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A comparative study of the responses of macrofaunal and nematode assemblages to the disposal of dredged material

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A COMPARATIVE STUDY OF THE RESPONSES OF MACROFAUNAL AND NEMATODE ASSEMBLAGES TO THE DISPOSAL OF DREDGED MATERIAL.

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A thesis submitted to the University of Wales, Bangor for the degree of Doctor of Philosophy.

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CONTENTS

SUMMARY

The present research was designed to provide information on the comparative responses of macrofaunal and nematode communities to the disposal of dredged material at a variety of locations, in order to clarify in which circumstances they are both best utilised.

Transect surveys were conducted at 4 major dredged material disposal sites in UK coastal waters and a response to dredgings disposal was observed in both macrofaunal and nematode communities, although there were clear differences in the nature and severity of impact. Gross effects due to the direct impact of dredgings disposal were detectable with both methods. However, effects beyond the disposal sites arising from the settling of fine particulates were often only discernible with nematode community analyses. Furthermore, the precision of the nematode data was generally higher than that for the macrofauna, largely due to the greater consistency in the quality of samples collected. The same nematode taxa, *Sabatieria pulchra* grp. (both *breviseta* and *punctata*) and *Daptonema tenuispiculum* were found to dominate at all disposal sites, despite appreciable environmental differences between locations and variability in the nature of the deposited dredged material. Such consistent patterns were not observed for macrofaunal species; rather, there appeared to be local enhancement of a range of different taxa characteristic of the sediments surrounding each of the disposal sites. At two of the disposal sites, however, the presence of some macrofaunal species more typical of estuarine conditions provided strong evidence for the transport of live animals via dredgings disposal. Although it is likely that nematode species are also capable of surviving transport to the site, establishing this was hampered by the lack of zoogeographical information for this group.

These studies have established, for the first time, that nematode communities can provide a sensitive indicator of change in response to dredged material disposal at a variety of locations and have introduced a new monitoring tool for a practice that has wide significance around the UK coast. The implications of the findings for the future monitoring of dredged material disposal and other waste inputs are discussed.

1. INTRODUCTION

1.1 RATIONALE FOR STUDY

The economic growth of coastal regions is often dependent on the accessibility of coastal ports, fishing harbours and navigable waterways (Engler *et al.*, 1991). These areas are rarely deep and navigable depths must be maintained by frequent dredging. Around 40 million wet tonnes of material arising from such dredging operations are relocated annually in licensed disposal sites in UK waters (see Table 1). Disposal of dredged material is controlled in the UK by a system of licences issued under Part II of the Food and Environment Protection Act (1985) following guidelines laid down by International Conventions (Great Britain - Parliament, 1972a,b, 1985). Prior to issuing a disposal licence, alternative disposal options including beneficial uses of dredged material e.g. for beach recharge must be explored by the applicant. However, open water disposal in designated sites is in many cases, the best practicable environmental option and also the only economically realistic one for dredged material. Criteria which must be satisfied before a licence is issued include the chemical quality of the material, the quantity to be disposed of and its nature and origin. Sediments containing unacceptably high levels of contaminants are not licensed for sea disposal. Table 1 shows the numbers of licences issued, the quantity licensed, and the quantity deposited together with figures for the quantity of a range of trace metals that enter the sea in the dredged materials.

Many of the disposal sites in UK waters were traditionally placed as close as possible to the port facilities, often irrespective of the fact that net bedload transport could be towards the site of dredging. Historically, the main considerations for siting a disposal site were operational rather than environmental, although there was a tendency to avoid the disposal of material that could provide obstructions on favoured fishing grounds and where there might be implications for navigation. The disposal of dredged material in coastal waters is a very different activity from sewage sludge disposal, a practice that ceased in UK waters in 1998. Dredged material disposal sites are much more numerous than sewage sludge sites, 177 of the former being used at least once since 1990 in UK waters as against just 13 sewage sludge sites which existed prior to 1998 (see Figure 1 and Figure 2 for location of dredgings disposal sites and the quantities disposed of in 1995 and 1996 respectively).

Table 1 Summary of dredged material licensed and disposed of at sea in 1995 and 1996 (source - CEFAS, 1998).

