. Indeed, in water depths up to 25 metres and peak spring tide velocities of 1.75 ms-1, very fine sand may potentially travel up to 11 kilometres from the dredging site, fine sand up to 5 kilometres, medium sand up to 1 kilometre and coarse sand less than 50 metres. In current regimes with a lower peak velocity of some 0.9 ms-1, similar sized material may only travel up to 6.5 kilometres from the point of release (HR Wallingford, 1993). Worst-case estimates have suggested that sediment plumes may persist for up to 4-5 tidal cycles.

Interestingly, detailed and extensive monitoring campaigns associated with the construction of the Størebælt Link have detected suspended sediment related to a specific dredging operation up to 35 kilometres from the source. However simulations have shown that 6 kilometres from the operations, the ‘monthly average surplus suspended solids concentrations’ caused by some of the most intensive dredging operations were at the same level as the background concentration (2 mg/l).

Investigations in Hong Kong were undertaken at an early stage when marine dredging for aggregate was considered (Holmes, 1988). The concern for plume impingement on sensitive spawning grounds necessitated monitoring of water quality during dredging operations. The investigations concluded that within the water column the practical effects of enhanced suspended solids concentrations are difficult, if not impossible to assess. The effects were observed to be short lived and have limited areal extent and therefore concluded that suspended sediment impacts within the water column were negligible, and away from spawning and mariculture zones.

Further, and probably related to the sampling methodology and dredging technique, suspended solids concentrations in the hopper surface waters were only 10000-30000 mg/l, reducing rapidly to 5000 mg/l adjacent to the dredge vessel in the sea. A rapid dilution is therefore observed. Indeed, Holmes (1988) observed that (i) the sand fraction settled quickly within a few hundred metres of the dredger (at a rate of 46mm/s for 320 μm particles); and (ii) the pelitic fines content will settle much slower at 0.1-1 mm/s and will therefore disperse over a wider area, observed up to 4 kilometres.

Similarly, Kiørboe and Møhlenberg (1981) monitored the operation of a sand suction dredge in the Øresund, Denmark and concluded that any suspended solids concentrations likely to be detrimental were not present more than 150 metres downstream of the dredge. Levels adjacent to the dredge were up to 5000 mg/l, rapidly decreasing to 100mg/l at 150 metres. Background levels were regained at 1000 metres downstream.

A plume dispersion model developed by Whiteside *et al*. (1995) for the surface layer (the upper 8 metres of the water column) for up to 40 minutes after discharge compares well with plume decay measurements in the vicinity of the dredger. The contours for sediment deposition evidently remain as a narrow band extending for approximately 100 metres on each side of the track of the dredging vessel, much as recorded by Gajewski and Uscinowicz (1993) for Baltic waters and observed here.

### 5.5 Impact Within The Dredge Boundary on Physical Resources

Processing of the Nab ADCP data has produced an image of the plume that confirms the presence of the near bed plume extension. This plume has the capacity to egress the 10 metre deep hole dredged below the level of the surrounding seabed. The limits of the plume extension may however, be limited by the flux of sediment available to contribute to the plume and also the limited time available for the plume excursion. An important operational feature of the Nab licence is that exploitation commonly takes place for around an hour either side of low water, this being the expedient time for the vessel to return to port to discharge in the tidal berths found locally.

### 5.5.1 Impact of Dredging on Seabed Sediment Principal Components

Figures 5.2a and 5.2c clearly show the distribution of sediments (as discussed above) and faunal communities. Importantly, the lack of correlation between the change in sediment type downstream of the dredging activity (the enhanced 'sandiness' of the gravels) and the faunal community suggests that either the type of community structure present is unaffected by the change in sediment composition or, more likely, is tolerant of the level of change that the community has been exposed to. However, an increased or prolonged exposure may cause a negative impact, or the existing exposure may cause a level of stress to the community that reduces its tolerance to other impacts.

Changes in composition of the seabed sediments may cause changes to the benthic community structure. Désprez and Duhamel (1993) noted that following intense dredging activity off Dieppe, the predominantly sandy gravel surface sediments were reduced to predominantly sandy sediments (possibly existing as a thin veneer of mobile sands deposited by the settling overboard returns). Further, they recorded dominance of several new species characteristic of finer sediments with establishment of communities of the *Polychaetes Ophelia acuminata, Nephtys sp.* and *Spiophanes bombyx* and the Echinoderm *Echinocardium cordatum*. These species were also observed in the sandy sediments present on the Klaverbank (Sips and Waardenburg, 1989) although in this case extensive rather than intensive dredging did not lead to distinguishable changes in predominant sediment grain size. A detailed assessment of the implications to benthic communities of dredging intensity is given in Section 6.

### 5.5.2 Impact of Dredging on Bathymetry

The most striking changes within the dredge boundary are produced by the dredging activity itself (Table 5.5.2). Anchor dredging produces the largest single features, with seabed pits reported by Dickson and Lee (1973) some 4 metres deep by 50 metres diameter. This study reports here bed levels up to 10 metres below the surrounding deposits, the base of the depression having dimensions of 300 metres x 100 metres (see Figures 5a, 5b and 5c).

The fisheries concerns against this type of dredging methodology centre on the risk of snagging towed gear within the depression, and general unsuitability for beam trawling. Such deep pits are considered to pose the risk of formation of an anoxic bottom layer of water with reduction of water circulation and accretion of fine sediments.

However, deployment of an underwater camera in the depressions formed at Nab 122/3 showed little difference to water turbidity of the surrounding natural bed levels, whilst a similar number of individual fish and other benthic invertebrates were observed, as may be expected in high energy well mixed coastal waters

| **Type of dredging** | **Advantages** | **Disadvantages** |
|---|---|---|
| Deep isolated pits | impact on small area<br>reduced or little modification of wave and current patterns | entrapment of bed load<br>irregular, hummocky terrain<br><br>increased possibility of disturbance of underlying strata e.g. clays<br>seabed topography unsuitable for trawling<br>stratification of water within deep pits<br>possibility of anaerobic conditions in deepest pits<br>reduced chances of faunal recovery |
| Shallow extensive furrows | reduced alteration of topography<br><br>improved conditions for faunal recovery<br>reduced possibility of exposure of underlying strata<br>suitability for modern dredgers | may effect current and wave patterns<br><br>extensive area impacted |

**Table 5.5.2** Summary of the principal pros and cons of intensive and localised anchor dredging forming large pits and extensive trailer dredging over wide areas

### 5.5.3 Impact of dredging on microtopographical seabed structures

Trailer dredging produces a ‘furrowed’ topography and has been observed by Dickson and Lee (1973), and more recently analysed in extensive detail by Davies and Hitchcock (1992). Different types of dredge imprint are reported in the latter work. The dredge imprint will vary according to the type of draghead used, but some features more generally associated with one particular type of draghead can occasionally be found on others. Importantly, however, the furrow width is generally less than approximately 1 metre greater than the width of the draghead. Narrower dragheads produce deeper furrows, approximately 2.5 metres width by 0.5 metres deep. Wider dragheads such as the ‘California Type’ produce shallower and wider furrows 0.35 metres deep by 3.5 metres wide.

Recently, some companies using the simple ‘Fixed Visor’ type of draghead have replaced them with California Type dragheads with significant improvements in the quality of cargoes loaded and simultaneous reduction in the loading times. Désprez and Duhamel (1993) report sidescan sonar observations of dredge furrows on the Klaverbank being 3 metres wide and approximately 0.5 metres deep. Kenny and Rees (1996) observed furrows 0.3-0.5 metres deep but only 1-2 metres wide: however it is known that the furrows were made with a ‘California Type’ draghead of some 2.6 metres wide. One year after dredging, the furrows were no longer distinguishable by underwater camera, whilst after 2 years the furrows were barely detectable by sidescan sonar. ICES (1975) concede that trailer dredging does not greatly affect the action of seabed trawls. There has been little data put forward since to change this statement.

Davies and Hitchcock (1992) noted that many furrows were characterised by the formation of lateral levées, resulting from the draghead digging deeper into the seabed than the pumps could remove. This is an inefficiency in the system, and it is apparent that the wider dragheads do not suffer from such losses as much as the narrower types. There is thus less potential for interference with trawling activities.

# 6.0 RESULTS - BIOLOGICAL RESOURCES

## 6.1 Impact of Dredging Outside the Boundaries of the Licence Area

### 6.1.2 Abundance and Variety of Benthos

A list of the taxa recorded from the sediments of the North Nab survey area is given in Appendix Table 3. In all, a total of as many as 316 taxa were recorded. Polychaeta and Crustacea dominated the whole assemblage, although hydroids, Mollusca and Bryozoa were also important at some stations.

The species variety and abundance of individuals of macrofauna at each of the sampling stations is summarised in Appendix Table 4. This shows the species identification code from Appendix 3 in parentheses, followed by the number of individuals of each species per 0.2 $m^2$ Hamon grab sample. The total number of individuals and the total number of species recorded in the sample is shown in the final columns of Appendix Table 4. Inspection of Appendix Table 4 shows that both the species variety and abundance of individuals varied widely throughout the survey area. A maximum species variety of 71 species was recorded at Station 144 with a minimum of only 1-4 species in sandy deposits at Stations 80-82.

The population density of macrobenthos also showed large variations throughout the survey area. Inspection of Appendix Table 4 shows that a maximum of as many as 1,423 individuals per 0.2$m^2$ Hamon grab sample was recorded at Station 144. A minimum value of only 1 individual per 0.2$m^2$ was recorded in sandy deposits at Station 82. The average values for the North Nab survey area were: total number of taxa recorded = 316: Number of species ($S$) = 26.8 (s.d. 14.96); Number of individuals ($N$) = 199.5 (s.d. 244.1).

The corresponding values for the biomass of the main faunal components are summarised in Appendix Table 5. This shows the biomass as grams ash-free dry weight (AFDW) estimated for each of the main faunal groups estimated from the blotted wet weight using the following conversion factors (Eleftheriou and Basford, 1989):

Polychaetes x 0.155;
Crustaceans x 0.225;
Molluscs x 0.085;
Echinoderms x 0.08;
Other Groups x 0.155

The total biomass of macrofauna expressed as AFDW in grams is shown for each of the sampling stations in the final column of Appendix Table 5.

The values for the number of species (*S*), the population density (*N*), the biomass (*B*) and the size of individuals (*B/N*) for each of the stations sampled in the North Nab study site are summarised in Text Table 6.1.2a

| Station # | Volume of sample (litres per 0.2m²) | No. of Species (S) | No. of Individuals per 0.2m² (N) | Biomass (AFDW) grams per 0.2m² (B) | Size (mg) biomass/ individuals (B/N) |
|---|---|---|---|---|---|
| 1 | 8 | 17 | 233 | 0.1904 | 0.817 |
| 3 | 6 | 40 | 266 | 1.4352 | 5.395 |
| 5 | 1 | 18 | 57 | 0.4358 | 7.646 |
| 6 | 6 | 24 | 71 | 0.2705 | 3.81 |
| 7 | 8 | 20 | 160 | 0.3264 | 2.04 |
| 8 | 4 | 27 | 107 | 0.3661 | 3.421 |
| 9 | 8 | 38 | 251 | 1.5378 | 6.127 |
| 10 | 10 | 22 | 116 | 0.7558 | 6.516 |
| 11 | 9 | 38 | 214 | 1.8789 | 8.78 |
| 12 | 1 | 15 | 34 | 0.0373 | 1.103 |
| 13 | 1 | 17 | 33 | 0.2201 | 6.67 |
| 16 | 8 | 51 | 299 | 1.4146 | 4.731 |
| 17 | 2 | 26 | 123 | 1.6352 | 13.294 |
| 18 | 20 | 33 | 623 | 5.5984 | 8.986 |
| 20 | 20 | 26 | 404 | 1.0606 | 2.625 |
| 21 | 5 | 38 | 210 | 0.5208 | 2.48 |
| 22 | 2 | 16 | 65 | 0.0189 | 0.291 |
| 23 | 10 | 35 | 166 | 0.7884 | 4.75 |
| 24 | 8 | 21 | 59 | 0.3856 | 6.536 |
| 25 | 20 | 9 | 17 | 0.0465 | 2.735 |
| 26 | 0.25 | 10 | 12 | 0.0709 | 5.908 |
| 27 | 8 | 6 | 8 | 0.0155 | 1.938 |
| 28 | 20 | 3 | 6 | 0.4464 | 74.4 |
| 32 | 6 | 46 | 116 | 0.263 | 2.267 |
| 33 | 0.25 | 4 | 5 | 0.0935 | 18.7 |
| 34 | 10 | 47 | 396 | 11.727 | 29.614 |
| 35 | 8 | 28 | 149 | 1.2726 | 8.541 |
| 36 | 8 | 15 | 302 | 1.9822 | 6.564 |
| 37 | 20 | 26 | 918 | 21.8398 | 23.791 |
| 38 | 0.25 | 30 | 1223 | 9.385 | 7.674 |
| 39 | 12 | 22 | 267 | 2.1763 | 8.151 |
| 40 | 4 | 29 | 274 | 1.9507 | 7.119 |
| 41 | 22 | 26 | 268 | 4.051 | 15.116 |
| 42 | 20 | 21 | 72 | 0.5515 | 7.66 |
| 43 | 20 | 4 | 9 | <0.01 | <1.11 |
| 44 | 15 | 3 | 6 | 0.2155 | 35.917 |
| 45 | 20 | 2 | 6 | 0.2604 | 43.4 |
| 46 | 20 | 5 | 16 | 0.217 | 13.563 |
| 47 | 20 | 4 | 12 | 0.0744 | 6.2 |
| 49 | 8 | 20 | 425 | 1.376 | 3.238 |
| 50 | 2 | 61 | 193 | 1.5327 | 7.941 |
| 51 | 0.25 | 17 | 33 | 1.0954 | 33.194 |
| 52 | 0.75 | 25 | 83 | 0.3385 | 4.078 |
| 53 | 20 | 24 | 192 | 3.7748 | 19.66 |
| 54 | 8 | 35 | 318 | 3.8566 | 12.128 |
| 55 | 0.25 | 8 | 88 | 5.0308 | 57.168 |
| 56 | 15 | 26 | 150 | 0.725 | 4.833 |
| 57 | 10 | 44 | 163 | 5.0756 | 31.139 |

| | | | | | |
|---|---|---|---|---|---|
| 58 | 5.25 | 39 | 142 | 4.4844 | 31.58 |
| 59 | 20 | 18 | 33 | 0.2148 | 6.509 |
| 60 | 2 | 17 | 20 | 0.376 | 18.8 |
| 61 | 1 | 13 | 15 | 0.0491 | 3.273 |
| 62 | 20 | 20 | 89 | 2.4184 | 27.173 |
| 63 | 20 | 6 | 18 | 0.1364 | 7.578 |
| 64 | 20 | 2 | 4 | 0.0032 | 0.8 |
| 65 | 7 | 19 | 37 | 0.1712 | 4.627 |
| 67 | 3 | 32 | 121 | 0.654 | 5.405 |
| 68 | 1 | 61 | 246 | 2.135 | 8.679 |
| 69 | 8 | 30 | 134 | 0.6785 | 5.063 |
| 70 | 20 | 19 | 97 | 0.168 | 1.732 |
| 71 | 18 | 37 | 518 | 9.5504 | 18.437 |
| 72 | 5 | 30 | 148 | 0.6708 | 4.532 |
| 73 | 15 | 34 | 386 | 2.387 | 6.184 |
| 74 | 4 | 23 | 111 | 1.4272 | 12.857 |
| 75 | 25 | 31 | 171 | 1.0322 | 6.036 |
| 76 | 20 | 23 | 175 | 1.1916 | 6.809 |
| 77 | 15 | 20 | 43 | 0.0839 | 1.951 |
| 78 | 7 | 13 | 22 | 0.038 | 1.727 |
| 79 | 10 | 9 | 14 | 0.0837 | 5.979 |
| 80 | 20 | 4 | 6 | 0.0093 | 1.55 |
| 81 | 20 | 4 | 12 | 0.1116 | 9.3 |
| 82 | 20 | 1 | 1 | <0.01 | <10 |
| 84 | 4 | 39 | 151 | 1.3361 | 88.483 |
| 85 | 7 | 42 | 189 | 8.3026 | 43.929 |
| 86 | 8 | 19 | 237 | 0.5613 | 2.368 |
| 87 | 8 | 29 | 163 | 2.9794 | 18.279 |
| 88 | 10 | 28 | 228 | 0.8527 | 3.74 |
| 89 | 15 | 29 | 253 | 0.842 | 3.328 |
| 90 | 20 | 29 | 135 | 0.1509 | 1.118 |
| 91 | 15 | 36 | 123 | 0.7176 | 5.834 |
| 92 | 15 | 35 | 136 | 0.3822 | 2.81 |
| 93 | 15 | 21 | 37 | 0.3625 | 9.797 |
| 94 | 10 | 28 | 73 | 0.3657 | 5.01 |
| 95 | 5 | 39 | 245 | 3.461 | 14.127 |
| 96 | 15 | 17 | 66 | 0.2189 | 3.317 |
| 97 | 4 | 20 | 33 | 0.1248 | 3.782 |
| 98 | 5 | 14 | 23 | 0.2525 | 10.978 |
| 99 | 20 | 4 | 14 | 0.2046 | 14.614 |
| 104 | 9 | 16 | 62 | 0.3961 | 6.389 |
| 106 | 20 | 24 | 114 | 0.914 | 8.018 |
| 108 | 21 | 35 | 289 | 26.1456 | 90.469 |
| 109 | 5 | 34 | 80 | 0.8845 | 11.056 |
| 111 | 0.5 | 14 | 31 | 0.0524 | 1.69 |
| 113 | 4 | 42 | 324 | 1.5361 | 4.741 |
| 115 | 10 | 33 | 279 | 0.9242 | 3.313 |
| 116 | 20 | 24 | 231 | 2.6636 | 11.531 |
| 117 | 6 | 29 | 106 | 0.4894 | 4.617 |
| 118 | 17 | 25 | 89 | 0.5939 | 6.673 |
| 119 | 10 | 23 | 83 | 0.5114 | 6.161 |
| 120 | 24 | 25 | 362 | 2.0996 | 5.8 |
| 121 | 5 | 18 | 126 | 0.1958 | 1.554 |

| | | | | | |
|---|---|---|---|---|---|
| 122 | 15 | 28 | 98 | 0.2353 | 2.401 |
| 123 | 7 | 30 | 109 | 0.3013 | 2.764 |
| 124 | 20 | 10 | 116 | 0.9642 | 8.312 |
| 125 | 8 | 35 | 125 | 1.2606 | 10.085 |
| 126 | 20 | 11 | 26 | 0.0259 | 0.996 |
| 127 | 15 | 35 | 77 | 0.2314 | 3.005 |
| 128 | 3 | 36 | 152 | 0.4626 | 3.043 |
| 129 | 6 | 24 | 135 | 0.6098 | 4.517 |
| 130 | 4 | 23 | 51 | 0.2556 | 5.011 |
| 131 | 7 | 46 | 296 | 0.8887 | 3.002 |
| 132 | 8 | 33 | 108 | 0.5134 | 4.754 |
| 133 | 8 | 43 | 104 | 0.3329 | 3.201 |
| 134 | 8 | 21 | 169 | 0.6055 | 3.583 |
| 135 | 9 | 36 | 1337 | 13.2447 | 9.906 |
| 136 | 8 | 33 | 360 | 0.1703 | 0.473 |
| 137 | 6 | 26 | 333 | 2.1058 | 6.324 |
| 138 | 7 | 55 | 677 | 2.3263 | 3.436 |
| 139 | 6 | 21 | 44 | 0.0369 | 0.839 |
| 140 | 8 | 20 | 157 | 0.258 | 1.643 |
| 141 | 9 | 22 | 130 | 0.1485 | 1.142 |
| 142 | 7 | 68 | 492 | 5.3613 | 10.897 |
| 143 | 14 | 64 | 848 | 10.6218 | 12.526 |
| 144 | 14 | 71 | 1423 | 27.8532 | 19.574 |
| 145 | 8 | 48 | 546 | 9.0035 | 16.49 |
| 146 | 14 | 52 | 599 | 7.6634 | 12.794 |
| 147 | 14 | 38 | 330 | 0.9828 | 2.978 |
| 148 | 10 | 52 | 270 | 0.4831 | 1.789 |
| 149 | 12 | 56 | 241 | 0.7837 | 3.252 |
| 150 | 14 | 60 | 679 | 3.1514 | 4.641 |
| 151 | 14 | 12 | 42 | 0.2486 | 5.919 |
| **Mean** | **10.55** | **26.77** | **199.52** | **2.11** | **10.38** |
| **S.D.** | **6.69** | **14.96** | **244.1** | **4.36** | **14.77** |
| **N** | **131** | **131** | **131** | **131** | **131** |

**Text Table 6.1.2a**. Values for the volume of sediment sampled, the number of species (S), the population density (N), the biomass (g AFDW per $0.2m^2$), and the body size (biomass mg AFDW / N) of macrofauna at each of a series of stations sampled with a $0.2m^2$ Hamon grab in March 1999 in the North Nab Study site. Data compiled from Appendix Tables 1, 4 and 5.

This shows several features of interest when compared with the results of surveys that we have carried out as part of baseline studies of unexploited deposits using similar methods in recent years and which are summarised in Text Table 6.1.2b.

| Site | Total Taxa | Mean Species per 0.2m² | Mean Individuals per 0.2m² | Biomass g AFDW | 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, 1997a |
| Lowestoft, Norfolk | - | 36 | 1488 | 5.66 | - | Recalculated from Kenny *et al.* 1998 |
| Lowestoft, Norfolk | 112 | 9±5 | 134±272 | 1.49±3.49 | 60 | MESL, 1997b |
| Tay Estuary | 38 | 6±4 | 108±243 | 0.036±0.076 | 25 | MESL, 1998 |
| 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** |

**Text Table 6.1.2b.**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

Inspection of the data summarised in Text Table 6.1.2b shows that the total number of taxa recorded in the North Nab survey area is generally similar to that in unexploited deposits in the central mid-English Channel, as well as in deposits near to the Isle of Wight and in the eastern English Channel. The average species variety (*S*) and population density (*N*) of macrofauna is also within the range of that recorded in unexploited deposits nearby. The values for biomass in the deposits of the worked North Nab Licence Area 122/3 are similar to those recorded elsewhere. In general, values of 1.5 g AFDW to 5.0 g AFDW per 0.2 $m^2$ have been recorded from unexploited deposits. The average biomass of benthic macrofauna in the vicinity of the North Nab Licence Area 122/3 was 2.11 g AFDW per 0.2 $m^2$.

It is noteworthy that in some instances the biomass values reached 30-90 g AFDW per 0.2 $m^2$ particularly in stations outside the boundaries of the dredged site and which correspond with the zone of dispersion of material discharged during normal loading operations. The significance of this is discussed in Section 6.5 of this Report.

### 6.1.3 Multivariate Analysis of Community Composition

It has been shown above that the macrofauna of the deposits in the survey area in the vicinity of North Nab Production Licence Area 122/3 shows considerable variation in both species variety and population density. Differences and similarities in community composition in the survey area are best analysed by non-parametric multivariate techniques, despite the variability in the samples.

Gray *et al*. (1988) showed that ordinations for macrobenthic community structure at six stations in Frierfjord, Norway, were similar to the results for the entire species complement even when only 20% of the species, selected at random, were used in the analyses. Warwick (1993) subsequently showed that analysis at taxonomic levels higher than that of species shows similar patterns to the full species analysis. The fact that there is a high degree of variability between single samples taken at each of the survey stations is therefore unlikely to affect the interpretation of the results of multivariate analysis of community composition, since each of the single samples taken evidently contains sufficient taxa to define the community from which the sample was taken (see also Clarke and Warwick, 1998).

A group average sorting dendrogram showing the percentage similarity of the macrofauna at each of the stations sampled in the North Nab survey area is shown in Figure 6.1.3a. This shows that there are several clearly defined assemblages or Groups of macrofauna in the survey area. These have been designated Group A (coded red), Group B (coded green), Group C (coded blue) and Group D (coded brown).

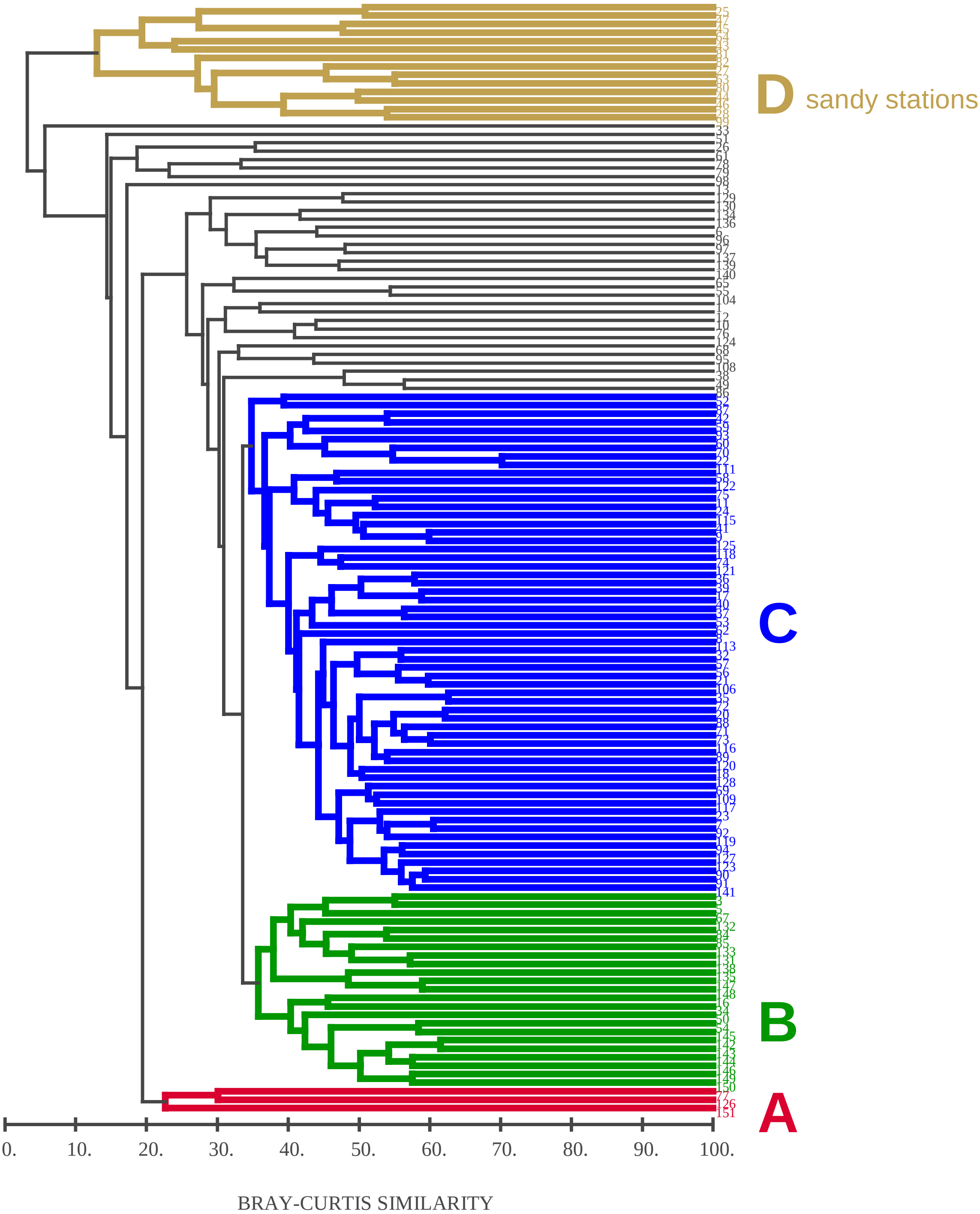


**Figure 6.1.3a.** Group average sorting dendrogram showing the percentage similarity of the macrofauna at each of the stations sampled in the North Nab survey area.

There are also a number of stations that do not clearly classify into any one group. The level of similarity of the faunal communities at each station within recognisable Groups is also rather low, reflecting the high degree of inter-sample variability in the macrofauna of marine gravels and sands. The Group D community corresponds with sandy deposits, and was so distinct that it was removed from subsequent analyses of the communities of the gravels in and surrounding the Licence Area. A group average sorting dendrogram for the reduced data set from which the fauna of sandy deposits had been excluded is shown in Figure 6.1.3b.

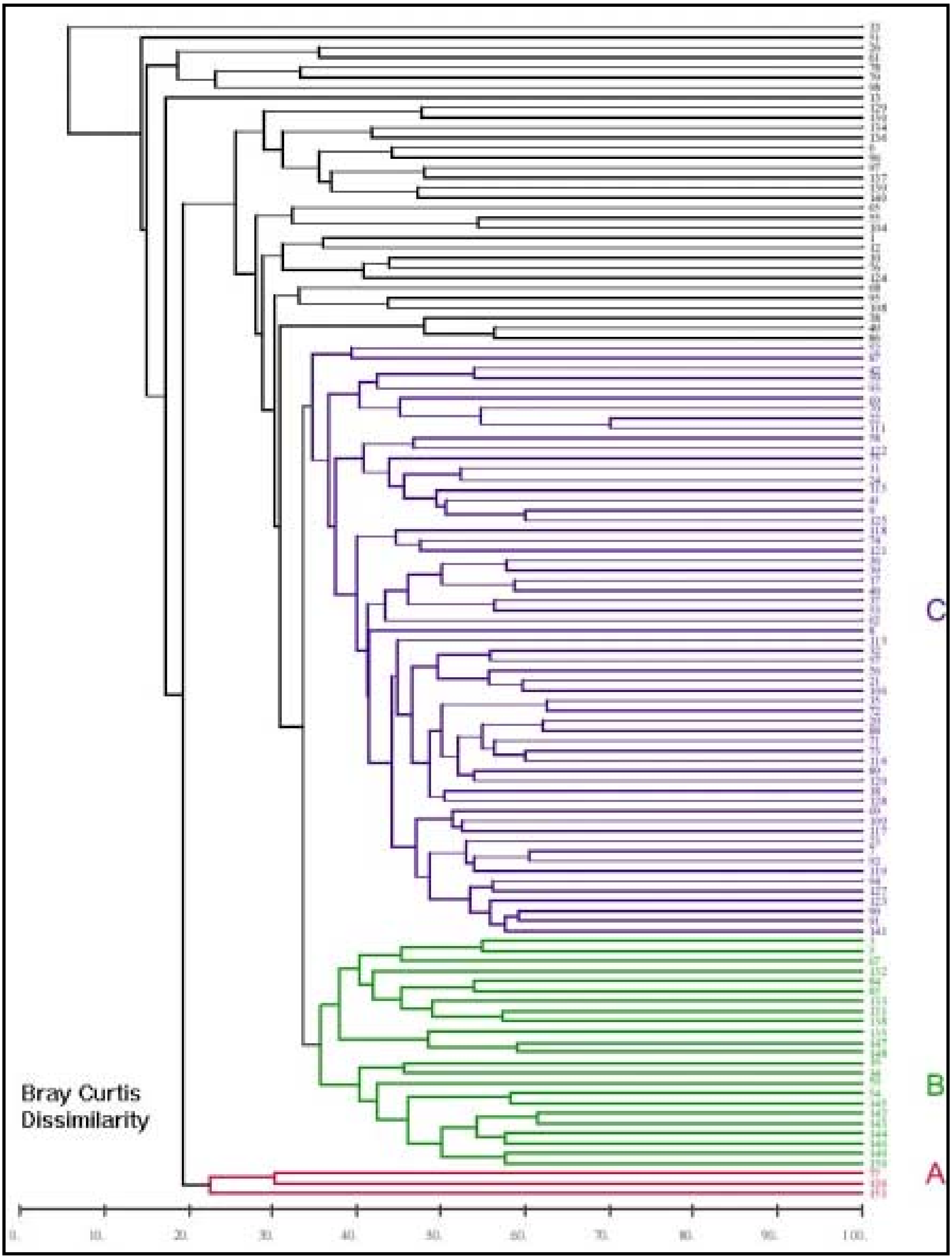


**Figure 6.1.3b**. Group average sorting dendrogram showing the percentage similarity of the macrofauna at a reduced number of sampling sites where the sandy deposits have been excluded.

The corresponding two-dimensional multidimensional scaling (MDS) ordination is shown in Figure 6.1.3c.

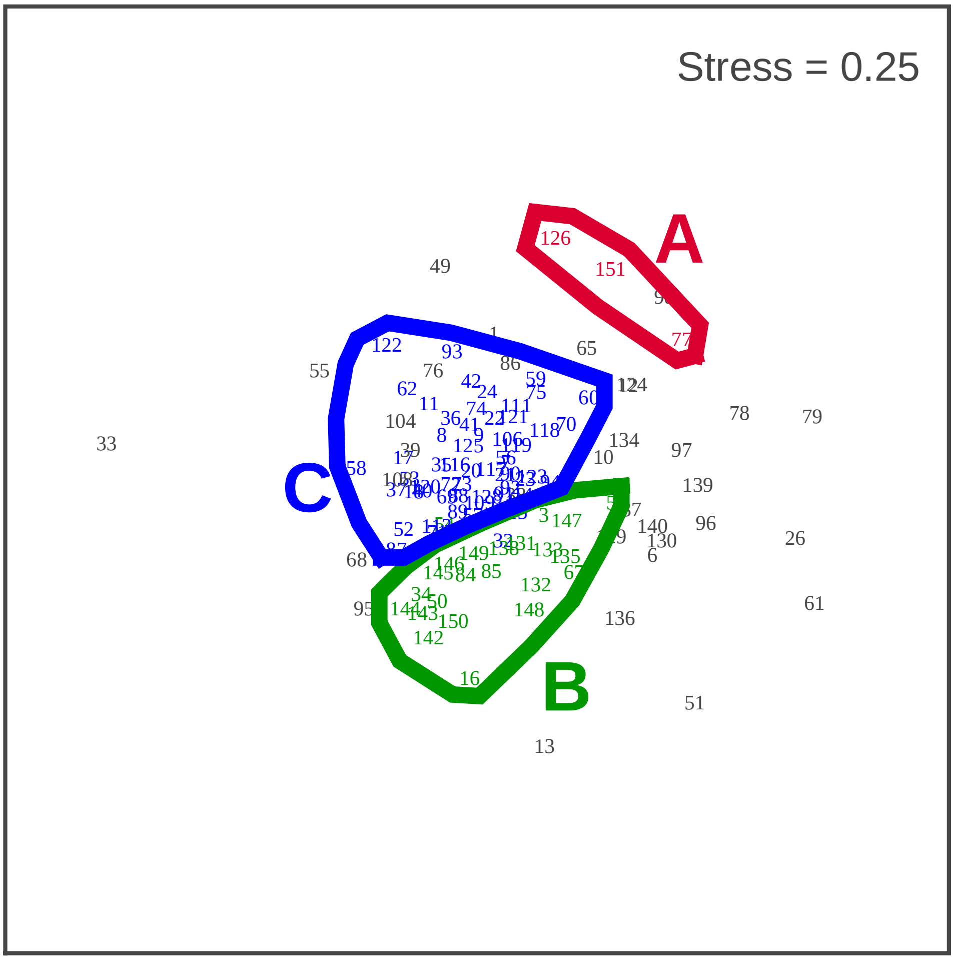


**Figure 6.1.3c**. Two-dimensional multidimensional scaling (MDS) ordination for the macrofauna of the North Nab survey site from which the sandy deposits have been excluded. Colour codes as in Figure 6.1.3a

These show that the macrofaunal communities fall into at least three distinct Groups or communities. These have been designated Group A (coded red), Group B (coded green) and Group C (coded blue). There is also a relatively large group of stations where the macrofaunal communities have a low level of similarity with one another and with the faunal groups that occur elsewhere in the survey area. This is very unusual, and may reflect disturbance of the macrofaunal communities in the vicinity of the dredged site, as well as other environmental factors. This group of dissimilar stations is also shown in Figure 6.1.3c. The distribution of the main faunal communities identified by multivariate analysis of macrofaunal community composition is shown in a map of the survey area in Figure 6.1.3d.

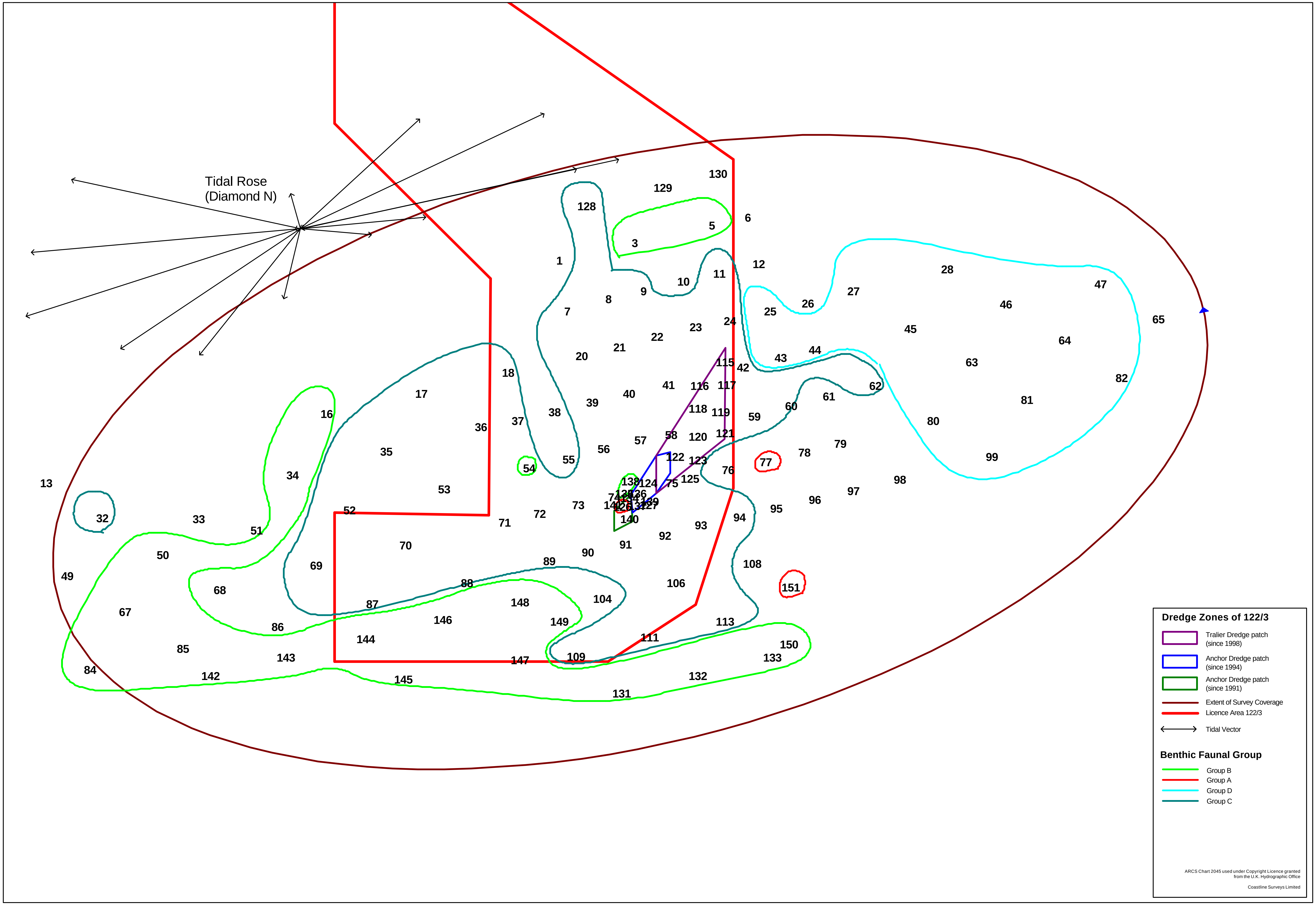


Figure 6.1.3d. Map of the survey area showing the distribution of the faunal groups identified by multivariate techniques in Figures 6.1.3b and 6.1.3c.

Figure 6.1.3d shows that the sandy community identified in Figure 6.1.3b occupies the deposits east of the Nab Tower. The Group B community (coded green in Figures 6.1.3b and 6.1.3c) occurs mainly in mixed muds and gravels to the west and south of the survey area, with a small patch to the north. The Group C community (coded blue in Figures 6.1.3b and 6.1.3c) evidently includes the macrofauna of the mixed sands and gravels of the main central part of the survey area.

Interestingly, the macrofaunal community within the immediate vicinity of the dredged site is quite distinct from that in the surrounding deposits. Similar poorly classified communities occur in mixed sands and reef communities to the south of the Nab Tower and bordering the coastal reefs in shallow waters to the south-east of the Isle of Wight. The location of the distinct group of sites where the macrofauna is dissimilar to that elsewhere is shown in an enlarged map of the dredged area and surrounding deposits in Figure 6.1.3e.

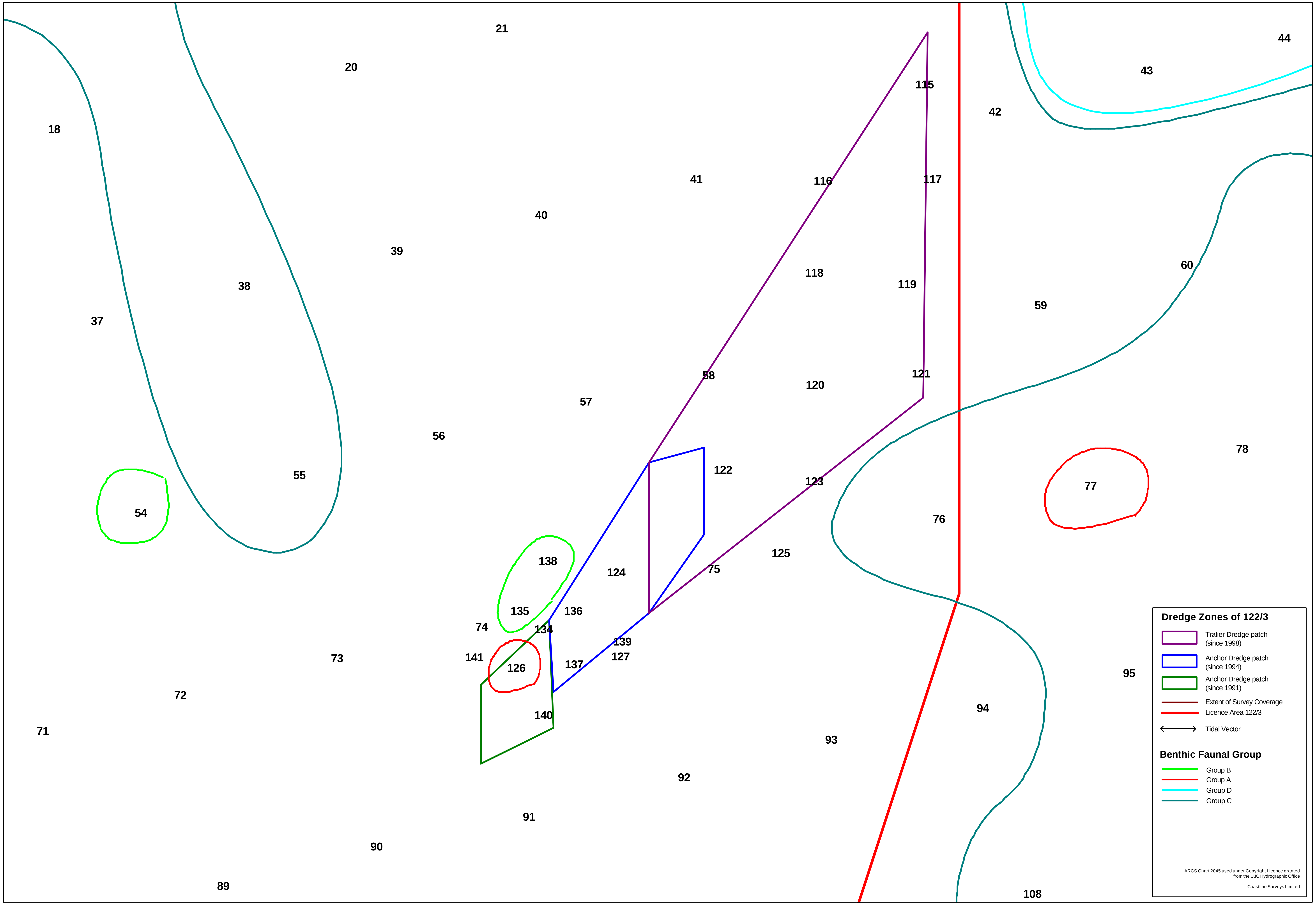


Figure 6.1.3e. Detail of the survey area showing the distribution of the faunal groups identified by multivariate techniques in Figures 6.1.3b and 6.1.3c.