Country	*Year*	*Licences issued*	*Licensed Quantity (tonnes)*	*Wet tonnage Deposited*	**Quantities of metal contaminants in wastes deposited (tonnes)*						
					Cd	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
England and Wales	1992	123	55,741,813	24,243,998	6.0	812	512	4.2	291	876	2,271
	1993	110	66,074,966	26,086,503	7.3	875	606	5.2	458	1,004	2,461
	1994	106	53,187,009	34,049,468	8.0	1,295	734	5.9	587	1,375	3,375
	1995	109	54,300,948	35,215,761	5.8	1,298	625	5.2	548	1,380	3,161
	1996	120	82,395,490	48,516,353	8.8	1,556	744	6.9	673	1,731	3,991
Scotland	1992	35	5,920,005	3,841,296	0.9	108	82	1.7	39	111	245
	1993	26	3,174,050	2,025,525	2.4	50	44	0.8	21	63	132
	1994	23	3,643,250	1,822,053	0.9	42	36	0.5	20	56	122
	1995	32	6,186,600	4,782,421	1.1	155	120	3.5	66	153	349
	1996	30	3,971,045	2,601,864	0.4	56	89	0.7	26	81	155
Northern Ireland	1992	7	2,956,601	891,087	0.3	2	3	0.2	2	3	10
	1993	7	996,500	3,392,994	1.8	11	26	1.1	13	23	70
	1994	5	113,200	91,314	0.0	0	0	0.0	0	0	1
	1995	9	335,280	249,593	0.2	2	1	0.1	2	2	8
	1996	6	166,000	135,550	0.0	2	2	0.0	3	2	4
UK Total	1992	165	64,618,419	28,976,381	7.2	923	597	6.1	332	990	2,527
	1993	143	70,245,516	31,505,022	11.5	937	676	7.1	491	1,090	2,663
	1994	134	56,943,459	35,962,835	8.9	1,338	770	6.4	608	1,432	3,498
	1995	150	60,822,828	40,247,775	7.2	1,455	746	8.7	616	1,535	3,518
	1996	156	86,532,535	51,253,767	9.2	1,613	835	7.6	702	1,814	4,149

*A proportion of the trace metals in dredged materials is natural and occurs within the mineral structure or is otherwise tightly bound, such that it will not be available to marine organisms.

The Ministry of Agriculture, Fisheries and Food (M.A.F.F.) has for many years conducted biological monitoring programmes at marine waste disposal sites, as part of its responsibilities under the Food and Environment Protection Act Part II, 1985. Monitoring is required to document both pre- and post- disposal conditions at new sites and to determine if unacceptable impacts are occurring (or if conditions that could lead to an unacceptable impact are developing) within and in the vicinity of the disposal site. In addition, monitoring is vital to check compliance with licence conditions and to provide data on environmental conditions to permit informed decisions regarding the continued acceptability of a particular disposal operation. A further purpose of monitoring is to provide information to assist in the assessment of any future applications for disposal licences.

The disposal of dredged material has its primary impact at the seabed. Therefore biological assessment of the effects of disposal has conventionally consisted of an analysis of the macrofaunal component of the benthos at selected disposal sites around the UK coast (Norton *et al.*, 1984; Rees *et al.*, 1992; Rees and Rowlatt, 1994). While there are sound reasons for continuation of such work (e.g. Rees *et al.*, 1990), recently it emerged that meiofaunal communities appear to be more sensitive to the ongoing disposal of dredgings, i.e. short-term events, in contrast to macrofaunal communities that may reflect longer-term changes in disposal practices (Somerfield *et al.*, 1995). The principal objective of the present study was, therefore, to evaluate the usefulness of meiofauna studies at dredged material disposal sites in comparison to more conventional approaches such as macrofaunal assessments. This objective was addressed by conducting surveys of the macrofauna and nematode communities at four major dredged material disposal sites around the UK coast (Tees Bay, Liverpool Bay, Lune Deep and Swansea Bay). There is much greater variability in the physical and chemical nature of material arising from dredging, and hence in ecological impacts following disposal, than is the case with, for example, sewage sludge (Marine Pollution Monitoring Management Group, 1996). Therefore an examination of four widely separated disposal sites permitted comparisons of the responses of nematode and macrofaunal communities to the disposal of dredged material varying in both sediment composition and contaminant burden. Such an approach was also designed to provide empirical data suitable for producing a generic model of responses applicable to other similar dredged material disposal sites.