There is clearly a correspondence between the area that is intensively worked by stationary dredgers and a macrofaunal community that is quite distinct from that in the surrounding 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 off Lowestoft, Norfolk by Kenny and Rees (1994, 1996).

The conclusion from multivariate analysis of biological community composition is that the sands to the east of the survey area support a clearly distinct macrofaunal community. The muddy gravels in the periphery of the survey area support a distinct (Group B) community and the mixed sands and gravels of the central part of the survey area support a third distinct (Group C) community. Superimposed on these spatial variations in community structure is a macrofaunal assemblage that shows a very low level of internal similarity and which is quite distinct in community composition to that in the surrounding deposits. This community coincides with mixed gravels and reefs and also with the zone of gravels exploitation by anchor dredging. The low level of similarity of the macrofauna within this group of stations is typical of disturbed communities or those that are in differing stages of recolonisation and recovery.

It is inferred that anchor dredging at this site has had an impact on community structure of the macrobenthos, much as reported for an intensively dredged experimental site off the Norfolk coast by Kenny and Rees (1994, 1996). Examination of Figure 6.1.3e suggests that this impact on macrofaunal community structure is confined to the dredge sites themselves and that communities in the surrounding deposits immediately outside the boundaries of the dredged area are typical of those elsewhere in the central survey area.

The fact that communities within the trailer-dredge site are similar to those in the surrounding deposits suggests that in contrast to anchor-dredging, trailer-dredging at the current level of exploitation in the Production Licence Area since 1998 has had no detectable impact on community composition of the macrofauna (see Figure 6.1.3e).

## 6.2 Community Structure in Relation to Aggregate Dredging

Variations in community structure of the macrobenthos in relation to aggregate dredging are generally interpreted in terms of community characteristics including population density expressed as the number of individuals (*N*), the species diversity (*S*), the biomass (*B*) and the size of individuals (*B/N*).

### 6.2.1 Population Density of Macrofauna in the Survey Area

A map summarising the numbers of individuals recorded per 0.2 $m^2$ Hamon grab at each of the stations sampled in the North Nab survey area is shown in Figure 6.2.1a.

This shows that the sandy deposits to the northeast of the survey area are characterised by a relatively low population density compared with the gravels that characterise the main part of the central survey area, including Production Licence Area 122/3. The muddy sands and gravels to the west of the survey area also support relatively low population densities of macrofauna. The spatial distribution of invertebrate abundance is therefore truncated by the sands to the east of the dredged site, and to some extent in the west of the survey area. The broad similarity of deposits throughout the central part of the survey area allows some inferences to be made on the impact of dredging on invertebrate community structure in gravels.

The distribution of areas of high invertebrate population density within the gravel deposits is of particular interest. Inspection of Figure 6.2.1a shows that there is a zone of high population density of >1000 individuals per 0.2 $m^2$ approximately 3 km downstream on the axis of dispersion of material discharged from the anchor-dredged site on the west-going (ebb) current. There are also zones of enhanced population density approximately 1-1.5 km across the axis of dispersion of material from the dredged site.

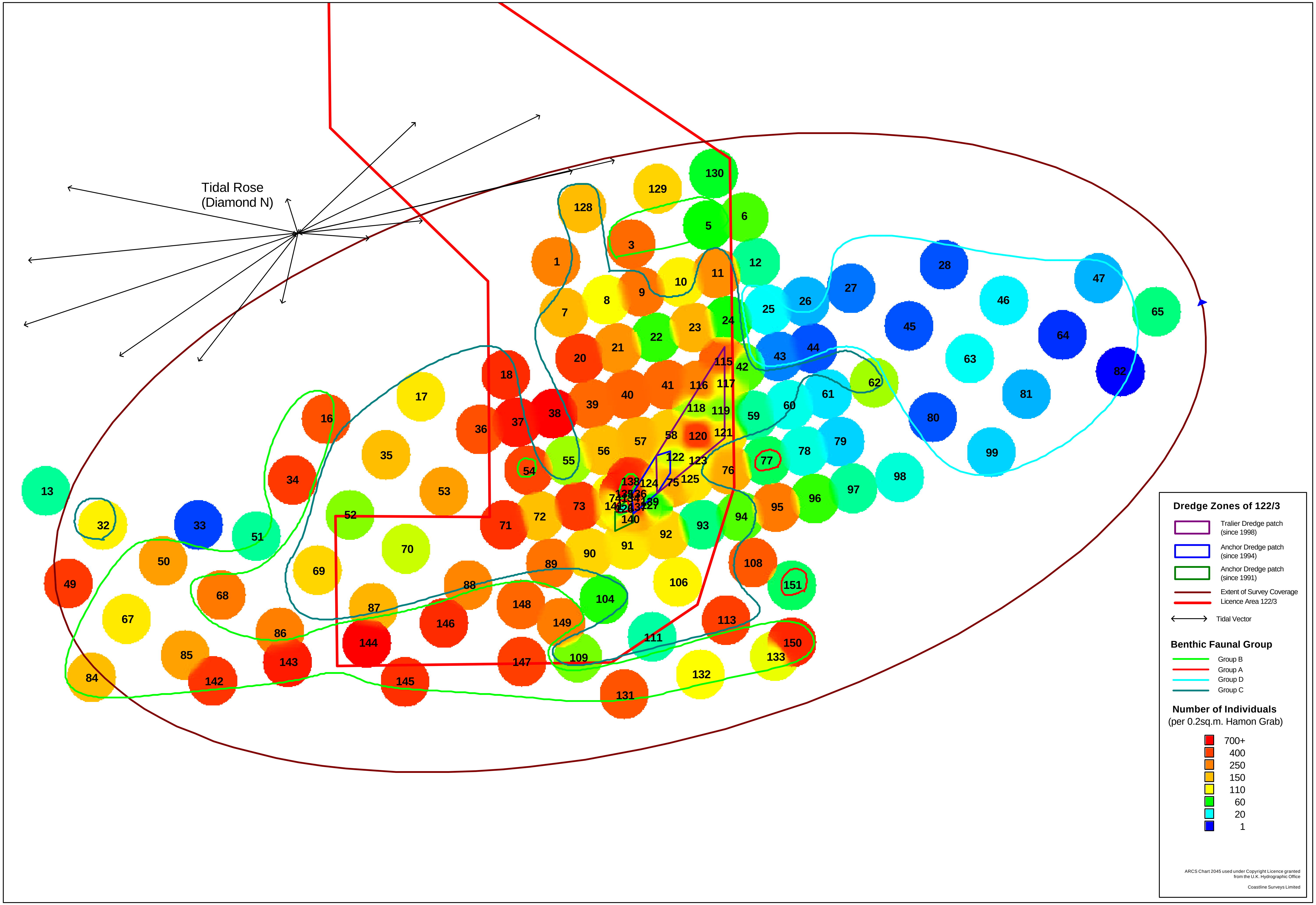


Figure 6.2.1a. Response surface diagram and corresponding spectral plot showing the number of individuals of macrofauna recorded per 0.2 m² Hamon grab sample at each of the stations sampled in the North Nab survey area.

These areas of enhanced invertebrate population density are similar to those reported to occur beyond the boundaries of dredged areas in Moreton Bay, Queensland, by Poiner and Kennedy (1984). They attributed this to the release of organic matter from the sediments during the dredging process; this material then being carried by currents outside the boundaries of the dredged area.

### 6.2.2 Species Diversity in the Survey Area

A map showing the number of species of macrofauna at each of the stations sampled in the survey area is shown in Figure 6.2.2a.

As in the case of population density, the sands to the northeast of the dredged site are relatively impoverished compared with the gravels that characterise the central part of the survey area.

Gravel deposits to the southwest of the dredged area show a broad zone of enhancement with maximum values of >50 species at stations approximately 3 km to the south west of the intensively dredged site. Other zones of high species variety occur up to 1.5 km to the northwest and southeast of the dredge site. This horseshoe-shaped zone of high species variety is truncated to the east by sandy deposits, and is consistent with a far-field impact enrichment from organic matter in the dispersing outwash from the dredged site.

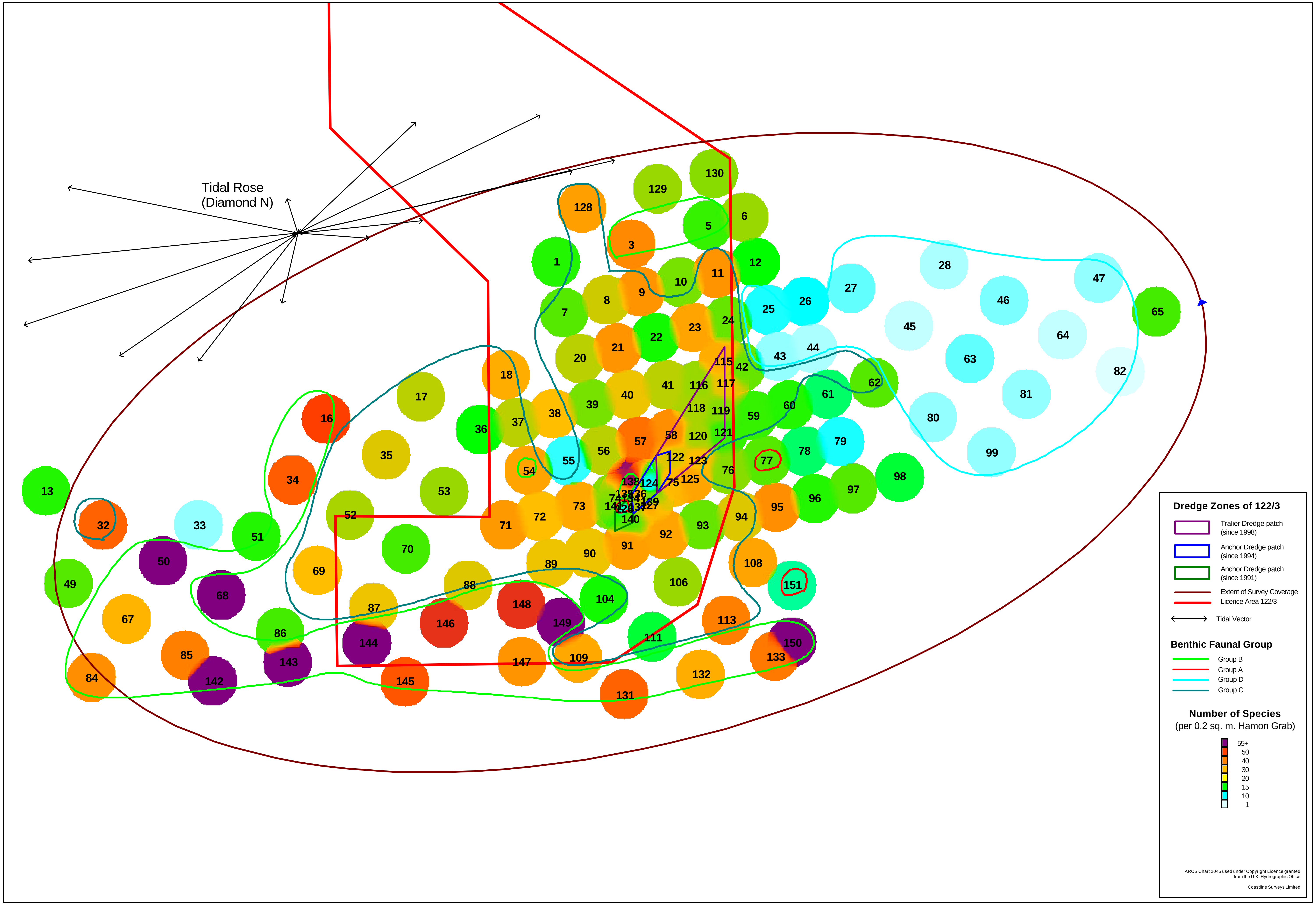


Figure 6.2.2a. Map of the North Nab survey area showing a grid thematic map for the number of species of macrofauna (<1mm) per 0.2sq.m.Hamon Grab

### 6.2.3 Distribution of Biomass in the Survey Area

A map for the total biomass recorded at each of the sampling stations in the survey area is shown in Figure 6.2.3a.

As in the case of population density and species variety, the distribution is clearly affected by the sand deposits that occur to the east and northeast of the dredge site. Elsewhere, however there is some evidence of a horseshoe-shaped zone of enhanced macrofaunal biomass that extends approximately 3 km to the southwest of the dredge site and approximately 1 km to the northwest and southeast. This distribution is again consistent with an enhancement of biomass associated with deposition of material on the west-going (ebb) current from the dredge site, and with near-site deposition across the axis of the main tidal current.

It is of interest to examine whether the enhanced biomass is attributable to any particular component of the macrofauna. Appendix Table 5 shows the contribution of each of the main faunal components to the total biomass recorded from each site. Values for the biomass of Mollusca are shown in Figure 6.2.3b.

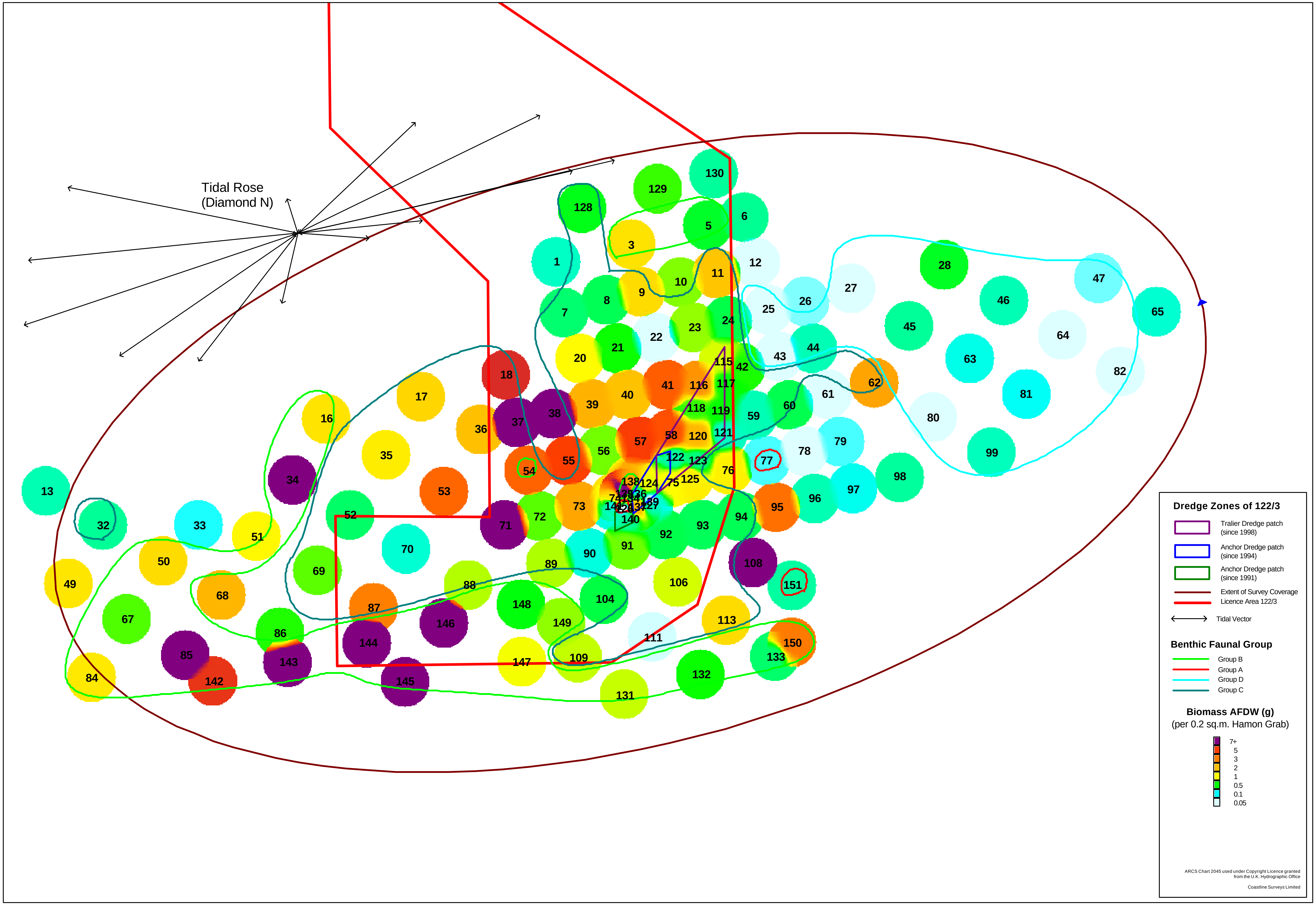


Figure 6.2.3a. Map of the North Nab survey area showing a grid thematic map for the biomass (AFDW/g) of macrofauna (>1mm) per 0.2 sq.m. Hamon Grab.

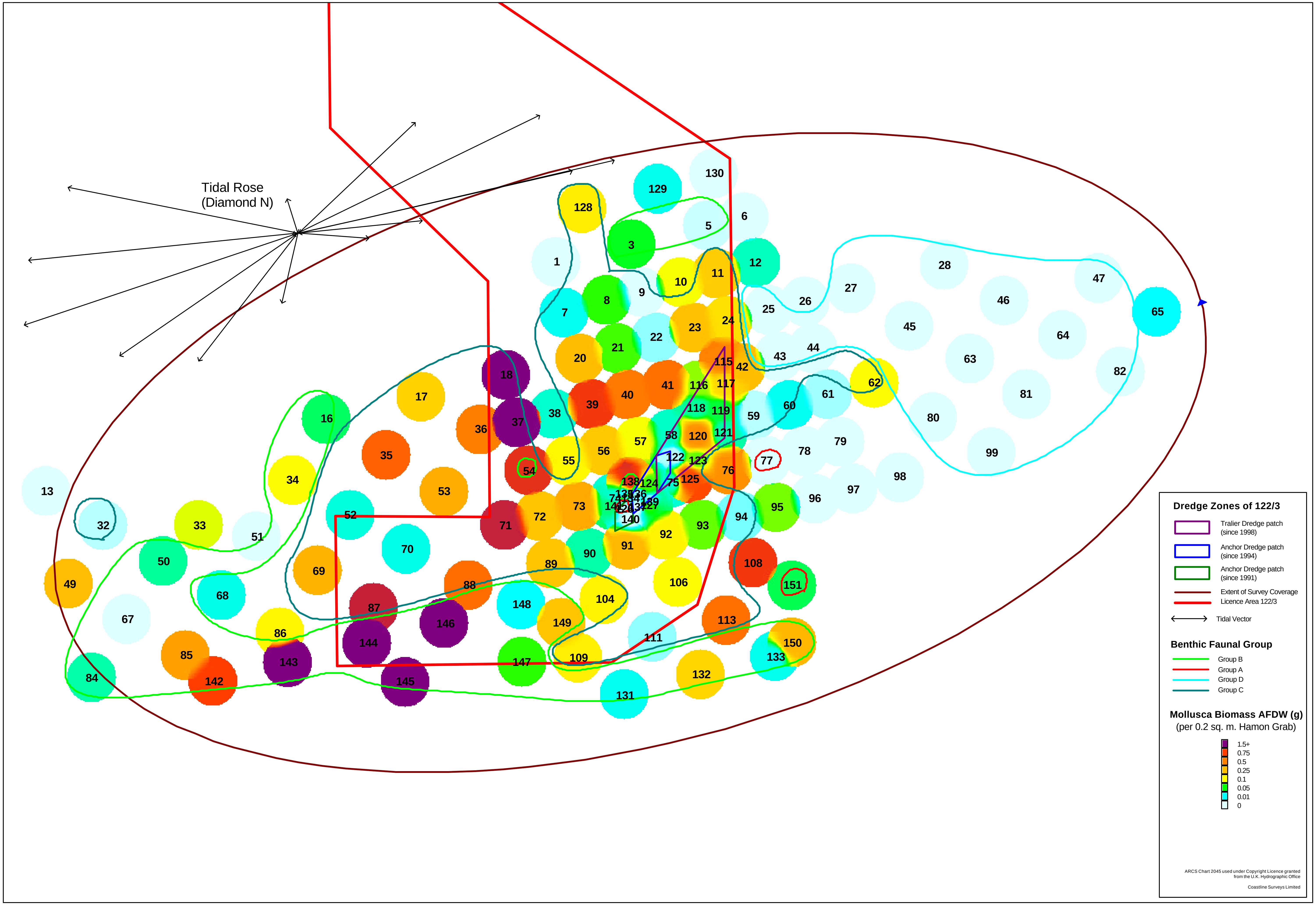


Figure 6.2.3b. Map of the North Nab survey area showing a grid thematic map for the mollusc biomass (AFDW/g) of macrofauna (>1mm) per 0.2 sq.m. Hamon Grab.

The Mollusca were dominated by high population densities of the filter-feeding American slipper-limpet (*Crepidula fornicata*). These reached maximum densities in gravel deposits approximately 2 km to the southwest of the intensively dredged area, and within 1 km to the northwest of the dredged area.

The biomass of the “Miscellaneous” groups of invertebrates shown in Appendix Table 6 comprises mainly filter-feeding particulate feeders including Bryozoa (mainly *Flustra* spp.), hydroids, ascidians and sponges.

Figure 6.2.3c shows that the sands to the east and northeast of the dredge site have a low biomass of these components, but that elsewhere there is a zone of high biomass surrounding the intensively dredged area, and extending as a truncated ‘halo’ approximately 3 km along the axis of the west-going tidal stream from the anchor-dredge area. This is again consistent with an anticipated zone of sedimentation of organic matter based on backscatter profiling data of outwash plume morphology from the Owers Bank to the east (Hitchcock and Drucker, 1996; Hitchcock *et al*., 1998).

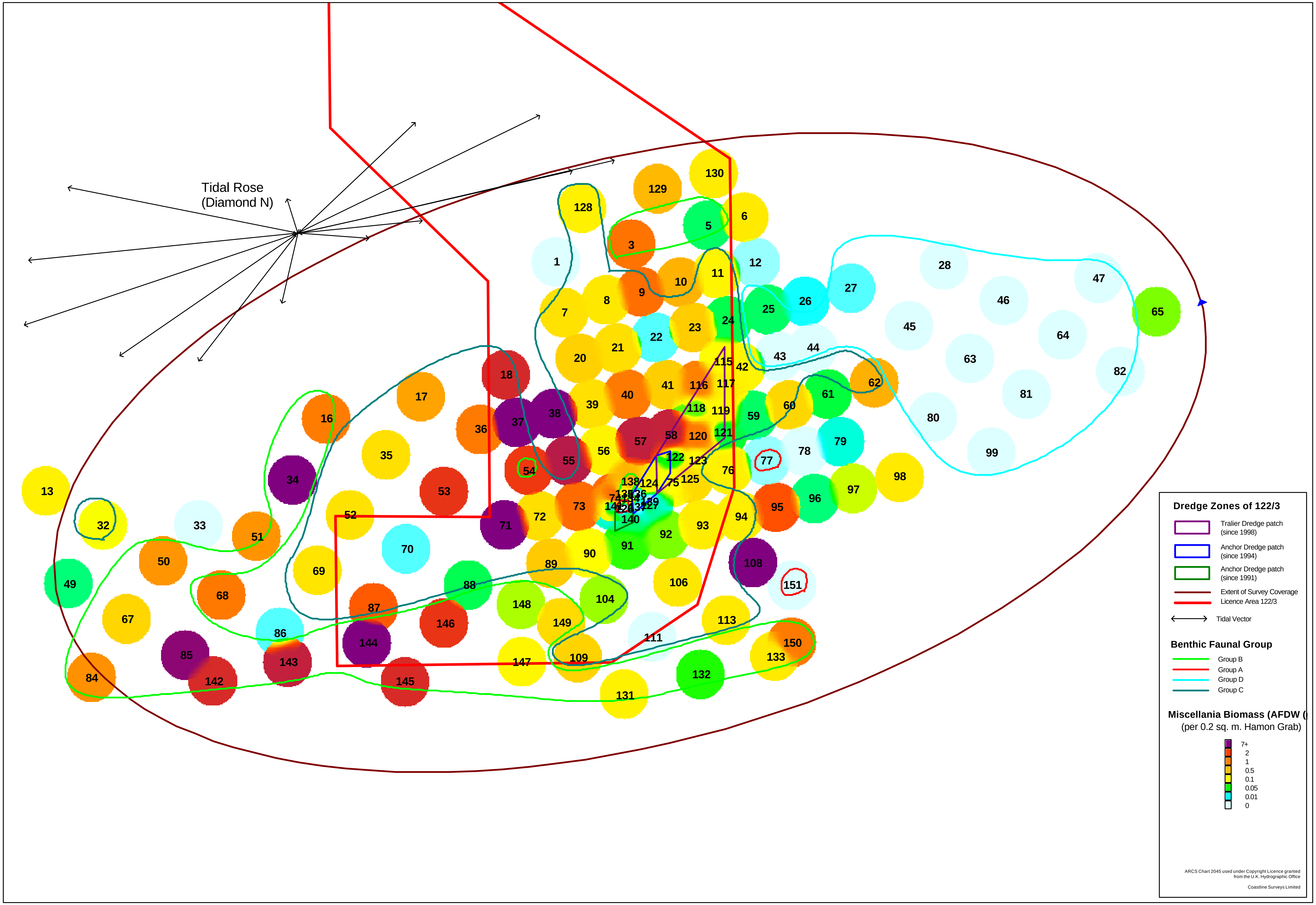


Figure 6.2.3c. Map of the North Nab survey area showing a grid thematic map for the miscellania biomass (AFDW/g) of macrofauna (>1mm) per 0.2 sq.m. Hamon Grab.

### 6.2.4 Body Size of Macrofauna in the Survey Area

A final feature that is often used in analysis of invertebrate population structure is the mean body size based on the biomass (B) and population density (N). The ratio of B/N is expressed as mg AFDW per individual in a response surface diagram and spectral plot in Figure 6.2.4.

This shows that relatively large individuals of macrofauna outside the boundaries of the intensively dredged anchor-dredge site along the axis of the tidal streams to the northeast and southwest. As in the case of the other population determinants, the zone of enhanced body size corresponds with what would be anticipated from what would be anticipated for far-field settlement of material from a dispersing plume originating at the intensively dredged anchor-dredge site in North Nab Production Licence Area 122/3.

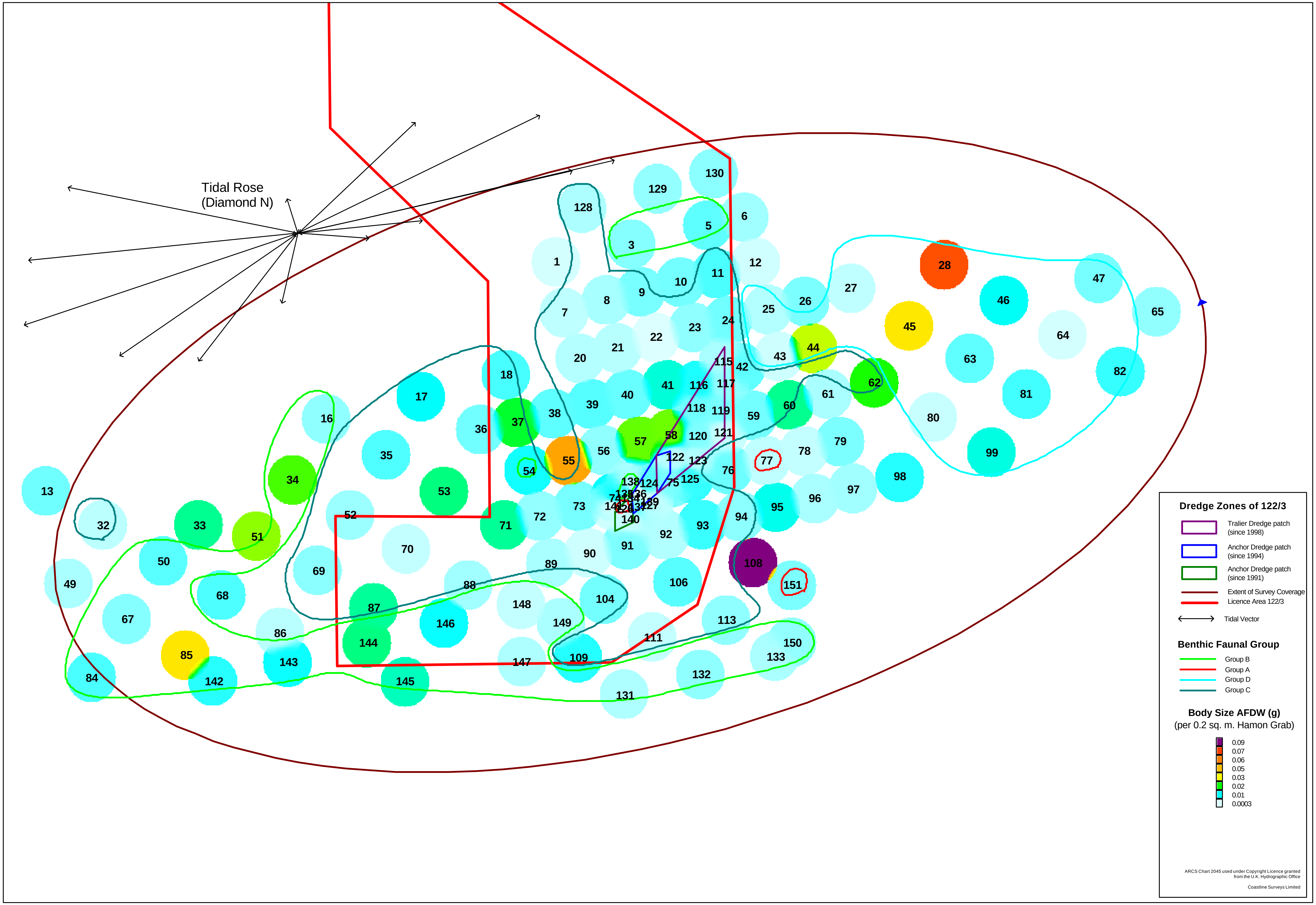


Figure 6.2.4. Map of the North Nab survey area showing a grid thematic map for the body size (AFDW/g) of macrofauna (>1mm) per 0.2 sq.m. Hamon Grab.

## 6.3 Conclusions

Organic matter discharged in dredger outwash has been reported by Newell *et al*. (1999) whilst direct measurements of plume morphology from dredgers operating during normal loading of screened cargoes on the Owers Bank close to the east of the North Nab survey area have been reported by Hitchcock and Drucker (1996; see also Hitchcock *et al*., 1998). These studies suggest that the main zone of sedimentation of organic matter from the dispersing plume is likely to be up to 3 km downstream along the axis of dispersion on the tidal stream, and closer to the site of discharge on an axis perpendicular to the tidal stream. An elongated ‘halo’ of deposition of fine material including fragmented organic matter, with a long axis of approximately 3 km downstream on each side of the dredge site would be anticipated from dispersion profiles recorded on the Owers Bank and from measurements of organic matter in dredger outwash in the southern North Sea.

The results reported here suggest that population density, species diversity, biomass and body size of the macrofauna are enhanced in a broad zone that corresponds with the anticipated elongated ‘halo’ of deposition of material from the dispersing outwash plume originating in the intensively-dredged site. The zone of enhanced benthic population density, species diversity and biomass is evidently truncated in the eastern part of the survey area by the presence of sand but in all other respects conforms with what might be anticipated from a regular release of particulate organic matter from a point source within the survey area. Values for the number of species (*S*), the number of individuals (*N*) and the biomass (*B*) expressed as grams AFDW per 0.2 $m^2$ at each of the stations showing enhancement of benthos surrounding the North Nab dredge site are summarised in Text Table 6.3.

It is clearly not possible to ascribe a cause-and-effect relationship between the zone of enhanced benthos surrounding the North Nab dredge site and dredging activities within the intensively dredged part of Production Licence Area 122/3. The results suggest, however, that repeated and intensive dredging at the North Nab anchor-dredge site may provide a sufficiently rich and predictable source of organic matter from dredger outwash to have an impact on benthic community structure up to 3 km downstream of the dredge site, and closer to the dredge site across the axis of dispersion on the tidal current.

| Station # | No. of Species (*S*) | Population Density (*N*) per 0.2 m² | Biomass (B) g AFDW per 0.2 m² |
|---|---|---|---|
| 18 | 33 | 623 | 5.5984 |
| 34 | 47 | 396 | 11.7270 |
| 37 | 26 | 918 | 21.8398 |
| 38 | 30 | 1223 | 9.3850 |
| 39 | 22 | 267 | 2.1763 |
| 40 | 29 | 274 | 1.9507 |
| 41 | 26 | 268 | 4.0510 |
| 53 | 24 | 192 | 3.7748 |
| 54 | 35 | 318 | 3.8566 |
| 55 | 8 | 88 | 5.0308 |
| 57 | 44 | 163 | 5.0756 |
| 58 | 39 | 142 | 4.4844 |
| 71 | 37 | 518 | 9.5504 |
| 85 | 42 | 189 | 8.3026 |
| 95 | 39 | 245 | 3.4610 |
| 108 | 35 | 289 | 26.1456 |
| 135 | 36 | 1337 | 13.2447 |
| 142 | 68 | 492 | 5.3613 |
| 143 | 64 | 848 | 10.6218 |
| 144 | 71 | 1423 | 27.8532 |
| 145 | 48 | 546 | 9.0035 |
| 146 | 52 | 599 | 7.6634 |
| 150 | 60 | 679 | 3.1514 |
| **Mean** | **39.8** | **523.3** | **8.8395** |
| **D** | **15.6** | **389.2** | **7.2621** |
| **N** | **23** | **23** | **23** |

**Text Table 6.3** Table summarising the species variety (*S*), the population density (*N*) and biomass (*B*) g AFDW per 0.2 m² Hamon Grab sample at each of the stations showing enhancement of benthos surrounding the North Nab 122/3 dredge site.

The only data available for organic releases in the outwash of an operating dredger are for a screened cargo in a newly exploited deposit in the southern North Sea (Newell *et al*., 1999). Such values are likely to be higher than those for non-screened ('all-in') cargoes taken from an area where the gravels have been heavily exploited and which therefore contain relatively poor benthic invertebrate communities. The following section gives some values for the particulate and organic matter actually released during anchor dredging at the North Nab site, together with estimates of the likely source of the organic matter and its significance for benthic communities.

### 6.4 Significance of Dredger Outwash: A Mass Balance Approach

In an earlier mass balance study of the inorganic particulate load and organic content of discharges from a dredger loading a screened cargo of 5,630 tonnes in the southern North Sea off Southwold, Suffolk it was shown that as much as 8713 tonnes of material were rejected via the screening chute and 360 tonnes through outwash from hopper spillways. Organic matter measured in the outwash and assumed to apply to the entire water discharged from both screening chute and hopper outwash was as much as 41.5 tonnes comprising 0.20 tonnes of lipids.

The corresponding concentrations in the outwash of the dredger were 12.6 g per litre of sediment, 1.45 g AFDW per litre of organic matter and 0.0007 g per litre of lipids. These values were the first direct measurements of the concentration of organic matter in the outwash from a marine aggregates dredger, and compare with a detrital load in rich kelp-bed ecosystems of 0.78-1.04 mg AFDW per litre (Seiderer and Newell, 1985; Newell *et al*., 1999).

That is, the organic matter in the outwash from a dredger operating in the southern North Sea in newly-exploited deposits to the east of Southwold, Suffolk was about 1,500 times the organic content of some of the richest detrital ecosystems in the world.

Estimates based on the biomass of benthic invertebrates likely to be ‘processed’ by the dredger during normal loading operations suggested that relatively large quantities of organic matter could be derived from fragmentation of the benthos. During loading of a 4,500 tonne cargo recorded by Hitchcock and Drucker (1996), a maximum of some 35.3 tonnes AFDW of organic matter based on benthic invertebrates could be discharged in the 33,866 tonnes of water from the dredger. Since the volume of the outwash is known, the concentration of the organic matter derived from fragmented benthic invertebrates can be calculated. This indicates that a yield of 1,012.6 mg AFDW per litre could be derived from benthic invertebrates fragmented during processing of the 14,703 tonnes of sediment required to obtain a screened cargo of 5,630 tonnes.

The work reported by Newell *et al*. (1999) suggested that for a newly exploited area in the southern North Sea, organic enrichment may be of sufficient concentration to account for the "far field" visibility of the dispersing plume downstream from aggregate dredgers. It may also account for the increase in species diversity and population density, which has been reported for the benthos adjacent to dredged areas (see Poiner and Kennedy, 1984). There have, however, been no measurements of the composition of the outwash from dredgers operating in other dredge areas, especially in those where previous dredging activities have already had an impact on the benthos.

In the case of the North Nab Production Licence Area 122/3, the benthic biomass is already relatively low in the dredged site, and this is likely to reduce the organic content of material derived from fragmented invertebrates in the outwash. Because the aggregate is loaded as an 'all-in' (unscreened) cargo, the amount of material processed by the dredger is lower than that for a screened cargo where as much as 1.5-1.6 x the cargo is rejected. Both inorganic and organic losses from unscreened cargoes are therefore likely to be lower than from screened ones.

It is of interest to quantify the inorganic particulate losses and the organic load discharged from the dredger actually operating at the North Nab site, and to assess the extent to which the known benthic resources at the dredge site could account for the organic emissions in the outwash. The following estimates were made based on analysis of data for outwash from the dredger *City of Chichester* operating on the North Nab anchor-dredge site on 1st February 2000. An unscreened cargo of 2,141 tonnes was loaded which, because of poor weather, was less than the normal cargo of 2,400 tonnes. The total volume of water discharged during loading was 1,178 tonnes, and is visible as a plume downstream of this and other dredgers during loading (Plate 6.4).

**Plate 6.4**. Photograph showing the plume of dispersing outwash being carried westwards on the ebbing tide during loading of a cargo at station 126 of the North Nab Study site by the City of Cardiff on 13.03.99.

The positions of the sites at which dredging took place, and where simultaneous samples of outwash water were taken are summarised in Text Table 6.4a.

| Time | Latitude ° N | Longitude ° W | Easting (m) | Northing (m) |
|---|---|---|---|---|
| 11:15:04 | 50 39.4871 | 00 58.9400 | 471925.1 | 84829.9 |
| 11:30:02 | 50 39.4839 | 00 58.9390 | 471926.4 | 84824.0 |
| 11:45:02 | 50 39.4871 | 00 58.9340 | 471935.3 | 84824.2 |
| 12:00:00 | 50 39.4880 | 00 58.9280 | 471939.2 | 84831.8 |
| 12:15:06 | 50 39.4900 | 00 58.9280 | 471939.2 | 84835.5 |
| 12:30:06 | 50 39.4910 | 00 58.9130 | 471956.8 | 84838.6 |
| 12:44:08 | 50 39.4900 | 00 58.8720 | 472005.2 | 84836.4 |
| 13:17:08 | 50 39.3469 | 00 59.1380 | 471695.6 | 84566.9 |
| 13:30:04 | 50 39.3459 | 00 59.1230 | 471713.2 | 84565.3 |
| 13:45:02 | 50 39.3379 | 00 59.1060 | 471733.4 | 84550.8 |
| 14:00:00 | 50 39.3401 | 00 59.1090 | 471729.8 | 84554.8 |
| 14:15:00 | 50 39.3369 | 00 59.1020 | 471738.1 | 84549.0 |
| 14:30:06 | 50 39.3401 | 00 59.1030 | 471736.9 | 84554.9 |
| 14:45:04 | 50 39.3379 | 00 59.1000 | 471740.5 | 84550.9 |
| 15:00:02 | 50 39.3391 | 00 59.0920 | 471749.8 | 84553.2 |
| 15:15:02 | 50 39.3411 | 00 59.0820 | 471761.6 | 84557.1 |
| 15:30:00 | 50 39.3420 | 00 59.0680 | 471778.0 | 84559.0 |

**Text Table 6.4a**.Table summarising the positions of the dredger City of Chichester during loading of a cargo on 01.02.00. when a series of samples of outwash were taken for subsequent analysis of particulate load and organic composition. Positions in latitude and longitude and in OSGB 36 were taken from the ship's log. See also Figure 6.4a.

Because of poor weather conditions, the dredger drifted eastwards from a starting position close to Station 124 at 11h15. At 12h44 dredging was stopped and the vessel relocated at 13h17 near Station 126 where loading continued until 15h30. A map showing the positions of the sampling stations in the anchor-dredge area is shown in Figure 6.4a. The boundaries of the anchor-dredge area are shown, as well as the tracks of the dredger City of Chichester during the loading of a cargo on 01.02.00.

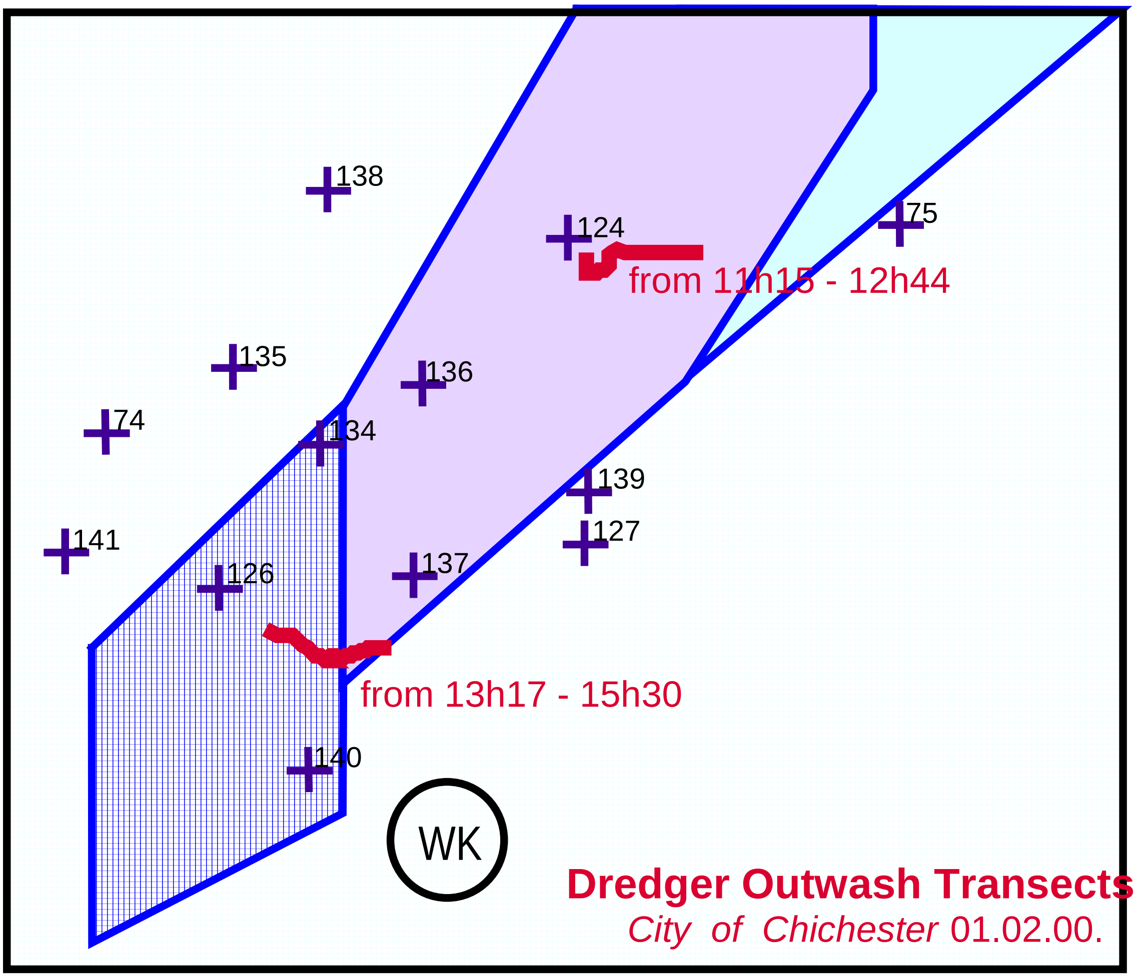


**Figure 6.4a**. Map of part of the dredge site showing the tracks of the dredger City of Chichester during loading of a cargo on 01.02.00 when samples of outwash were taken for analysis of particulate load and organic material discharged during loading operations. See also Text Table 6.4.

A total of 50 water samples were taken from the hopper outwash at intervals during the loading period of 3 hours 13 min. From the results obtained, the background values for suspended solids and organic matter were subtracted to give the results shown in Text Table 6.4b. The average values for suspended solids and organic matter (mg AFDW per litre) were calculated from the data shown in Text Table 6.4b.

| Sample | Time after start of dredging (minutes) | Total suspended solids (- controls) mg/l | Ashed suspended solids (- controls) mg/l | Organics AFDW mg/l |
|---|---|---|---|---|
| 1 | 1 | 248 | 208 | 40 |
| 2 | 3 | 419 | 249 | 170 |
| 3 | 6 | 521 | 417 | 104 |
| 4 | 9 | 177 | 134 | 43 |
| 5 | 12 | 479 | 385 | 94 |
| 6 | 15 | 533 | 413 | 120 |
| 7 | 18 | 663 | 529 | 134 |
| 8 | 21 | 457 | 378 | 79 |
| 9 | 24 | 514 | 418 | 96 |
| 10 | 27 | 553 | 451 | 102 |
| 11 | 30 | 779 | 635 | 144 |
| 12 | 33 | 1589 | 1363 | 226 |
| 13 | 36 | 1299 | 1103 | 196 |
| 14 | 39 | 711 | 593 | 118 |
| 15 | 42 | 424 | 363 | 61 |
| 16 | 45 | 683 | 578 | 105 |
| 17 | 48 | 655 | 541 | 114 |
| 18 | 51 | 641 | 541 | 100 |
| 19 | 54 | 845 | 719 | 126 |
| 20 | 57 | 452 | 389 | 63 |
| 21 | 60 | 853 | 693 | 160 |
| 22 | 65 | 905 | 747 | 158 |
| 23 | 68 | 1059 | 895 | 164 |
| 24 | 109 | 1259 | 1073 | 186 |
| 25 | 113 | 2239 | 1893 | 346 |
| 26 | 117 | 1129 | 989 | 140 |
| 27 | 121 | 2439 | 2103 | 336 |
| 28 | 125 | 1629 | 1393 | 236 |
| 29 | 129 | 2389 | 2033 | 356 |
| 30 | 133 | 1789 | 1543 | 246 |
| 31 | 137 | 2479 | 2163 | 316 |
| 32 | 141 | 1569 | 1313 | 256 |
| 33 | 145 | 2029 | 1733 | 296 |
| 34 | 149 | 1649 | 1413 | 236 |
| 35 | 153 | 1629 | 1393 | 236 |
| 36 | 159 | 1819 | 1543 | 276 |
| 37 | 163 | 3399 | 2963 | 436 |
| 38 | 167 | 2259 | 1923 | 336 |
| 39 | 171 | 2519 | 2163 | 356 |
| 40 | 175 | 1439 | 1223 | 216 |
| 41 | 182 | 764 | 652 | 112 |
| 42 | 188 | 1209 | 1046 | 163 |
| 43 | 194 | 792 | 678 | 114 |
| 44 | 200 | 2629 | 2245 | 384 |
| 45 | 206 | 2179 | 1843 | 336 |
| 46 | 212 | 3339 | 2853 | 486 |
| 47 | 219 | 3489 | 2983 | 506 |
| 48 | 226 | 5371 | 4653 | 718 |
| 49 | 231 | 426 | 359 | 67 |

| | | | | |
|---|---|---|---|---|
| 50 | 233 | 642 | 535 | 107 |
| **Mean** | **-** | **1399.24** | **1188.29** | **210.32** |
| **SD** | **-** | **1047.17** | **910.4** | **138.55** |

**Text Table 6.4b**.Showing the total suspended solids minus the mean background value (mg/l), the ashed suspended solids minus the mean background value (mg/l) and the organic component (AFDW mg/l), recorded in a series of 50 water samples taken from "outwash" water discharged from the marine aggregate dredger City of Chichester anchored in North Nab Licence Area 122/3, South East of the Isle of Wight, on 01.02.00. Background levels based on two samples of seawater taken before dredging started and two samples taken after dredging had ceased. Total background suspended solids = 31.25 mg per litre, N = 4; organic matter (AFDW) = 24 mg per litre, N = 4.

| | |
|---|---|
| **Inorganic Matter:** | |
| Volume of Water Discharged | = 1,178 tonnes. |
| Concentration of Inorganic Suspended Solids | = 1,399.24 mg per litre (sd 1,047.17) |
| | = 1,399.24 grams per tonne of discharge water |
| Therefore 1,178 tonnes of Discharge Water | = 1,178 x 1,399.24 grams |
| **Inorganic Matter Discharged:** | **= 1,648.3 kg per cargo load of 2,141 tonnes.** |

| | |
|---|---|
| **Organic Matter:** | |
| Volume of Water Discharged | = 1,178 tonnes |
| Concentration of Organic Matter | = 210.32 mg AFDW per litre (s.d. 138.55) |
| | = 210.32 grams per tonne of discharge water |
| Therefore 1,178 tonnes of Discharge Water | = 1,178 x 210.32 grams AFDW Organics |
| **Organic Matter Discharged:** | **= 247.8 kg per cargo load of 2,141 tonnes.** |

This can be compared with approximately 9,000 tonnes total sediment released from a screened cargo of 5,630 tonnes and an organic discharge of 41.5 tonnes from a cargo loaded off Southwold in the southern North Sea (Newell *et al*., 1999). A comparison of the mass balance for discharges from a dredger loading a screened cargo of 5,630 tonnes off Southwold, Suffolk in April 1998 and that for the City of Chichester loading an unscreened cargo of 2,141 tonnes in the North Nab Production Licence Area 122/3 is shown in Text Table 6.4c.

| | **Tonnes Discharged for a screened cargo of 5,630 tonnes** | **Tonnes discharged for an unscreened cargo of 2,141 tonnes** |
|---|---|---|
| Water | 28,552 | 1,178 |
| Sediment in hopper outwash | 360 | 1.648 |
| Sediment rejected by screening | 8,713 | - |
| TOTAL SEDIMENT REJECTED | 9,073 | 1.648 |
| Organic matter (AFDW) | 41.5 | 0.248 |

**Text Table 6.4c**. Mass discharges of material from a trailer-dredger loading a screened cargo of 5,630 tonnes of gravel off Southwold, Suffolk in April 1998 (based on Newell *et al*., 1999). Also shown are data for mass discharges from the City of Chichester loading an unscreened cargo of 2,141 tonnes in February 2000 at North Nab Production Licence Area 122/3 to the east of the Isle of Wight, UK.

| **Source of Organic Matter in the Outwash** | |
|---|---|
| Total Organic Matter Discharged | = 247.8 kg AFDW per cargo of 2,141 tonnes |
| | = 115.74 grams AFDW per tonne |
| **Organic Matter in Outwash:** | **= 115.74 mg AFDW per kg sediment** |

| **Source of Organic Matter Available from Benthos** | |
|---|---|
| AFDW Benthos in Anchor-Dredge Area | = 2.0 g AFDW per 0.2 m² (see Figure 26 ) |
| | = 2.0 g AFDW per 19.1 kg sediment (App. 1) |
| Benthos in 19.1 kg sediment | = 2000 mg AFDW |
| Benthic contribution to 1 kg sediment | = 2000 / 19.1 mg AFDW |
| **Organic Matter from Benthos** | **= 104.71 mg AFDW per kg sediment** |

That is, the amount of organic matter actually measured from spillways of the City of Chichester operating at the North Nab anchor-dredge site on 1st February 2000 amounted to an equivalent of 115.74 mg AFDW per kg sediment loaded. Of this, the measured benthic resources in the dredge area itself could supply at least 104.7 mg AFDW organic matter per kg of sediment.

Clearly there is a correspondence between the organic composition of the outwash, and the concentration of material that would be anticipated from fragmented invertebrates discharged from the dredger at the actual site of dredging. The total annual cargo loaded is approximately 150,000 tonnes. The total organic matter released into the water column by dredging from this very restricted area of seabed is therefore 0.11574 kg x 150,000 = 17.36 tonnes AFDW organic matter per year. It is not known whether this value is sufficient to sustain and enhance the filter-feeding benthic invertebrate populations that occur along the axis of dispersion of outwash from the dredge site.

## 6.5 Production Estimates for the Benthic Community

Production values for benthic communities are often estimated from the biomass using Production/Biomass (P/B) ratios derived from a variety of sources including whole communities and individual species. The mean value for the biomass of benthic invertebrates in the North Nab survey area was 2.11 g AFDW per 0.2 $m^2$ Hamon grab sample (Text Table 6.1.2a) and the mean value for those stations surrounding the dredged area which showed an enhanced benthos was 8.8 g AFDW per 0.2m (Text Table 6.2.5). Mann (1982) gives the ratio of 1 gram of carbon = 2.6 grams AFDW organic matter. The average biomass of benthos in the North Nab survey area as a whole is therefore 0.8115 g C per 0.2 $m^2$ and that in the zone of enhancement or "halo" surrounding the dredged area is 3.4 g C per 0.2 $m^2$. This is equivalent to an average biomass of 4.06 g C per $m^2$ and a biomass in the zone of enhancement of 17 g C per $m^2$. Some values for coastal communities summarised from the literature are shown in Text Table 6.5a.

| **Location** | **Depth (m)** | **B gC/m²** | **P/B** | **P gC/m²/yr** | **Reference** |
|---|---|---|---|---|---|
| Estuary, Netherlands | 0 | 10 | 1.6 | 16.5 | Wolff and de Wolff (1977) |
| Estuary, Cornwall | 0 | 5.3 | 1.0 | 5.3 | Warwick and Price (1975) |
| Severn Estuary | 17 | 17.0 | 0.6 | 10.0 | Warwick *et al*. (1979) |
| Long Island Sound | 18 | 4.8 | 2.5 | 12.0 | Sanders (1958) |
| Baltic | 46 | 1.7 | 1.6 | 2.7 | Cederwall (1977) |
| North Sea | 80 | 1.7 | 0.4 | 0.7 | Buchanan and Warwick (1974) |
| All Areas Mean | - | 6.75 | 1.28 | 7.87 | |
| SD | - | 5.87 | 0.78 | 6.01 | |
| **North Nab Mean** | **10-20** | **4.06** | **(1.28)** | **5.2** | **This study** |
| **Max.** | | **17.0** | | **21.8** | **This study** |

**Text Table 6.5a** Table showing values for the biomass of benthic macrofauna from various habitats. Data have been converted to grams of carbon per m² using the ratio of AFDW X 0.4 (based on Mann, 1982). Note that the average biomass for the study area at North Nab is generally similar to that recorded for other habitats, but that the biomass adjacent to the dredged area is comparable with that of estuaries. Assuming a P/B ratio of 1.28 for the North Nab study site, the production (P) value is 5.2 gC/m²/yr for the survey area as a whole, but is as high as 21.8 gC/m²/yr for the zone of enhanced benthos adjacent to the dredged site.

Several features of interest emerge from comparison of the data for the North Nab survey area with those for other coastal habitats. The biomass values for typical estuarine communities are 10-17 grams carbon per $m^2$ whilst those for the Baltic and North Sea are reported to be only 1.7 grams carbon per $m^2$. Clearly the average biomass of 4.06 grams carbon per $m^2$ for the North Nab survey area is relatively high compared with shelf seas whilst that in the 'halo' of enhanced benthos approaches that of the Severn estuary (Warwick *et al*., 1979). Benthic biomass in estuaries is enhanced by fragmented organic debris from coastal wetlands. We surmise that the release of 17.36 tonnes of organic matter per year from the North Nab dredge site may be sufficient to account for benthic production values that approach those of estuarine communities.

Whilst there is no data on annual production values for the benthos of the North Nab survey area, there is some information on the American slipper limpet (*Crepidula fornicata*), which occurs in abundance outside the boundaries of the dredged area. Production / Biomass ratios vary a good deal, but an average value of 1.28 is obtained for the sites summarised in Text Table 6.5a. Using this value, average annual production by the benthos in the North Nab survey area is likely to be approximately 5.2 grams carbon per $m^2$ with values as high as 21.8 grams carbon per $m^2$ in peripheral stations of enhanced biomass extending down the tidal stream from the dredged site.

## 6.6 Biomass and Production Estimates for a Key Consumer

### 6.6.1 Population Structure of *Crepidula fornicata*.

The mollusc community adjacent to the dredged area is dominated by the filter-feeding American Slipper Limpet (*Crepidula fornicata*). This gastropod feeds on particulate matter suspended in the water column and was introduced to Europe with the American oyster, *Crassostrea virginica*. The numbers of *Crepidula fornicata* recorded per 0.2 $m^2$ Hamon grab sample in the deposits adjacent to the North Nab dredge site are summarised in Figure 6.6.1a (see also Appendix Table 8).

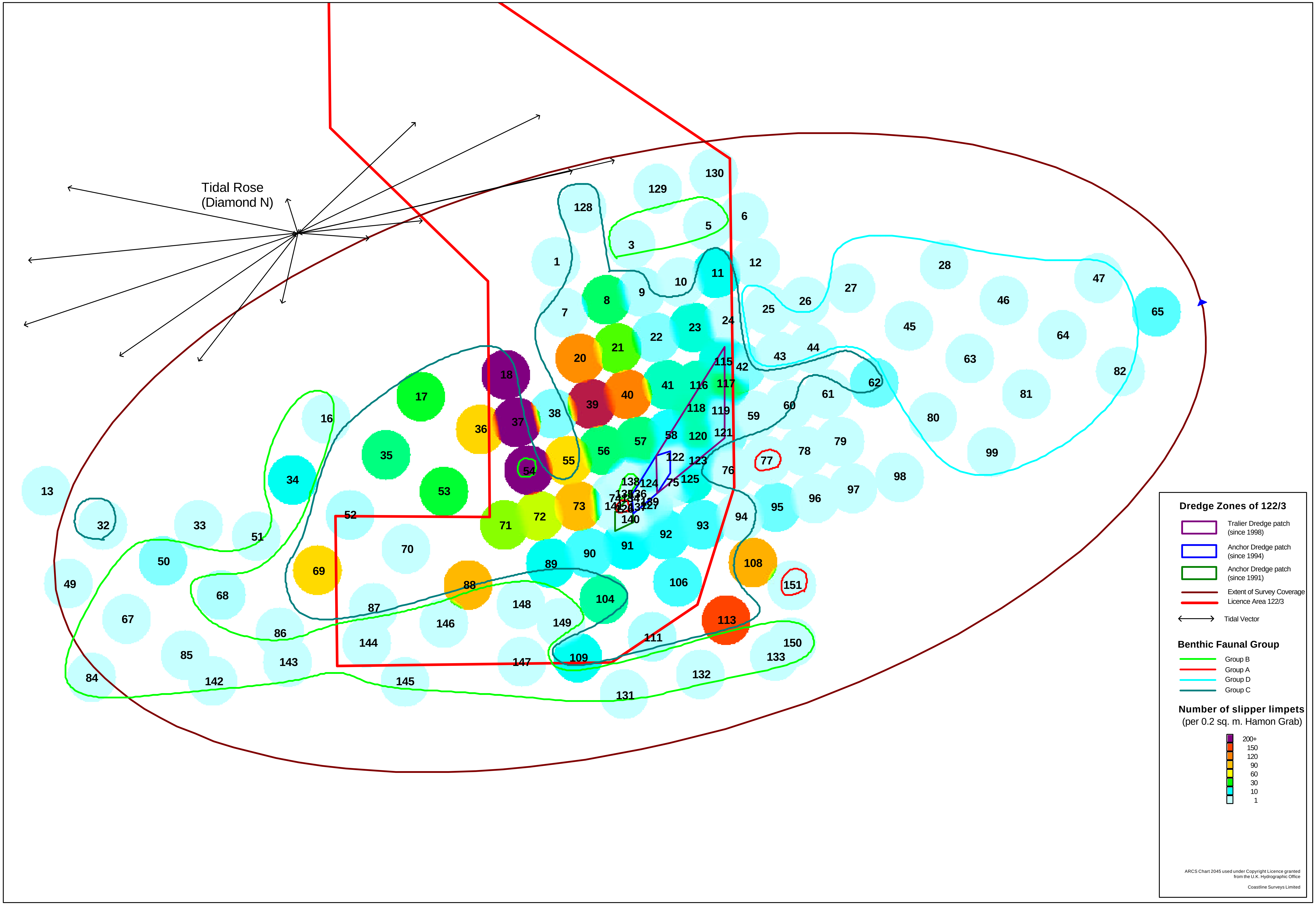


Figure 6.6.1a. Map of the North Nab survey area showing a grid thematic map
for the number of slipper limpets per 0.2 sq.m. Hamon Grab.

This shows that population densities as high as 250 individuals per 0.2 $m^2$ occur close to the west of the dredge site and that similar relatively high densities occur approximately 1 km to the south-east of the dredge site.

Appendix Table 6 shows the distribution of size-classes of *Crepidula fornicata* in the deposits, together with the percentage frequency of occurrence of each size class. Clearly the populations were dominated by specimens of <20 mm although some much larger individuals were recorded at most stations. Size frequency histograms for the shell length of *Crepidula fornicata* for some typical stations are shown in Figure 6.6.1b.

The annual growth rate of Crepidula fornicata can be calculated using growth bands which are well-defined on the shell of this mollusc (see Plate 6.6.1); this allows some estimates to be made of the age of the different size classes recorded above. Determination of the age structure allows estimates to be made of annual production by this mollusc.

**Plate 6.6.1.** Shells of the American slipper limpet *Crepidula fornicata* showing annual growth bands. The specimens shown are between 4 - 5 years in age.

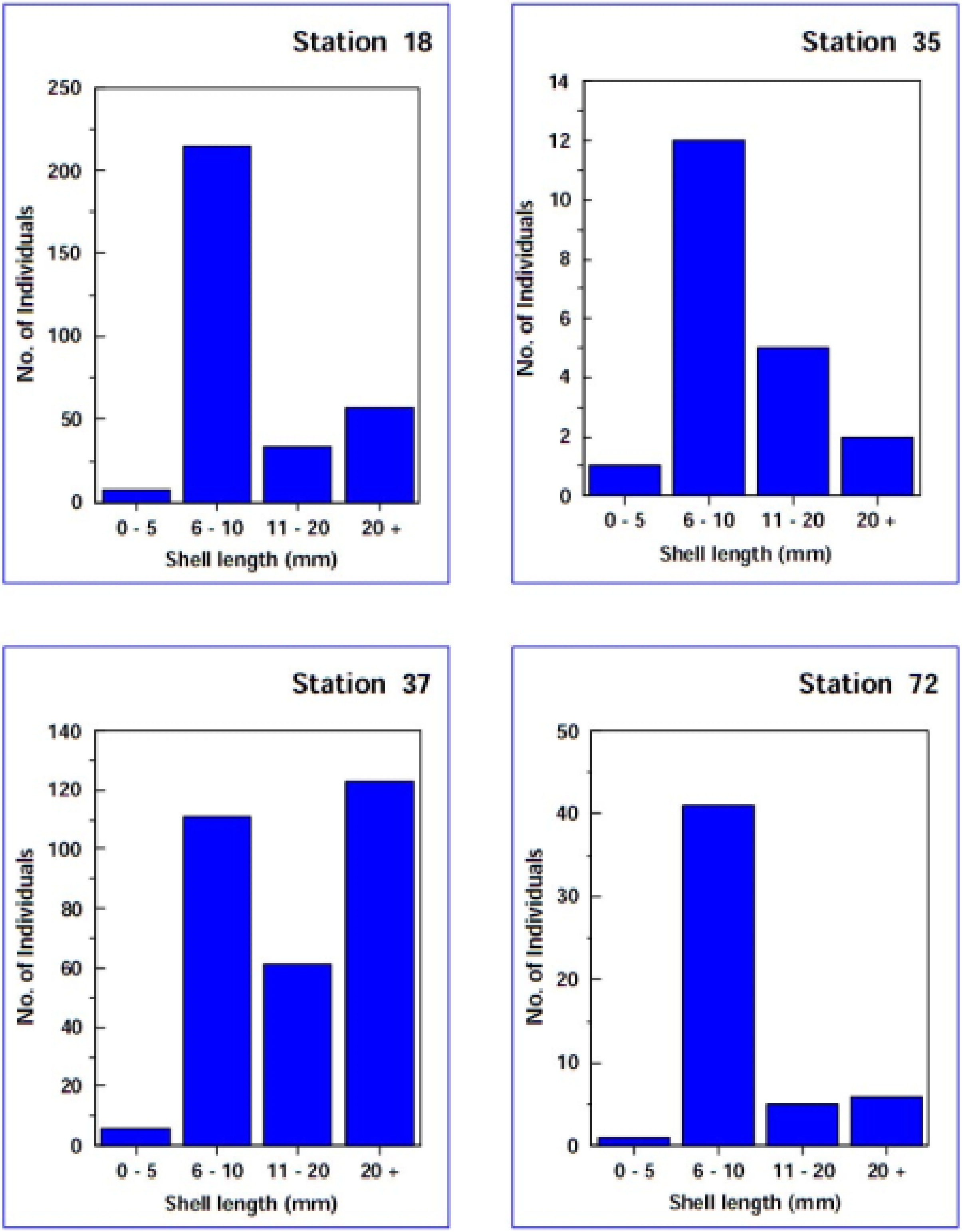


**Figure 6.6.1b**. Size-frequency histograms for shell length of *Crepidula fornicata* at Stations 18, 35, 37 and 72. Similar data for other stations at which *Crepidula fornicata* was recorded are summarised in Appendix Table 6.

Values for the shell size and age distribution in a series of 69 specimens of *Crepidula fornicata* are summarised in Appendix Table 7 and in Figure 6.6.1c.

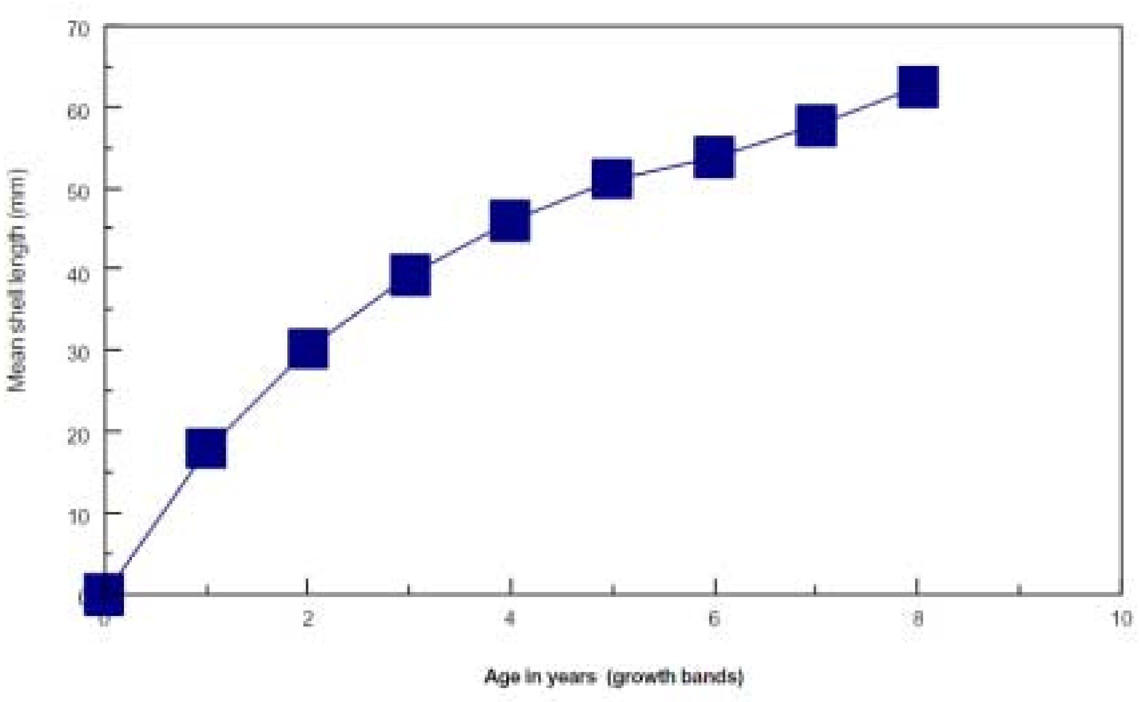


**Figure 6.6.1c.** Graph showing the relationship between the age of *Crepidula fornicata* established from shell growth bands, and mean shell length (mm). See also Appendix Table 7.

This shows that growth rate is initially rapid in the first 2-3 years, reaching a shell length of up to 30 mm. After this, growth rate decreases with the majority of the larger specimens attaining a shell length of approximately 50 mm at 6 years of age. A few specimens were recorded of up to 8 years of age. These data can be converted to tissue weight from the relationship between blotted wet weight of tissues and shell length. Text Table 6.6.1a shows the mean blotted tissue weights (g) for groups of *Crepidula fornicata* of differing shell lengths.

| Shell length (mm) | Mean wet tissue weight (g) | Standard deviation | N |
|---|---|---|---|
| 0-5 | 0.001 | - | 7 |
| 6-10 | 0.00791 | 0.0044 | 13 |
| 11-15 | 0.0288 | 0.0310 | 11 |
| 16-19 | 0.0396 | 0.0719 | 5 |
| 20-24 | 0.1496 | 0.0726 | 8 |
| 25-30 | 0.2723 | 0.0383 | 6 |
| 31-35 | 0.4633 | 0.2397 | 3 |

**Text Table 6.6.1a**. Table showing the mean blotted wet tissue weights (g) for groups of Crepidula fornicata of differing shell lengths (mm) from North Nab Study site.

These data are summarised in Figure 6.6.1d and can be used to calculate the incremental increase in tissue weight attained as a function of age in the slipper limpet.

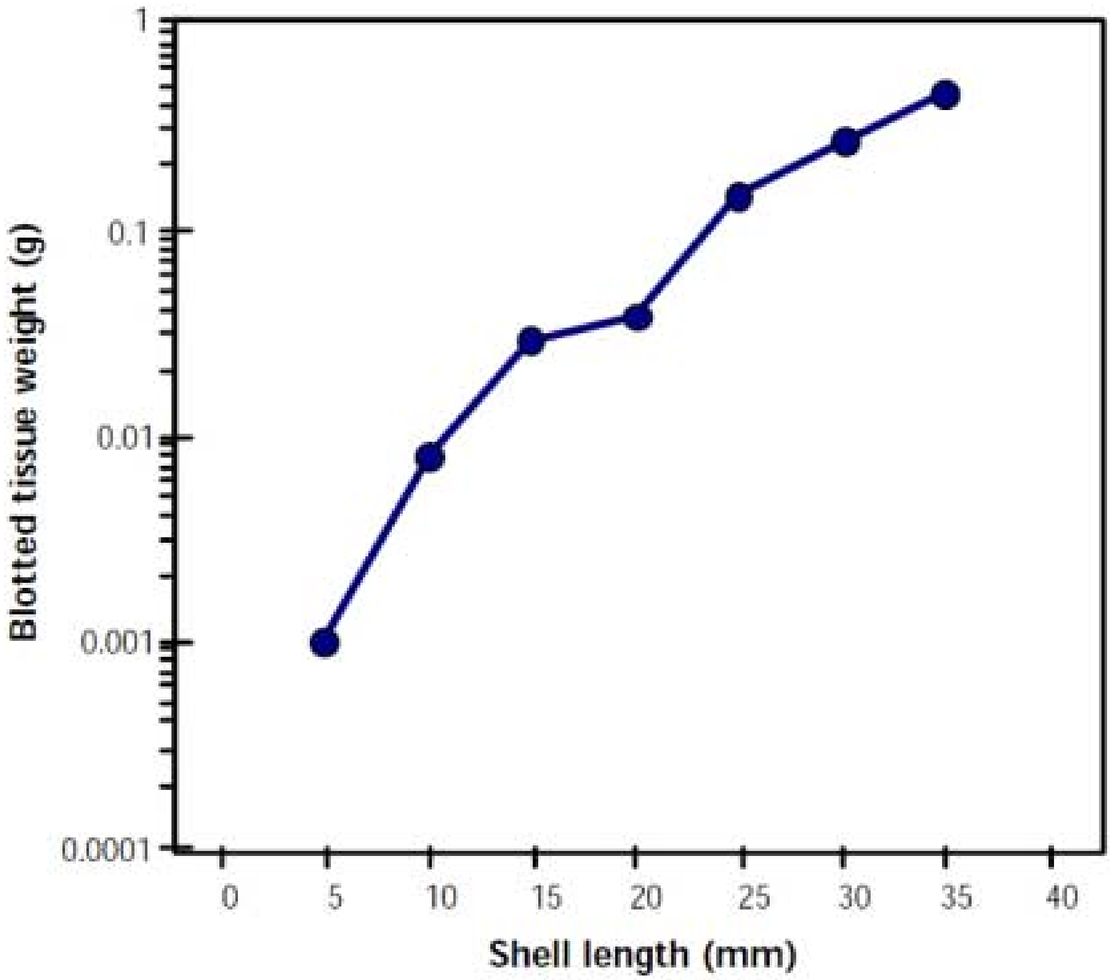


**Figure 6.6.1d** Graph showing the relationship between shell length (mm) of *Crepidula fornicata* and the blotted (wet weight) of tissues in grams. See also Text Table 6.6.1a.

### 6.6.2 Production Estimates for *Crepidula fornicata*.

Biomass and production values have been reported for *Crepidula fornicata* populations in the Bay of Marennes-Oleron, France by Deslous-Paoli (1980). He recorded an average yearly production of approximately 275 g per $m^2$ from a population of dry flesh biomass 583 g per $m^2$, the Production/Biomass ratio (P/B) being 0.46.

It is not possible to make any direct comparisons with the results of Deslous-Paoli (1980). However, some estimates can be made of annual production of *Crepidula fornicata* in the North Nab survey area by calculating the tissue weights of the Year 1 class, which correspond with shell lengths of 20 mm (Figure 6.6.1d). Appendix Table 8 shows the total number of individuals recorded at each of the survey stations at which *Crepidula fornicata* was recorded, and the number of specimens of <20 mm shell length (i.e. Year 1 individuals). The wet weight and AFDW in grams estimated from Eleftheriou and Basford (1989) are also shown in Appendix Table 8.

Text Table 6.6.2a summarises the number of *Crepidula fornicata* of shell length <20 mm (ascribed to Year 1 size class) and the number with a shell length >20 mm (ascribed to year classes 2 and 3). From Figure 6.6.1d, the biomass of Year Class 1 slipper limpets is the number of individuals x 0.05 g wet weight per 0.2 $m^2$. Equally the biomass equivalent of the Year 2 and 3 individuals of mean size 30 mm can be estimated from the number of individuals (N) x the mean wet biomass of 0.3 grams wet weight per 0.2 $m^2$. From Text Table 6.6.2a it can be seen that the average biomass of Year 1 *Crepidula fornicata* was 5.45 (s.d. 3.47) grams wet weight per 0.2 $m^2$ or 27.25 grams wet weight per $m^2$. The equivalent biomass in the larger size classes is 7.71 grams wet weight per 0.2 $m^2$ or 38.6 grams wet weight per $m^2$ and the total biomass estimated for all size classes is 13.16 grams wet weight per 0.2 $m^2$.

| Station | Year Class 1 (<20 mm shell length) | | Year Classes 2-4 (>20 mm shell length) | | Total Biomass g per 0.2 m² |
|---|---|---|---|---|---|
| | No. of individuals (*N*) per 0.2 m² | Biomass wet tissue weight (g) | No. of individuals (*N*) per 0.2 m² | Biomass wet tissue weight (g) | |
| 18 | 257 | 12.85 | 57 | 17.10 | 29.95 |
| 20 | 109 | 5.45 | 4 | 1.20 | 6.65 |
| 35 | 28 | 1.40 | 2 | 36.90 | 45.80 |
| 39 | 157 | 7.85 | 21 | 6.30 | 14.50 |
| 40 | 107 | 5.35 | 12 | 3.60 | 8.95 |
| 54 | 198 | 9.90 | 67 | 20.10 | 30.00 |
| 69 | 72 | 3.60 | 5 | 1.50 | 5.10 |
| 72 | 47 | 2.35 | 6 | 1.80 | 4.15 |
| 73 | 82 | 4.10 | 9 | 2.70 | 6.80 |
| 88 | 73 | 3.65 | 20 | 6.00 | 9.65 |
| 106 | 4 | 0.20 | 2 | 0.60 | 0.80 |
| 108 | 84 | 4.20 | 13 | 3.90 | 8.10 |
| 113 | 129 | 6.45 | 19 | 5.70 | 12.15 |
| **Mean** | **108.9** | **5.45** | **25.7** | **7.71** | **13.16** |
| **S.D.** | **69.47** | **3.47** | **34.3** | **10.29** | **12.99** |
| **N** | **14** | **14** | **13** | **14** | **14** |

**Text Table 6.6.2a.**Table summarising the numbers of slipper limpet *Crepidula fornicata* in Year Class 1 (<20 mm) and in older Year Classes (> 20 mm) per 0.2 m² in the North Nab Study site. The equivalent biomass has been estimated from the numbers of individuals (N) and the relation between shell length and wet tissue weight (Figure 6.6.1d)

The biomass achieved at the end of Year 1 by *Crepidula fornicata* is the annual production for that size class. Production at the end of Year 1 is therefore 5.45 grams wet weight per 0.2 m². The equivalent ash-free dry weight (AFDW) value is 5.45 x 0.085 (Eleftheriou and Basford, 1989) = 0.4633 g AFDW per 0.2 m² or 2.32 g AFDW per m².

Since carbon represents AFDW x 0.4 (see Mann, 1982) the carbon equivalent of production by *Crepidula fornicata* is equivalent to 0.89 grams carbon per m² at the end of year 1. Because the biomass of the larger size classes are similar to those for Year 1 individuals, the annual production by *Crepidula fornicata* in the North Nab site is likely to be approximately 1.8 grams carbon per m² per year in parts of the survey area where this mollusc is common.

This value may be compared with annual production estimates for benthos in the North Sea of 0.7 g carbon per m² (Buchanan and Warwick, 1974) and 2.7 grams carbon per m² for the Baltic (Cederwall, 1977) (see Text Table 6.5a).

The inference is that production by the slipper limpet (*Crepidula fornicata*) is alone comparable with that for typical total benthic production reported for coastal sediments elsewhere. When the contribution of other components of the benthos including dense communities of Bryozoans (notably *Flustra* spp), hydroids and other components are added, production by the benthos surrounding the dredge area is likely to considerably exceed that recorded for offshore sediments in the North Sea and Baltic Sea.

## 6.7 Impact of Dredging and Nature of the Recovery Processes

### 6.7.1 Impact of Dredging on Species Diversity, Population Density and Biomass

In Section 6.2 of this Report, it was shown that the benthic community recorded in the sands that occur to the east of the survey area in the vicinity of the Nab Tower are relatively impoverished. Elsewhere in the survey area, the species diversity, population density and biomass of benthos are typical of those recorded by similar methods in coastal deposits in U.K waters (Text Table 6.1.2b). Surrounding the intensively dredged North Nab Production Licence Area 122/3 is an elongated zone or 'halo' of enhanced species diversity, population density and benthic biomass that corresponds with the main axis of dispersion of material from the worked deposits.

It is inferred that this zone of enhanced benthos could reflect the 17.36 tonnes AFDW organic matter estimated to be released per year in the outwash of dredgers operating within the restricted worked site in the North Nab Production Licence Area 122/3 (see Section 6.3). This material is likely to be carried beyond the boundaries of the Licence Area along the axis of dispersion by tidal currents and may be associated with "far field" effects of dredging outside the boundaries of the dredged area. The following Section focuses on the impact of dredging within the areas that are exploited by both anchor-dredge and trailer-dredging techniques.

### 6.7.2 Impact on Population Density

Values for the population density expressed as number of individuals per 0.2 $m^2$ Hamon grab sample recorded at sampling stations in the vicinity of the dredged site within the North Nab Production Licence Area 122/3 are shown in Figure 6.7.2a.

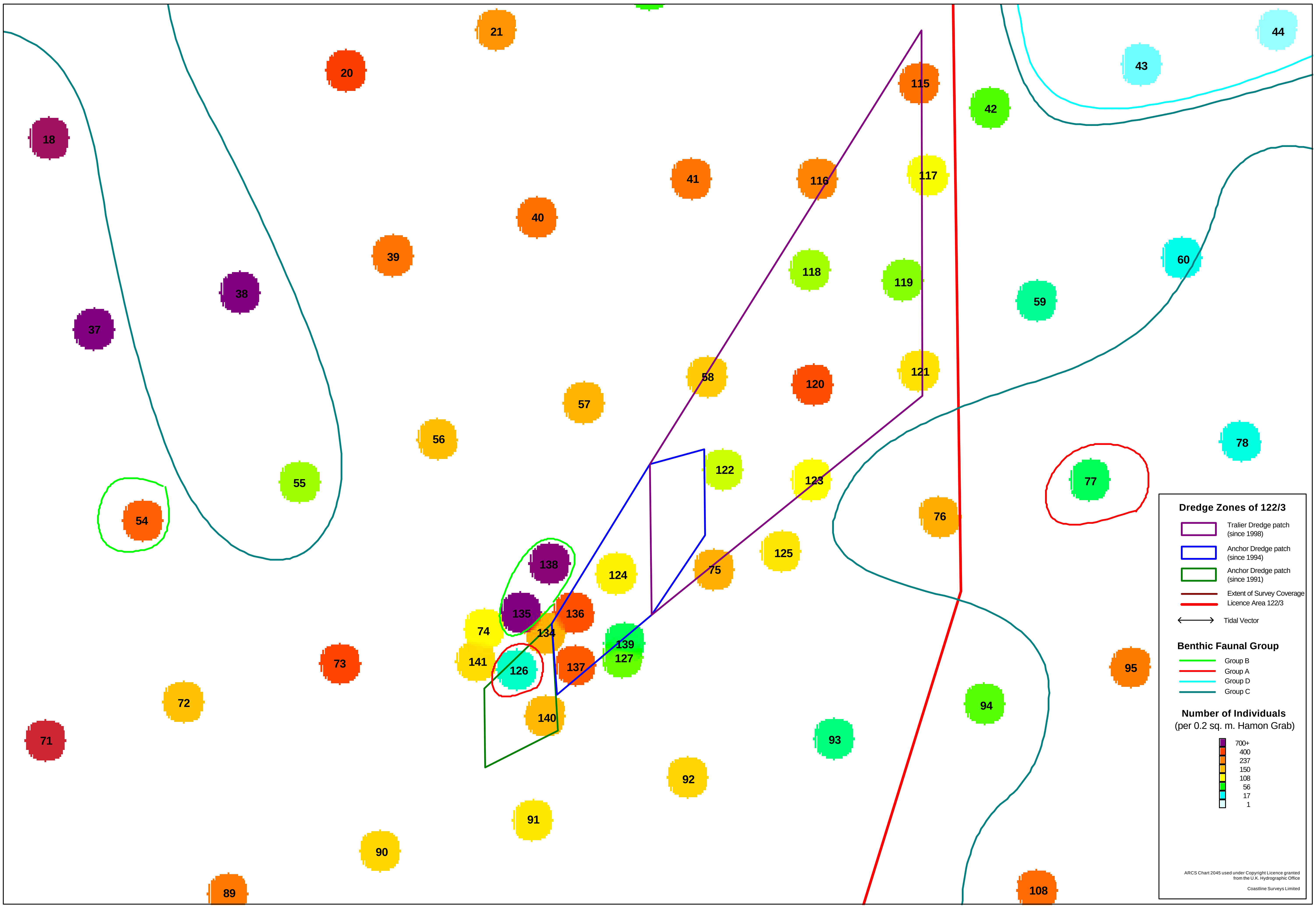


Figure 6.7.2a. Map of the intensively - dredged area showing a grid thematic map for the number of individuals of macrofauna (>1mm) per 0.2 sq.m. Hamon Grab.

Inspection of Figure 6.7.2a shows that a number of sampling sites were characterised by a low population density of marine invertebrates (see also Text Table 6.1.2a) Stations 124, 126, 127, 139 and to a lesser extent Stations 134 and 140 show a suppressed population density compared with the benthos in the surrounding deposits both within and outside the boundaries of the worked area. It can also be seen that there is some suppression of numbers of benthos at Stations 74 and 141 approximately 50-100 metres to the East of the marked boundary of the anchor-dredge area.

Inspection of Text Table 6.7.2a shows that each of the stations where a reduced population density of benthos has been recorded corresponds with zones where anchor dredging had taken place. It is clear therefore, that anchor dredging has a significant impact on population density of the benthos, although the exact level of suppression recorded depends on whether our samples coincided with the middle of the dredge pit, and the number of days elapsed since dredging took place.

| Station # | Date sampled | Date last dredged | Days elapsed | Species (S) per 0.2m² | | Individuals (N) per 0.2m² | | Biomass (B) g AFDW | | Size (B/N) mg | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | No. | % | No. | % | g | % | mg | % |
| **Anchor Dredge** | | | | | | | | | | | |
| 126 | 13.03.99. | - | - | 11 | -62 | 26 | -87 | 0.257 | -83 | 1.0 | -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 | 0.037 | -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 | 0.170 | -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 | 2.100 | +36 | 5.9 | -16 |

**Text Table 6.7.2a.** 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*) (g AFDW) per 0.2 m², the body size (*B/N* mg) at each station is shown, together with the % reduction compared with average background values for all stations outside the dredge area shown in Figure 6.2.2.

From Text Table 6.7.2a, it can be seen that at Station 126 the population density showed an 87% reduction compared with average values for the survey area as a whole. This station is near a site that was being dredged at the time of our survey on 13.03.99, but we have no detailed record of when it was previously dredged, or whether disturbance by anchors has had an impact at this site. An 88% reduction in population density was recorded at Station 139 despite the fact that records from the dredger show that this site was last dredged 178 days prior to our survey. On the other hand, 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 (see Text Table 6.7.2a). This variability probably reflects the complexity of the seabed topography in the intensely worked anchor dredge site.

These data showing a variable reduction in the population density in dredged areas agrees 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 (Désprez, 1992; 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).

Clearly the level of discrimination is controlled partly by the distance between sampling stations in our survey grid. However Figure 6.7.2a shows that samples taken at stations within approximately 100 metres of the dredge sites show high population densities of benthos. The impact of anchor dredging on population density of benthic invertebrates does not therefore extend beyond approximately 100 metres from the anchor-dredge sites in a Licence Area where discharge of material from overboard screening is minimal.

### 6.7.3 Impact on Species Variety

Figure 6.7.3 shows a map of the species variety recorded in the vicinity of the intensively dredged part of North Nab Licence Area 122/3.

In this case, the species diversity at Stations 126 and 124 show a significant suppression of 62- 66%, despite the fact that up to 312 days had passed since this station had been dredged (see Text Table 6.7.2a).