1.2 RESEARCH OBJECTIVES

In 1995 the Chief Scientist's Group in M.A.F.F. funded a three-year Ph.D. studentship to undertake the following research:

1. To establish "in-house" methodology for the field sampling and laboratory analysis of meiofauna on a routine basis (Chapter 2).
2. To apply meiofauna studies to assessments of anthropogenic effects alongside established approaches at the Burnham Laboratory of the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) (Chapters 3, 4, 5, & 6). Because of the importance of dredged material disposal to the UK economy through maintenance of port and harbour facilities and the regulatory role of the funding agency (M.A.F.F.) in this activity, the disposal of dredged material was chosen as the main activity to investigate for this assessment.
3. To evaluate the cost-effectiveness of meiofauna studies relative to other established measures of biological effect (Chapter 7).
4. To develop "models" describing the responses of meiofauna populations to anthropogenic influences in the field (Chapter 7).

Figure 1 UK dredged material disposal sites and amounts deposited in wet tonnes for 1995 (reproduced from CEFAS, 1998).

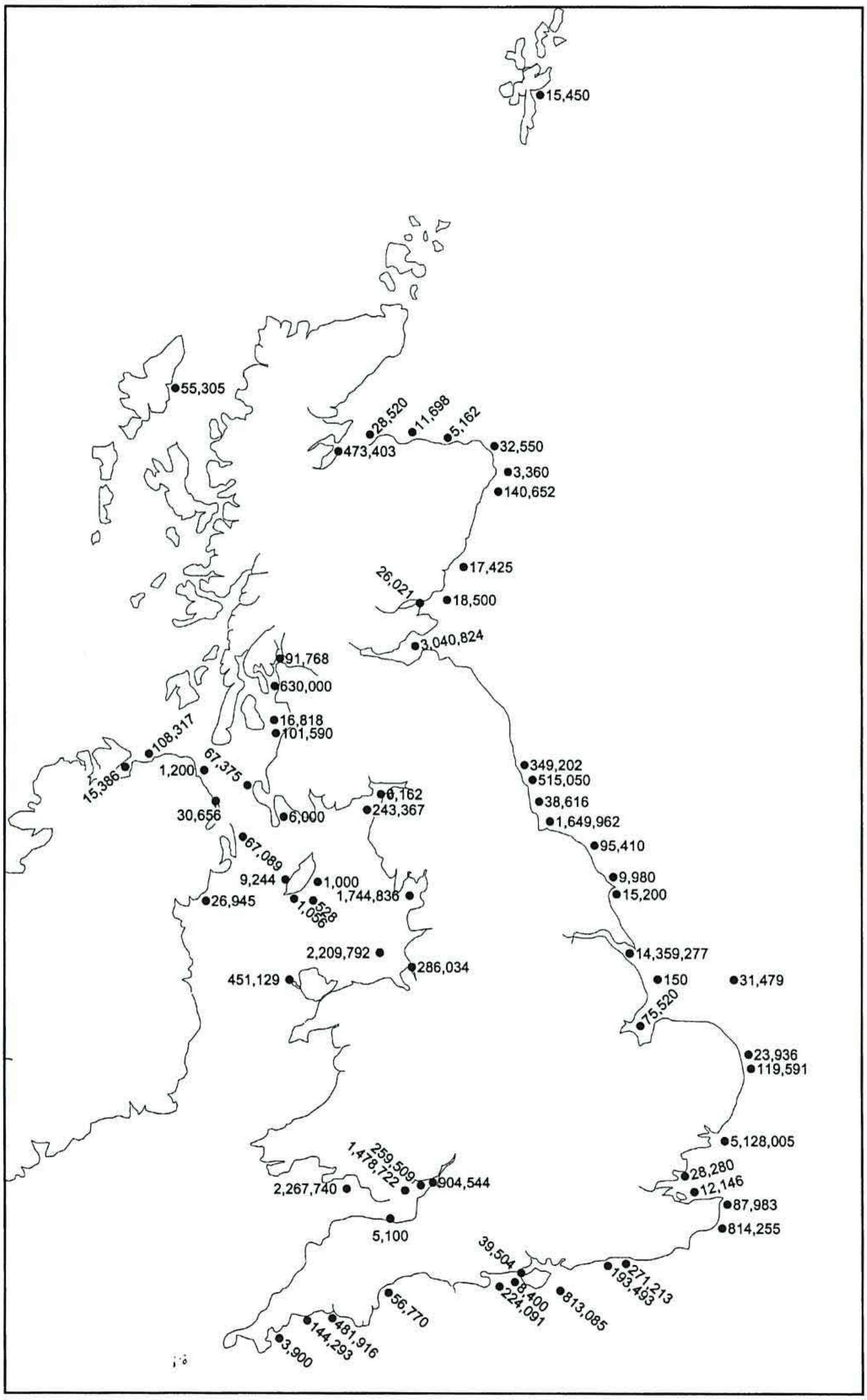
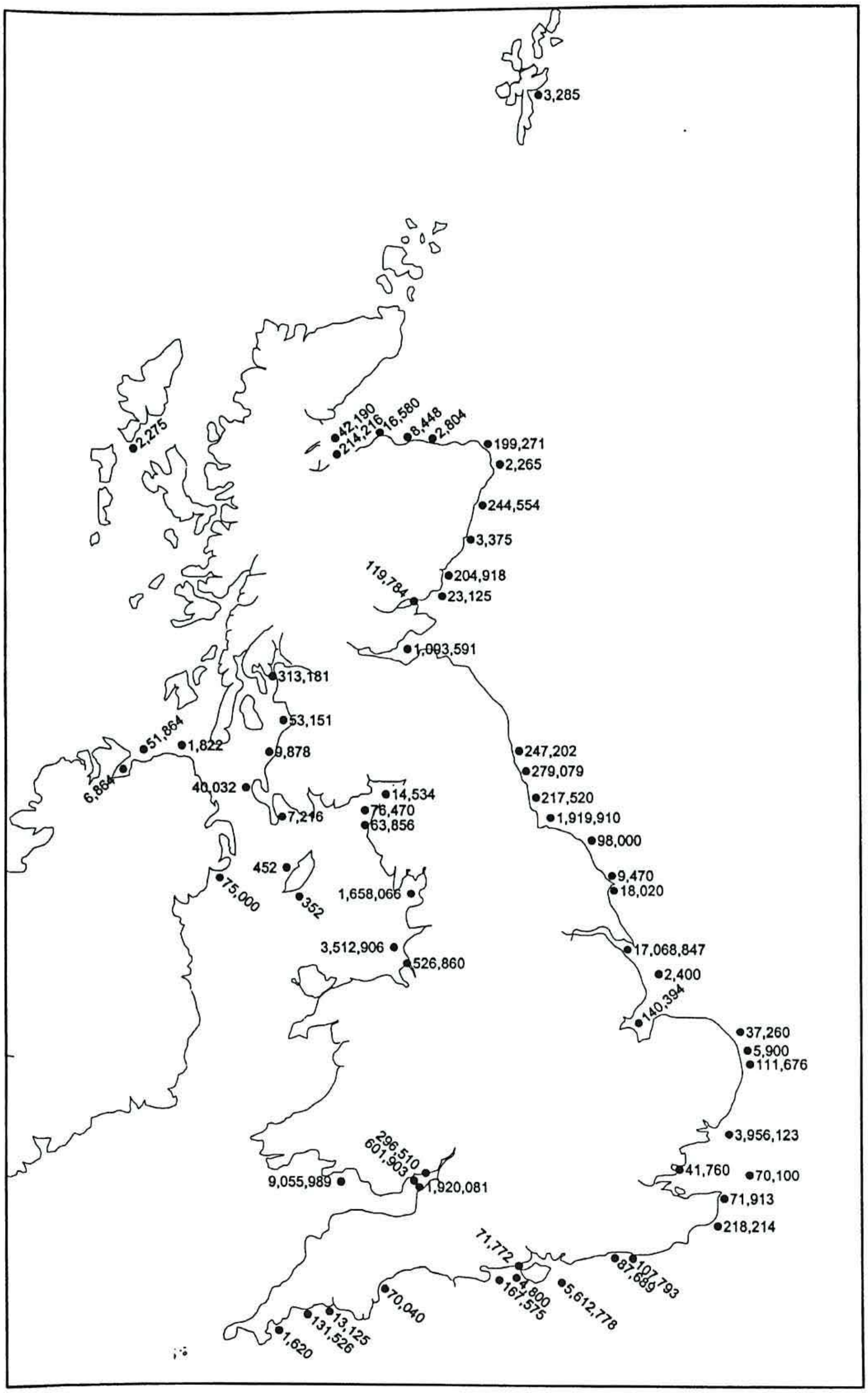


Figure 2 UK dredged material disposal sites and amounts deposited in wet tonnes for 1996 (reproduced from CEFAS, 1998).