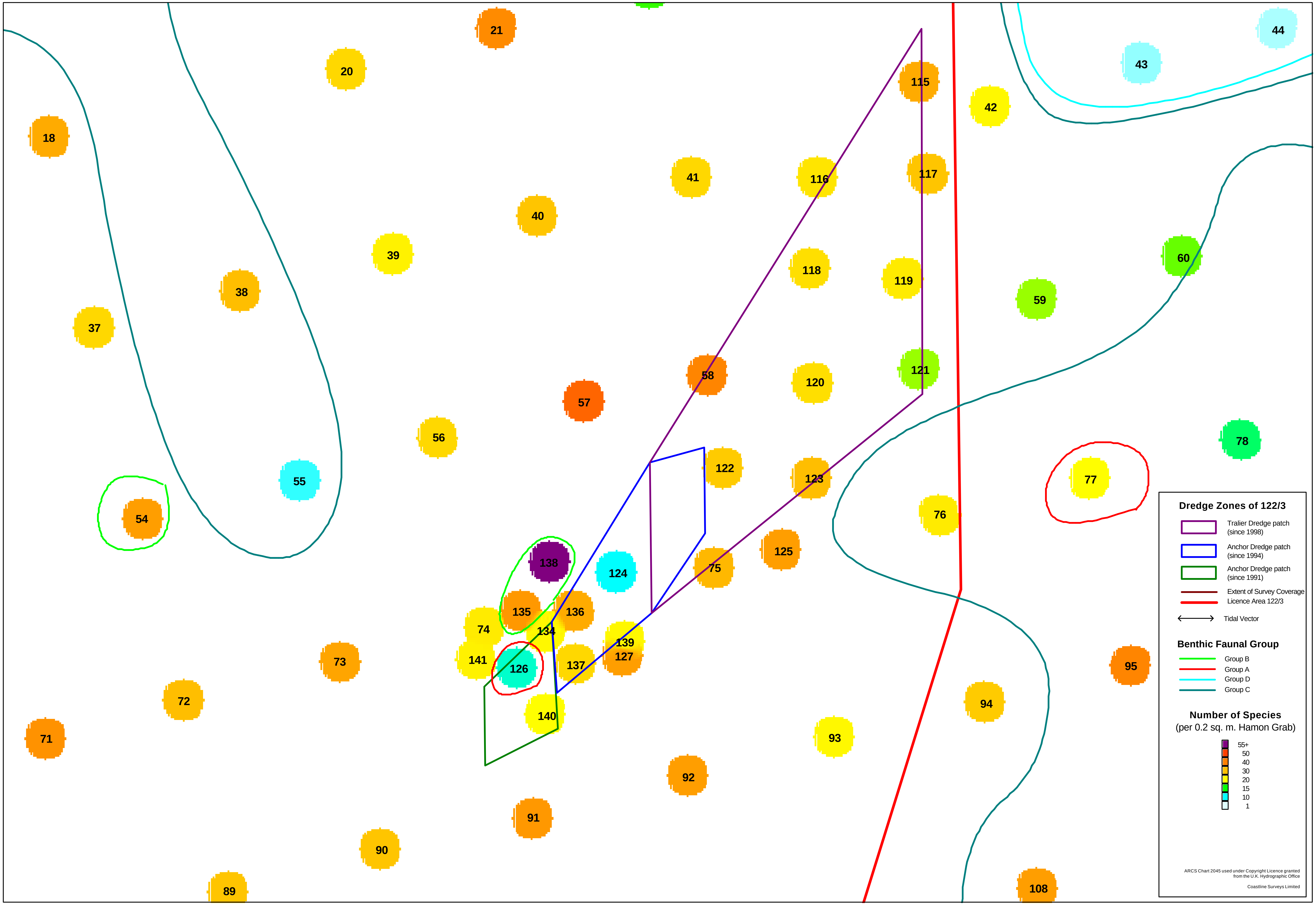


Figure 6.7.3. Map of the intensively-dredged area showing a grid thematic map for the number of species of macrofauna (>1mm) per 0.2 sq.m. Hamon Grab.

### 6.7.4 Impact on Biomass

The impact of anchor dredging on the total macrofaunal biomass is summarised in Figure 6.7.4a.

This shows that a large number of previously dredged sites remained low in biomass despite the fact that the population density (Figure 6.7.2a) and the species variety (Figure 6.7.3) had largely recovered. Inspection of Text Table 6.7.2 shows that a major suppression of biomass of 80-90% was commonly recorded in previously dredged sites. Further, it is clear that this suppression persisted for periods in excess of 18 months after cessation of dredging.

Figure 6.7.4b shows similar data for the molluscan macrofauna close to the sites of anchor dredging.

Again it is clear that the biomass of Mollusca are significantly impacted at previously dredged sites, even though Text Table 6.7.2a shows that some of these had remained undredged for over 18 months. A suppression of the biomass of long-lived and slow growing components of the macrofaunal community has been commonly reported following dredging (see van Moorsel, 1994; Newell *et al*., 1998; Désprez, 2000).

The corresponding data for the biomass of “miscellaneous” macrofaunal groups comprising *Bryozoa* (mainly *Flustra spp.*) and hydroids are summarised in Figure 6.7.4c.

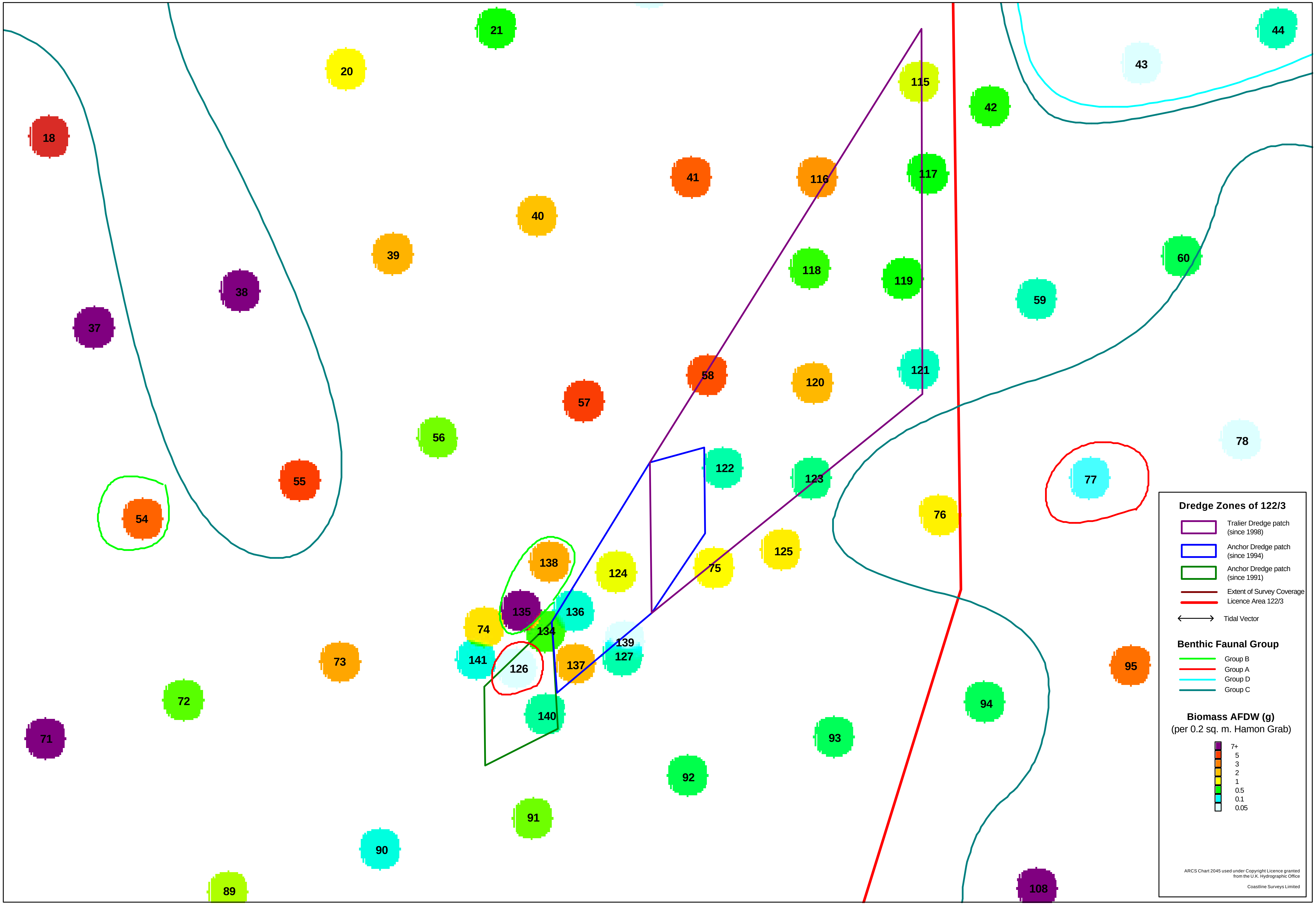


Figure 6.7.4a. Map of the intensively-dredged area showing a grid thematic map for the biomass (AFDW/g) of macrofauna (>1mm) per 0.2 sq.m. Hamon Grab.

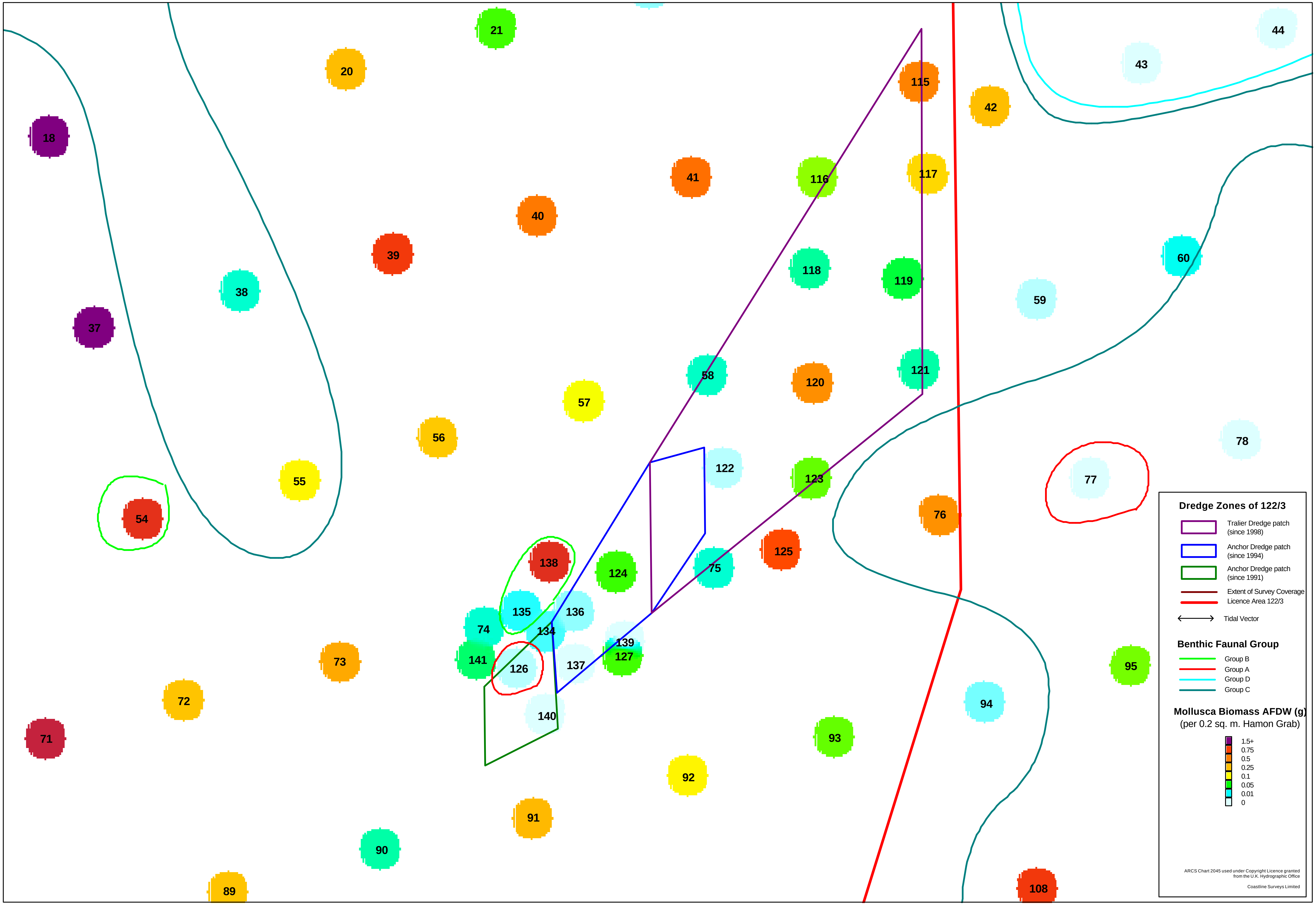


Figure 6.7.4b. Map of the intensively-dredged area showing a grid thematic map for the mollusc biomass (AFDW/g) per 0.2 sq.m. Hamon Grab.

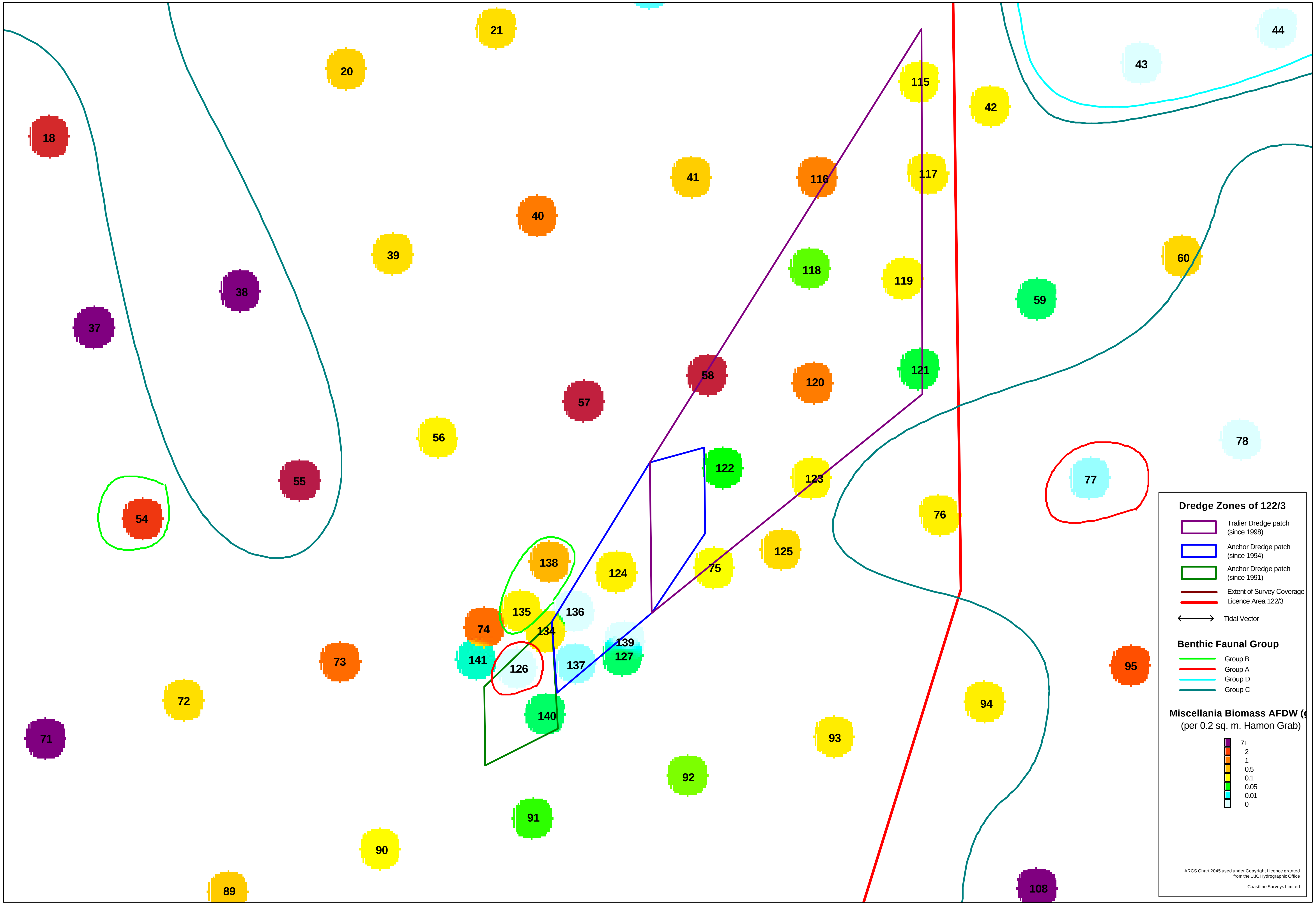


Figure 6.7.4c. Map of the intensively-dredged area showing a grid thematic map for the miscellania biomass (AFDW/g) per 0.2 sq.m. Hamon Grab.

### 6.7.5 Impact on Body Size

These data for species variety, population density and biomass of benthic macrofauna close to the sites of anchor dredging imply that after cessation of dredging initial recolonisation results in an increase in population density of typical species from the surrounding deposits. These species then increase in diversity as more species colonise the deposits; biomass is subsequently restored by growth of the individuals in the population once species composition has been largely restored.

Figure 6.7.5a shows a map of the average body size (B/N) of the macrofauna at each of the sampling sites within the anchor-dredge area. Restoration of the body size by growth of the colonising species is clearly far from complete at Station 136 after more than 395 days post-dredging (see also Table 6.7.2a). Again, there is some suppression of the size of the macrofauna at Station 140, more than 18 months after cessation of dredging.

These data for the time taken for restoration of biomass agree with those in the literature where recovery of the biomass after initial recolonisation by the macrofauna of sands and gravels has been reported to take 2-3 years (Désprez, 1992, 2000; Kenny and Rees, 1994, 1996; Newell *et al*., 1998). Figure 6.7.5b shows the relative rates of recovery of species variety, population density and biomass recorded by Désprez (2000) in deposits off Dieppe, France, following cessation of dredging in 1994. Species richness (S) and population density (N) evidently reached maximal values within 16 months of cessation of dredging. Biomass values, however, showed only a modest increase at 16 months, and continued to increase at 28 months after dredging had ceased.

These data show that critical stages in the recolonisation process, including an increase in species variety and population density, occur soon after cessation of dredging, but an increase in biomass following growth of the colonising species is achieved over a longer time.

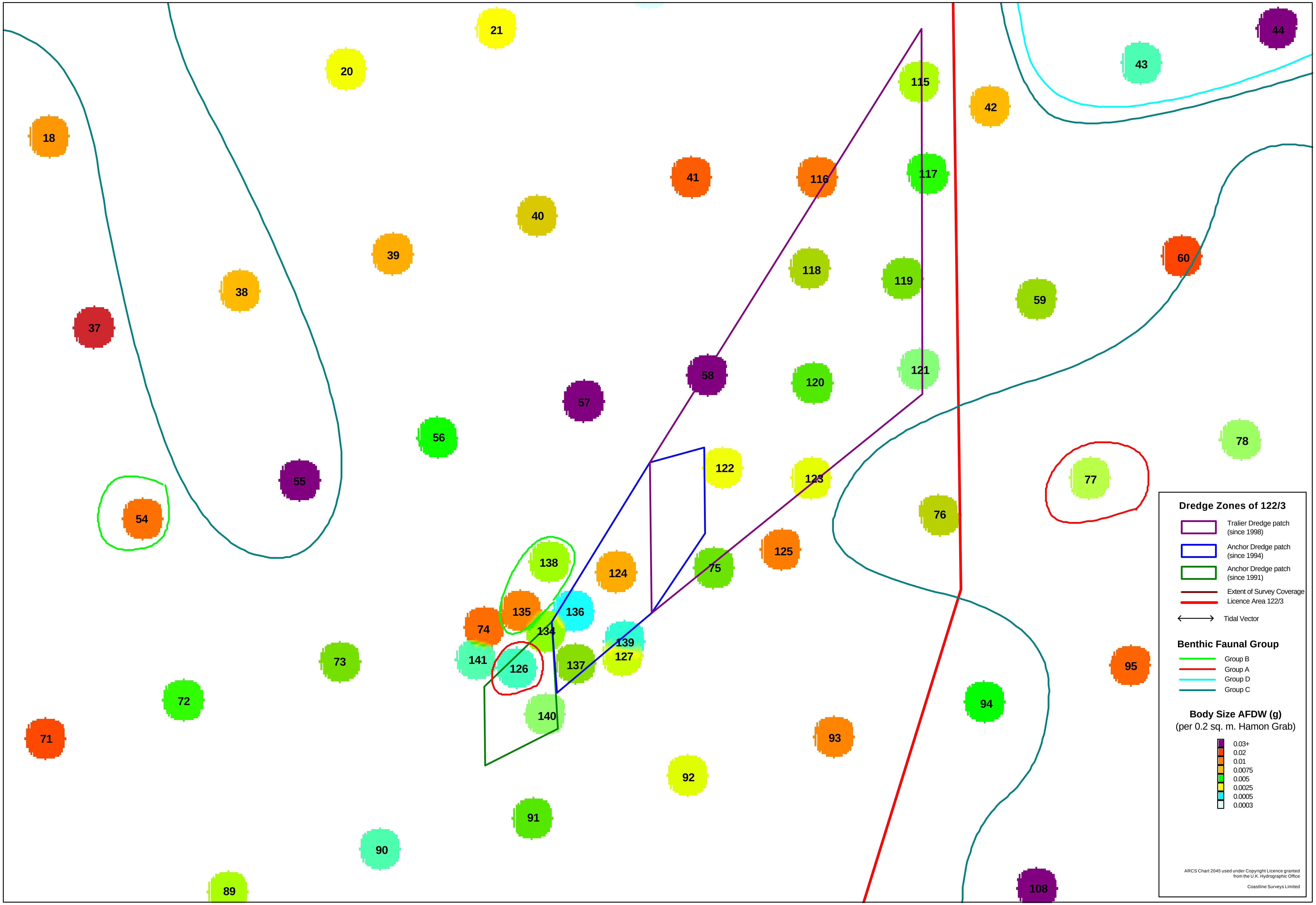


Figure 6.7.5a. Map of the intensively-dredged area showing a grid thematic map for the body size per 0.2 sq.m. Hamon Grab.

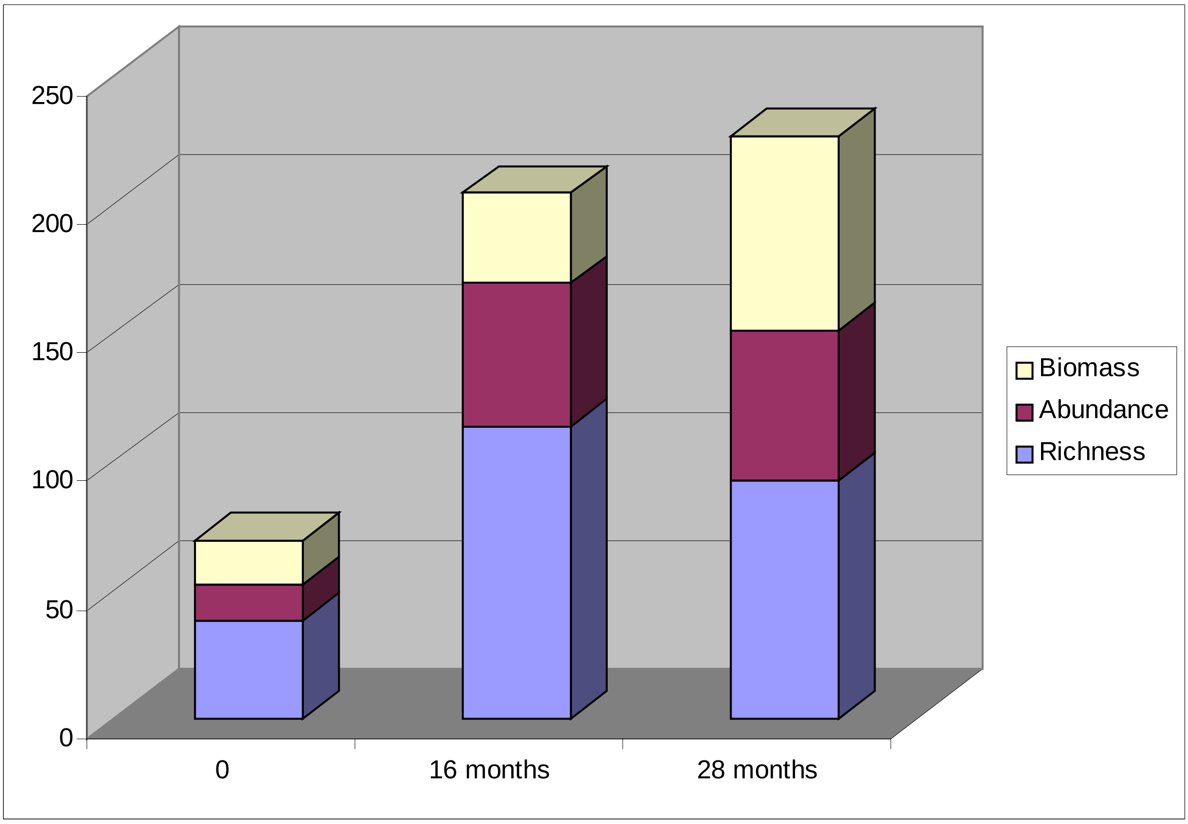


**Figure 6.7.5b** Diagram showing the rate of recovery of species richness, abundance (number per $m^2$), and biomass (g per m2) of benthic invertebrates following cessation population density and biomass recorded by Désprez (2000) in deposits off Dieppe, France, following cessation of dredging in 1994

## 6.8 Nature and Rate of Recovery Processes

These data show that anchor dredging has an impact on species variety, population density and biomass of benthic macrofauna within the boundaries of the dredged sites. Inspection of the records from the operating dredgers allows some estimates of the time course and sequence of recovery in the initial phases of the recolonisation process. Restoration of the species variety in the dredged areas to within 70-80% of that which occurs in the surrounding deposits occurs in 7 days after dredging at Station 134, and generally within 100 days at other stations. Restoration of the population density can also occur rapidly. At Station 134, for example, restoration of population density to within 86% of that in the surrounding deposits evidently occurred within 7 days. In general, the data summarised in Table 6.7.2 suggest that restoration of population density is achieved to within 60-80% of that in the surrounding deposits in approximately 175 days after cessation of dredging.

Finally, restoration of biomass by growth of the individuals is far from complete even after 18 months. A generalised flow diagram showing the sequence of recovery of the macrofauna in marine deposits based on the above data is shown in Figure 6.8.

Obviously the nature and rate of the recolonisation and recovery processes needs to be studied systematically at time intervals that reflect the rapid initial colonisation phase and the slower rates of increase in species diversity, population density and biomass. Inspection of Text Table 6.7.2a does, however, allow some comparisons between the rates of recolonisation and recovery in anchor-dredge sites with those in the trailer-dredge site to the northeast (see Figure 3).

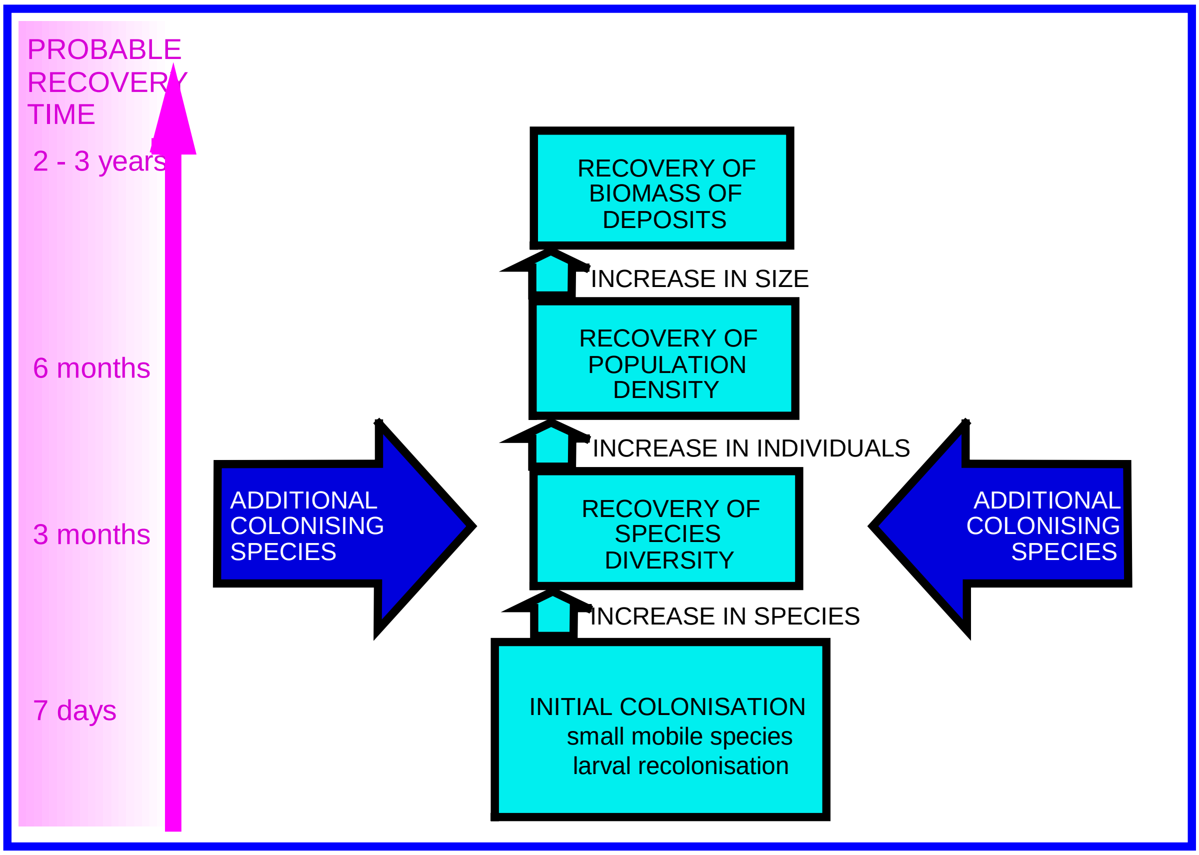


**Figure 6.8**. Generalised flow diagram showing the sequence of recolonisation and recovery in marine gravel deposits, based on the population density and species diversity in gravel deposits following known periods since the deposits were anchor-dredged.

Inspection of Text Table 6.7.2 shows that a recovery of 86% of the species diversity can occur within 20 days after trailer dredging, and that full recovery is achieved in approximately 80 days. Recovery of the population density to within 30-60% of that in the surrounding deposits is achieved within 80 days, but this is not significantly faster than that recorded in anchor-dredge pits. The biomass in general shows less than 20% recovery in a similar period.

The data for trailer-dredge areas suggest, therefore, that recovery of species diversity may occur somewhat faster within the narrow trailer-dredge tracks compared with the larger pits in the seabed associated with anchor-dredging. The time required for restoration of population density is not dissimilar to that for anchor-dredge sites. Finally, the biomass in trailer-dredge areas shows some recovery after 80 days but as in the case of anchor-dredging, is still suppressed by at least 80% compared with that in the surrounding deposits 80 days after cessation of dredging.

One of the problems encountered in analysis of seabed resources is that sampling of biological communities is often carried out under difficult conditions in sediments that show strong spatial variations in habitat type and associated community composition. Univariate indices of community composition such as species variety (*S*), population density (*N*), biomass (*B*) and indices such as body size (*B/N*) that depend on them show considerable variability. The ratio of 'noise-to-signal' in the data that is caused by sample-to-sample variability can then mask important indices of recolonisation and recovery such as those described above.

What is clearly needed, therefore, are systematic data on the recovery processes that are linked to what we now know to be the likely timing of the recovery processes and (importantly) for a sampling strategy to be devised that reduces sample-to-sample variability sufficiently to define recovery in anchor-dredge and trailer-dredge sites more precisely than we have been able to so far. The following section presents results that show the number of samples that are required to define species diversity in marine deposits, and the implications of this for marine environmental impact assessment and monitoring strategies.

## 6.9 Biological Diversity in Coastal Habitats

Appendix Tables 9, 10 and 11 show the species variety and abundance of individuals in three types of sediments identified by multivariate analysis of the deposits from the North Nab survey area. Appendix Table 9 summarises the data for the biota of sands and muds, Appendix Table 10 for the biota of coarse gravel and Appendix Table 11 the biota for gravels.

Figure 6.9a shows a series of 'Species Discovery Curves' for the macrofauna in the three types of sediments. The species in each of a series of samples of 0.2 $m^2$ have been plotted as a cumulative curve showing the additional taxa recorded in repeated replicates for each of the three types of sediment. The samples have been arranged in decreasing order of additional species discovered and can be used to determine both the total number of species that occur in each type of deposit, and the number of replicate samples that are required to provide a reliable estimate of species diversity.

Inspection of Figure 6.9a shows that the total number of species, as judged from the point at which no further taxa were discovered despite further replicate samples, was 82 in the 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, probably reflecting the habitat complexity of gravels compared with sands and muds. The total number of taxa in the deposits is therefore linked to the types of substratum in the survey area.

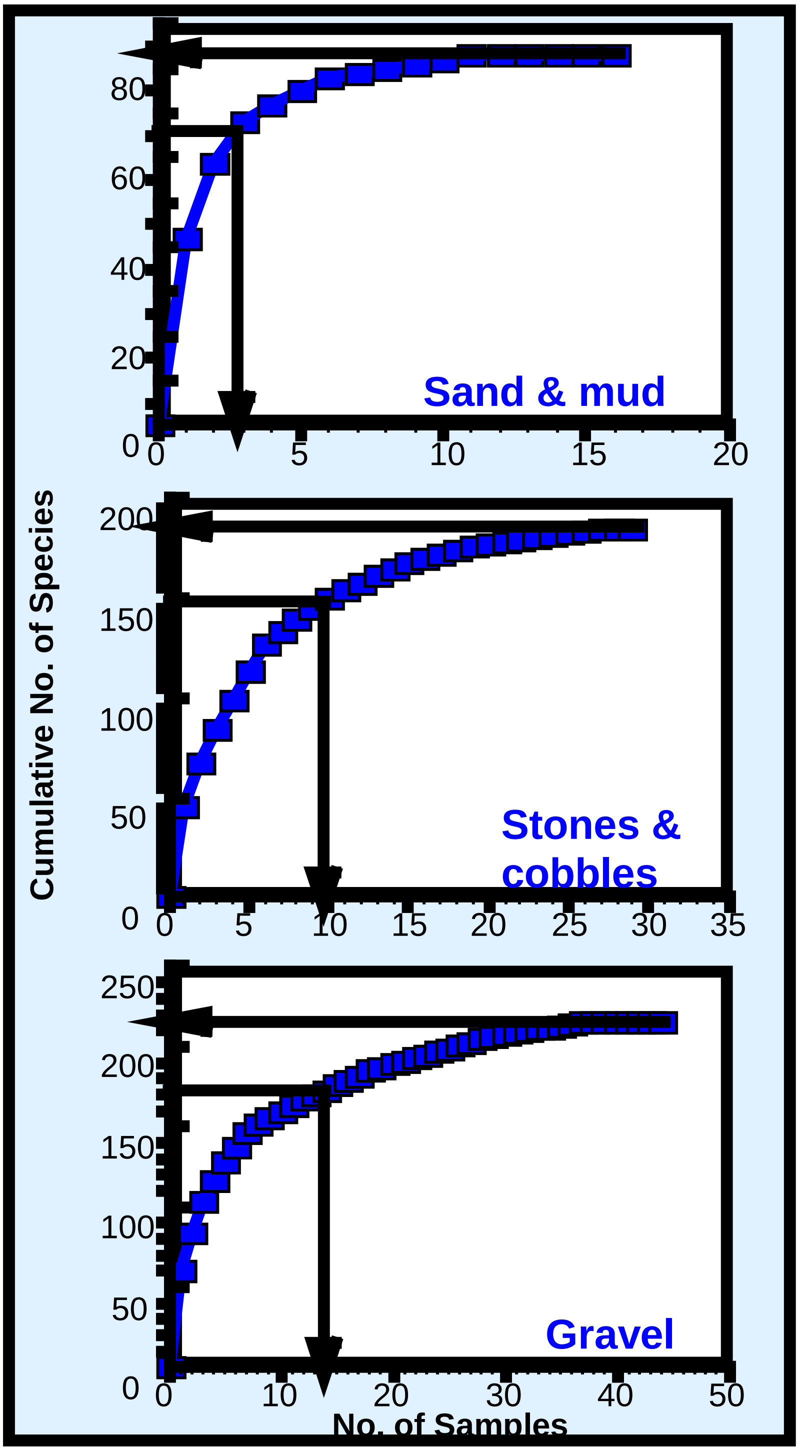


**Figure 6.9a.** Species discovery curves for the macrofauna in the three types of deposit recorded from the North Nab survey area in March 1999. The species recorded from a series of samples have been plotted as a cumulative curve showing the additional taxa recorded in a series of samples that comprise each of the three types of sediment. The total species complement and the number of samples required to establish 80% of the species diversity is indicated by arrows.

A second feature of interest is that the number of replicate samples 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 2-3 replicate samples of 0.2 $m^2$ are required to discover at least 80% of the species present in the deposits, even if as many as 82 taxa are present. Similar results have been obtained for sands and muddy deposits off Folkestone, Kent by Newell *et al*. (2001). Where the deposits have a more even distribution and comprise a larger species variety as in the coarse gravel samples, up to 10 replicate samples are required to define 80% of the species present. Finally, in gravels of the survey area, at least 13 replicates 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 clearly show that dredging for marine aggregates at North Nab Area 122/3 does have an impact on the relative contribution of different species comprising the benthic biological resources. A k-dominance curve shows the relative contribution of each component species to the total species complement in the community. Dredged areas (coded green in Figure 6.9b) are dominated by one, or a few species compared with undredged deposits. Dredging therefore has an impact on the relative proportions of species in the community. The question arises whether this is imposed by anchor dredging, by trailer dredging, or is associated with both types of extraction of seabed deposits.

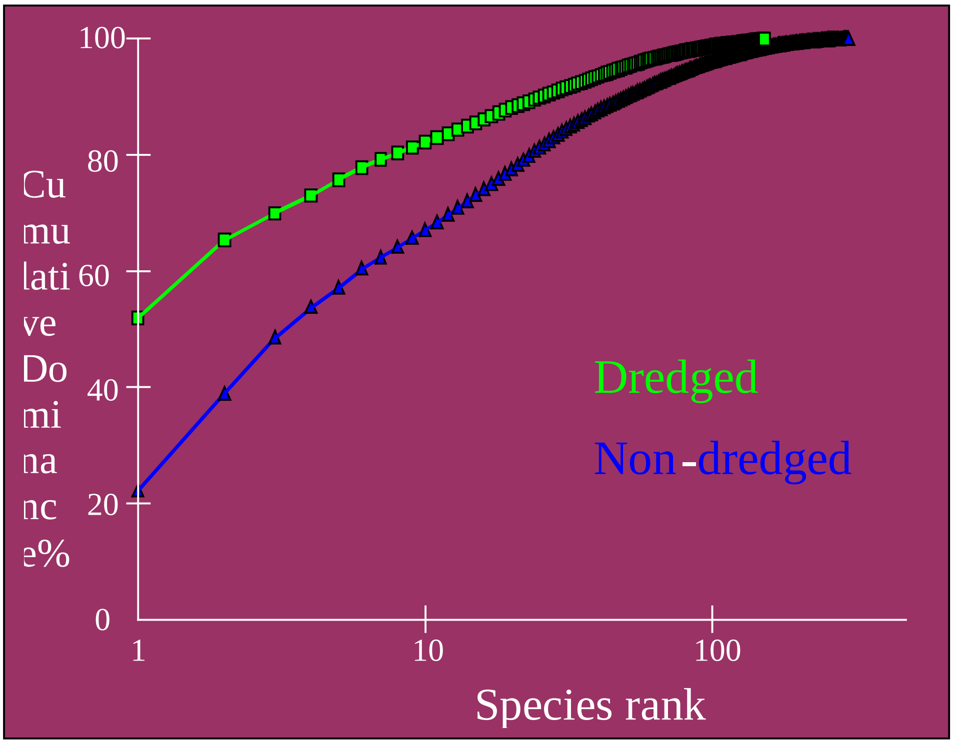


**Figure 6.9b.** Dominance curves plotted for pooled samples from dredged and non-dredged sites of Production Licence Area 122/3.

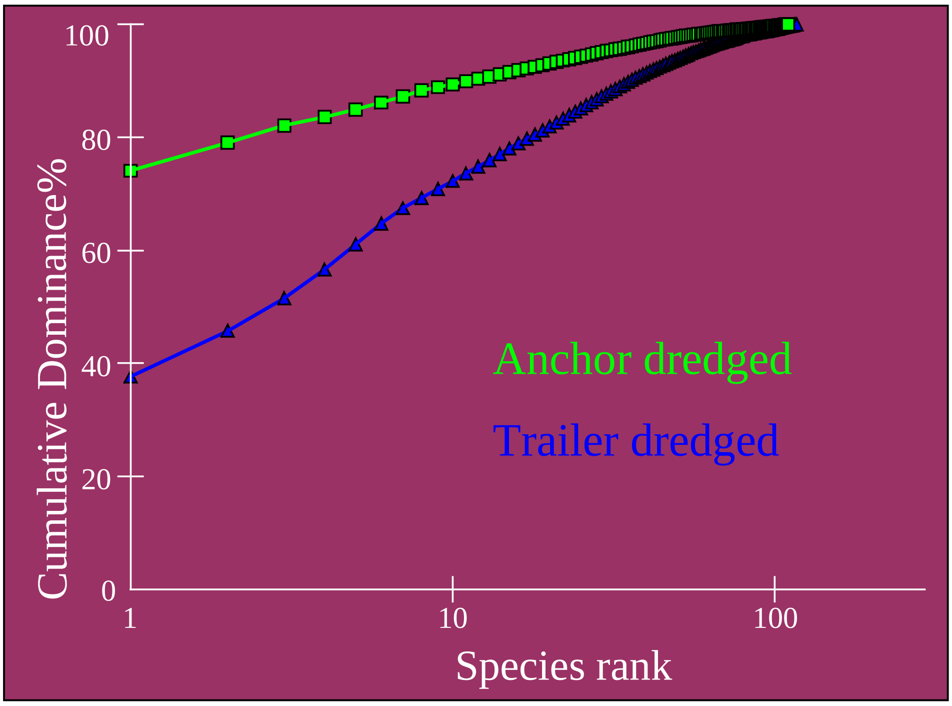


**Figure 6.9c.** Dominance curves plotted for pooled samples from within the anchor dredge site and within the trailer dredge part of Production Licence Area 122/3.

Figure 6.9c shows dominance curves plotted for pooled samples from within the anchor dredge site and within the trailer dredged part of Production Licence Area 122/3. The data show that anchor dredged sites are heavily dominated by one species (*Ampelisca* sp) whilst trailer dredged sites show a normal distribution of species composition. These differences account for the differing impacts of anchor dredging and trailer dredging on biological community composition identified by multivariate techniques (Figure 6.1.3c). Whether this is related to the type of dredging itself, or to differences in the relative intensity of dredging in the anchor-dredge and trailer dredging sites is at present unknown.

## 6.10 Implications for Sampling Strategies

Our results for the North Nab Production Licence Area 122/3 have implications for the spatial scale and frequency of marine monitoring programmes designed to assess the impact of marine sand and gravel mining, and the rate of recolonisation following cessation of dredging. We have shown that the principal impacts of dredging of non-screened cargoes are confined to the immediate dredge area itself. It has also been shown that for a non-screened aggregate mining area, far-field effects on benthic macrofauna may be associated with sedimentation of organic components in the outwash downstream from the dredge site. These occur mainly in an elongated 'halo' up to 3 km along the axis of dispersion of outwash on the ebb and flood tidal streams. This potential impact zone accords well with direct measurements of the morphology of dispersing plumes, including those from screened cargoes using acoustic backscatter methodology (Hitchcock and Drucker, 1996; Hitchcock *et al*., 1998; Newell *et al*., 1998, 1999).

The implication for marine monitoring surveys elsewhere is that the principal sites of impact of sand and aggregate mining is likely to be in the immediate vicinity of the dredge site, and for a distance of up to 3 km along the axis of the tidal streams, depending on the speed and direction of local currents. Sampling stations therefore need to be arranged relatively closely to define biological impact in relation to the dredge areas, the exact location and boundaries of which need to be defined with side-scan sonar at the time of the survey. Additional sampling stations then need to be arranged to define 'far-field' impact along the axis of dispersing material discharged from screening and hopper overspill, depending partly on the speed and direction of tidal currents in the discharge area.

In general, a survey zone extending at least 4 km on each side of a dredge site will be required to define the boundaries of potential ‘far field’ components of the outwash, and further sampling stations are advisable to establish background values downstream from the dredge site. With heavily screened cargoes, the indications from the plume monitoring are that this ‘far field’ component may extend as far as one tidal excursion by virtue of the near bed benthic plume extension discussed in Section 5.

The results for the North Nab study site also show that the statistical methods used to assess environmental impact have an important bearing on the number of replicate samples required to establish environmental impact of sand and aggregate dredging on benthic biological resources. Changes in community composition of benthic macrofauna in relation to environmental gradients, including disturbance by man, have been widely studied in the North Sea and U.K coastal waters in recent years. In many cases non-parametric multivariate analysis of community structure has revealed changes along gradients some distance from point sources of environmental disturbance whereas univariate indices are less sensitive (Gray *et al*., 1988, 1990; Warwick and Clarke, 1991; Dawson Shepherd *et al*., 1992; Clarke, 1993; Clarke and Warwick, 1994b).

Such work has also shown that many species within the benthic communities that occur in coastal muds, sands and gravels are interchangeable in the way that they characterise the community. Community composition required for multivariate analysis of community structure can therefore be adequately defined by analysis of only a proportion of the taxa present (Gray *et al*., 1988) or by consideration of higher taxonomic levels than species (Warwick, 1993; Somerfield and Clarke, 1995; Clarke and Warwick, 1998).

Clarke and Warwick (1998) have referred to this excess of taxa required for satisfactory definition of the structure of benthic communities as “structural redundancy”. It may account for the fact that communities of macrobenthos (>1 mm) in a number of recent surveys of sands and gravels can be satisfactorily defined and separated by multivariate analytical techniques, despite evidence of serious under-sampling by conventional 0.2 $m^2$ Hamon grab techniques (see also Newell *et al*., 2001).

In contrast, univariate indices of community composition are generally strongly dependent on sample size. Such indices are often used to determine the changes in community composition that occur in relation to pollution gradients and have been used to define the nature and rate of recolonisation processes in our study of the North Nab site. They include the number of species (*S*), population density (*N*), biomass (*B*), body size (*B/N*) and common diversity measures such as evenness (*J*), diversity (*H'*) and richness (*d*). Because individuals of a species are rarely distributed randomly and are clustered often in relation to small-scale environmental variations, adequate sampling of the larger macrofauna may require larger samples and more widely-spaced replicates than smaller sized components of the benthos (Clarke and Green, 1988; Gage and Tyler, 1991; Grassle and Maciolek, 1992; Gray, 1994; Warwick and Clarke, 1995, 1996). The size of sample, number of replicates and number of individuals within the sample thus affects the univariate indices of community structure that are often used in interpretation of environmental disturbance on the benthos.

The implications of the results that have been presented for the North Nab survey area are that a decision needs to be made at an early stage in the monitoring programme on whether non-parametric multivariate analyses are to be used as a method for detection of environmental impact and recovery, or whether univariate analyses are preferred. If multivariate methods are to be used, then single samples with a 0.2 $m^2$ Hamon grab evidently yield sufficient information on population structure to separate macrofaunal communities, despite large sample-to-sample variability associated with under-sampling of the rich benthic communities of gravels with conventional grabs.

If, on the other hand, impact and recovery processes are to be monitored using single population variables such as number of species (*S*), population density (*N*), biomass (*B*) or body size (*B/N*), we have shown that as many as 10-12 replicates may be required to satisfactorily define 80% of the taxonomic diversity in marine gravel deposits. On pragmatic grounds it is probably then preferable to confine the number of sampling stations to a series along the axis of dispersion of outwash from the dredge site, and to avoid excessive 'noise to signal ratios' at those stations by ensuring that the number of replicates is sufficient to identify at least 80% of the taxa present.

## 7.0 DISCUSSION

The terms of reference for this study were, overall, to undertake an integrated physical and biological assessment of the seabed resources as may be impacted by marine aggregates dredging. These objectives have been met. In the early stages of the project, following the analysis of the first set of biological grabs, the resources of the project allocated to physical investigation of the seabed by more extensive underwater video and diver investigation were re-allocated to extending the scope of the biological studies. In particular, this was to identify the very near-field effects and, unexpectedly, to make first approximations to rates of recovery of biological resources that was originally not included within the work-scope.

We have demonstrated that ADCP techniques supported by traditional water sample characterisation still provide a best value approach to defining the gross morphology of the dispersing plume. New developments in data manipulation and image processing have enabled us to re-process datasets we collected for earlier studies (Hitchcock *et al*., 1998) and find new components and sub-divisions. Specifically, the extension to the near-bed sediment plume at the benthic boundary that is seen to persist beyond the limits of past surveys is important and should be considered in great detail. This is especially so in light of the trend towards offshore resources where water depths are deeper and sediments may have the propensity to travel further before deposition.

### 7.1 Physical Effects of Dredging

We have shown that a small-scale operation of some 150,000 tonnes per annum, even with intensive extraction rates per $km^2$, has a limited impact on the environment. The evidence suggests that, other than where sediments are physically disturbed by removal, physical resources are largely unaffected. There is some minor change in sediment characteristics. Benthic biological resources would appear to be able to cope with the stresses induced by the minor change in sediment type, and indeed appear to benefit by the increased food resource provided by disturbance of the sediments.

What is now apparent with the development of image analysis techniques is that with the development of an extension to the nearbed benthic boundary, the sediment plume provides a mechanism for potential extension of the impact beyond the zone of extraction. This effect, apparently not significant on the North Nab 122/3 site, is expected to be significant for those areas where screening of cargoes takes place. More importantly, this may hold especially true for those deeper water communities (40 metres or so), less exposed to and tolerant of natural disturbances to the sedimentary regime.

It is stressed that scaling up of the results recorded so far from the comparatively shallow water small scale operations to deeper water and more extensive operations with screening of cargoes is not a realistic option. Fundamental data collection at these deep-water sites is required to understand the response signatures of the benthic communities to disturbances, both natural and anthropogenic, and the extent of plume migration under the different phases of development and dispersion.

## 7.2 Biological Effects of Dredging

The results that have been cited above for the North Nab survey area show that the data for particle size composition of the sediments fall into well-defined groups that show a high level of internal similarity between stations in any one Group. In contrast, whilst the data for samples of macrobenthos also fall into well defined Groups or communities, there is considerable sample-to-sample variability in species numbers (*S*), population density (*N*) and biomass (*B*) (see Text Table 6.1.2a). Similar results have been obtained for gravel and sand deposits off Hastings, Kent by Kenny (1998), off Orford Ness, Suffolk (Seiderer and Newell, 1999) and off Folkestone, Kent (Newell *et al*. 2001).

A probable explanation for the clear separation of the macrofaunal groups that occurs despite the variability of the samples used in the multivariate analysis of community composition is that there is a high degree of “redundancy” in the species that characterise community composition (Clarke and Warwick, 1998). Gray *et al*. (1988) showed, for example, that ordinations for macrobenthic community structure at six stations in Frierfjord, Norway, were similar to the results for the entire species complement even when only 20% of the species, selected at random, were used in the analyses.

Warwick (1993) subsequently showed that analysis at taxonomic levels higher than that of species shows similar patterns to the full species analysis. The fact that there is a high degree of variability between the single samples taken at each of the survey stations is therefore unlikely to affect interpretation of the results of multivariate analysis community composition in the survey area adjacent to North Nab Production Licence Area 122/3. Each of the single samples taken evidently contains sufficient taxa to define the community from which the sample was taken, despite the under-sampling incurred by use of a 0.2 $m^2$ Hamon grab in the complex communities of macrobenthos that occur in coastal gravel deposits (*see also* Whitlatch, 1981; Morse *et al*., 1985; Parry *et al*., 1999)

The variability between samples of macrobenthos obtained with a 0.2 $m^2$ Hamon grab has important implications, however, for marine environmental monitoring programs that depend on univariate analysis of species diversity, population density or biomass of the macrofauna for an assessment of the impact of environmental variables, including disturbance by man, on benthic biological resources. A high diversity of species that are uniformly represented in the population evidently leads to serious under-sampling of the macrofauna by conventional methods such as the 0.2 $m^2$ Hamon grab commonly used in benthic surveys of sands and gravels. Estimates of species numbers, population density, biomass and indices that depend directly on these are likely to be heavily dependent on the number of replicate samples taken, the type of deposit, the number of taxa present the distribution of species within the population and probably the size of grab sample taken (see also Warwick and Clarke, 1995; 1996).

The conclusion from our survey of the macrobenthos of sands and gravels in the North Nab survey area is that multivariate analyses of community composition are evidently robust, and give a clear separation of faunal groups based on single samples, despite variability in the data between stations in the survey area. However, as many as 10-13 replicate samples are evidently required for assessment of indices that depend on species composition and distribution of species within the macrobenthic population. Conventional 0.2 $m^2$ Hamon grab samples are commonly used to obtain data on species variety (*S*), population density (*N*) and biomass (*B*) for analysis of community composition. The results show that at least 3 replicate samples are required to obtain a satisfactory assessment of the species composition of the macrobenthos of sands and muds, but 10 or more replicates are required for gravels.

## 7.3 Synthesis: Implications for Management

Efforts to define impact generally concentrate on the biological resources. Within this project, significant progress has been made into defining these biological components from first principles. Re-allocation of funds from the physical investigations originally proposed reflects the importance associated with these aspects. The findings of this project may be used to refine best practice procedures for conducting benthic studies at aggregate sites, a number of which have recently been produced (*see*, for example, John *et al*, 2000 and Boyd *et al*, 2002).

Impacts due to marine aggregate mining in small intensively dredged sites such as the study area North Nab 122/3, which are subject to reasonable natural disturbance, appear to be relatively localised and minor. Natural disturbances prior to dredging operations have encouraged development of adaptive communities suitable for such environments, and appear capable of dealing with and recovering from stresses caused by the dredging activities within reasonable time spans.

Physical effects from the non-screening operation are largely confined to the physical actions of the draghead on the seabed. Sidescan sonar and high-resolution bathymetry provide robust evidence of disturbances. Persistence of disturbances and recovery of the seabed to pre-dredge conditions has not been possible to determine within the timescale of the project, without abandoning an area of the production licence. However, the lack of evidence of physical impacts beyond the dredge activity is in itself proof of the small potential for cumulative impacts with other dredging operations nearby.

Sites which have been left undredged for known times suggests that initial recolonisation by mobile components of the benthos can occur within weeks with some 70-80% of the species variety returning. Restoration of biomass is achieved by growth of the small individuals that recolonise the deposits.

This stage is incomplete even after 18 months compared with areas some distance away from the dredge site, and this finding is in keeping with anecdotal information available from the literature.  The results for trailer-dredged studies elsewhere indicate that species diversity may initially recover much quicker.  Population density is not dissimilar to anchor dredge sites, with biomass recovering to within 80% of the undredged sites within 3 months.

We conclude with the following general hypothesis based on this study and another partial study carried out in the Southern North Sea (Newell *et al*, 2002) on a trailer dredge study site:-

(1) The degree of suppression of the fauna in the dredge site itself is clearly dependent on the intensity of dredging. In high intensity dredging (North Nab) the suppression of population density, species variety and biomass can be as high as 60-80%. In areas that are dredged less intensively by trailer techniques, the suppression is either less than at anchor dredge areas (North Nab), or undetectable (North Sea).

(2) There is no evidence of an impact outside the immediate dredge sites.

(3) Both sites show some evidence of an enhanced biomass and population density at some distance from the dredge site, possibly reflecting the deposition of organic components from fragmented invertebrates discharged in the outwash.

(4) Recovery of population density and species variety can be very rapid indeed. This depends on the degree of disturbance to which the area is subjected under natural conditions. In shallow water wave disturbed areas such as the North Sea, colonising species are mobile and well adapted to rapid recolonisation. In more stable (equilibrium) communities such as occur on coarse rocks and cobbles, recolonisation is slower.

(5) Recovery of biomass is achieved by growth of the recolonising individuals. In this case restoration of biomass generally requires at least several years. In some of the deeper water communities that we have recently analysed, individual species may be at least 20 years old. This implies that deep-water stable equilibrium communities may require a time of at least 20 years for recovery, compared with 2-3 years in shallow water coastal sands.

(6) Anchor dredging has a significant impact on the species variety, population density and biomass of benthic macrofauna, although without screening is largely limited to within a hundred metres of the active dredged zone. Trailer dredging, on the other hand, appears to have a much lesser impact on species variety, population density and biomass, although this may be limited to the lower intensity of trailer dredging activities in the study areas. However, species recovery data suggests that recovery is quicker for trailer dredge areas, due to the reduced distance of ‘inwalk’ for colonising species (only the widths of trailer tracks), compared with the larger total destruction of an anchor dredged area.

(7) On the available evidence collected herein, we would suggest that trailer dredging over a wide area at an intensity carefully matched to the potential times for species recovery (indicated by the response times to natural disturbances e.g. turbulent shallow water or less disturbed deeper waters) will be more sustainable than intensively dredging small areas of seabed.

Survey protocol must take notice of the implications of grab sample size and sediment type. In the case of sands and muds that are dominated by one or a few taxa, only 0.4-0.6 $m^2$ of seabed (i.e. 2-3 replicate samples with a 0.2 $m^2$ Standard Hamon Grab) are required to discover at least 80% of the species present in the deposits, even when s many as 82 taxa are present. Where deposits comprise a larger species variety such as in coarse gravel samples, a area of seabed of up to 2.0 $m^2$ (i.e. 10 replicates of a 0.2 $m^2$ grab) are required to define 80% of the species present. Finally, we have shown that in coarse gravels found at North Nab, an area of seabed of at least 2.6 $m^2$ (i.e. 13 replicate samples of a 0.2 $m^2$ grab) are required.

The project has indicated that the effects of dredging in deeper waters and those less disturbed by natural events, and specifically those sites where screening takes place, may be more susceptible to impact and less capable of quick recovery. The near bed extension to the plume that has been proven in both this study, reprocessing the data of our previous work (Hitchcock *et al*., 1998) and work in the southern North Sea (Dickson and Rees, 1998) provides an important mechanism for potential extension of impacts beyond the boundaries discovered so far. Investigation of these ‘far field’ effects integrating monitoring of the near bed plume extension is clearly required.

The results of this study and a recent study at Area 408 in the southern North Sea (Newell *et al*, 2002) show that the rate of recolonisation by mobile 'opportunistic' species characteristic of disturbed sands and gravels can be sufficiently rapid to be in equilibrium with the rate of loss by trailer dredging at small scales. However, restoration by growth of the colonising individuals takes longer, and at Area 408 would appear to be largely complete within 12 months. Moreover, these results should not be applied uncritically to other areas. At higher levels of exploitation, for example, it is probable that the rate of removal of macrofauna by dredging may exceed the rate of recolonisation, even in high-energy sites.

Where deposits are stable, as in low energy coastal or deep-water sites, or where deposits are coarse, the biological community is represented by long-lived and slow growing components that have a slow rate of reproduction. These '*k*-strategists' or 'equilibrium species' may take longer to recover both species variety and population density and for the biomass to be restored by growth of the individuals.

Importantly, the detailed analyses of these and other data for this project has revealed the susceptibility of analysis methods to 'noise' within the datasets. This is caused by inter-sample variability due to significant under sampling of the diverse benthic macrofauna of sands and gravels by conventional methods. We have shown that single samples of macrofauna obtained from a 'Hamon' type grab contain sufficient taxa to use non-parametric multivariate analytical techniques to define community composition. Values for individual variables, such as species variety are, however, heavily dependent on the number of replicate samples taken. At least 3 replicate samples are required to obtain a satisfactory assessment of the species composition of the macrobenthos of sands and muds, but that 13 or more replicates are required for gravels. The repercussions of this in terms of scale, frequency, density of sampling sites and number of replicate samples and subsequent cost implications must be carefully considered when designing suitable monitoring protocols.

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# APPENDICES

**Appendix Table 1.** Listing of the benthic samples taken at the North Nab study site in 1999-2001, using a 0.2m$^2$ Hamon Grab. Positions are shown reference to OSGB36 (in metres). Also listed are the percentage passing each particle size fraction used for the statistical and multi-dimensional scaling analysis.

| Site # | Easting | Northing | % Gravel | % Sand | % Fines | d50 |
|---|---|---|---|---|---|---|
| 1 | 470961.4 | 87143.3 | 69 | 29 | 2 | 8.68 |
| 6 | 472908.2 | 87609.7 | 69 | 30 | 1 | 7.89 |
| 7 | 471045.2 | 86619.1 | 62 | 37 | 1 | 5.33 |
| 8 | 471481.1 | 86749.8 | 76 | 23 | 1 | 9.69 |
| 9 | 471839.7 | 86834.8 | 57 | 42 | 1 | 4.59 |
| 10 | 472248.2 | 86935.0 | 57 | 42 | 1 | 4.06 |
| 11 | 472621.0 | 87025.2 | 72 | 27 | 1 | 10.4 |
| 17 | 469562.2 | 85749.1 | 78 | 21 | 1 | 12 |
| 18 | 470440.5 | 85974.7 | 76 | 22 | 2 | 11.82 |
| 20 | 471208.0 | 86148.1 | 64 | 34 | 2 | 6.71 |
| 23 | 472382.6 | 86468.1 | 69 | 30 | 1 | 9.26 |
| 24 | 472736.2 | 86537.3 | 61 | 38 | 1 | 5.65 |
| 25 | 473151.5 | 86650.5 | 51 | 49 | 0 | 5.83 |
| 27 | 474008.4 | 86874.3 | 33 | 66 | 1 | 0.22 |
| 28 | 474970.1 | 87111.5 | 0 | 99 | 1 | 0.19 |
| 32 | 466280.6 | 84418.7 | 62 | 36 | 2 | 7.23 |
| 34 | 468238.0 | 84887.5 | 61 | 37 | 2 | 5.65 |
| 35 | 469207.5 | 85146.1 | 74 | 24 | 2 | 12.9 |
| 36 | 470176.8 | 85412.4 | 70 | 28 | 2 | 7.15 |
| 37 | 470557.8 | 85481.5 | 65 | 34 | 1 | 8.15 |
| 38 | 470937.4 | 85575.0 | 63 | 35 | 2 | 5.98 |
| 39 | 471330.1 | 85670.8 | 73 | 26 | 1 | 10.8 |
| 40 | 471703.0 | 85771.4 | 63 | 36 | 1 | 4.79 |
| 41 | 472104.6 | 85870.6 | 72 | 28 | 0 | 10.44 |
| 42 | 472875.3 | 86053.3 | 54 | 44 | 2 | 3.35 |
| 43 | 473263.7 | 86165.4 | 45 | 55 | 0 | 1.7 |
| 44 | 473617.1 | 86251.8 | 4 | 95 | 1 | 0.19 |
| 45 | 474610.1 | 86480.7 | 1 | 99 | 0 | 0.21 |
| 46 | 475590.1 | 86747.1 | 1 | 98 | 1 | 0.2 |
| 47 | 476567.8 | 86973.9 | 38 | 61 | 1 | 0.43 |
| 49 | 465922.4 | 83816.2 | 37 | 58 | 5 | 0.77 |
| 53 | 469805.1 | 84770.1 | 66 | 33 | 1 | 6.61 |
| 54 | 470680.2 | 84986.6 | 80 | 19 | 1 | 12.55 |
| 56 | 471447.4 | 85198.4 | 79 | 21 | 0 | 10.53 |
| 57 | 471825.0 | 85290.4 | 79 | 21 | 0 | 12.22 |
| 58 | 472142.6 | 85359.6 | 79 | 20 | 1 | 15.09 |

| Site # | Easting | Northing | % Gravel | % Sand | % Fines | d50 |
|---|---|---|---|---|---|---|
| 59 | 472999.0 | 85554.8 | 57 | 41 | 2 | 5.87 |
| 62 | 474249.0 | 85891.1 | 74 | 24 | 2 | 11.71 |
| 63 | 475237.5 | 86145.7 | 3 | 97 | 0 | 0.23 |
| 64 | 476195.0 | 86390.0 | 2 | 98 | 0 | 0.35 |
| 65 | 477171.3 | 86628.9 | 61 | 37 | 2 | 5 |
| 67 | 466524.5 | 83451.3 | 44 | 54 | 2 | 1.97 |
| 68 | 467503.4 | 83698.0 | 54 | 44 | 2 | 3.15 |
| 69 | 468499.4 | 83955.5 | 52 | 45 | 3 | 2.69 |
| 70 | 469413.4 | 84172.3 | 73 | 26 | 1 | 12 |
| 71 | 470430.7 | 84420.4 | 67 | 31 | 2 | 9.54 |
| 72 | 470788.0 | 84517.6 | 77 | 22 | 1 | 11.33 |
| 73 | 471190.9 | 84618.1 | 71 | 28 | 1 | 8.86 |
| 75 | 472160.9 | 84861.2 | 72 | 27 | 1 | 10.8 |
| 76 | 472742.6 | 84999.1 | 74 | 25 | 1 | 9.47 |
| 77 | 473132.2 | 85091.4 | 78 | 22 | 0 | 9.54 |
| 78 | 473523.7 | 85190.7 | 75 | 25 | 0 | 13.11 |
| 79 | 473899.0 | 85286.2 | 64 | 36 | 0 | 7.65 |
| 80 | 474853.9 | 85534.9 | 4 | 95 | 1 | 0.18 |
| 81 | 475822.5 | 85777.8 | 0 | 99 | 1 | 0.25 |
| 82 | 476794.2 | 86006.9 | 1 | 98 | 1 | 0.25 |
| 84 | 466162.6 | 82841.9 | 42 | 54 | 4 | 1.07 |
| 85 | 467128.4 | 83076.7 | 43 | 53 | 4 | 1.33 |
| 86 | 468109.1 | 83311.8 | 44 | 52 | 4 | 0.95 |
| 87 | 469072.6 | 83564.1 | 53 | 44 | 3 | 3.35 |
| 88 | 470054.0 | 83801.6 | 56 | 43 | 1 | 3.35 |
| 89 | 470906.1 | 84025.4 | 57 | 42 | 1 | 3.76 |
| 90 | 471300.3 | 84132.5 | 77 | 23 | 0 | 9.13 |
| 91 | 471693.4 | 84213.6 | 64 | 35 | 1 | 6.04 |
| 92 | 472094.1 | 84321.2 | 72 | 28 | 0 | 8.77 |
| 93 | 472471.3 | 84424.5 | 62 | 37 | 1 | 5.52 |
| 94 | 472862.7 | 84512.4 | 85 | 15 | 0 | 10.92 |
| 95 | 473238.4 | 84606.8 | 85 | 15 | 0 | 17.23 |
| 96 | 473634.6 | 84695.7 | 87 | 13 | 0 | 15.71 |
| 97 | 474030.3 | 84798.9 | 88 | 12 | 0 | 12.57 |
| 98 | 474511.9 | 84918.0 | 55 | 44 | 1 | 4.45 |
| 99 | 475463.0 | 85173.6 | 12 | 88 | 0 | 0.21 |
| 104 | 471455.3 | 83655.0 | 63 | 36 | 1 | 5.52 |
| 106 | 472215.6 | 83832.2 | 70 | 29 | 1 | 8.58 |
| 108 | 472996.2 | 84032.7 | 60 | 38 | 2 | 6.83 |
| 109 | 471189.3 | 83050.9 | 60 | 39 | 1 | 5.33 |

| Site # | Easting | Northing | % Gravel | % Sand | % Fines | d50 |
|---|---|---|---|---|---|---|
| 113 | 472722.8 | 83437.9 | 75 | 25 | 0 | 10 |
| 115 | 472689.5 | 86119.9 | 83 | 17 | 0 | 13 |
| 116 | 472431.3 | 85868.1 | 59 | 40 | 1 | 5 |
| 117 | 472712.6 | 85878.5 | 68 | 32 | 0 | 7.53 |
| 118 | 472409.9 | 85632.4 | 75 | 25 | 0 | 14 |
| 119 | 472648.6 | 85604.5 | 79 | 21 | 0 | 14 |
| 120 | 472418.0 | 85340.6 | 69 | 30 | 1 | 9.08 |
| 121 | 472691.6 | 85375.2 | 70 | 29 | 1 | 8.29 |
| 122 | 472184.0 | 85120.2 | 73 | 27 | 0 | 10.4 |
| 123 | 472416.2 | 85091.5 | 81 | 18 | 1 | 13.6 |
| 124 | 471909.4 | 84847.6 | 68 | 31 | 1 | 8.77 |
| 125 | 472336.1 | 84905.3 | 76 | 23 | 1 | 9.26 |
| 126 | 471652.6 | 84601.1 | 85 | 15 | 0 | 7.65 |
| 127 | 471924.4 | 84634.2 | 76 | 24 | 0 | 11.33 |
| 129 | 472012.8 | 87902.3 | 68 | 31 | 1 | 9.26 |
| 131 | 471664.7 | 82670.1 | 52 | 47 | 1 | 3.35 |
| 132 | 472452.6 | 82873.0 | 75 | 24 | 1 | 14 |
| 133 | 473223.5 | 83063.9 | 64 | 35 | 1 | 7.53 |
| 134 | 471724.0 | 84699.2 | 100 | 21 | 0 | 33.15 |
| 135 | 471660.9 | 84747.2 | 78 | 13 | 1 | 10 |
| 136 | 471799.3 | 84747.2 | 87 | 21 | 0 | 14.75 |
| 137 | 471802.7 | 84611.4 | 79 | 40 | 0 | 9.31 |
| 138 | 471733.1 | 84877.0 | 59 | 27 | 1 | 4.53 |
| 139 | 471929.4 | 84670.0 | 72 | 25 | 1 | 10.89 |
| 140 | 471725.7 | 84479.2 | 74 | 46 | 1 | 7.72 |
| 141 | 471546.4 | 84623.9 | 53 | 55 | 1 | 3.1 |
| 142 | 467415.1 | 82805.4 | 43 | 32 | 2 | 1.05 |
| 143 | 468189.0 | 82999.1 | 66 | 40 | 2 | 8.61 |
| 144 | 469007.6 | 83202.6 | 57 | 25 | 3 | 3.56 |
| 145 | 469402.1 | 82799.0 | 74 | 33 | 1 | 8.52 |
| 146 | 469803.2 | 83404.8 | 65 | 22 | 2 | 6.71 |
| 147 | 470608.9 | 83006.3 | 77 | 24 | 1 | 7.82 |
| 148 | 470598.7 | 83601.1 | 75 | 31 | 1 | 9.47 |
| 149 | 471012.9 | 83414.3 | 68 | 36 | 1 | 7.65 |
| 150 | 473398.8 | 83205.3 | 63 | 34 | 1 | 8.15 |
| 151 | 473398.6 | 83795.5 | 65 |  | 1 | 7.78 |

**Appendix Table 2** Listing of the benthic samples taken at the North Nab study site in 1999-2001, using a 0.2m$^2$ Hamon Grab. Positions are shown reference to OSGB36 (in metres). Particle size distribution figures are % passing particular sieve sizes (125.0mm – 10.0mm this table).

| grab | easting | northing | 125.0mm | 90.0mm | 75.0mm | 63.0mm | 50.0mm | 37.5mm | 28.0mm | 20.0mm | 14.0mm | 10.0mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 470961.4 | 87143.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.5 | 89.5 | 79.8 | 67.6 | 54.8 |
| 6 | 471737.7 | 87327.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 90.8 | 89.0 | 77.2 | 68.4 | 57.8 |
| 7 | 472527.1 | 87522.1 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 96.3 | 92.0 | 84.9 | 72.9 | 63.6 |
| 8 | 472908.2 | 87609.7 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 96.1 | 82.4 | 65.2 | 51.4 |
| 9 | 471045.2 | 86619.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.0 | 86.0 | 73.0 | 64.0 |
| 10 | 471481.1 | 86749.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.9 | 88.0 | 79.6 | 69.9 |
| 11 | 471839.7 | 86834.8 | 100.0 | 100.0 | 100.0 | 100.0 | 87.0 | 83.0 | 78.0 | 68.0 | 59.0 | 49.0 |
| 17 | 472248.2 | 86935.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 90.5 | 80.6 | 75.2 | 55.7 | 44.3 |
| 18 | 472621.0 | 87025.2 | 100.0 | 100.0 | 100.0 | 100.0 | 96.7 | 92.4 | 84.3 | 72.4 | 56.3 | 45.0 |
| 20 | 473025.8 | 87141.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 89.5 | 83.4 | 74.3 | 65.3 | 57.8 |
| 23 | 465675.8 | 84780.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.7 | 86.4 | 73.7 | 62.5 | 52.1 |
| 24 | 466648.7 | 85029.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 92.0 | 88.0 | 83.0 | 72.0 | 63.0 |
| 25 | 467618.1 | 85276.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 93.9 | 85.2 | 77.1 | 69.2 |
| 27 | 468584.8 | 85518.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.2 | 88.7 | 81.2 | 78.0 |
| 28 | 469562.2 | 85749.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 32 | 470440.5 | 85974.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 34 | 470826.7 | 86061.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 92.2 | 82.9 | 74.6 | 61.3 | 55.9 |
| 35 | 471208.0 | 86148.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 79.1 | 70.1 | 52.5 | 42.2 |
| 36 | 471596.2 | 86252.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 91.0 | 84.0 | 72.0 | 60.0 |
| 37 | 471990.8 | 86362.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 92.6 | 81.5 | 72.3 | 60.8 | 53.7 |
| 38 | 472382.6 | 86468.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.0 | 85.0 | 74.0 | 62.0 |
| 39 | 472736.2 | 86537.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 92.5 | 87.7 | 72.6 | 58.2 | 48.3 |
| 40 | 473151.5 | 86650.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.7 | 92.2 | 80.5 | 70.3 |
| 41 | 473534.9 | 86737.1 | 100.0 | 100.0 | 100.0 | 100.0 | 97.7 | 94.1 | 87.4 | 74.7 | 63.8 | 52.6 |
| 42 | 474008.4 | 86874.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.8 | 93.2 | 86.9 | 76.6 | 68.1 |
| 43 | 474970.1 | 87111.5 | 100.0 | 100.0 | 100.0 | 100.0 | 93.0 | 93.0 | 89.0 | 83.0 | 78.0 | 72.0 |

| grab | easting | northing | 125.0mm | 90.0mm | 75.0mm | 63.0mm | 50.0mm | 37.5mm | 28.0mm | 20.0mm | 14.0mm | 10.0mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | 466280.6 | 84418.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.1 |
| 45 | 467261.7 | 84665.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 46 | 468238.0 | 84887.5 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 |
| 47 | 469207.5 | 85146.1 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 98.3 | 97.4 | 91.7 | 81.9 |
| 49 | 470176.8 | 85412.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.5 | 89.5 | 86.4 |
| 53 | 470557.8 | 85481.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.4 | 84.2 | 70.1 | 61.0 |
| 54 | 470937.4 | 85575.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.0 | 84.0 | 69.0 | 54.0 | 43.0 |
| 56 | 471330.1 | 85670.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.1 | 89.8 | 80.4 | 63.2 | 47.6 |
| 57 | 471703.0 | 85771.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 91.5 | 85.4 | 68.9 | 54.2 | 44.6 |
| 58 | 472104.6 | 85870.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 88.9 | 75.6 | 59.5 | 48.3 | 39.6 |
| 59 | 472875.3 | 86053.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 88.2 | 86.0 | 81.1 | 69.8 | 60.9 |
| 62 | 473263.7 | 86165.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 91.6 | 83.3 | 71.7 | 57.9 | 44.2 |
| 63 | 473617.1 | 86251.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.6 | 98.0 |
| 64 | 474610.1 | 86480.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 65 | 475590.1 | 86747.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.0 | 83.2 | 74.4 | 67.3 |
| 67 | 476567.8 | 86973.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.7 | 91.2 | 83.8 |
| 68 | 465922.4 | 83816.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.2 | 91.1 | 81.6 | 72.7 |
| 69 | 466901.0 | 84047.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 93.0 | 83.0 | 76.0 |
| 70 | 467867.4 | 84306.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.0 | 82.0 | 68.0 | 56.0 | 44.0 |
| 71 | 468831.9 | 84525.2 | 100.0 | 100.0 | 100.0 | 100.0 | 94.4 | 94.4 | 82.6 | 69.3 | 57.8 | 50.6 |
| 72 | 469805.1 | 84770.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 87.4 | 69.8 | 55.9 | 47.3 |
| 73 | 470680.2 | 84986.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 92.6 | 89.3 | 77.2 | 64.6 | 53.8 |
| 75 | 471086.0 | 85087.7 | 100.0 | 100.0 | 100.0 | 100.0 | 89.7 | 87.2 | 77.1 | 68.1 | 57.7 | 48.4 |
| 76 | 471447.4 | 85198.4 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 96.6 | 87.8 | 79.2 | 64.8 | 51.5 |
| 77 | 471825.0 | 85290.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.0 | 88.0 | 79.0 | 65.0 | 52.0 |
| 78 | 472142.6 | 85359.6 | 100.0 | 100.0 | 100.0 | 100.0 | 89.0 | 84.0 | 78.0 | 65.0 | 52.0 | 43.0 |
| 79 | 472999.0 | 85554.8 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 94.7 | 84.6 | 69.1 | 56.6 |
| 80 | 473372.8 | 85664.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.6 |
| 81 | 473767.6 | 85779.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.9 | 99.9 |

| grab | easting | northing | 125.0mm | 90.0mm | 75.0mm | 63.0mm | 50.0mm | 37.5mm | 28.0mm | 20.0mm | 14.0mm | 10.0mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82 | 474249.0 | 85891.1 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.5 |
| 84 | 475237.5 | 86145.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.5 | 93.5 | 91.3 | 82.2 | 78.5 |
| 85 | 476195.0 | 86390.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.0 | 95.9 | 88.5 | 83.4 | 78.3 |
| 86 | 477171.3 | 86628.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 88.3 | 79.9 | 73.2 |
| 87 | 466524.5 | 83451.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 90.6 | 87.5 | 80.7 | 72.2 | 63.8 |
| 88 | 467503.4 | 83698.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.0 | 91.0 | 82.0 | 75.0 |
| 89 | 468499.4 | 83955.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.7 | 91.3 | 83.2 | 74.5 |
| 90 | 469413.4 | 84172.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 93.4 | 84.6 | 72.0 | 61.7 | 51.5 |
| 91 | 470430.7 | 84420.4 | 100.0 | 100.0 | 100.0 | 100.0 | 96.4 | 90.1 | 86.1 | 80.1 | 71.3 | 61.9 |
| 92 | 470788.0 | 84517.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.6 | 90.0 | 78.1 | 66.6 | 54.3 |
| 93 | 471190.9 | 84618.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.6 | 89.3 | 77.5 | 65.5 |
| 94 | 471563.5 | 84704.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 91.0 | 85.0 | 74.0 | 60.0 | 47.0 |
| 95 | 472160.9 | 84861.2 | 100.0 | 100.0 | 100.0 | 92.5 | 84.2 | 78.0 | 66.8 | 55.8 | 42.7 | 33.8 |
| 96 | 472742.6 | 84999.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 92.0 | 78.0 | 60.0 | 46.0 | 34.0 |
| 97 | 473132.2 | 85091.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.0 | 85.0 | 71.0 | 55.0 | 41.0 |
| 98 | 473523.7 | 85190.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 91.8 | 78.9 | 67.9 |
| 99 | 473899.0 | 85286.2 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 97.4 | 97.4 | 94.1 | 92.4 |
| 104 | 474853.9 | 85534.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.0 | 91.0 | 86.0 | 77.0 | 66.0 |
| 106 | 475822.5 | 85777.8 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | 94.0 | 86.6 | 77.4 | 67.0 | 54.5 |
| 108 | 476794.2 | 86006.9 | 100.0 | 100.0 | 100.0 | 100.0 | 91.0 | 85.4 | 79.7 | 72.8 | 63.1 | 56.5 |
| 109 | 466162.6 | 82841.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 89.0 | 87.0 | 80.0 | 72.0 | 63.0 |
| 113 | 467128.4 | 83076.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.9 | 73.3 | 63.2 | 50.4 |
| 115 | 468109.1 | 83311.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 88.0 | 68.0 | 53.0 | 41.0 |
| 116 | 469072.6 | 83564.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.0 | 94.0 | 88.0 | 78.0 | 68.0 |
| 117 | 470054.0 | 83801.6 | 100.0 | 100.0 | 100.0 | 100.0 | 96.0 | 93.0 | 84.0 | 76.0 | 66.0 | 58.0 |
| 118 | 470906.1 | 84025.4 | 100.0 | 100.0 | 100.0 | 100.0 | 92.9 | 83.7 | 76.5 | 63.8 | 50.4 | 41.4 |
| 119 | 471300.3 | 84132.5 | 100.0 | 100.0 | 100.0 | 100.0 | 92.1 | 85.8 | 71.5 | 59.1 | 49.6 | 40.5 |
| 120 | 471693.4 | 84213.6 | 100.0 | 100.0 | 100.0 | 100.0 | 97.7 | 94.1 | 87.4 | 74.7 | 63.8 | 52.6 |
| 121 | 472094.1 | 84321.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 92.0 | 79.0 | 68.0 | 56.0 |

| grab | easting | northing | 125.0mm | 90.0mm | 75.0mm | 63.0mm | 50.0mm | 37.5mm | 28.0mm | 20.0mm | 14.0mm | 10.0mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 122 | 472471.3 | 84424.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.0 | 80.0 | 72.0 | 59.0 | 49.0 |
| 123 | 472862.7 | 84512.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 90.0 | 78.2 | 66.3 | 51.4 | 41.0 |
| 123 | 473238.4 | 84606.8 | 100.0 | 100.0 | 100.0 | 90.6 | 86.1 | 80.0 | 72.2 | 60.7 | 50.1 | 40.2 |
| 124 | 473634.6 | 84695.7 | 100.0 | 100.0 | 100.0 | 97.0 | 94.6 | 91.7 | 83.7 | 73.1 | 62.4 | 52.8 |
| 125 | 474030.3 | 84798.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.0 | 84.0 | 74.0 | 63.0 | 53.0 |
| 126 | 474511.9 | 84918.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.0 | 90.0 | 78.0 | 64.0 |
| 127 | 475463.0 | 85173.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.0 | 81.0 | 66.0 | 56.0 | 47.0 |
| 129 | 471455.3 | 83655.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.2 | 84.9 | 75.8 | 63.7 | 52.0 |
| 131 | 472215.6 | 83832.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.7 | 89.8 | 78.4 | 68.4 |
| 133 | 472996.2 | 84032.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.7 | 86.8 | 75.5 | 64.7 | 55.9 |
| 134 | 471189.3 | 83050.9 | 100.0 | 100.0 | 100.0 | 100.0 | 93.5 | 60.7 | 36.8 | 12.8 | 4.7 | 2.3 |
| 135 | 471957.4 | 83262.2 | 100.0 | 100.0 | 100.0 | 100.0 | 94.6 | 85.3 | 79.2 | 72.5 | 59.9 | 49.6 |
| 136 | 472722.8 | 83437.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 91.8 | 82.8 | 64.1 | 48.2 | 37.2 |
| 137 | 472689.5 | 86119.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.1 | 87.0 | 77.9 | 68.0 | 53.2 |
| 138 | 472431.3 | 85868.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.0 | 89.8 | 83.6 | 73.8 | 66.1 |
| 139 | 472712.6 | 85878.5 | 100.0 | 100.0 | 100.0 | 100.0 | 95.0 | 91.5 | 80.1 | 68.3 | 56.9 | 48.2 |
| 140 | 472409.9 | 85632.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.6 | 88.9 | 77.2 | 67.7 | 57.9 |
| 141 | 472648.6 | 85604.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.4 | 90.3 | 80.1 | 70.9 |
| 142 | 472418.0 | 85340.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.9 | 90.6 | 83.6 | 79.5 |
| 143 | 472691.6 | 85375.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.2 | 81.5 | 70.3 | 61.3 | 52.8 |
| 144 | 472184.0 | 85120.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.2 | 91.9 | 84.1 | 74.4 | 66.3 |
| 145 | 472416.2 | 85091.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.1 | 95.9 | 90.7 | 71.4 | 56.4 |
| 146 | 471909.4 | 84847.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.6 | 90.2 | 78.1 | 63.9 | 57.6 |
| 147 | 472336.1 | 84905.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.5 | 96.0 | 87.7 | 74.3 | 59.5 |
| 148 | 471652.6 | 84601.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.0 | 86.7 | 70.5 | 52.5 |
| 149 | 471924.4 | 84634.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.0 | 93.4 | 81.7 | 68.6 | 57.1 |
| 150 | 471231.6 | 87704.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.5 | 89.7 | 81.0 | 71.6 | 61.4 | 53.5 |
| 151 | 472012.8 | 87902.3 | 100.0 | 100.0 | 100.0 | 100.0 | 94.0 | 92.0 | 87.7 | 79.1 | 66.2 | 55.7 |
| 162 | 472590.4 | 88059.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 91.0 | 79.0 | 70.0 | 61.0 |

| grab | easting | northing | 125.0mm | 90.0mm | 75.0mm | 63.0mm | 50.0mm | 37.5mm | 28.0mm | 20.0mm | 14.0mm | 10.0mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 163 | 471664.7 | 82670.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 89.0 | 84.0 | 76.0 | 65.0 | 56.0 |
| 164 | 472452.6 | 82873.0 | 100.0 | 100.0 | 100.0 | 100.0 | 88.0 | 83.0 | 81.0 | 67.0 | 44.0 | 28.0 |
| 165 | 473223.5 | 83063.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 90.0 | 78.0 | 59.0 | 38.0 |
| 166 | 471724.0 | 84699.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 93.0 | 83.0 | 62.0 | 45.0 | 34.0 |
| 167 | 471660.9 | 84747.2 | 100.0 | 100.0 | 100.0 | 100.0 | 92.0 | 83.0 | 70.0 | 57.0 | 43.0 | 36.0 |
| 168 | 471799.3 | 84747.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 94.0 | 84.0 | 60.0 | 42.0 | 28.0 |
| 169 | 471802.7 | 84611.4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 83.0 | 67.0 | 55.0 | 43.0 |
| 170 | 471733.1 | 84877.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 90.0 | 79.0 | 69.0 | 59.0 |
| 171 | 471929.4 | 84670.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 83.0 | 65.0 | 43.0 |
| 172 | 471725.7 | 84479.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 94.0 | 89.0 | 74.0 |
| 173 | 471546.4 | 84623.9 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 95.0 | 92.0 | 88.0 | 81.0 | 72.0 |
| 174 | 467415.1 | 82805.4 | 100.0 | 100.0 | 100.0 | 93.0 | 93.0 | 73.0 | 57.0 | 50.0 | 40.0 | 32.0 |
| 175 | 468189.0 | 82999.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 83.0 | 65.0 | 43.0 |
| | | **Mean** | **100.0** | **100.0** | **100.0** | **99.8** | **98.6** | **94.8** | **88.6** | **79.2** | **68.5** | **59.1** |
| | | **Min** | **99.8** | **99.8** | **99.8** | **90.6** | **84.2** | **60.7** | **36.8** | **12.8** | **4.7** | **2.3** |
| | | **Max** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |
| | | **s.d.** | **0.0** | **0.0** | **0.0** | **1.3** | **3.3** | **6.3** | **9.4** | **12.8** | **15.6** | **18.0** |

**Appendix Table 2 (continued)** Listing of the benthic samples taken at the North Nab study site in 1999-2001, using a 0.2m$^2$ Hamon Grab. Positions are shown reference to OSGB36 (in metres). Particle size distribution figures are % passing particular sieve sizes (6.3mm – 75µm this table).

| grab | easting | northing | 6.3mm | 5.0mm | 3.35mm | 2.36mm | 1.18mm | 600µm | 425µm | 300µm | 212µm | 150µm | 75µm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 470961.4 | 87143.3 | 41.3 | 38.4 | 33.7 | 30.6 | 26.7 | 23.2 | 20.3 | 16.1 | 12.1 | 5.6 | 1.5 |
| 6 | 471737.7 | 87327.3 | 43.5 | 39.3 | 34.1 | 31.0 | 26.8 | 23.7 | 22.1 | 20.3 | 18.0 | 5.6 | 0.6 |
| 7 | 472527.1 | 87522.1 | 53.1 | 49.1 | 41.9 | 37.8 | 32.1 | 27.4 | 23.3 | 18.0 | 13.0 | 6.1 | 1.4 |
| 8 | 472908.2 | 87609.7 | 39.0 | 34.2 | 27.8 | 24.2 | 18.6 | 15.2 | 13.4 | 11.5 | 9.3 | 4.1 | 0.8 |
| 9 | 471045.2 | 86619.1 | 55.0 | 51.0 | 47.0 | 43.0 | 38.0 | 33.0 | 29.0 | 23.0 | 16.0 | 7.0 | 1.0 |
| 10 | 471481.1 | 86749.8 | 58.2 | 53.8 | 47.2 | 43.0 | 37.4 | 32.7 | 29.2 | 23.4 | 15.3 | 4.6 | 1.0 |
| 11 | 471839.7 | 86834.8 | 39.0 | 35.0 | 31.0 | 28.0 | 25.0 | 22.0 | 20.0 | 18.0 | 16.0 | 6.0 | 1.0 |
| 17 | 472248.2 | 86935.0 | 33.1 | 29.2 | 24.0 | 21.6 | 18.0 | 15.7 | 14.1 | 11.9 | 9.2 | 4.3 | 1.1 |
| 18 | 472621.0 | 87025.2 | 34.4 | 31.8 | 27.3 | 23.5 | 18.2 | 15.0 | 13.1 | 11.0 | 8.5 | 4.7 | 1.7 |
| 20 | 473025.8 | 87141.5 | 48.8 | 45.0 | 39.6 | 36.3 | 31.6 | 27.1 | 22.9 | 17.9 | 13.9 | 6.4 | 1.7 |
| 23 | 465675.8 | 84780.0 | 42.4 | 39.3 | 34.6 | 31.1 | 26.3 | 21.8 | 18.5 | 14.2 | 10.3 | 3.9 | 1.1 |
| 24 | 466648.7 | 85029.6 | 52.0 | 48.0 | 43.0 | 39.0 | 34.0 | 30.0 | 27.0 | 22.0 | 17.0 | 6.0 | 1.0 |
| 25 | 467618.1 | 85276.4 | 59.8 | 56.2 | 51.7 | 48.8 | 43.9 | 37.2 | 29.4 | 14.4 | 4.9 | 1.6 | 0.3 |
| 27 | 468584.8 | 85518.5 | 74.7 | 72.3 | 69.2 | 67.0 | 63.0 | 60.3 | 58.9 | 56.7 | 49.4 | 11.5 | 0.6 |
| 28 | 469562.2 | 85749.1 | 100.0 | 100.0 | 100.0 | 99.7 | 98.5 | 96.2 | 94.0 | 89.6 | 70.2 | 18.2 | 1.2 |
| 32 | 470440.5 | 85974.7 | 100.0 | 100.0 | 100.0 | 99.7 | 98.5 | 96.2 | 94.0 | 89.6 | 70.2 | 18.2 | 1.2 |
| 34 | 470826.7 | 86061.3 | 51.3 | 49.2 | 43.2 | 39.4 | 29.9 | 21.3 | 17.6 | 13.1 | 9.4 | 5.8 | 2.0 |
| 35 | 471208.0 | 86148.1 | 33.1 | 30.4 | 27.9 | 26.2 | 23.3 | 20.6 | 18.5 | 15.4 | 11.2 | 5.5 | 1.7 |
| 36 | 471596.2 | 86252.7 | 47.0 | 42.0 | 36.0 | 30.0 | 27.0 | 23.0 | 20.0 | 17.0 | 14.0 | 6.0 | 2.0 |
| 37 | 471990.8 | 86362.4 | 45.9 | 42.9 | 38.1 | 34.9 | 30.6 | 26.4 | 22.9 | 18.8 | 14.3 | 5.9 | 1.3 |
| 38 | 472382.6 | 86468.1 | 51.0 | 47.0 | 41.0 | 37.0 | 32.0 | 28.0 | 26.0 | 23.0 | 18.0 | 8.0 | 2.0 |
| 39 | 472736.2 | 86537.3 | 37.9 | 34.4 | 29.4 | 26.6 | 22.4 | 18.9 | 16.3 | 13.0 | 10.0 | 4.6 | 1.0 |
| 40 | 473151.5 | 86650.5 | 57.0 | 50.8 | 42.9 | 37.4 | 31.4 | 27.2 | 23.9 | 18.6 | 12.9 | 5.0 | 0.8 |
| 41 | 473534.9 | 86737.1 | 41.5 | 37.6 | 33.7 | 30.8 | 26.3 | 21.6 | 17.9 | 13.2 | 9.4 | 3.5 | 1.2 |
| 42 | 474008.4 | 86874.3 | 57.8 | 54.4 | 49.9 | 46.0 | 41.1 | 36.3 | 32.3 | 26.7 | 19.6 | 6.9 | 1.7 |
| 43 | 474970.1 | 87111.5 | 65.0 | 62.0 | 58.0 | 55.0 | 46.0 | 30.0 | 17.0 | 7.0 | 2.0 | 1.0 | 0.4 |

| grab | easting | northing | 6.3mm | 5.0mm | 3.35mm | 2.36mm | 1.18mm | 600µm | 425µm | 300µm | 212µm | 150µm | 75µm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | 466280.6 | 84418.7 | 98.5 | 98.2 | 97.1 | 95.8 | 94.1 | 92.4 | 91.3 | 88.9 | 70.3 | 14.5 | 0.6 |
| 45 | 467261.7 | 84665.6 | 100.0 | 100.0 | 100.0 | 99.0 | 99.0 | 98.0 | 96.0 | 83.0 | 49.0 | 11.0 | 0.5 |
| 46 | 468238.0 | 84887.5 | 99.5 | 99.4 | 99.4 | 99.2 | 98.7 | 97.7 | 96.5 | 91.4 | 61.2 | 14.8 | 0.7 |
| 47 | 469207.5 | 85146.1 | 72.9 | 69.4 | 65.2 | 61.9 | 56.8 | 52.6 | 50.3 | 42.2 | 24.9 | 6.7 | 0.5 |
| 49 | 470176.8 | 85412.4 | 82.4 | 77.6 | 69.4 | 62.8 | 53.6 | 48.0 | 45.6 | 41.6 | 32.6 | 16.6 | 5.2 |
| 53 | 470557.8 | 85481.5 | 48.5 | 44.2 | 37.6 | 33.8 | 28.8 | 24.6 | 21.3 | 17.5 | 12.1 | 4.9 | 1.1 |
| 54 | 470937.4 | 85575.0 | 31.0 | 27.0 | 23.0 | 20.0 | 16.0 | 14.0 | 12.0 | 10.0 | 8.0 | 3.0 | 1.0 |
| 56 | 471330.1 | 85670.8 | 32.4 | 27.8 | 23.7 | 21.2 | 17.6 | 14.8 | 12.8 | 10.3 | 7.4 | 2.7 | 0.4 |
| 57 | 471703.0 | 85771.4 | 33.1 | 28.9 | 23.5 | 20.7 | 16.7 | 13.8 | 11.1 | 6.1 | 2.5 | 0.9 | 0.3 |
| 58 | 472104.6 | 85870.6 | 30.5 | 27.4 | 23.4 | 20.7 | 16.3 | 13.1 | 10.9 | 8.4 | 5.9 | 2.4 | 0.6 |
| 59 | 472875.3 | 86053.3 | 51.1 | 48.0 | 45.7 | 43.4 | 39.8 | 35.5 | 31.2 | 24.8 | 18.1 | 7.4 | 2.3 |
| 62 | 473263.7 | 86165.4 | 34.6 | 31.8 | 28.0 | 26.0 | 23.2 | 20.9 | 19.5 | 17.9 | 14.9 | 6.0 | 1.6 |
| 63 | 473617.1 | 86251.8 | 97.9 | 97.9 | 97.4 | 96.8 | 95.6 | 94.0 | 91.9 | 84.0 | 40.8 | 9.3 | 0.4 |
| 64 | 474610.1 | 86480.7 | 100.0 | 100.0 | 99.0 | 98.0 | 94.0 | 84.0 | 68.0 | 37.0 | 10.0 | 3.0 | 0.7 |
| 65 | 475590.1 | 86747.1 | 56.2 | 50.4 | 43.9 | 39.4 | 34.6 | 32.8 | 31.8 | 28.6 | 20.4 | 8.4 | 2.1 |
| 67 | 476567.8 | 86973.9 | 77.2 | 72.9 | 64.5 | 56.4 | 37.8 | 18.5 | 11.3 | 7.5 | 5.7 | 3.5 | 1.6 |
| 68 | 465922.4 | 83816.2 | 62.6 | 58.6 | 51.3 | 46.1 | 38.4 | 31.0 | 25.9 | 20.1 | 13.8 | 7.1 | 2.2 |
| 69 | 466901.0 | 84047.9 | 67.0 | 63.0 | 54.0 | 48.0 | 41.0 | 36.0 | 32.0 | 25.0 | 18.0 | 9.0 | 3.0 |
| 70 | 467867.4 | 84306.0 | 36.0 | 33.0 | 29.0 | 27.0 | 21.0 | 11.0 | 7.0 | 6.0 | 4.0 | 2.0 | 1.0 |
| 71 | 468831.9 | 84525.2 | 42.7 | 39.7 | 35.8 | 33.4 | 29.0 | 24.0 | 20.1 | 15.4 | 11.6 | 5.8 | 1.7 |
| 72 | 469805.1 | 84770.1 | 36.2 | 32.2 | 26.7 | 23.4 | 18.2 | 14.5 | 12.6 | 10.3 | 7.5 | 3.2 | 0.9 |
| 73 | 470680.2 | 84986.6 | 41.3 | 36.8 | 32.5 | 29.0 | 23.5 | 19.7 | 17.6 | 15.0 | 11.4 | 4.7 | 1.1 |
| 75 | 471086.0 | 85087.7 | 38.3 | 35.0 | 31.2 | 28.2 | 23.8 | 19.6 | 15.9 | 10.1 | 5.5 | 2.1 | 0.5 |
| 76 | 471447.4 | 85198.4 | 38.0 | 33.6 | 29.2 | 26.3 | 21.9 | 18.4 | 15.9 | 13.3 | 10.6 | 4.3 | 0.6 |
| 77 | 471825.0 | 85290.4 | 36.0 | 32.0 | 26.0 | 22.0 | 17.0 | 12.0 | 9.0 | 6.0 | 4.0 | 1.0 | 0.2 |
| 78 | 472142.6 | 85359.6 | 34.0 | 31.0 | 27.0 | 25.0 | 20.0 | 14.0 | 8.0 | 3.0 | 1.0 | 1.0 | 0.3 |
| 79 | 472999.0 | 85554.8 | 45.9 | 42.7 | 38.5 | 35.9 | 32.6 | 30.0 | 27.8 | 21.5 | 12.6 | 2.8 | 0.3 |
| 80 | 473372.8 | 85664.1 | 98.5 | 98.3 | 96.9 | 95.9 | 94.6 | 93.3 | 92.6 | 91.4 | 81.9 | 14.8 | 0.7 |
| 81 | 473767.6 | 85779.8 | 99.9 | 99.9 | 99.9 | 99.7 | 99.4 | 97.4 | 93.6 | 74.1 | 34.6 | 6.2 | 1.0 |

| grab | easting | northing | 6.3mm | 5.0mm | 3.35mm | 2.36mm | 1.18mm | 600µm | 425µm | 300µm | 212µm | 150µm | 75µm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82 | 474249.0 | 85891.1 | 99.5 | 99.5 | 99.2 | 98.5 | 97.4 | 96.2 | 94.7 | 85.5 | 27.0 | 6.4 | 0.5 |
| 84 | 475237.5 | 86145.7 | 72.6 | 69.2 | 63.1 | 58.4 | 50.7 | 40.3 | 35.3 | 29.8 | 19.2 | 9.0 | 3.6 |
| 85 | 476195.0 | 86390.0 | 71.3 | 67.9 | 62.3 | 56.9 | 48.6 | 42.3 | 38.6 | 32.8 | 22.6 | 10.5 | 3.9 |
| 86 | 477171.3 | 86628.9 | 65.9 | 62.8 | 58.9 | 56.5 | 51.5 | 46.1 | 39.4 | 30.3 | 21.9 | 11.5 | 3.7 |
| 87 | 466524.5 | 83451.3 | 55.6 | 53.1 | 49.9 | 46.7 | 40.9 | 35.7 | 31.0 | 26.7 | 18.7 | 8.5 | 2.6 |
| 88 | 467503.4 | 83698.0 | 63.0 | 57.0 | 50.0 | 44.0 | 34.0 | 27.0 | 24.0 | 20.0 | 15.0 | 6.0 | 1.0 |
| 89 | 468499.4 | 83955.5 | 61.3 | 56.0 | 48.0 | 43.3 | 36.8 | 31.8 | 28.6 | 23.4 | 17.4 | 5.6 | 1.2 |
| 90 | 469413.4 | 84172.3 | 38.6 | 33.7 | 27.3 | 22.7 | 16.6 | 12.2 | 10.4 | 8.3 | 6.1 | 2.2 | 0.3 |
| 91 | 470430.7 | 84420.4 | 50.8 | 45.9 | 40.2 | 35.6 | 29.6 | 24.4 | 20.5 | 15.8 | 11.8 | 4.2 | 0.9 |
| 92 | 470788.0 | 84517.6 | 42.3 | 38.2 | 31.5 | 28.1 | 23.8 | 21.0 | 18.7 | 15.4 | 11.8 | 4.1 | 0.4 |
| 93 | 471190.9 | 84618.1 | 52.7 | 48.1 | 42.8 | 37.7 | 33.6 | 29.6 | 26.0 | 21.0 | 15.5 | 5.1 | 1.3 |
| 94 | 471563.5 | 84704.9 | 30.0 | 25.0 | 19.0 | 15.0 | 11.0 | 8.0 | 7.0 | 6.0 | 4.0 | 2.0 | 0.5 |
| 95 | 472160.9 | 84861.2 | 24.1 | 21.0 | 17.2 | 14.7 | 11.4 | 9.2 | 7.2 | 5.5 | 4.3 | 1.7 | 0.4 |
| 96 | 472742.6 | 84999.1 | 22.0 | 18.0 | 15.0 | 13.0 | 10.0 | 7.0 | 6.0 | 5.0 | 4.0 | 1.0 | 0.5 |
| 97 | 473132.2 | 85091.4 | 28.0 | 23.0 | 16.0 | 12.0 | 7.0 | 4.0 | 3.0 | 2.0 | 2.0 | 0.5 | 0.3 |
| 98 | 473523.7 | 85190.7 | 55.2 | 51.4 | 47.7 | 44.8 | 40.9 | 38.2 | 36.5 | 34.0 | 27.2 | 5.9 | 0.6 |
| 99 | 473899.0 | 85286.2 | 90.2 | 89.5 | 88.5 | 87.7 | 86.2 | 84.9 | 83.6 | 81.0 | 51.0 | 5.7 | 0.5 |
| 104 | 474853.9 | 85534.9 | 53.0 | 48.0 | 41.0 | 37.0 | 31.0 | 26.0 | 23.0 | 19.0 | 13.0 | 4.0 | 1.0 |
| 106 | 475822.5 | 85777.8 | 42.0 | 38.1 | 32.9 | 29.7 | 24.8 | 20.6 | 18.2 | 15.5 | 12.5 | 3.8 | 0.5 |
| 108 | 476794.2 | 86006.9 | 49.4 | 46.6 | 42.6 | 40.2 | 36.9 | 33.9 | 30.8 | 26.6 | 20.6 | 7.0 | 1.6 |
| 109 | 466162.6 | 82841.9 | 53.0 | 49.0 | 43.0 | 40.0 | 33.0 | 26.0 | 22.0 | 18.0 | 13.0 | 5.0 | 1.0 |
| 113 | 467128.4 | 83076.7 | 37.7 | 33.4 | 27.9 | 24.8 | 20.3 | 17.2 | 15.0 | 11.8 | 7.8 | 2.2 | 0.4 |
| 115 | 468109.1 | 83311.8 | 29.0 | 25.0 | 20.0 | 17.0 | 13.0 | 10.0 | 8.0 | 6.0 | 4.0 | 1.0 | 0.5 |
| 116 | 469072.6 | 83564.1 | 55.0 | 50.0 | 45.0 | 41.0 | 35.0 | 31.0 | 27.0 | 22.0 | 17.0 | 6.0 | 1.0 |
| 117 | 470054.0 | 83801.6 | 46.0 | 42.0 | 36.0 | 32.0 | 26.0 | 8.0 | 3.0 | 2.0 | 1.0 | 1.0 | 0.5 |
| 118 | 470906.1 | 84025.4 | 33.6 | 31.0 | 27.7 | 25.4 | 21.6 | 18.2 | 15.2 | 11.0 | 6.1 | 1.5 | 0.3 |
| 119 | 471300.3 | 84132.5 | 30.9 | 27.5 | 23.5 | 20.9 | 17.1 | 14.2 | 11.8 | 9.0 | 5.7 | 1.8 | 0.4 |
| 120 | 471693.4 | 84213.6 | 41.5 | 37.6 | 33.7 | 30.8 | 26.3 | 21.6 | 17.9 | 13.2 | 9.4 | 3.5 | 1.2 |
| 121 | 472094.1 | 84321.2 | 43.0 | 39.0 | 33.0 | 30.0 | 25.0 | 22.0 | 19.0 | 14.0 | 10.0 | 4.0 | 1.0 |

| grab | easting | northing | 6.3mm | 5.0mm | 3.35mm | 2.36mm | 1.18mm | 600µm | 425µm | 300µm | 212µm | 150µm | 75µm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 122 | 472471.3 | 84424.5 | 37.0 | 34.0 | 30.0 | 27.0 | 23.0 | 19.0 | 16.0 | 12.0 | 8.0 | 2.0 | 0.5 |
| 123 | 472862.7 | 84512.4 | 30.7 | 27.0 | 22.3 | 19.1 | 15.1 | 10.9 | 8.6 | 6.2 | 3.5 | 2.5 | 0.5 |
| 123 | 473238.4 | 84606.8 | 31.3 | 28.8 | 26.3 | 24.6 | 22.6 | 20.2 | 17.9 | 15.8 | 12.0 | 4.7 | 1.1 |
| 124 | 473634.6 | 84695.7 | 43.5 | 40.1 | 35.1 | 32.3 | 27.2 | 21.9 | 17.0 | 11.5 | 7.0 | 3.1 | 0.7 |
| 125 | 474030.3 | 84798.9 | 38.0 | 33.0 | 27.0 | 24.0 | 19.0 | 16.0 | 14.0 | 11.0 | 8.0 | 3.0 | 1.0 |
| 126 | 474511.9 | 84918.0 | 42.0 | 31.0 | 21.0 | 15.0 | 10.0 | 9.0 | 8.0 | 7.0 | 4.0 | 1.0 | 0.5 |
| 127 | 475463.0 | 85173.6 | 36.0 | 32.0 | 27.0 | 24.0 | 19.0 | 14.0 | 11.0 | 6.0 | 4.0 | 2.0 | 0.5 |
| 129 | 471455.3 | 83655.0 | 42.0 | 38.6 | 34.2 | 31.6 | 27.7 | 24.3 | 21.5 | 18.4 | 15.2 | 6.0 | 1.1 |
| 131 | 472215.6 | 83832.2 | 58.8 | 55.6 | 50.5 | 47.8 | 43.8 | 40.7 | 37.6 | 33.0 | 23.0 | 6.5 | 1.5 |
| 133 | 472996.2 | 84032.7 | 47.1 | 44.0 | 39.1 | 36.4 | 32.1 | 28.0 | 24.5 | 21.1 | 13.4 | 3.1 | 0.6 |
| 134 | 471189.3 | 83050.9 | 1.1 | 0.8 | 0.5 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 |
| 135 | 471957.4 | 83262.2 | 35.9 | 31.6 | 25.2 | 21.8 | 17.1 | 12.8 | 10.0 | 7.9 | 6.1 | 2.9 | 0.7 |
| 136 | 472722.8 | 83437.9 | 27.3 | 22.8 | 17.1 | 12.7 | 6.7 | 4.0 | 3.1 | 2.6 | 2.1 | 1.2 | 0.5 |
| 137 | 472689.5 | 86119.9 | 37.0 | 31.6 | 25.3 | 21.5 | 16.5 | 12.8 | 7.4 | 2.5 | 1.4 | 0.6 | 0.5 |
| 138 | 472431.3 | 85868.1 | 55.6 | 51.7 | 45.5 | 41.2 | 35.3 | 30.1 | 25.9 | 20.4 | 15.2 | 5.0 | 0.9 |
| 139 | 472712.6 | 85878.5 | 38.6 | 35.3 | 30.9 | 28.0 | 23.7 | 19.5 | 16.1 | 11.9 | 8.2 | 2.9 | 0.6 |
| 140 | 472409.9 | 85632.4 | 45.1 | 39.8 | 32.5 | 25.7 | 17.7 | 12.5 | 9.0 | 6.4 | 4.6 | 2.3 | 1.2 |
| 141 | 472648.6 | 85604.5 | 59.7 | 55.7 | 50.9 | 46.7 | 38.5 | 28.8 | 22.2 | 15.8 | 10.3 | 3.7 | 0.9 |
| 142 | 472418.0 | 85340.6 | 74.1 | 70.3 | 63.6 | 56.8 | 50.6 | 42.8 | 38.7 | 30.5 | 20.8 | 10.6 | 1.6 |
| 143 | 472691.6 | 85375.2 | 44.6 | 41.0 | 36.4 | 34.0 | 30.3 | 27.2 | 24.7 | 21.0 | 15.1 | 6.9 | 2.1 |
| 144 | 472184.0 | 85120.2 | 59.9 | 56.9 | 49.3 | 43.4 | 34.8 | 28.7 | 25.5 | 22.8 | 17.1 | 8.6 | 3.0 |
| 145 | 472416.2 | 85091.5 | 40.9 | 36.7 | 29.3 | 26.1 | 22.1 | 19.6 | 18.5 | 17.1 | 12.7 | 5.3 | 1.3 |
| 146 | 471909.4 | 84847.6 | 49.2 | 45.5 | 39.1 | 35.3 | 30.4 | 26.6 | 24.8 | 22.8 | 17.7 | 7.6 | 2.1 |
| 147 | 472336.1 | 84905.3 | 43.1 | 37.5 | 28.5 | 22.8 | 16.2 | 13.8 | 12.9 | 12.2 | 10.3 | 3.7 | 0.6 |
| 148 | 471652.6 | 84601.1 | 38.0 | 33.7 | 28.3 | 24.8 | 19.5 | 16.2 | 14.7 | 13.1 | 11.1 | 4.9 | 1.1 |
| 149 | 471924.4 | 84634.2 | 45.6 | 41.6 | 35.3 | 31.5 | 26.4 | 22.7 | 20.2 | 16.6 | 12.8 | 5.3 | 1.2 |
| 150 | 471231.6 | 87704.0 | 46.1 | 44.0 | 39.5 | 36.7 | 32.8 | 28.7 | 25.4 | 21.8 | 15.1 | 4.7 | 1.3 |
| 151 | 472012.8 | 87902.3 | 45.8 | 42.9 | 38.1 | 35.5 | 31.7 | 28.6 | 26.2 | 23.3 | 16.1 | 4.2 | 1.1 |
| 162 | 472590.4 | 88059.5 | 53.0 | 50.0 | 47.0 | 45.0 | 41.0 | 30.0 | 23.0 | 16.0 | 11.0 | 6.0 | 2.0 |

| grab | easting | northing | 6.3mm | 5.0mm | 3.35mm | 2.36mm | 1.18mm | 600µm | 425µm | 300µm | 212µm | 150µm | 75µm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 163 | 471664.7 | 82670.1 | 44.0 | 38.0 | 28.0 | 23.0 | 16.0 | 11.0 | 8.0 | 5.0 | 2.0 | 1.0 | 0.0 |
| 164 | 472452.6 | 82873.0 | 17.0 | 15.0 | 11.0 | 9.0 | 8.0 | 7.0 | 6.0 | 5.0 | 4.0 | 2.0 | 0.5 |
| 165 | 473223.5 | 83063.9 | 19.0 | 13.0 | 8.0 | 5.0 | 4.0 | 4.0 | 4.0 | 3.0 | 2.0 | 1.0 | 0.5 |
| 166 | 471724.0 | 84699.2 | 23.0 | 19.0 | 15.0 | 13.0 | 11.0 | 10.0 | 9.0 | 7.0 | 4.0 | 1.0 | 0.5 |
| 167 | 471660.9 | 84747.2 | 31.0 | 29.0 | 27.0 | 25.0 | 23.0 | 21.0 | 19.0 | 17.0 | 13.0 | 7.0 | 2.0 |
| 168 | 471799.3 | 84747.2 | 20.0 | 17.0 | 14.0 | 13.0 | 12.0 | 11.0 | 9.0 | 8.0 | 5.0 | 2.0 | 0.3 |
| 169 | 471802.7 | 84611.4 | 31.0 | 27.0 | 23.0 | 21.0 | 18.0 | 15.0 | 12.0 | 10.0 | 5.0 | 1.0 | 0.3 |
| 170 | 471733.1 | 84877.0 | 48.0 | 45.0 | 40.0 | 37.0 | 32.0 | 29.0 | 26.0 | 21.0 | 14.0 | 5.0 | 1.0 |
| 171 | 471929.4 | 84670.0 | 24.0 | 19.0 | 14.0 | 12.0 | 10.0 | 9.0 | 9.0 | 8.0 | 5.0 | 2.0 | 1.0 |
| 172 | 471725.7 | 84479.2 | 48.0 | 40.0 | 30.0 | 27.0 | 24.0 | 21.0 | 19.0 | 18.0 | 15.0 | 9.0 | 2.0 |
| 173 | 471546.4 | 84623.9 | 58.0 | 50.0 | 38.0 | 31.0 | 27.0 | 24.0 | 22.0 | 19.0 | 15.0 | 8.0 | 2.0 |
| 174 | 467415.1 | 82805.4 | 25.0 | 22.0 | 19.0 | 16.0 | 14.0 | 11.0 | 10.0 | 8.0 | 6.0 | 4.0 | 2.0 |
| 175 | 468189.0 | 82999.1 | 24.0 | 19.0 | 14.0 | 12.0 | 10.0 | 9.0 | 9.0 | 8.0 | 5.0 | 2.0 | 1.0 |
| | | **Mean** | **49.0** | **45.4** | **40.6** | **37.6** | **33.0** | **28.8** | **25.8** | **21.7** | **15.0** | **5.1** | **1.1** |
| | | **Min** | **1.1** | **0.8** | **0.5** | **5.0** | **4.0** | **4.0** | **3.0** | **2.0** | **1.0** | **0.5** | **0.0** |
| | | **Max** | **100.0** | **100.0** | **100.0** | **99.7** | **99.4** | **98.0** | **96.5** | **91.4** | **81.9** | **18.2** | **5.2** |
| | | **s.d.** | **20.5** | **21.2** | **22.0** | **22.2** | **22.6** | **22.7** | **22.5** | **21.1** | **14.7** | **3.6** | **0.8** |

**Appendix Table 3** Table summarising he species of macrofauna (>1mm) extracted from the sediments of the North Nab study site in 1999.

| Species Code | Taxon |
|---|---|
| | ***Phylum*** **PORIFERA** |
| 1 | *Leuconia gossei* |
| 2 | *Stelligera stuposa* |
| 3 | *Halichondria panicea* |
| 4 | *Dysidea fragilis* |
| 294 | *Hymeniacidon perleve* |
| | ***Phylum*** **CNIDARIA** |
| | **HYDROZOA** |
| 5 | *Tubularia indivisa* |
| 6 | *Sarsia eximia* |
| 7 | *Obelia sp.* |
| 8 | *Gonothyraea loveni* |
| 9 | *Lafoea dumosa* |
| 10 | *Halecium halecinum* |
| 11 | *Abietinaria abietum* |
| 12 | *Diphasia attenuata* |
| 13 | *Diphasia sp.* |
| 14 | *Sertularia cupressina* |
| 15 | *Sertularella sp.* |
| 16 | *Sertularella rugosa* |
| 17 | *Nemertesia ramosa* |
| 18 | *Nemertesia antennina* |
| 19 | *Plumularia setacea* |
| 20 | *Aglaophenia sp.* |
| 21 | *Aglaophenia pluma* |
| 22 | *Thuiaria (c.f. thuja)* |
| 23 | *Thuiaria articulata* |
| 24 | *Dynamena pumila* |
| 25 | *Clytia hemisphaerica* |
| 26 | *Campanularia sp.* |
| 301 | *Hydrallmania falcata* |
| | **ANTHOZOA** |
| 27 | *Cerianthus lloydii* |
| 28 | *ACTINARIA (Type #1)* |
| 29 | *ACTINARIA (Type #2)* |
| 315 | *Edwardsia claparedii* |
| 30 | *Sagartia troglodytes* |
| 295 | *Urticina felina* |
| | **OCTOCORALLIA** |
| 31 | *Alcyonium digitatum* |
| 32 | Unidentified *Turbellarian* |
| | ***Phylum*** **NEMERTEA** |
| 33 | *Nemertea sp.* |
| 34 | *Cerebratulus fuscus* |
| | ***Phylum*** **ANNELIDA: POLYCHAETA** |
| 35 | *Harmothoë impar* |
| 36 | *Harmothoë lunulata* |
| 37 | *Harmothoë sp.* |
| 38 | *Lagisca extenuata* |
| 39 | *Lepidonotus clava* |
| 40 | *Lepidonotus squamatus* |
| 41 | *Polynoid sp.* |
| 42 | *Sthenelais boa* |
| 43 | *Phloë minuta* |
| 44 | *Phyllodocid sp.* |
| 45 | *Eteone longa* |
| 46 | *Phyllodoce lamelligera* |
| 47 | *Phyllodoce laminosa* |
| 48 | *Phyllodoce maculata* |
| 49 | *Eulalia pusilla* |
| 50 | *Eulalia tripunctata* |
| 51 | *Eulalia bilineata* |
| 316 | *Paranaitis kosteriensis* |
| 52 | *Eumida punctifera* |
| 53 | *Eumida sanguinea* |
| 54 | *Glycera sp. (Juvenile)* |
| 55 | *Glycera alba* |
| 56 | *Glycera lapidum* |
| 57 | *Glycera tridactyla* |
| 58 | *Goniada maculata* |
| 59 | *Amblyosyllis formosa* |
| 60 | *Haplosyllis spongicola* |
| 61 | *Syllis gracillis* |
| 62 | *Trypanosyllis zebra* |
| 63 | *Trypanosyllis coeliaca* |
| 64 | *Pionosyllis sp.* |
| 65 | *Typosyllis prolifera* |
| 66 | *Odontosyllis gibba.* |
| 67 | *Odontosyllis ctenostoma* |
| 68 | *Exogone naidina* |
| 69 | *Exogone hebes* |
| 70 | *Exogone verugera* |
| 71 | *Sphaerosyllis sp.* |
| 72 | *Spermosylis sp.* |
| 73 | *Autolytus sp. (Type #1)* |
| 74 | *Autolytus sp. (Type #2)* |

| Species Code | Taxon |
|---|---|
| 75 | *Unidet. Syllidae* |
| 76 | *Kefersteinia cirrata* |
| 77 | *Nereis fucata* |
| 78 | *Nereis pelagica* |
| 79 | *Nereis zonata* |
| 80 | *Nereis sp. (Juv.)* |
| 81 | *Platynereis (c.f. dumerili)* |
| 82 | *Nephtys caeca* |
| 83 | *Nephtys hombergi* |
| 84 | *Nephtys incisa* |
| 85 | *Nephtys sp.* |
| 86 | *Lysidice ninetta* |
| 87 | *Marphysa belli* |
| 88 | *Marphysa sanguinea* |
| 89 | *Nematonereis unicornis* |
| 90 | *Arabella iricolor* |
| 91 | *Drilonereis filum* |
| 92 | *Lumbrineris gracilis* |
| 93 | *Lumbrineris latreilli* |
| 94 | *Lumbrineris sp.* |
| 95 | *Protodorvillea kefersteini* |
| 96 | *Schistomeringos neglecta* |
| 97 | *Schistomeringos rudolphi* |
| 98 | *Ophryotrocha sp.* |
| 99 | *Eunicid sp.* |
| 100 | *Orbinia latreilli* |
| 101 | *Scoloplos armiger* |
| 102 | *Poecilochaetus serpens* |
| 103 | *Aonides oxycephala* |
| 14 | *Aonides paucibranchiata* |
| 105 | *Polydora sp. (Type #1)* |
| 106 | *Polydora sp. (Type #2)* |
| 107 | *Pygospio elegans* |
| 108 | *Spio folicornis* |
| 109 | *Prionospio sp.* |
| 110 | *Nerinides (c.f. cantabra)* |
| 111 | *Spiophanes bombyx* |
| 112 | *Scolelepsis foliosa* |
| 113 | *Malacoceros (c.f. fuliginosus)* |
| 114 | *Unidet. Spionidae* |
| 115 | *Magelona mirabilis* |
| 116 | *Chaetozone setosa* |
| 117 | *Cirratulus filiformis* |
| 118 | *Cirriformia tentaculata* |
| 119 | *Tharyx marioni* |
| 120 | *Heterocirrus sp.* |
| 121 | *Capitella sp.* |

| Species Code | Taxon |
|---|---|
| 122 | *Notomastus sp.* |
| 123 | *Maldane sarsi* |
| 124 | *Euclymene sp.* |
| 125 | *Nicomache lumbricalis* |
| 126 | *Ophelia bicornis* |
| 127 | *Travisia forbesi* |
| 128 | *Scalibregma inflatum* |
| 129 | *Sabellaria alveolata* |
| 130 | *Sabellaria spinulosa* |
| 131 | *Owenia fusiformis* |
| 132 | *Ampharete acutifrons* |
| 133 | *Amphicteis gunneri* |
| 134 | *Melinna palmata* |
| 135 | *Melinna cristata* |
| 136 | *Amphitrite figulus* |
| 137 | *Terebellides stroemi* |
| 138 | *Nicolea venustula* |
| 139 | *Nicolea zostericola* |
| 140 | *Lanice conchilega* |
| 141 | *Eupolymnia nebulosa* |
| 142 | *Eupolymnia (c.f. nesidensis)* |
| 143 | *Polycirrus sp.* |
| 144 | *Thelepus cincinnatus* |
| 145 | *Thelepus setosus* |
| 146 | *Trichobranchus glacialis* |
| 147 | *Unidet. Terebllid sp.* |
| 148 | *Branchiomma bombyx* |
| 296 | *Pista cristata* |
| 149 | *Chone duneri* |
| 150 | *Chone (c.f. fauveli)* |
| 151 | *Demonax brachychone* |
| 152 | *Jasmineira elegans* |
| 153 | *Pseudopotamilla reniformis* |
| 154 | *Megalomma vesiculosum* |
| 155 | *Perkinsiana rubra* |
| 156 | *Sabella sp.* |
| 157 | *Pomatoceros sp.* |
| 158 | *Filograna implexa* |
| 159 | *Apomatus similis* |
| 160 | *Unidet. Polychaete (Juv)* |
| | ***Phylum*** **SIPUNCULA** |
| 161 | *Golfingia vulgaris* |
| | ***Phylum*** **CRUSTACEA** |
| 162 | *Scalpellum scalpellum* |
| 163 | *Verruca stroemia* |
| 164 | *Balanus balanus* |
| 165 | *Balanus improvisus* |

| Species Code | Taxon |
|---|---|
| 166 | *Balanus crenatus* |
| 167 | *Gammarellus angulosus* |
| 168 | *Amphilochus manudens* |
| 169 | *Leucothoe incisa* |
| 170 | *Metopa (c.f. alderi)* |
| 171 | *Stenothoe marina* |
| 172 | *Stenothoe monoculoides* |
| 173 | *Urothoe marina* |
| 174 | *Metaphoxus fultoni* |
| 175 | *Metaphoxus (c.f. pectinatus)* |
| 176 | *Harpinia antennaria* |
| 313 | *Orchomene humilis* |
| 177 | *Lysianassidae sp.* |
| 178 | *Socarnes erythrophthalmus* |
| 179 | *Tryphosella sarsi* |
| 180 | *Iphimedia minuta* |
| 181 | *Iphimedia eblanae* |
| 182 | *Iphimedia (c.f. perplexa)* |
| 183 | *Iphimedia sp.* |
| 184 | *Liljeborgia pallida* |
| 185 | *Atylus falcatus* |
| 186 | *Atylus guttatus* |
| 187 | *Atylus swammerdami* |
| 188 | *Atylidae sp.* |
| 189 | *Ampelisca brevicornis* |
| 190 | *Bathyporeia guilliamsoniana* |
| 191 | *Gammaridae sp.* |
| 192 | *Melita gladiosa* |
| 193 | *Abludomelita obtusata* |
| 194 | *Melita hergensis* |
| 195 | *Cheirocratus intermedius* |
| 196 | *Cheirocratus sundevalli* |
| 197 | *Cheirocratus sp.* |
| 198 | *Maerella tenuimana* |
| 199 | *Maera othonis* |
| 200 | *Apherusa bispinosa* |
| 201 | *Apherusa sp.* |
| 202 | *Parapleustes sp.* |
| 203 | *Gammaropsis maculata* |
| 204 | *Gammaropsis sp.* |
| 205 | *Photis longicaudata* |
| 206 | *Photis sp.* |
| 207 | *Leptocheirus hirsutimanus* |
| 208 | *Microdeutopus versiculatus* |
| 209 | *Corophium sextonae* |
| 210 | *Unciola crenatipalma* |
| 305 | *Ericthonius punctatus* |

| Species Code | Taxon |
|---|---|
| 306 | *Microprotopus maculatus* |
| 211 | *Synchelidium haplocheles* |
| 212 | *Perioculodes longimanus* |
| 213 | *Monoculodes carinatus* |
| 214 | *Dyopedos (c.f. monacanthus)* |
| 300 | *Megamphopus cornutus* |
| 215 | *Pseudoprotella phasma* |
| 303 | *Phtisica marina* |
| 304 | *Caprellid sp. (c.f. Parvipalpus)* |
| 216 | *Gnathia oxyuraea* |
| 217 | *Gnathia maxillaris* |
| 218 | *Gnathia sp.* |
| 219 | *Gnathia sp. (juv)* |
| 309 | unidentified Isopod |
| 220 | *Eurydice sp.* |
| 221 | *Anthura gracilis* |
| 302 | *Astacilla longicornis* |
| 222 | *Pseudoparatanais batei* |
| 223 | *Bodotria scorpioides* |
| 307 | *Nannastacus unguiculatus* |
| 224 | *Siriella armata* |
| 225 | *Praunus sp.* |
| 311 | *Thoralus cranchii* |
| 226 | *Pandalina brevirostris* |
| 227 | *Axius stirhynchus* |
| 310 | *Meiosquilla desmaresti* |
| 228 | *Callianassa subterranea* |
| 229 | *Upogebia deltaura* |
| 230 | *Pagurus bernhardus* |
| 231 | *Galathea intermedia* |
| 232 | *Galathea squamifera* |
| 233 | *Pisidia longicornis* |
| 234 | *Pinnotheres pisum* |
| 235 | *Pisa tetraodon* |
| 236 | *Macropodia linaresi* |
| 237 | *Macropodia rostrata* |
| 238 | *Carcinus meanas* |
| 239 | *Liocarcinus pusillus* |
| 240 | *Liocarcinus depurator* |
| 241 | *Portunidae sp.(Juv)* |
| 242 | *Pilumnus hirtellus* |
| | ***Phylum*** **CHELICERATA** |
| 243 | *Nymphon brevirostre* |
| 244 | *Nymphon gracile* |
| 245 | *Achelia echinata* |
| 308 | *Endeis spinosa* |
| 312 | *Endeis charybdaea* |

| Species Code | Taxon |
|---|---|
| | ***Phylum*** **MOLLUSCA: GASTROPODA** |
| 246 | *Leptochiton asellus* |
| 247 | *Leptochiton cancellatus* |
| 248 | *Acanthochitona crinitus* |
| 249 | *Crepidula fornicata* |
| 250 | *Gibbula tumida* |
| 251 | *Hinia reticulata* |
| 252 | *Buccinum undatum* |
| 252 | *Buccinum undatum (juv)* |
| 253 | *Ocenebra erinacea* |
| 297 | *Tricolia pullus* |
| | **OPISTHOBRANCHIA** |
| 254 | *Unidet. Opisthobranch* |
| 255 | *Doto sp.* |
| 256 | *Onchidoris muricata* |
| | **BIVALVIA** |
| 257 | *Unidet. Bivalve (Juvenile)* |
| 258 | *Nucula nucleus* |
| 259 | *Spisula subtruncata* |
| 314 | *Spisula elliptica* |
| 260 | *Anomia ephippium* |
| 261 | *Modiolarca tumida* |
| 262 | *Rhomboidella prideauxi* |
| 263 | *Chlamys varia* |
| 264 | *Timoclea ovata* |
| 265 | *Papia rhomboides* |
| 266 | *Venerupis sp.* |
| 267 | *Gari depressa* |
| 268 | *Abra alba* |
| 269 | *Hiatella arctica* |
| 270 | *Mya truncata* |
| 271 | *Ensis ensis* |
| | ***Phylum*** **PHORONIDA** |
| 272 | *Phoronis sp.* |
| | ***Phylum*** **BRYOZOA** |

| Species Code | Taxon |
|---|---|
| 273 | *Aetea anguina* |
| 274 | *Disporella hispida* |
| 275 | *Membranipora membranacea* |
| 276 | *Flustra foliacea* |
| 277 | *Crisiidae sp.* |
| 278 | *Schizoporella unicornis* |
| 298 | *Schizomavella auriculata* |
| 279 | *Microporella ciliata* |
| 280 | *Bicellariella ciliata* |
| 281 | *Unidet.Anascan* |
| 282 | *Alcyonidium diaphanum* |
| 283 | *Alcyondium gelatinosum* |
| | ***Phylum*** **ECHINODERMATA** |
| 284 | *Amphipholis squamata* |
| 285 | *Ophiura ophiura* |
| 286 | *Lapidoplax digitata* |
| 299 | *Echinocyamus pusillus* |
| | ***Phylum*** **CHORDATA : ASCIDIACEA** |
| 287 | *Styela clava* |
| 288 | *Ascidiella scabra* |
| 289 | *Molgula sp. (Type #1)* |
| 290 | *Molgula sp. (Type #2)* |
| 291 | *Distomus variolosus* |
| 292 | *Dendrodoa grossularia* |
| 293 | *Pyura sp.* |
| **Total number of species = 316** | |

**Appendix Table 4** Table summarising the variety and abundance of the macrofauna (>1 mm) extracted from the sediments of the North Nab Study site in 1999. The species identification codes are shown in parentheses and are followed by the number of individuals per Hamon Grab sampler of sediment ($0.2m^2$). Also shown are the total number of individuals (abundance) and species (variety) recorded at each sampling station. Note that P1 denotes a small colonial organism, whilst P2 denotes a large colonial organism. These colonial data were included in the multivariate analysis as P1 = 1 and P2 = 10.

| Station | Identification code & Number per Hamon Grab sample ($0.2\ m^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| 1 | (8)P1;(15)P1;(19)P1;(27)5;(42)1;(70)1;(102)1;(117)1;(124)1;(141)2; (157)1;(189)5;(206)1;(249)3;(258)2;(268)3;(291)203 | 233 | 17 |
| 3 | (10)P1;(11)P1;(15)P1;(27)2; (39)1;(42)1;(43)1;(65)2;(68)1;(70)2;(76)1; (85)2;(91)1;(93)3;(97)2;(108)1;(118)3;(122)2;(124)5;(130)3;(140)3; (141)1;(145)1;(157)14;(164)3;(174)1;(189)1;(196)1;(222)1;(223)1; (230)1;(257)1;(258)3;(259)2;(268)1;(276)P1;(282)P1;(289)2;(291)190; (301)P1 | 266 | 40 |
| 5 | (10)P1;(11)P1;(61)1;(65)1;(68)1;(70)1;(108)1;(118)2;(124)1;(130)2; (157)13;(164)3;(229)1;(230)1;(268)1;(276)P1;(282)P1;(291)24 | 57 | 18 |
| 6 | (8)P1;(24)P1;(42)1;(61)1;(65)1;(66)1;(73)1;(92)1;(97)2;(111)2;(118)1; (124)2;(164)33;(189)1;(207)1;(230)1;(276)P1;(280)P1;(282)P1;(289)2; (291)12;(301)P1;(303)1;(304)1 | 71 | 24 |
| 7 | (15)P1;(16)P1;(27)4;(65)1;(68)2;(93)2;(97)1;(101)1;(122)9;(130)3; (132)2;(152)1;(157)7;(233)1;(249)3;(258)2;(268)2;(276)P1;(291)115; (301)P1 | 160 | 20 |
| 8 | (11)P1;(27)5;(36)1;(37)1;(53)1;(66)1;(97)3;(118)5;(119)1;(122)7; (124)2;(125)3;(132)3;(137)1;(145)1;(154)1;(157)3;(161)1;(173)2; (199)1;(216)1;(249)26;(250)1;(251)1;(258)2;(276)P1;(291)32 | 107 | 27 |
| 9 | (9)P2;(20)P1;(21)P1;(33)2;(34)1;(48)4;(57)1;(61)7;(66)1;(83)1;(91)4; (93)4;(95)3;(118)3;(119)1;(121)1;(122)6;(124)5;(130)7;(149)1;(157)16; (162)1;(171)2;(173)1;(186)2;(187)1;(189)1;(207)7;(210)1;(211)2; (225)1;(230)1;(233)1;(245)1;(249)2;(276)P1;(283)P1;(291)145; | 251 | 38 |
| 10 | (10)P1;(19)P1;(24)P1;(56)2;(58)2;(61)2;(65)2;(70)2;(119)2;(122)4; (157)12;(164)2;(207)6;(209)4;(234)2;(249)4;(258)2;(259)8;(276)P1; (277)P1;(291)54;(301)P1 | 116 | 22 |
| 11 | (9)P1;(10)P1;(21)P1;(24)P1;(25)P1;(55)2;(61)1;(77)1;(83)1;(88)1; (91)2;(102)1;(105)1;(118)2;(122)9;(123)1;(125)1;(130)1;(131)2;(140)1; (148)1;(157)8;(158)1;(173)3;(188)1;(216)1;(222)3;(230)1;(246)1; (249)13;(250)1;(254)1;(258)1;(268)1;(276)P1;(283)P1;(287)1;(291)142 | 214 | 38 |
| 12 | (70)1;(93)1;(101)1;(111)1;(118)1;(141)2;(157)9;(173)2;(189)1;(207)1; (212)1;(249)1;(259)1;(291)10;(301)P1 | 34 | 15 |
| 13 | (6)P1;(15)P1;(16)P1;(37)1;(61)1;(65)1;(68)9;(73)1;(109)1;(130)2; (152)2;(157)3;(161)3;(170)1;(269)1;(280)P1;(289)3 | 33 | 17 |
| 16 | (15)P1;(19)P1;(25)P1;(28)1;(37)17;(40)7;(43)1;(48)2;(52)1;(53)4; | 299 | 51 |

| Station | Identification code & Number per Hamon Grab sample (0.2 $m^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (61)7;(65)9;(68)4;(80)4;(81)2;(86)2;(88)1;(105)5;(110)1;(118)5; (124)1;(130)3;(152)9;(153)9;(157)7;(261)2;(164)79;(175)1;(179)2; (189)1;(204)1;(209)1;(210)1;(218)4;(223)2;(233)8;(239)1;(241)2; (242)1;(249)1;(260)3;(262)1;(267)2;(269)8;(272)1;(280)P1;(284)2; (289)61;(290)3;(291)4;(293)1 | | |
| 17 | (27)3;(37)1;(39)1;(58)1;(65)1;(67)1;(73)1;(82)1;(88)1;(117)1;(122)4; (124)2;(128)1;(130)3;(138)1;(145)1;(157)2;(191)2;(206)1;(233)4; (242)1;(249)28;(252)1;(258)4;(276)P1;(291)55 | 123 | 26 |
| 18 | (11)P1;(13)P1;(19)P1;(27)14;(33)1;(37)3;(40)1;(42)2;(55)1;(75)1; (79)1;(82)3;(87)1;(97)3;(118)2;(122)6;(124)4;(130)12;(139)1;(145)1; (146)1;(157)12;(168)1;(174)1;(196)1;(206)1;(233)3;(242)1;(249)371; (253)1;(258)11;(276)P2;(291)150 | 623 | 33 |
| 20 | (16)P1;(27)18;(42)2;(66)2;(70)2;(87)2;(93)4;(118)6;(122)6;(124)2; (130)14;(131)2;(132)2;(157)12;(168)2;(189)2;(206)2;(230)2;(233)2; (249)276;(258)10;(268)4;(275)P1;(276)P1;(291)26;(301)P1 | 404 | 26 |
| 21 | (13)P1;(19)P2;(24)P1;(27)1;(43)1;(48)1;(54)1;(56)1;(61)1;(66)2;(68)1; (83)1;(91)1;(97)5;(101)1;(108)1;(109)1;(117)1;(118)10;(122)2;(124)4; (130)3;(132)2;(133)1;(140)3;(141)1;(157)5;(173)1;(189)3;(204)1; (207)1;(222)1;(230)1;(249)39;(258)3;(276)P1;(282)P1;(291)95 | 210 | 38 |
| 22 | (27)1;(61)1;(83)1;(93)1;(118)1;(122)5;(124)3;(130)2;(132)2;(157)13; (207)1;(249)4;(258)1;(275)P1;(283)P1;(291)27 | 65 | 16 |
| 23 | (5)P1;(10)P1;(13)P1;(15)P1;(16)P1;(19)P1;(27)3;(43)1;(65)2;(70)1; (82)3;(93)4;(97)4;(104)1;(118)2;(122)8;(124)1;(125)2;(130)1;(139)1; (144)2;(157)10;(173)1;(189)1;(207)6;(230)1;(249)16;(256)2;(258)2; (273)P1;(276)P1;(281)P1;(289)1;(291)80;(301)P1 | 166 | 35 |
| 24 | (9)P1;(21)P1;(23)P1;(27)10;(34)1;(91)3;(102)1;(118)1;(122)3;(130)1; (140)1;(157)1;(173)4;(189)1;(207)3;(216)1;(249)1;(258)2;(268)1; (276)P1;(291)20 | 59 | 21 |
| 25 | (26)P1;(56)4;(103)1;(126)2;(127)5;(157)1;(186)1;(280)P1;(301)P1 | 17 | 9 |
| 26 | (47)1;(111)1;(122)1;(124)1;(164)1;(190)3;(230)1;(276)P1;(280)P1; (282)P1 | 12 | 10 |
| 27 | (82)3;(110)1;(111)1;(126)1;(190)1;(276)P1 | 8 | 6 |
| 28 | (83)2;(100)2;(101)2 | 6 | 3 |
| 32 | (11)P1;(15)P1;(18)P1;(19)P1;(29)1;(33)2;(40)4;(43)1;(48)1;(54)1; (66)1;(68)5;(70)1;(76)4;(82)1;(91)1;(93)11;(97)3;(105)1;(108)1; (118)6;(122)2;(125)7;(124)4;(130)2;(157)1;(173)1;(174)2;(189)2; (198)1;(204)5;(207)6;(210)4;(218)2;(219)1;(222)1;(230)2;(231)1; (233)6;(249)1;(258)2;(269)1;(276)P1;(277)P1;(280)P1;(291)10 | 116 | 46 |
| 33 | (246)1;(249)2;(275)P1;(278)P1 | 5 | 4 |
| 34 | (1)P1;(4)P2;(5)P1;(28)4;(37)1;(40)16;(46)1;(48)3;(61)10;(65)3;(68)4; (73)1;(86)2;(88)3;(91)7;(93)1;(97)1;(117)3;(123)1;(124)2;(128)1; (130)126;(132)1;(140)3;(152)8;(153)4;(157)18;(161)2;(174)1;(181)2; | 396 | 47 |

| Station | Identification code & Number per Hamon Grab sample (0.2 $m^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (186)13;(189)1;(204)6;(207)1;(210)26;(221)3;(222)1;(233)33;(242)3; | | |
| | (249)19;(258)25;(269)1;(278)P1;(282)P1;(284)1;(289)14;(291)6 | | |
| 35 | (5)P1;(11)P1;(19)P1;(27)4;(28)2;(33)1;(40)2;(48)1;(80)1;(83)2;(85)3; (93)5;(94)2;(108)1;(117)1;(122)4;(124)2;(128)1;(130)10;(157)5;(199)1; | 149 | 28 |
| | (210)3;(233)3;(249)26;(258)3;(276)P1;(282)P1;(291)60 | | |
| 36 | (27)14;(55)2;(88)2;(93)4;(101)2;(121)2;(122)10;(124)2;(130)4;(157)6; (249)110;(258)6;(276)P1;(282)P1;(291)136 | 302 | 15 |
| 37 | (27)18;(33)4;(39)2;(42)6;(56)2;(66)2;(85)2;(86)2;(88)2;(91)2;(118)2; (122)2;(130)18;(134)2;(140)4;(157)28;(161)2;(226)4;(233)8;(239)2; (249)690;(258)12;(276)P2;(289)4;(291)82;(292)6 | 918 | 26 |
| 38 | (16)P1;(42)2;(48)1;(54)1;(56)1;(61)2;(65)1;(83)2;(91)3;(93)1;(97)8; (118)2;(122)4;(124)1;(130)1;(133)2;(152)1;(157)1;(164)3;(173)1; (189)1149;(203)4;(230)1;(233)1;(249)4;(251)1;(258)9;(268)4;(276)P2; (291)1 | 1223 | 30 |
| 39 | (15)P1;(27)9;(28)1;(40)1;(55)1;(82)1;(87)1;(88)1;(91)1;(118)5;(130)5; (157)11;(210)2;(227)1;(239)1;(249)198;(252)1;(258)3;(276)P1;(282)P1; (291)20;(301)P1 | 267 | 22 |
| 40 | (13)P1;(16)P1;(27)4;(39)1;(40)1;(61)1;(65)2;(88)1;(93)1;(117)1; (118)3;(124)1;(130)14;(131)1;(138)1;(145)1;(157)8;(211)1;(214)1; (233)1;(249)119;(252)1;(258)3;(264)1;(268)2;(276)P1;(289)3;(291)95; (293)3 | 274 | 29 |
| 41 | (21)P1;(27)18;(70)2;(85)2;(91)6;(98)2;(118)2;(119)2;(121)2;(122)18; (124)4;(125)2;(130)8;(131)8;(140)2;(157)16;(160)2;(170)2;(173)2; (207)6;(228)2;(230)4;(233)4;(249)30;(276)P1;(291)120 | 268 | 26 |
| 42 | (9)P1;(14)P1;(21)P1;(37)1;(46)1;(88)1;(91)1;(108)1;(114)1;(124)1; (130)4;(157)2;(169)1;(189)1;(207)8;(230)1;(249)6;(258)1;(259)1; (276)P1;(291)36 | 72 | 21 |
| 43 | (13)P1;(33)2;(73)2;(127)4 | 9 | 4 |
| 44 | (82)3;(101)2;(190)1 | 6 | 3 |
| 45 | (100)2;(127)4 | 6 | 2 |
| 46 | (82)6;(83)2;(101)4;(114)2;(127)2 | 16 | 5 |
| 47 | (56)2;(91)2;(126)2;(127)6 | 12 | 4 |
| 49 | (13)P1;(19)P1;(30)1;(33)1;(42)3;(82)2;(88)1;(91)1;(121)1;(122)2; (130)5;(152)1;(189)306;(224)1;(233)1;(240)2;(251)2;(258)43;(267)1; (268)49 | 425 | 20 |
| 50 | (5)P1;(7)P1;(13)P1;(16)P1;(25)P1;(31)P1;(33)4;(37)1;(39)3;(40)3; (42)5;(43)1;(48)1;(51)1;(55)1;(58)2;(61)3;(64)1;(65)2;(66)2;(67)1; (70)1;(76)1;(83)1;(84)2;(92)3;(93)12;(105)2;(117)1;(118)5;(122)7; (124)7;(126)1;(130)10;(133)1;(138)2;(144)1;(145)3;(147)3;(152)3; (153)2;(156)6;(157)8;(161)1;(168)1;(171)1;(174)1;(176)1;(189)6; (191)2;(210)4;(213)1;(214)1;(221)1;(233)2;(244)1;(249)4;(258)27; (280)P1;(289)7;(291)11 | 193 | 61 |

| Station | Identification code & Number per Hamon Grab sample (0.2 $m^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| 51 | (2)P1;(4)P1;(5)P2;(60)1;(65)2;(121)1;(123)1;(130)1;(144)3;(153)1;(157)1;(163)1;(164)3;(166)3;(230)1;(279)P1;(291)1 | 33 | 17 |
| 52 | (28)1;(40)2;(62)1;(63)1;(68)2;(80)2;(91)2;(97)1;(105)1;(122)2;(124)1;(130)7;(147)1;(157)32;(204)2;(210)2;(218)1;(230)2;(233)7;(243)1;(249)2;(258)5;(282)P1;(289)1;(291)2 | 83 | 25 |
| 53 | (40)1;(56)1;(61)2;(66)1;(84)1;(88)2;(91)3;(108)1;(117)6;(122)8;(130)20;(137)1;(157)4;(161)1;(204)1;(209)4;(230)2;(233)6;(238)1;(249)32;(258)6;(276)P2;(289)3;(291)75 | 192 | 24 |
| 54 | (27)3;(28)1;(37)1;(42)1;(43)1;(61)13;(65)3;(66)4;(68)1;(88)2;(91)4;(93)1;(101)2;(118)14;(122)2;(124)2;(125)2;(130)2;(157)4;(182)1;(197)1;(203)7;(208)3;(210)7;(222)1;(227)1;(229)1;(233)3;(242)1;(249)200;(258)5;(276)P2;(289)3;(291)10;(302)1 | 318 | 35 |
| 55 | (4)P1;(42)1;(130)1;(157)3;(249)70;(258)1;(275)P1;(276)P2 | 88 | 8 |
| 56 | (13)P1;(16)P1;(19)P1;(27)6;(33)2;(68)2;(73)2;(85)2;(88)2;(91)4;(93)2;(97)2;(116)4;(117)4;(118)2;(124)2;(130)4;(157)18;(173)2;(189)6;(207)12;(239)2;(249)32;(258)6;(282)P1;(291)28 | 150 | 26 |
| 57 | (11)P1;(16)P1;(19)P1;(27)2;(33)1;(39)2;(40)2;(66)4;(70)1;(73)1;(76)1;(83)2;(84)1;(91)1;(93)1;(97)1;(105)2;(118)5;(120)1;(122)4;(124)4;(130)14;(140)17;(153)1;(157)17;(168)1;(173)2;(174)1;(186)1;(189)3;(203)2;(207)2;(210)4;(233)1;(236)1;(249)21;(258)4;(263)1;(269)1;(276)P1;(282)P1;(289)1;(291)25;(295)1 | 163 | 44 |
| 58 | (9)P2;(12)P2;(17)P1;(21)P1;(34)1;(38)2;(40)1;(48)4;(54)1;(61)3;(66)1;(76)1;(91)1;(95)1;(107)1;(108)3;(116)1;(118)2;(122)9;(123)2;(125)13;(130)13;(137)1;(148)1;(150)1;(156)2;(157)12;(173)1;(191)4;(192)1;(193)1;(199)1;(207)4;(230)1;(233)7;(249)9;(266)1;(276)P2;(291)4 | 142 | 39 |
| 59 | (10)P1;(21)P1;(40)1;(91)3;(108)1;(118)1;(122)4;(124)1;(130)3;(165)1;(230)1;(189)3;(191)1;(207)1;(249)1;(258)1;(291)7;(299)1 | 33 | 18 |
| 60 | (11)P1;(83)1;(92)1;(118)1;(121)1;(122)1;(124)3;(125)1;(130)1;(157)2;(189)1;(207)1;(268)1;(275)P1;(276)P1;(291)1;(301)P1 | 20 | 17 |
| 61 | (19)P1;(28)1;(73)1;(108)1;(111)2;(118)1;(122)1;(126)1;(143)1;(145)1;(190)2;(271)1;(280)P1 | 15 | 13 |
| 62 | (27)10;(41)2;(56)2;(76)2;(80)2;(85)2;(88)2;(117)6;(122)8;(124)8;(130)6;(156)4;(157)6;(186)2;(249)10;(258)4;(275)P1;(276)P2;(282)P1;(301)P1 | 89 | 20 |
| 63 | (82)6;(108)2;(110)2;(122)4;(127)2;(190)2 | 18 | 6 |
| 64 | (56)2;(100)2 | 4 | 2 |
| 65 | (13)P1;(27)1;(33)2;(93)3;(101)1;(102)1;(118)2;(121)1;(122)1;(124)1;(147)1;(189)1;(230)2;(249)5;(258)1;(275)P1;(280)P2;(282)P1;(301)P1 | 37 | 19 |
| 67 | (15)P1;(24)P1;(33)1;(37)1;(61)1;(65)1;(67)1;(68)36;(70)3;(104)2;(105)1;(109)4;(111)1;(118)3;(122)1;(124)1;(125)1;(130)1;(145)1;(152)1;(157)1;(161)1;(164)10;(189)15;(204)1;(207)5;(222)1;(268)1;(276)P1;(277)P1;(289)1;(291)20 | 121 | 32 |

| Station | Identification code & Number per Hamon Grab sample (0.2 m$^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| 68 | (4)P2;(10)P1;(13)P1;(16)P1;(21)P1;(24)P1;(28)1;(33)2;(38)3;(40)6;(48)1;(61)4;(83)2;(88)1;(91)5;(105)1;(106)2;(114)1;(117)6;(121)1;(122)3;(124)1;(130)12;(133)1;(135)3;(136)1;(138)5;(144)10;(153)2;(155)2;(157)10;(161)22;(179)3;(183)2;(184)1;(189)3;(191)1;(199)1;(205)1;(207)2;(210)20;(216)1;(221)3;(230)5;(233)5;(249)2;(258)13;(261)1;(268)1;(269)5;(276)P2;(277)P1;(278)P2;(291)3;(292)1;(294)P2;(295)1;(296)1;(297)1;(298)P2 | 246 | 61 |
| 69 | (15)P1;(16)P1;(27)2;(28)1;(39)1;(40)1;(42)1;(65)2;(70)2;(84)1;(91)1;(93)3;(117)1;(118)4;(122)1;(130)3;(156)1;(157)3;(189)1;(203)2;(210)4;(221)1;(248)1;(249)67;(258)23;(264)1;(269)1;(276)P1;(282)P1;(291)2 | 134 | 30 |
| 70 | (3)P1;(61)2;(79)2;(85)2;(93)4;(97)2;(109)6;(118)2;(122)12;(124)2;(130)2;(132)2;(137)2;(157)6;(184)2;(189)40;(222)2;(258)2;(291)4; | 97 | 19 |
| 71 | (13)P1;(16)P1;(28)2;(40)4;(42)4;(48)2;(53)2;(66)2;(68)2;(91)8;(93)8;(97)2;(108)2;(117)2;(118)2;(122)8;(124)6;(130)30;(140)2;(152)6;(157)20;(161)2;(168)4;(173)2;(177)2;(203)2;(208)4;(210)6;(233)12;(249)136;(258)40;(263)2;(269)2;(276)P2;(284)2;(289)4;(291)170 | 518 | 37 |
| 72 | (5)P1;(19)P1;(27)4;(29)1;(32)1;(33)1;(37)1;(40)2;(66)1;(80)1;(85)1;(92)2;(93)2;(96)1;(117)3;(122)1;(124)4;(130)12;(145)3;(152)1;(157)6;(189)1;(208)2;(210)1;(230)1;(249)58;(258)6;(276)P1;(289)5;(291)23 | 148 | 30 |
| 73 | (13)P1;(16)P1;(19)P1;(27)26;(40)2;(42)8;(48)2;(56)2;(66)2;(80)2;(83)2;(91)2;(93)2;(97)4;(103)2;(117)2;(118)2;(122)16;(124)2;(130)36;(137)2;(145)2;(157)22;(189)6;(210)2;(227)4;(230)2;(249)108;(251)2;(258)10;(276)P1;(287)2;(289)2;(291)104 | 386 | 34 |
| 74 | (19)P1;(37)2;(83)1;(88)1;(91)1;(117)3;(122)3;(124)1;(130)4;(131)1;(137)1;(157)5;(170)1;(189)3;(199)1;(207)3;(210)2;(249)2;(274)P1;(276)P1;(282)P1;(288)1;(291)71 | 111 | 23 |
| 75 | (9)P1;(10)P1;(13)P1;(21)P1;(40)2;(48)2;(49)2;(61)2;(66)2;(69)2;(70)2;(91)4;(93)4;(95)4;(104)2;(111)2;(118)2;(122)10;(131)4;(140)2;(156)8;(157)4;(165)52;(189)2;(207)30;(230)2;(249)2;(251)2;(258)2;(275)P1;(291)14 | 171 | 31 |
| 76 | (19)P1;(33)2;(56)2;(65)2;(91)4;(96)2;(103)2;(122)2;(125)2;(157)2;(167)2;(207)2;(239)2;(249)74;(250)2;(251)4;(252)2;(258)16;(275)P1;(276)P1; (282)P1;(291)44;(293)2 | 175 | 23 |
| 77 | (21)P1;(45)1;(48)2;(55)1;(65)2;(87)2;(91)1;(93)2;(97)1;(117)2;(118)3;(121)1;(122)2;(165)9;(169)1;(173)1;(184)1;(207)8;(230)1;(300)1 | 43 | 20 |
| 78 | (16)P1;(19)P1;(56)1;(61)1;(65)2;(92)1;(118)1;(122)1;(124)1;(165)6;(193)1;(207)4;(301)P1 | 22 | 13 |
| 79 | (13)P1;(19)P1;(56)2;(82)2;(85)4;(93)1;(118)1;(280)P1;(301)P1 | 14 | 9 |
| 80 | (56)1;(82)3;(110)1;(127)1 | 6 | 4 |
| 81 | (83)6;(115)2;(122)2;(127)2 | 12 | 4 |
| 82 | (82)1 | 1 | 1 |
| 84 | (10)P1;(11)P1;(19)P1;(28)1;(40)7;(50)1;(53)2;(61)1;(65)2;(91)1;(93)2; | 151 | 39 |

| Station | Identification code & Number per Hamon Grab sample (0.2 m$^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (97)1;(105)4;(119)1;(130)14;(138)1;(142)1;(145)9;(152)1;(157)3; (161)5;(164)2;(185)1;(189)4;(210)4;(212)1;(230)1;(233)6;(249)3; (257)1;(258)14;(261)1;(276)P1;(282)P1;(284)2;(289)10;(290)1;(291)36; (293)2 | | |
| 85 | (2)P1;(10)P1;(11)P1;(15)P1;(19)P1;(39)5;(40)3;(48)2;(61)3;(65)6; (76)2;(82)4;(88)1;(91)1;(93)1;(97)1;(104)1;(105)3;(118)1;(122)3; (130)24;(137)1;(145)12;(152)6;(157)2;(173)1;(174)1;(189)4;(204)3; (210)6;(221)1;(230)1;(243)1;(249)6;(258)53;(268)2;(269)2;(276)P1; (280)P1;(282)P2;(289)8;(301)P1 | 189 | 42 |
| 86 | (15)P1;(19)P1;(42)1;(91)1;(93)2;(105)P1;(122)4;(124)4;(130)3;(132)2; | 237 | 19 |
| | (152)2;(164)1;(189)176;(240)1;(249)2;(258)13;(268)19;(272)2;(291)1; | | |
| 87 | (11)P1;(16)P1;(42)4;(61)1;(67)1;(82)3;(118)1;(122)1;(124)1;(130)5; (161)1;(168)1;(174)1;(179)1;(204)1;(208)1;(210)7;(213)1;(228)2; (230)2;(233)3;(249)81;(258)33;(261)1;(268)4;(276)P1;(289)1;(291)1; (292)1 | 163 | 29 |
| 88 | (16)P1;(27)2;(42)2;(61)1;(65)1;(66)4;(82)1;(91)3;(97)2;(101)1;(118)3; (122)2;(130)13;(131)1;(132)1;(140)1;(157)12;(161)1;(203)2;(208)1; (210)3;(230)2;(233)1;(249)126;(258)8;(269)2;(276)P1;(291)31 | 228 | 28 |
| 89 | (16)P1;(19)P1;(28)2;(33)4;(37)2;(42)4;(46)2;(68)2;(79)2;(83)2;(87)2; (93)4;(105)2;(108)2;(118)14;(119)2;(122)8;(124)2;(130)30;(145)2; (161)2;(173)2;(189)4;(208)2;(210)2;(249)38;(258)16;(276)P1;(291)96; | 253 | 29 |
| 90 | (10)P1;(27)4;(61)2;(68)2;(91)2;(93)2;(97)2;(103)2;(109)4;(118)6; (122)6;(124)2;(125)4;(130)2;(145)2;(157)10;(174)2;(189)2;(197)4; (207)2;(208)2;(245)2;(249)14;(258)2;(276)P1;(287)2;(291)46;(293)2; (301)P1 | 135 | 29 |
| 91 | (10)P1;(16)P1;(42)1;(61)2;(66)4;(68)5;(72)1;(73)1;(82)2;(89)1;(91)4; (93)1;(97)1;(109)1;(118)5;(119)1;(122)5;(124)1;(125)1;(130)18;(132)2; (144)1;(157)4;(173)2;(177)1;(189)1;(207)8;(210)4;(233)1;(249)18; (258)1;(275)P1;(276)P1;(282)P1;(291)19;(301)P1 | 123 | 36 |
| 92 | (15)P1;(16)P1;(39)2;(48)1;(61)1;(65)2;(68)2;(88)1;(91)7;(93)2;(97)5; (101)1;(118)3;(122)5;(125)2;(130)13;(132)2;(145)1;(152)2;(157)8; (173)7;(189)3;(202)2;(207)2;(214)1;(216)2;(227)1;(249)8;(255)2; (258)2;(265)1;(276)P1;(282)P1;(291)40;(301)P1 | 136 | 35 |
| 93 | (10)P1;(21)P1;(28)1;(38)1;(56)1;(59)1;(91)1;(121)1;(122)2;(124)3; (130)1;(148)2;(151)1;(157)3;(189)2;(233)1;(249)9;(258)1;(275)P1; (276)P1;(285)1 | 37 | 21 |
| 94 | (10)P1;(13)P1;(42)1;(56)2;(65)4;(66)1;(73)1;(91)3;(93)2;(97)2;(118)4; (122)7;(130)2;(144)1;(157)8;(164)15;(168)1;(169)1;(173)3;(197)1; (207)2;(214)2;(249)3;(258)2;(275)P1;(276)P1;(291)2;(301)P2 | 73 | 28 |
| 95 | (9)P1;(13)P1;(16)P1;(35)2;(40)2;(61)48;(66)2;(70)1;(88)2;(91)5;(97)1; (118)2;(121)3;(122)2;(124)5;(157)2;(159)2;(164)20;(168)12;(180)3; (184)1;(199)1;(204)49;(206)17;(210)1;(220)1;(222)2;(232)1;(233)24; | 245 | 39 |

| Station | Identification code & Number per Hamon Grab sample (0.2 $m^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (242)1;(245)5;(249)4;(250)5;(253)2;(263)1;(275)P1;(276)P2;(283)P1; | | |
| | (284)1 | | |
| 96 | (13)P1;(24)P1;(65)6;(66)4;(68)4;(85)2;(91)4;(118)2;(121)2;(125)4; (164)8;(174)2;(207)18;(230)4;(282)P1;(291)2;(301)P1 | 66 | 17 |
| 97 | (10)P1;(15)P1;(39)1;(54)1;(56)2;(65)2;(68)1;(88)1;(117)2;(118)1; (122)2;(124)1;(189)2;(199)1;(207)8;(214)2;(230)1;(233)1;(282)P1; | 33 | 20 |
| | (301)P1 | | |
| 98 | (19)P1;(26)P2;(56)1;(85)1;(93)1;(108)1;(112)1;(117)1;(121)1;(130)1; (230)1;(249)1;(276)P1;(282)P1 | 23 | 14 |
| 99 | (82)8;(83)2;(100)2;(110)2 | 14 | 4 |
| 104 | (15)P1;(27)2;(42)1;(93)5;(129)1;(130)15;(157)3;(189)1;(210)4;(230)1; (249)19;(258)4;(269)1;(275)P1;(276)P1;(301)P1; | 62 | 16 |
| 106 | (9)P1;(19)P1;(27)2;(33)2;(48)2;(56)4;(66)2;(79)2;(91)2;(97)6;(108)8; (118)2;(122)2;(124)6;(130)12;(157)4;(189)4;(204)2;(206)2;(207)10; (247)2;(249)12;(258)2;(291)22; | 114 | 24 |
| 108 | (9)P1;(16)P2;(38)1;(40)1;(48)1;(55)1;(87)1;(88)1;(89)2;(91)1;(117)3; (122)1;(124)3;(130)12;(134)1;(145)1;(157)14;(164)58;(173)4;(189)1; (199)1;(204)3;(207)1;(222)1;(229)1;(230)3;(235)1;(242)1;(245)1; (249)132;(253)3;(268)1;(276)P2;(283)P1;(291)11 | 289 | 35 |
| 109 | (7)P1;(16)P1;(28)1;(39)1;(42)1;(61)1;(65)1;(66)2;(70)1;(80)1;(82)1; (88)1;(91)2;(92)3;(93)2;(97)2;(122)4;(124)4;(130)13;(144)2;(145)1; (152)2;(157)9;(189)1;(207)2;(233)1;(249)10:(252)1;(258)2;(269)1; (275)P1;(276)P1;(289)1;(291)2 | 80 | 34 |
| 111 | (61)1;(91)1;(93)1;(101)1;(118)2;(122)6;(124)4;(130)1;(157)2;(189)3; (249)2;(258)1;(275)P1;(291)5 | 31 | 14 |
| 113 | (10)P1;(16)P1;(21)P1;(32)1;(38)6;(39)1;(40)3;(48)1;(61)1;(65)1; (66)10;(83)1;(88)1;(91)7;(101)1;(103)1;(105)1;(118)3;(122)11;124)2; (130)35;(132)2;(139)9;(140)1;(151)2;(157)10;(160)2;(168)1;(173)4; (185)1;(189)2;(196)2;(204)2;(206)2;(210)13;(222)1;(233)4;(249)148; (258)9;(263)2;(276)P1;(291)16 | 324 | 42 |
| 115 | (7)P1;(9)P1;(19)P1;(61)2;(65)4;(66)2;(68)4;(69)2;(70)6;(83)2;(92)6; (97)2;(109)2;(111)2;(116)2;(118)6;(119)2;(122)12;(124)10;(125)8; (128)2;(130)10;(157)34;(169)2;(173)4;(207)20;(210)2;(230)2;(249)24; (258)10;(276)P1;(280)P1;(291)90 | 279 | 33 |
| 116 | (19)P1;(27)6;(42)2;(66)2;(68)2;(78)2;(93)6;(97)4;(117)2;(122)10; (130)12;(131)2;(137)2;(157)2;(161)2;(173)2;(210)2;(249)30;(258)4; (268)2;(276)P1;(282)P1;(287)2;(291)130 | 231 | 24 |
| 117 | (10)P1;(11)P1;(16)P1;(19)P1;(28)P1;(42)2;(65)1;(83)1;(91)2;(97)2; (117)1;(118)1;(122)4;(125)1;(130)7;(145)1;(147)1;(157)17;(189)1; (196)1;(207)8;(210)2;(216)1;(247)1;(249)22;(258)3;(276)P1;(287)1; (291)19 | 106 | 29 |
| 118 | (11)P1;(15)P1;(16)P1;(27)3;(33)1;(42)2;(58)1;(65)1;(77)2;(79)1;(88)1; | 89 | 25 |

| Station | Identification code & Number per Hamon Grab sample (0.2 $m^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (93)2;(118)1;(122)3;(124)4;(128)1;(130)2;(131)3;(140)1;(189)2;(207)4; | | |
| | (249)9;(282)P1;(291)40;(301)P1 | | |
| 119 | (15)P1;(19)P1;(27)2;(61)2;(68)2;(83)2;(88)1;(92)1;(93)2;(97)1;(122)1; (123)2;(130)1;(136)1;(138)1;(157)15;(189)1;(207)2;(230)2;(249)4; (258)3;(276)P1;(291)34 | 83 | 23 |
| 120 | (15)P1;(16)P1;(19)P1;(40)2;(54)4;(66)4;(87)4;(93)8;(124)2;(130)32: (131)2;(145)4;(157)12;(161)2;(173)2;(199)2;(207)2;(208)2;(230)2; | 362 | 25 |
| | (233)2;(249)28;(258)8;(276)P1;(287)2;(291)232 | | |
| 121 | (19)P1;(42)2;(65)2;(67)2;(78)2;(85)2;(93)12;(117)2;(122)4;(130)4; (157)2;(161)2;(207)2;(230)2;(233)4;(249)8;(282)P1;(291)72 | 126 | 18 |
| 122 | (9)P2;(10)P2;(21)P2;(44)1;(48)4;(61)1;(84)1;(91)5;(94)1;(99)1;(108)1; (122)10;(123)4;(125)1;(130)1;(132)1;(140)1;(151)2;(157)2;(160)1; (168)1;(173)9;(196)1;(198)1;(207)2;(249)1;(276)P2;(291)5 | 98 | 28 |
| 123 | (10)P1;(19)P1;(27)2;(56)1;(61)1;(66)1;(91)6;(97)2;(101)1;(109)1; (118)7;(122)1;(125)4;(130)1;(157)4;(164)5;(168)1;(169)1;(173)1; (189)5;(203)1;(207)14;(210)1;(223)1;(230)1;(233)1;(249)8;(275)P1; (282)1;(291)33 | 109 | 30 |
| 124 | (19)P1;(56)2;(85)2;(117)2;(164)44;(189)4;(207)2;(249)12;(276)P1 (291)46 | 116 | 10 |
| 125 | (9)P1;(10)P1;(21)P1;(27)1;(33)2;(40)1;(61)2;(66)4;(71)1;(80)1;(91)4; (95)1;(118)1;(119)1;(121)1;(122)6;(124)1;(128)1;(130)3;(136)1;(157)6; (165)1;(173)1;(189)1;(207)10;(210)2;(216)1;(222)1;(249)12;(258)1; (275)P1;(276)P1;(283)P1;(286)1;(291)50 | 125 | 35 |
| 126 | (38)1;(40)1;(91)1;(97)1;(117)3;(121)3;(122)9;(124)3;(125)2;(189)1; (268)1 | 26 | 11 |
| 127 | (10)P1;(15)P1;(19)P1;(27)1;(33)1;(42)1;(43)1;(61)2;(65)6;(66)1;(68)2; (73)1;(80)1;(91)7;(92)2;(118)1;(122)3;(124)2;(125)1;(128)1;(130)4; (141)1;(144)1;(157)2;(161)1;(164)7;(173)1;(199)1;(207)6;(233)1; (249)6;(258)2;(259)1;(275)P1;(291)5 | 77 | 35 |
| 128 | (8)P1;(11)P1;(16)P1;(25)P1;(27)3;(37)1;(66)2;(68)1;(70)1;(75)1;(80)1; (82)1;(83)1;(93)2;(101)2;(108)1;(118)4;(119)2;(122)5;(124)4;(130)5; (132)1;(140)2;(145)1;(157)18;(164)3;(189)1;(206)2;(222)2;(233)2; (249)8;(258)1;(276)P1;(279)P1;(282)P1;(291)66 | 152 | 36 |
| 129 | (10)P1;(13)P1;(15)P1;(56)1;(66)2;(82)2;(93)1;(102)2;(111)3;(124)1; (130)2;(157)1;(161)1;(164)12;(168)1;(189)3;(204)1;(206)1;(230)4; (253)1;(276)P1;(277)P1;(291)90;(301)P1 | 135 | 24 |
| 130 | (19)P1;(22)P1;(25)P1;(82)2;(85)1;(93)1;(101)2;(104)4;(108)1;(111)2; (118)3;(124)1;(130)2;(139)1;(157)2;(164)9;(190)1;(230)1;(243)1; (277)P1;(289)1;(291)11;(301)P1 | 51 | 23 |
| 131 | (8)P1;(10)P1;(15)P1;(17)P1;(19)P1;(33)1;(37)2;(39)2;(58)1;(65)1; (68)1;(82)7;(88)1;(91)1;(93)7;(105)4;(118)3;(119)1;(124)5;(125)1; (128)2;(130)6;(140)1;(152)2;(157)21;(164)100;(168)1;(173)7;(174)1; | 296 | 46 |

| Station | Identification code & Number per Hamon Grab sample (0.2 m$^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (178)1;(189)85;(196)2;(207)1;(208)1;(210)2;(215)2;(230)2;(233)1; | | |
| | (249)2;(258)1;(268)3;(270)1;(276)P1;(282)P1;(291)5;(301)P1 | | |
| 132 | (10)P1;(11)P1;(19)P1;(33)1;(42)2;(46)1;(56)1;(73)1;(76)1;(80)1;(82)2; (102)1;(105)5;(106)1;(111)1;(118)2;(122)2;(124)1;(128)2;(130)9; (132)1;(137)1;(152)1;(157)11;(173)1;(189)3;(210)1;(259)42;(258)2; (268)6;(276)P1;(289)1;(301)P1 | 108 | 33 |
| 133 | (10)P2;(11)P1;(25)P1;(34)1;(56)1;(65)1;(68)1;(73)1;(79)1;(82)1;(85)2; (92)1;(97)1;(105)1;(107)3;(108)1;(109)1;(118)3;(125)1;(130)13;(132)1; (140)1;(151)2;(152)4;(157)5;(164)3;(173)8;(189)8;(207)2;(210)3; (229)1;(230)1;(249)1;(258)5;(261)1;(268)2;(272)1;(276)P1;(280)P1; (282)P1;(287)1;(291)4;(301)P1 | 104 | 43 |
| 134 | (15)P1;(19)P1;(27)1;(45)1;(85)1;(91)1;(118)2;(121)1;(122)11;(132)1; (137)2;(157)9;(164)124;(193)1;(203)5;(217)2;(258)1;(268)2;(276)P1; (291)1;(301)P1 | 169 | 21 |
| 135 | (19)P1;(27)1;(37)1;(42)2;(48)1;(61)1;(65)1;(66)3;(68)3;(76)1;(85)3; (92)1;(93)2;(97)3;(105)1;(108)2;(118)1;(121)2;(122)11;(128)2;(130)1; (157)1;(164)1270;(173)1;(189)5;(196)2;(199)2;(208)2;(232)1;(249)1; (250)1;(268)3;(276)P1;(282)P1;(284)1;(301)P1 | 1337 | 36 |
| 136 | (8)P1;(15)P1;(66)1;(68)3;(70)1;(76)3;(83)1;(91)2;(101)1;(105)1; (107)2;(109)2;(121)1;(122)3;(132)3;(154)1;(157)2;(164)287;(168)1; (174)1;(179)9;(189)6;(192)1;(194)11;(197)1;(201)4;(207)3;(239)1; (241)1;(258)1;(268)2;(291)1;(301)P1 | 360 | 33 |
| 137 | (8)P1;(10)P1;(15)P1;(66)2;(68)14;(70)2;(73)1;(74)1;(85)1;(91)1;(93)2; (97)1;(117)1;(118)1;(122)5;(124)1;(125)1;(128)1;(164)271;(189)2; (199)2;(207)15;(208)2;(230)1;(233)1;(258)1 | 333 | 26 |
| 138 | (10)P1;(15)P1;(19)P1;(24)P1;(32)1;(37)2;(39)3;(42)1;(65)2;(66)2; (68)7;(76)3;(82)6;(85)6;(93)2;(97)8;(102)1;(108)5;(113)2;(118)2; (119)3;(122)2;(124)2;(128)1;(129)1;(130)11;(132)1;(140)2;(145)1; (157)29;(160)1;(164)349;(173)6;(182)1;(185)2;(189)11;(194)1;(200)1; (204)1;(207)3;(209)1;(210)1;(215)1;(230)3;(233)2;(239)1;(249)73; (250)1;(258)11;(276)P1;(282)P1;(289)1;(291)83;(293)1;((301)P2 | 677 | 55 |
| 139 | (8)P1;(10)P1;(11)P1;(56)1;(68)2;(92)1;(97)2;(108)3;(118)1;(121)1; (122)1;(142)1;(157)2;(164)17;(173)2;(189)1;(197)2;(207)1;(222)1; (223)1;(301)P1 | 44 | 21 |
| 140 | (7)P1;(10)P1;(15)P1;(27)1;(68)1;(82)1;(93)1;(97)1;(104)1;(105)2; (118)2;(121)1;(157)3;(164)124;(189)6;(207)1;(208)2;(243)1;(291)5; (301)P1 | 157 | 20 |
| 141 | (15)P1;(25)P1;(65)1;(66)1;(68)5;(91)1;(97)2;(118)4;(125)1;(130)2; (157)4;(164(47);(189)1;(207)12;(208)1;(210)1;(233)1;(249)11;(258)2; (276)P1;(291)29;(301)P1 | 130 | 22 |
| 142 | (10)P1;(15)P1;(39)5;(40)9;(42)2;(43)4;(53)3;(61)8;(65)10;(72)1;(73)1; (76)2;(85)5;(88)1;(91)1;(93)8;(97)3;(105)1;(107)1;(118)4;(122)3; | 492 | 68 |

| Station | Identification code & Number per Hamon Grab sample (0.2 m$^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (124)4;(126)2;(130)42;(134)4;(145)15;(152)5;(153)3;(157)2;(161)2;(167)1;(170)1;(174)2;(176)1;(179)1;(183)2;(184)1;(185)3;(189)16;(197)2;(203)4;(204)20;(208)22;(209)5;(210)21;(215)3;(221)1;(230)1;(233)28;(242)4;(245)2;(249)11;(258)37;(261)1;(263)1;(269)2;(272)1;(280)P1;(284)8;(287)1;(289)14;(290)2;(291)3;(303)3;(305)66;(306)3;(307)2;(308)1 | | |
| 143 | (11)P1;(15)P1;(28)10;(29)2;(37)4;(40)10;(42)4;(43)4;(55)2;(61)14;(65)12;(68)4;(70)2;(76)6;(85)12;(86)4;(89)2;(91)2;(93)10;(97)6;(105)4;(117)4;(118)8;(122)6;(123)2;(124)2;(128)6;(130)140;(132)2;(134)4;(145)2;(152)16;(153)4;(157)34;(161)8;(168)6;(171)4;(184)4;(185)4;(189)8;(204)22;(208)12;(209)52;(210)44;(221)2;(223)2;(228)2;(233)38;(239)2;(242)10;(249)160;(258)62;(260)2;(261)2;(263)4;(268)2;(276)P1;(278)P1;(284)2;(287)2;(289)16;(291)16;(305)10;(309)2 | 848 | 64 |
| 144 | (7)P1;(11)P1;(16)P1;(27)30;(33)4;(37)12;(40)4;(42)4;(43)2;(45)2;(48)4;(61)6;(65)46;(66)2;(76)6;(83)2;(84)2;(85)12;(86)2;(87)2;(88)2;(93)12;(97)6;(101)4;(104)2;(105)6;(117)8;(118)8;(119)2;(122)6;(124)4;(128)2;(130)34;(137)2;(145)4;(157)12;(161)2;(168)8;(180)2;(183)6;(184)4;(189)12;(196)2;(201)2;(203)74;(204)30;(205)32;(208)34;(209)20;(210)18;(213)2;(233)62;(237)2;(239)2;(245)8;(249)352;(258)72;(268)2;(272)4;(275)P1;(276)P2;(284)4;(289)10;(291)176;(292)4;(301)P1;(303)2;(305)198;(308)2;(310)2;(311)2 | 1423 | 71 |
| 145 | (11)P1;(16)P1;(27)1;(40)4;(42)1;(45)1;(61)2;(65)6;(66)1;(68)1;(76)1;(84)1;(85)4;(86)1;(93)4;(97)1;(101)2;(118)7;(122)2;(124)1;(128)1;(130)10;(157)3;(179)1;(203)2;(208)14;(210)7;(211)2;(222)2;(228)1;(233)19;(242)2;(245)1;(247)1;(249)402;(258)12;(268)1;(269)1;(272)1;(276)P2;(280)P1;(284)1;(289)1;(291)1;(301)P1;(305)2;(311)2;(312)1 | 546 | 48 |
| 146 | (10)P1;(11)P1;(16)P1;(27)30;(28)2;(40)6;(42)4;(54)2;(56)2;(65)4;(66)4;(76)2;(82)2;(85)4;(88)2;(93)12;(97)16;(101)2;(118)14;(119)2;(122)30;(128)6;(130)24;(131)4;(134)4;(137)2;(152)2;(157)12;(161)2;(164)2;(168)2;(171)4;(184)2;(189)8;(204)2;(205)6;(208)16;(210)10;(222)4;(230)4;(231)2;(233)10;(249)246;(258)28;(261)2;(268)6;(269)2;(272)4;(276)P1;(282)P1;(289)6;(291)32 | 599 | 52 |
| 147 | (10)P1;(19)P1;(27)2;(33)6;(37)2;(40)2;(48)2;(56)4;(65)2;(66)14;(68)2;(85)8;(87)2;(93)6;(97)10;(109)10;(118)2;(121)2;(122)14;(124)2;(125)2;(132)2;(137)2;(157)10;(164)6;(165)156;(173)12;(189)14;(207)2;(208)12;(222)6;(249)6;(275)P1;(276)P1;(282)P1;(301)P1;(313)2;(314)2 | 330 | 38 |
| 148 | (1)P1;(8)P1;(10)P1;(19)P1;(37)1;(40)1;(42)1;(56)2;(61)1;(65)2;(66)10;(68)5;(70)1;(73)1;(76)3;(85)3;(91)1;(93)12;(97)4;(104)1;(109)7;(118)6;(122)8;(124)6;(128)3;(137)9;(145)1;(157)12;(165)51;(167)1;(168)1;(169)1;(173)13;(174)3;(189)19;(194)6;(196)1;(204)1;(207)18;(208)26;(210)1;(222)4;(233)4;(268)1;(275)P1;(276)P1;(280)P1;(284)3;(288)1;(301)P1;(312)1;(315)7 | 270 | 52 |
| 149 | (10)P1;(11)P1;(19)P1;(27)3;(33)1;(37)1;(40)2;(43)1;(54)2;(61)1;(65)2; | 241 | 56 |

| Station | Identification code & Number per Hamon Grab sample (0.2 $m^2$) | No. of Indiv. | No. of Spp. |
|---|---|---|---|
| | (66)4;(70)1;(71)1;(73)2;(76)2;(93)4;(97)2;(102)2;(108)1;(109)2; (119)2;(122)14;(124)4;(125)1;(128)3;(130)9;(145)1;(152)2;(157)19; (161)1;(165)37;(168)1;(171)1;(173)4;(174)3;(189)27;(204)6;(207)6; (208)6;(209)1;(210)3;(215)1;(233)4;(242)1;(249)19;(258)4;(264)1; (275)P1;(276)P1;(282)P1;(290)1;(291)15;(301)P1;(305)12;(315)1 | | |
| 150 | (16)P1;(19)P1;(40)10;(42)2;(43)2;(48)2;(61)8;(65)4;(66)8;(73)6;(76)4; (84)2;(85)4;(93)10;(97)4;(101)2;(102)2;(104)2;(105)4;(118)4;(119)4; (122)16;(124)44;(125)4;(128)4;(130)132;(132)2;(134)2;(145)10;(152)6; (154)60;(161)2;(168)6;(169)2;(173)72;(179)2;(189)86;(196)2;(204)2; (205)2;(207)8;(208)6;(210)34;(219)2;(227)2;(233)6;(242)2;(249)18; (256)2;(263)4;(268)2;(275)P1;(276)P1;(282)P1;(289)6;(290)14;(291)8; (305)14;(312)2;(316)4 | 679 | 60 |
| 151 | (11)P1;(16)P1;(58)2;(79)2;(85)2;(97)4;(101)2;(118)2;(122)6;(124)16; (130)2;(228)2 | 42 | 12 |
| | **MEAN =** | **199.56** | **26.77** |
| | **STANDARD DEVIATION =** | **244.08** | **14.96** |

**Appendix Table 5** Table summarising the biomass results for macrofauna (>1mm) extracted from the sediments of the North Nab Study site in 1999. Data have been calculated as Ash-Free Dry Weight (AFDW) from the blotted wet weight using conversion factors from Eleftheriou and Basford (1989). Values are expressed as grams AFDW per 0.2m$^2$ Hamon Grab sample.

| Station | Polychaeta | Mollusca | Crustacea | Miscellania | Total |
|---|---|---|---|---|---|
| 1 | 0.031 | 0.0357 | 0.009 | 0.1147 | 0.1904 |
| 3 | 0.1705 | 0.0459 | 0.0315 | 1.1873 | 1.4352 |
| 5 | 0.0093 | 0.0009 | 0.3915 | 0.0341 | 0.4358 |
| 6 | 0.0186 | - | 0.0225 | 0.2294 | 0.2705 |
| 7 | 0.031 | 0.0119 | 0.0045 | 0.279 | 0.3264 |
| 8 | 0.0651 | 0.0578 | 0.0045 | 0.2387 | 0.3661 |
| 9 | 0.2387 | 0 | 0.0405 | 1.2586 | 1.5378 |
| 10 | 0.062 | 0.0986 | 0 | 0.5952 | 0.7558 |
| 11 | 1.4973 | 0.2159 | 0.0045 | 0.1612 | 1.8789 |
| 12 | 0.0093 | 0.0204 | 0.0045 | 0.0031 | 0.0373 |
| 13 | 0.0341 | 0 | 0 | 0.186 | 0.2201 |
| 16 | 0.1674 | 0.0349 | 0.18 | 1.0323 | 1.4146 |
| 17 | 0.496 | 0.2057 | 0.2205 | 0.713 | 1.6352 |
| 18 | 0.1612 | 1.7136 | 0.0315 | 3.6921 | 5.5984 |
| 20 | 0.4216 | 0.255 | - | 0.384 | 1.0606 |
| 21 | 0.1271 | 0.0629 | 0.027 | 0.3038 | 0.5208 |
| 22 | 0.0093 | 0.0034 | - | 0.0062 | 0.0189 |
| 23 | 0.1147 | 0.2448 | 0.0135 | 0.4154 | 0.7884 |
| 24 | 0.1736 | 0.17 | 0.0045 | 0.0375 | 0.3856 |
| 25 | 0.0124 | - | 0 | 0.0341 | 0.0465 |
| 26 | 0.0031 | - | 0.0585 | 0.0093 | 0.0709 |
| 27 | 0.0093 | - | 0 | 0.0062 | 0.0155 |
| 28 | 0.4464 | - | - | - | 0.4464 |
| 32 | 0.0496 | 0.0017 | 0.1125 | 0.0992 | 0.263 |
| 33 | | 0.0935 | - | - | 0.0935 |
| 34 | 1.0943 | 0.1071 | 0.2925 | 10.2331 | 11.727 |
| 35 | 0.3162 | 0.62 | 0.045 | 0.2914 | 1.2726 |
| 36 | 0.4092 | 0.5066 | - | 1.0664 | 1.9822 |
| 37 | 1.0416 | 6.8476 | 0.261 | 13.6896 | 21.8398 |
| 38 | 0.0589 | 0.0175 | 0.6255 | 8.6831 | 9.385 |
| 39 | 0.9145 | 0.816 | 0.1575 | 0.2883 | 2.1763 |
| 40 | 0.3534 | 0.5202 | 0.0045 | 1.0726 | 1.9507 |
| 41 | 1.395 | 0.561 | 1.692 | 0.403 | 4.051 |
| 42 | 0.1333 | 0.2525 | 0.0045 | 0.1612 | 0.5515 |
| 43 | 0.0016 | - | - | - | 0.0016 |
| 44 | 0.2155 | - | 0 | - | 0.2155 |

| Station | Polychaeta | Mollusca | Crustacea | Miscellania | Total |
|---|---|---|---|---|---|
| 45 | 0.2604 | - | - | - | 0.2604 |
| 46 | 0.217 | - | - | - | 0.217 |
| 47 | 0.0744 | - | - | - | 0.0744 |
| 49 | 0.4836 | 0.2584 | 0.603 | 0.031 | 1.376 |
| 50 | 0.6696 | 0.0264 | 0.009 | 0.8277 | 1.5327 |
| 51 | 0.1116 | | 0.153 | 0.8308 | 1.0954 |
| 52 | 0.0279 | 0.0153 | 0.0225 | 0.2728 | 0.3385 |
| 53 | 0.3317 | 0.3213 | 0.2295 | 2.8923 | 3.7748 |
| 54 | 0.1147 | 0.9061 | 0.207 | 2.6288 | 3.8566 |
| 55 | 0.0837 | 0.1173 | | 4.8298 | 5.0308 |
| 56 | 0.0992 | 0.2244 | 0.234 | 0.1674 | 0.725 |
| 57 | 0.4557 | 0.0986 | 0.0945 | 4.4268 | 5.0756 |
| 58 | 0.1054 | 0.0188 | 0.063 | 4.2972 | 4.4844 |
| 59 | 0.062 | 0.0017 | 0.117 | 0.0341 | 0.2148 |
| 60 | 0.0124 | 0.0119 | 0.0045 | 0.3472 | 0.376 |
| 61 | 0.0062 | 0.0026 | 0 | 0.0403 | 0.0491 |
| 62 | 1.6988 | 0.1088 | 0 | 0.6108 | 2.4184 |
| 63 | 0.1364 | - | 0 | - | 0.1364 |
| 64 | 0.0032 | - | - | - | 0.0032 |
| 65 | 0.0372 | 0.0101 | 0.0495 | 0.0744 | 0.1712 |
| 67 | 0.2449 | 0 | 0.0495 | 0.3596 | 0.654 |
| 68 | 0.9703 | 0.0136 | 0.063 | 1.0881 | 2.135 |
| 69 | 0.1147 | 0.2975 | 0.009 | 0.2573 | 0.6785 |
| 70 | 0.1302 | 0.0136 | 0.018 | 0.0062 | 0.168 |
| 71 | 0.31 | 1.1016 | 0.054 | 8.0848 | 9.5504 |
| 72 | 0.1023 | 0.238 | 0.036 | 0.2945 | 0.6708 |
| 73 | 0.7006 | 0.3332 | 0.045 | 1.3082 | 2.387 |
| 74 | 0.1054 | 0.017 | 0.009 | 1.2958 | 1.4272 |
| 75 | 0.682 | 0.017 | 0.234 | 0.0992 | 1.0322 |
| 76 | 0.3162 | 0.4284 | 0.261 | 0.186 | 1.1916 |
| 77 | 0.0403 | - | 0.0405 | 0.0031 | 0.0839 |
| 78 | 0.0155 | - | 0.0225 | 0 | 0.038 |
| 79 | 0.0682 | - | - | 0.0155 | 0.0837 |
| 80 | 0.0093 | - | - | - | 0.0093 |
| 81 | 0.1116 | - | - | - | 0.1116 |
| 82 | 0.0016 | - | - | - | 0.0016 |
| 84 | 0.3844 | 0.0238 | 0.063 | 0.8649 | 1.3361 |
| 85 | 1.364 | 0.3672 | 0.0676 | 6.5038 | 8.3026 |
| 86 | 0.0744 | 0.1207 | 0.36 | 0.0062 | 0.5613 |
| 87 | 0.0961 | 1.0897 | 0.225 | 1.5686 | 2.9794 |

| Station | Polychaeta | Mollusca | Crustacea | Miscellania | Total |
|---|---|---|---|---|---|
| 88 | 0.2325 | 0.5695 | 0.0135 | 0.0372 | 0.8527 |
| 89 | 0.1612 | 0.238 | 0.018 | 0.4248 | 0.842 |
| 90 | 0.0186 | 0.0238 | 0 | 0.1085 | 0.1509 |
| 91 | 0.3596 | 0.272 | 0.027 | 0.059 | 0.7176 |
| 92 | 0.1674 | 0.1224 | 0.018 | 0.0744 | 0.3822 |
| 93 | 0.0775 | 0.0697 | 0.0045 | 0.2108 | 0.3625 |
| 94 | 0.1581 | 0.0047 | 0.0045 | 0.1984 | 0.3657 |
| 95 | 1.3113 | 0.0731 | 0.3375 | 1.7391 | 3.461 |
| 96 | 0.0124 | - | 0.1755 | 0.031 | 0.2189 |
| 97 | 0.0124 | - | 0.0225 | 0.0899 | 0.1248 |
| 98 | 0.0217 | 0 | 0.0045 | 0.2263 | 0.2525 |
| 99 | 0.2046 | - | - | - | 0.2046 |
| 104 | 0.1798 | 0.1267 | 0.009 | 0.0806 | 0.3961 |
| 106 | 0.5302 | 0.1088 | 0.027 | 0.248 | 0.914 |
| 108 | 0.186 | 0.8245 | 4.3155 | 20.8196 | 26.1456 |
| 109 | 0.3751 | 0.136 | 0.0045 | 0.3689 | 0.8845 |
| 111 | 0.031 | 0.0034 | 0.018 | - | 0.0524 |
| 113 | 0.7533 | 0.5576 | - | 0.2252 | 1.5361 |
| 115 | 0.0744 | 0.4862 | 0.252 | 0.1116 | 0.9242 |
| 116 | 1.6058 | 0.0782 | 0 | 0.9796 | 2.6636 |
| 117 | 0.0961 | 0.1904 | 0.0045 | 0.1984 | 0.4894 |
| 118 | 0.4867 | 0.0255 | 0.0135 | 0.0682 | 0.5939 |
| 119 | 0.3131 | 0.0408 | 0.018 | 0.1395 | 0.5114 |
| 120 | 0.6076 | 0.4352 | 0.009 | 1.0478 | 2.0996 |
| 121 | 0.0806 | 0.0238 | 0.0495 | 0.0419 | 0.1958 |
| 122 | 0.1705 | 0.0017 | 0.0135 | 0.0496 | 0.2353 |
| 123 | 0.031 | 0.0697 | 0.0518 | 0.1488 | 0.3013 |
| 124 | 0.5704 | 0.0612 | 0.153 | 0.1796 | 0.9642 |
| 125 | 0.186 | 0.7072 | 0.045 | 0.3224 | 1.2606 |
| 126 | 0.0217 | 0.0017 | 0.0025 | - | 0.0259 |
| 127 | 0.1209 | 0.0629 | 0.0135 | 0.0341 | 0.2314 |
| 128 | 0.1085 | 0.1411 | 0.027 | 0.186 | 0.4626 |
| 129 | 0.0155 | 0.0128 | 0.0405 | 0.541 | 0.6098 |
| 130 | 0.0341 | - | 0.0045 | 0.217 | 0.2556 |
| 131 | 0.3302 | 0.0119 | 0.3668 | 0.1798 | 0.8887 |
| 132 | 0.2604 | 0.1972 | 0 | 0.0558 | 0.5134 |
| 133 | 0.0713 | 0.0128 | 0.0225 | 0.2263 | 0.3329 |
| 134 | 0.1643 | 0.0068 | 0.2205 | 0.2139 | 0.6055 |
| 135 | 0.1085 | 0.0085 | 12.951 | 0.1767 | 13.2447 |
| 136 | 0.0589 | 0.0034 | 0.108 | 0 | 0.1703 |

| Station | Polychaeta | Mollusca | Crustacea | Miscellania | Total |
|---|---|---|---|---|---|
| 137 | 0.0372 | 0 | 2.0655 | 0.0031 | 2.1058 |
| 138 | 0.1178 | 0.9299 | 0.702 | 0.5766 | 2.3263 |
| 139 | 0.0279 | - | 0.009 | 0 | 0.0369 |
| 140 | 0.0124 | - | 0.2115 | 0.0341 | 0.258 |
| 141 | 0.0248 | 0.0332 | 0.072 | 0.0185 | 0.1485 |
| 142 | 0.6696 | 0.7531 | 0.324 | 3.6146 | 5.3613 |
| 143 | 1.2152 | 3.8352 | 1.188 | 4.3834 | 10.6218 |
| 144 | 1.9096 | 6.2696 | 2.376 | 17.298 | 27.8532 |
| 145 | 0.1457 | 5.0541 | 0.279 | 3.5247 | 9.0035 |
| 146 | 1.7112 | 2.9478 | 0.171 | 2.8334 | 7.6634 |
| 147 | 0.5332 | 0.0578 | 0.243 | 0.1488 | 0.9828 |
| 148 | 0.2542 | 0.0102 | 0.135 | 0.0837 | 0.4831 |
| 149 | 0.1457 | 0.2346 | 0.081 | 0.3224 | 0.7837 |
| 150 | 1.6802 | 0.2788 | 0.126 | 1.0664 | 3.1514 |
| 151 | 0.1302 | 0.0374 | 0.081 | - | 0.2486 |

**Appendix Table 6** Table summarising the shell length data for *Crepidula fornicata*. The numbers of specimens occurring in each size class are shown for each station in which the slipper limpet occurred, together with the total number in each station, and the percentage of the total in each size class.

| Station | Nos. of *Crepidula fornicata* | | | | TOTAL | % of Total | | | |
|---|---|---|---|---|---|---|---|---|---|
| # | 0 - 5 mm | 6 -10 mm | 11 -20mm | 20 + mm | | 0 -5 mm | 6 - 10 mm | 11 -20mm | 20 +mm |
| 7 | | 1 | | | 1 | | 100 | | |
| 8 | | 20 | 2 | | 22 | | 90.9 | 10 | |
| 9 | | | 1 | 1 | 2 | | | 50 | 50 |
| 10 | | | | 1 | 1 | | | | 100 |
| 11 | | 9 | 1 | 1 | 11 | | 81.8 | 9.1 | 9.1 |
| 12 | | 1 | | | 1 | | 100 | | |
| 17 | | 17 | 6 | 4 | 27 | | 63 | 22.2 | 14.8 |
| 18 | 8 | 215 | 34 | 57 | 314 | 2.5 | 68.5 | 10.8 | 18.2 |
| 20 | | 99 | 10 | 4 | 113 | | 87.6 | 8.8 | 3.5 |
| 21 | | 31 | 7 | 1 | 39 | | 79.5 | 17.9 | 2.6 |
| 22 | | 2 | 2 | | 4 | | 50 | 50 | |
| 23 | | 5 | 4 | 4 | 13 | | 38.5 | 30.8 | 30.8 |
| 34 | | 5 | 4 | 2 | 11 | | 45.5 | 36.4 | 18.2 |
| 35 | 1 | 12 | 5 | 2 | 20 | 5 | 60 | 25 | 10 |
| 36 | | 65 | 9 | 5 | 79 | | 82.3 | 11.4 | 6.3 |
| 37 | 6 | 111 | 61 | 123 | 301 | 2 | 36.9 | 20.3 | 40.9 |
| 38 | | 4 | | | 4 | | 100 | | |
| 39 | 1 | 131 | 25 | 21 | 178 | 0.6 | 73.6 | 14 | 11.8 |
| 40 | 4 | 78 | 25 | 12 | 119 | 3.4 | 65.5 | 21 | 10.1 |
| 41 | | 7 | 2 | 6 | 15 | | 46.7 | 13.3 | 40 |
| 42 | | | 1 | 3 | 4 | | | 25 | 75 |
| 50 | | 4 | | | 4 | | 100 | | |
| 52 | | 2 | | | 2 | | 100 | | |
| 53 | | 16 | 2 | 8 | 26 | | 61.5 | 7.7 | 30.8 |
| 54 | 1 | 139 | 58 | 67 | 265 | 0.04 | 52.5 | 21.9 | 25.3 |
| 55 | | 64 | 6 | 5 | 75 | | 85.3 | 8 | 6.7 |
| 56 | | 15 | 4 | 2 | 21 | | 71.4 | 19.4 | 9.5 |
| 57 | | 15 | 3 | 2 | 20 | | 75 | 15 | 10 |
| 58 | | 8 | 1 | | 9 | | 88.9 | 11.1 | |
| 62 | | 2 | 1 | 2 | 5 | | 40 | 20 | 40 |
| 65 | 1 | 3 | 1 | 1 | 6 | 16.7 | 50 | 16.7 | 16.7 |
| 68 | | 2 | | | 2 | | 100 | | |
| 69 | 2 | 62 | 8 | 5 | 77 | 2.6 | 80.5 | 10.4 | 6.5 |
| 71 | | 28 | 6 | 12 | 46 | | 60.9 | 13 | 26.1 |
| 72 | 1 | 41 | 5 | 6 | 53 | 1.9 | 77.4 | 9.4 | 11.3 |
| 73 | | 68 | 14 | 9 | 91 | | 74.7 | 15.4 | 9.9 |

| Station # | Nos. of *Crepidula fornicata* | | | | TOTAL | % of Total | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 - 5 mm | 6 -10 mm | 11 -20mm | 20 + mm | | 0 -5 mm | 6 - 10 mm | 11 -20mm | 20 +mm |
| 74 | | | 1 | 1 | 2 | | | 50 | 50 |
| 75 | | 1 | | | 1 | | 100 | | |
| 88 | 2 | 61 | 10 | 20 | 93 | 2.2 | 65.6 | 10.8 | 21.5 |
| 89 | | 5 | 2 | 4 | 11 | | 45.8 | 18.2 | 36 |
| 90 | | 5 | 2 | | 7 | | 71.4 | 28.6 | |
| 91 | | 2 | 1 | 7 | 10 | | 20 | 10 | 70 |
| 92 | | 5 | 2 | 1 | 8 | | 62.5 | 25 | 12.5 |
| 93 | | 4 | 2 | 1 | 7 | | 57.1 | 28.6 | 14.3 |
| 95 | | 4 | 1 | | 5 | | 80 | 20 | |
| 98 | 1 | | | | 1 | 100 | | | |
| 104 | | 11 | 1 | 5 | 17 | | 68.7 | 5.9 | 29.4 |
| 106 | 1 | 3 | 1 | 2 | 7 | 14.2 | 42.9 | 14.2 | 28.6 |
| 108 | 7 | 16 | 61 | 13 | 97 | 7.2 | 16.5 | 62.9 | 13.4 |
| 109 | | 5 | 4 | 2 | 11 | | 45.5 | 36.4 | 18.2 |
| 111 | | 2 | | | 2 | | 100 | | |
| 113 | 14 | 90 | 25 | 19 | 148 | 9.5 | 60.8 | 16.9 | 12.8 |
| 115 | | 2 | 3 | 7 | 12 | | 16.7 | 25 | 58.3 |
| 116 | | 6 | 9 | | 15 | | 40 | 60 | |
| 117 | | 10 | 5 | 7 | 22 | | 45.5 | 22.7 | 31.8 |
| 118 | | 8 | 7 | 1 | 16 | | 50 | 43.7 | 6.3 |
| 119 | | 2 | 2 | | 4 | | 50 | 50 | |
| 120 | | 6 | 4 | 6 | 16 | | 37.5 | 25 | 37.5 |
| 121 | | 1 | 1 | 2 | 4 | | 25 | 25 | 50 |
| 122 | | | | 1 | 1 | | | | 100 |
| 123 | | 6 | | 2 | 8 | | 75 | | 25 |
| 124 | | 3 | 2 | 1 | 6 | | 50 | 33.3 | 16.7 |
| 125 | | 2 | 4 | 6 | 12 | | 16.7 | 33.3 | 50 |
| 127 | | 1 | 2 | 3 | 6 | | 16.7 | 33.3 | 50 |

**Appendix Table 7** Table summarising the shell length (mm) for *Crepidula fornicata* as a function of age, assessed from growth bands

| Specimen # | Shell length (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 |
| 1 | 18 | 35 | 43 | 50 | 56 | 60 | | |
| 2 | 18 | 37 | 51 | 61 | 68 | | | |
| 3 | 20 | 40 | 55 | 60 | | | | |
| 4 | 24 | 33 | 40 | 49 | 56 | 61 | | |
| 5 | 18 | 29 | 39 | 49 | | | | |
| 6 | 10 | 21 | 38 | 52 | 63 | | | |
| 7 | 7 | 22 | 29 | 36 | 41 | | | |
| 8 | 15 | 45 | 51 | | | | | |
| 9 | 22 | 28 | 35 | 42 | 47 | | | |
| 10 | 25 | 35 | 43 | 51 | | | | |
| 11 | 15 | 29 | 37 | 45 | | | | |
| 12 | 26 | 36 | 44 | 49 | | | | |
| 13 | 14 | 24 | 32 | 39 | | | | |
| 14 | 15 | 29 | 37 | 46 | 53 | | | |
| 15 | 14 | 22 | 28 | 38 | 50 | 56 | 64 | |
| 16 | 17 | 33 | 43 | 48 | 55 | 61 | | |
| 17 | 22 | 44 | 56 | 59 | | | | |
| 18 | 18 | 28 | 33 | 40 | 46 | 48 | | |
| 19 | 22 | 42 | 52 | | | | | |
| 20 | 19 | 25 | 36 | 40 | 42 | | | |
| 21 | 22 | 37 | 46 | 51 | 56 | | | |
| 22 | 23 | 33 | 45 | 51 | 56 | | | |
| 23 | 25 | 32 | 43 | 53 | 61 | | | |
| 24 | 22 | 38 | 49 | 53 | | | | |
| 25 | 16 | 29 | 39 | 49 | 57 | | | |
| 26 | 18 | 26 | 33 | 39 | 44 | 51 | 54 | |
| 27 | 23 | 30 | 38 | 42 | 46 | | | |
| 28 | 19 | 28 | 36 | 40 | 46 | 52 | 57 | |
| 29 | 17 | 29 | 37 | | | | | |
| 30 | 16 | 27 | 42 | 50 | | | | |
| 31 | 21 | 30 | 39 | 48 | 51 | 53 | | |
| 32 | 20 | 32 | 39 | 44 | | | | |
| 33 | 27 | 37 | | | | | | |
| 34 | 26 | 34 | | | | | | |
| 35 | 19 | 35 | 39 | 44 | | | | |
| 36 | 17 | 33 | 39 | 45 | | | | |

| Specimen | Shell length (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| # | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 |
| 37 | 6 | 24 | 34 | 43 | 51 | | | |
| 38 | 21 | 33 | 44 | 49 | 55 | 62 | 67 | |
| 39 | 13 | 20 | 29 | 40 | 50 | 58 | 66 | 72 |
| 40 | 20 | 27 | 32 | 37 | 45 | 51 | 57 | 63 |
| 41 | 12 | 27 | 38 | 46 | 54 | | | |
| 42 | 10 | 17 | 25 | 34 | 49 | 60 | | |
| 43 | 19 | 29 | 35 | 42 | | | | |
| 44 | 13 | 26 | 53 | 59 | | | | |
| 45 | 22 | 39 | 51 | 57 | 64 | | | |
| 46 | 17 | 31 | 39 | | | | | |
| 47 | 21 | 32 | 41 | 52 | | | | |
| 48 | 13 | 23 | 32 | 42 | 49 | 55 | | |
| 49 | 17 | 34 | 42 | 49 | | | | |
| 50 | 13 | 23 | 39 | 50 | 57 | 63 | | |
| 51 | 18 | 39 | 47 | 53 | | | | |
| 52 | 16 | 24 | 33 | 40 | | | | |
| 53 | 23 | 34 | 39 | | | | | |
| 54 | 23 | 33 | 39 | | | | | |
| 55 | 9 | 15 | 21 | 31 | 40 | 48 | 55 | 59 |
| 56 | 30 | 40 | 48 | | | | | |
| 57 | 15 | 29 | 35 | 41 | | | | |
| 58 | 20 | 40 | 53 | 60 | 66 | | | |
| 59 | 10 | 38 | 46 | 50 | 54 | | | |
| 60 | 25 | 28 | 37 | 43 | | | | |
| 61 | 25 | 37 | 44 | | | | | |
| 62 | 22 | 32 | 39 | | | | | |
| 63 | 26 | 41 | 51 | 58 | | | | |
| 64 | 20 | 30 | 38 | 45 | 49 | 55 | 58 | |
| 65 | 10 | 27 | 37 | 47 | | | | |
| 66 | 13 | 19 | 25 | 34 | 40 | 44 | | |
| 67 | 12 | 22 | 32 | 41 | 45 | 49 | 54 | 58 |
| 68 | 6 | 14 | 26 | 35 | 39 | 44 | 48 | |
| 69 | 10 | 14 | 20 | 26 | 37 | 45 | 54 | 60 |
| **Mean** | **17.9** | **30.2** | **39.3** | **46** | **51.1** | **53.8** | **57.6** | **62.4** |
| **S.D.** | **5.5** | **7.1** | **8** | **7.7** | **7.8** | **6.2** | **5.8** | **5.7** |
| **N** | **69** | **69** | **67** | **58** | **36** | **20** | **11** | **5** |

**Appendix Table 8** Table summarising the total number of individuals of *Crepidula fornicata* at each of the survey stations at which the slipper limpet was found. Also shown are the number of year 1 (<20 mm) individuals, the equivalent biomass (g wet weight) and the ash free dry weight (g AFDW) calculated from wet weight x 0.085 (from Eleftheriou and Basford 1989).

| Station # | Total # of Individuals | Total # of Year 1 (<20mm) | Biomass of Year 1 *Crepidula fornicata* | |
|---|---|---|---|---|
| | | | g Wet Weight | g AFDW |
| 7 | 1 | 1 | 0.05 | 0.0043 |
| 8 | 22 | 22 | 1.1 | 0.0935 |
| 9 | 2 | 1 | 0.05 | 0.0043 |
| 10 | 1 | 0 | 0 | 0 |
| 11 | 11 | 10 | 0.5 | 0.0425 |
| 12 | 1 | 1 | 0.05 | 0.0043 |
| 17 | 27 | 23 | 1.15 | 0.0978 |
| 18 | 314 | 257 | 12.85 | 1.0923 |
| 20 | 113 | 109 | 5.45 | 0.4633 |
| 21 | 39 | 38 | 1.9 | 0.1615 |
| 22 | 4 | 4 | 0.2 | 0.017 |
| 23 | 13 | 9 | 0.45 | 0.0383 |
| 34 | 11 | 9 | 0.45 | 0.0383 |
| 35 | 20 | 18 | 0.9 | 0.0765 |
| 36 | 79 | 74 | 3.7 | 0.3145 |
| 37 | 301 | 178 | 8.9 | 0.7565 |
| 38 | 4 | 4 | 0.2 | 0.017 |
| 39 | 178 | 157 | 7.85 | 0.6673 |
| 40 | 119 | 107 | 5.35 | 0.4548 |
| 41 | 15 | 9 | 0.45 | 0.0383 |
| 42 | 4 | 1 | 0.05 | 0.0043 |
| 50 | 4 | 4 | 0.2 | 0.017 |
| 52 | 2 | 2 | 0.1 | 0.0085 |
| 53 | 26 | 18 | 0.9 | 0.0765 |
| 54 | 265 | 198 | 9.9 | 0.8415 |
| 55 | 75 | 70 | 3.5 | 0.2975 |
| 56 | 21 | 19 | 0.95 | 0.0808 |
| 57 | 20 | 18 | 0.9 | 0.0765 |
| 58 | 9 | 9 | 0.45 | 0.0383 |
| 62 | 5 | 3 | 0.15 | 0.0128 |
| 65 | 6 | 5 | 0.25 | 0.0213 |
| 68 | 2 | 2 | 0.1 | 0.0085 |
| 69 | 77 | 65 | 3.25 | 0.2763 |
| 71 | 46 | 34 | 1.7 | 0.1445 |
| 72 | 53 | 47 | 2.35 | 0.1998 |

| Station # | Total # of Individuals | Total # of Year 1 (<20mm) | Biomass of Year 1 *Crepidula fornicata* | |
|---|---|---|---|---|
| | | | g Wet Weight | g AFDW |
| 73 | 91 | 82 | 4.1 | 0.3485 |
| 74 | 2 | 1 | 0.05 | 0.0043 |
| 75 | 1 | 1 | 0.05 | 0.0043 |
| 87 | 52 | 38 | 1.9 | 0.1615 |
| 88 | 93 | 73 | 3.65 | 0.3103 |
| 89 | 11 | 7 | 0.35 | 0.0298 |
| 90 | 7 | 7 | 0.35 | 0.0298 |
| 91 | 10 | 3 | 0.15 | 0.0128 |
| 92 | 8 | 7 | 0.35 | 0.0298 |
| 93 | 7 | 6 | 0.3 | 0.0255 |
| 95 | 5 | 5 | 0.25 | 0.213 |
| 98 | 1 | 1 | 0.05 | 0.0043 |
| 104 | 17 | 12 | 0.6 | 0.051 |
| 106 | 7 | 5 | 0.25 | 0.0213 |
| 108 | 97 | 84 | 4.2 | 0.357 |
| 109 | 11 | 9 | 0.45 | 0.0383 |
| 111 | 2 | 2 | 0.1 | 0.0085 |
| 113 | 148 | 129 | 6.45 | 0.5483 |
| 116 | 15 | 15 | 0.75 | 0.0638 |
| 115 | 12 | 5 | 0.25 | 0.0213 |
| 117 | 22 | 15 | 0.75 | 0.0638 |
| 118 | 16 | 15 | 0.75 | 0.0638 |
| 119 | 4 | 4 | 0.2 | 0.017 |
| 120 | 16 | 10 | 0.5 | 0.0425 |
| 121 | 4 | 2 | 0.1 | 0.0085 |
| 122 | 1 | 0 | 0 | 0 |
| 123 | 8 | 6 | 0.3 | 0.0255 |
| 124 | 6 | 5 | 0.25 | 0.0213 |
| 125 | 12 | 6 | 0.3 | 0.0255 |
| 127 | 6 | 3 | 0.15 | 0.0128 |
| 128 | 8 | 5 | 0.25 | 0.0213 |
| 132 | 28 | 25 | 1.25 | 0.1063 |
| 138 | 74 | 48 | 2.4 | 0.204 |
| 141 | 6 | 5 | 0.25 | 0.213 |

**Appendix Table 9** Table summarising the cumulative numbers of species discovered, the number of new species, the numbers of individuals and the total number of species recorded in a series of sand and mud samples of 0.2 $m^2$ taken in and adjacent to the North Nab Study site during March 1999. The species identification codes are shown in parentheses.

| Station # | Identification code | Cumulative No. of Species | No. of New Species | No. of Individuals | No. of Species |
|---|---|---|---|---|---|
| 85 | (2) (10) (11) (15) (19) (39) (40) (48) (61) (65) (76) (82) (88) (91) (93) (97) (104) (105) (118) (122) (130) (137) (145) (152) (157) (173) (174) (189) (204) (210) (221) (230) (243) (249) (258) (268) (269) (276) (280) (282) (289) (301) | 42 | 42 | 189 | 42 |
| 84 | (28) (50) (53) (119) (138) (142) (161) (164) (185) (212) (233) (257) (261) (284) (290) (291) (293) | 59 | 17 | 151 | 39 |
| 49 | (13) (30) (33) (42) (121) (224) (240) (251) (267) | 68 | 9 | 425 | 20 |
| 27 | (110) (111) (126) (190) | 72 | 4 | 8 | 6 |
| 86 | (124) (132) (272) | 75 | 3 | 237 | 19 |
| 28 | (83) (100) (101) | 78 | 3 | 6 | 3 |
| 45 | (127) | 79 | 1 | 6 | 2 |
| 46 | (114) | 80 | 1 | 16 | 5 |
| 47 | (56) | 81 | 1 | 12 | 4 |
| 63 | (108) | 82 | 1 | 18 | 6 |
| 81 | (115) | 83 | 1 | 12 | 4 |
| 44 | | 83 | 0 | 6 | 3 |
| 64 | | 83 | 0 | 4 | 2 |
| 80 | | 83 | 0 | 6 | 4 |
| 82 | | 83 | 0 | 1 | 1 |
| 99 | | 83 | 0 | 14 | 4 |

**Appendix Table 10** Table summarising the cumulative numbers of species discovered, the number of new species, the numbers of individuals and the total number of species recorded in a series of coarse gravel samples of 0.2 $m^2$ taken in and adjacent to the North Nab Study site during March 1999. The species identification codes are shown in parentheses.

| Station # | Identification code | Cumulative No. of Species | No. of New Species | No. of Individuals | No. of Species |
|---|---|---|---|---|---|
| 131 | (8) (10) (15) (17) (19) (33) (37) (39) (58) (65) (68) (82) (88) (91) (93) (105)(118) (119) (124) (125) (128) (130) (140) (152) (157) (164) (168) (173) (174) (178) (189) (196) (207) (208) (210) (215) (230) (233) (249) (258) (268) (270) (276) (282) (291) (301) | 46 | 46 | 296 | 46 |
| 57 | (11) (16) (27) (40) (66) (70) (73) (76) (83) (84) (97) (120) (122) (153) (174) (186) (203) (236) (263) (269) (289) (295) | 68 | 22 | 163 | 44 |
| 133 | (25) (34) (56) (79) (85) (92) (107) (108) (109) (132) (151) (229) (261) (272) (280) (287) | 84 | 16 | 104 | 43 |
| 58 | (9) (12) (54) (95) (116) (123) (137) (148) (150) (156) (191) (192) (193) (199) (266) | 99 | 15 | 142 | 39 |
| 95 | (13) (35) (121) (159) (180) (184) (220) (232) (242) (245) (250) (253) (275) (283) (284) | 114 | 15 | 245 | 39 |
| 113 | (21) (32) (38) (48) (61) (101) (103) (139) (160) (185) (204) (206) (222) | 127 | 13 | 324 | 42 |
| 8 | (36) (53) (145) (154) (161) (216) (251) | 134 | 7 | 107 | 27 |
| 54 | (28) (43) (182) (197) (227) (302) | 140 | 6 | 318 | 35 |
| 18 | (42) (55) (75) (87) (146) | 145 | 5 | 623 | 33 |
| 75 | (49) (69) (104) (111) (165) | 150 | 5 | 171 | 31 |
| 17 | (67) (117) (138) (252) | 154 | 4 | 123 | 26 |
| 41 | (98) (131) (170) (228) | 158 | 4 | 268 | 26 |
| 72 | (5) (29) (80) (96) | 162 | 4 | 148 | 30 |
| 77 | (45) (169) (300) | 165 | 3 | 43 | 20 |
| 130 | (22) (190) (243) | 168 | 3 | 51 | 23 |
| 94 | (144) (214) | 170 | 2 | 73 | 28 |
| 117 | (147) (247) | 172 | 2 | 106 | 29 |
| 127 | (141) (259) | 174 | 2 | 77 | 35 |
| 129 | (102) (277) | 176 | 2 | 135 | 24 |
| 132 | (46) (106) | 178 | 2 | 108 | 33 |
| 56 | (239) | 179 | 1 | 150 | 26 |
| 70 | (3) | 180 | 1 | 97 | 19 |

| Station # | Identification code | Cumulative No. of Species | No. of New Species | No. of Individuals | No. of Species |
|---|---|---|---|---|---|
| 96 | (24) | 181 | 1 | 66 | 17 |
| 115 | (7) | 182 | 1 | 279 | 33 |
| 118 | (77) | 183 | 1 | 89 | 25 |
| 119 | (136) | 184 | 1 | 83 | 23 |
| 128 | (279) | 185 | 1 | 152 | 36 |
| 78 | | 185 | 0 | 22 | 13 |
| 97 | | 185 | 0 | 33 | 20 |

**Appendix Table 11** Table summarising the cumulative numbers of species discovered, the number of new species, the numbers of individuals and the total number of species recorded in a series of gravel samples of 0.2 $m^2$ taken in and adjacent to the North Nab Study site during March 1999. The species identification codes are shown in parentheses.

| Station # | Identification Code | Cumulative No. of Species | No. of New Species | No. of Individuals | No. of Species |
|---|---|---|---|---|---|
| 68 | (4) (10) (13) (16) (21) (24) (28) (33) (38) (40) (48) (61) (83) (88) (91) (105) (106) (114) (117) (121) (122) (124) (130) (133) (135) (136) (138) (144) (153) (155) (157) (161) (179) (183) (184) (189) (191) (199) (205) (207) (210) (216) (221) (230) (233) (249) (258) (261) (268) (269) (276) (277) (278) (291) (292) (294) (295) (296) (297) (298) | 60 | 60 | 246 | 60 |
| 34 | (1) (5) (37) (46) (65) (68) (73) (86) (93) (97) (123) (128) (132) (140) (152) (174) (181) (186) (204) (222) (242) (282) (284) (289) | 84 | 24 | 396 | 47 |
| 131 | (8) (15) (17) (19) (39) (58) (82) (118) (119) (125) (164) (168) (173) (178) (196) (208) (215) (270) (301) | 103 | 19 | 296 | 46 |
| 133 | (25) (34) (79) (85) (92) (107) (108) (109) (151) (229) (272) (280) (287) | 116 | 13 | 104 | 43 |
| 9 | (9) (20) (57) (95) (149) (162) (171) (187) (211) (225) (245) (283) | 128 | 12 | 251 | 38 |
| 132 | (11) (42) (56) (76) (80) (102) (111) (137) (173) (259) | 138 | 10 | 108 | 33 |
| 11 | (55) (77) )131) (148) (158) (188) (246) (250) (254) | 147 | 9 | 214 | 38 |
| 23 | (43) (104) (139) (256) (273) (281) | 152 | 6 | 166 | 35 |
| 1 | (27) (70) (141) (206) | 156 | 4 | 233 | 17 |
| 25 | (26) (103) (126) (127) | 160 | 4 | 17 | 9 |
| 40 | (145) (214) (264) (293) | 164 | 4 | 274 | 29 |
| 6 | (66) (303) (304) | 167 | 3 | 71 | 24 |
| 20 | (87) (168) (275) | 170 | 3 | 404 | 26 |
| 37 | (134) (226) (239) | 173 | 3 | 918 | 26 |

| Station # | Identification Code | Cumulative No. of Species | No. of New Species | No. of Individuals | No. of Species |
|---|---|---|---|---|---|
| 38 | (54) (203) (251) | 176 | 3 | 1223 | 30 |
| 71 | (53) (177) (263) | 179 | 3 | 518 | 37 |
| 87 | (67) (213) (228) | 182 | 3 | 163 | 29 |
| 92 | (202) (255) (265) | 185 | 3 | 136 | 35 |
| 10 | (209) (234) | 187 | 2 | 116 | 22 |
| 39 | (227) (252) | 189 | 2 | 267 | 22 |
| 42 | (14) (169) | 191 | 2 | 72 | 21 |
| 53 | (84) (238) | 193 | 2 | 192 | 24 |
| 59 | (165) (299) | 195 | 2 | 33 | 18 |
| 62 | (41) (156) | 197 | 2 | 89 | 20 |
| 63 | (110) (190) | 199 | 2 | 18 | 6 |
| 76 | (96) (167) | 201 | 2 | 175 | 23 |
| 91 | (72) (89) | 203 | 2 | 123 | 36 |
| 93 | (59) (285) | 205 | 2 | 37 | 21 |
| 108 | (235) (253) | 207 | 2 | 289 | 35 |
| 7 | (101) (0) | 208 | 1 | 160 | 20 |
| 24 | (23) (0) | 209 | 1 | 59 | 21 |
| 35 | (94) (0) | 210 | 1 | 149 | 28 |
| 65 | (147) (0) | 211 | 1 | 37 | 19 |
| 69 | (248) (0) | 212 | 1 | 134 | 30 |
| 98 | (112) (0) | 213 | 1 | 23 | 14 |
| 104 | (129) (0) | 214 | 1 | 62 | 16 |
| 106 | (247) (0) | 215 | 1 | 114 | 24 |
| 109 | (7) (0) | 216 | 1 | 80 | 34 |
| 36 | | 216 | 0 | 302 | 15 |
| 73 | | 216 | 0 | 386 | 34 |
| 79 | | 216 | 0 | 14 | 9 |
| 88 | | 216 | 0 | 228 | 28 |
| 89 | | 216 | 0 | 253 | 29 |
| 129 | | 216 | 0 | 135 | 24 |