1.3 MEIOFAUNA : DEFINITIONS

The term meiofauna was first coined by Mare (1942) to describe animals of intermediate size between protozoans and the macrofauna. However, the classical work of Remane (1933) is generally considered to be the cornerstone of modern meiobenthology. The meiofauna have since been defined as those micrometazoans and Foraminiferans that pass through a 0.5mm sieve and are retained on a mesh size of less than 100μm (Coull and Chandler, 1992). Although this definition may be considered to be arbitrary, in that it discriminates solely on the basis of size, it does serve to loosely separate this group of organisms from the larger macrofauna and the unicellular microfauna. Nevertheless, the distinction between the meiofauna and macrofauna often becomes indiscernible, particularly in areas of severe organic pollution, as some organisms considered to be typically meiofaunal (e.g. some nematodes) are large enough to be retained on a 1mm sieve and therefore exceed the upper limit of this definition.

McIntyre (1969) considered that the meiofauna were simply an artificial construct of the total size spectra of benthic organisms, having no evolutionary or biological basis for existing as a separate component. Invoking arguments based on discontinuities in the distribution of body sizes of benthic organisms, Warwick (1982) rejected this and proposed that the meiofauna could be considered as a distinct biological unit. He concluded that there is a particular body size at which meiofaunal life history traits are optimised and another for macrofaunal traits.

Members of the meiofauna can be further classified in terms of their permanency within this size spectrum. Organisms that are represented only by larval or juvenile life-stages and whose adults invariably reach macrofaunal size are termed temporary meiofauna whereas permanent meiofauna occupy this size group for their entire life-cycle.

Nematodes are usually the most abundant, constituting up to 94% of the meiofaunal community (McIntyre, 1969; Platt and Warwick, 1980). Harpacticoid copepods are usually the second most abundant taxon. Peak densities of nematodes are reached in muddy estuaries where densities as high as 20 x 10^6 m $^{-2}$ have been reported (Warwick and Price, 1979).

Sediment granulometry is a major determinant of meiobenthic community structure (Warwick and Buchanan, 1970; Heip *et al.*, 1985; Coull, 1988). Even though the species complement of sandy substrates is different to those of muddier habitats, they are comparable in terms of diversity in the absence of significant disturbance (Coull and Fleeger, 1977). Indeed, Coull (1988) speculated that similar diversities could be expected from shallow sedimentary biotopes world-wide.

1.4 THE USE OF MARINE MEIOFAUNA IN POLLUTION ASSESSMENT

Traditionally, most studies investigating the effects of pollution or disturbance on the benthos have concentrated on monitoring changes in the macrofauna (Norton *et al.*, 1984; Rees *et al.*, 1992; Rees and Rowlatt, 1994). However, the meiofauna is being increasingly used as a means of detecting environmental perturbation. This expansion into meiofaunal pollution research has led to an extensive literature (e.g. McIntyre, 1977; Ferris and Ferris, 1979; Heip, 1980; Heip *et al.*, 1982; Hargrave and Thiel, 1983; Heip *et al.*, 1985; Hicks and Coull, 1983; Coull and Palmer, 1984; Sandulli, 1986; Vincx and Heip, 1987; Moore and Bett, 1989). The findings from these and other studies have been incorporated into a comprehensive review by Coull and Chandler (1992).

From a theoretical standpoint, the meiofauna possess many ecological characteristics that make them suitable as a tool in environmental assessment. These include their conservative life-cycles with non-pelagic larval stages and an intimate association with their sedimentary environment. Thus, in an area subject to regular waste inputs, an investigator can be assured that all meiofaunal taxa within the zone of input have been subjected to the influence in question. This is in contrast to macrofaunal communities where populations may be maintained by recruitment from unaffected areas; a proportion are also motile and may therefore be able to avoid effects depending on the area affected. Furthermore, the short generation times of most meiofaunal species allow the effects of an acute pollution incident to be rapidly revealed. Conversely, with their rapid regeneration times, some authors have suggested that the meiofauna appear earlier than the macrofauna in the regeneration cycle in the aftermath of such an incident (Somerfield *et al.*, 1995).

Short generation times, coupled with advances in culturing techniques (particularly for nematodes and copepods), have led to their utilisation in laboratory microcosms, enabling the measurement of the sublethal effects of toxicants on fecundity, growth rates, genetic expression, longevity and behaviour (Coull and Chandler, 1992). The results from such studies can then be validated in the field.

In addition to these favourable life-history traits, the meiofauna, especially nematodes tend to have considerably higher individual densities and species richness than the macrofauna per unit area (Attrill *et al.*, 1996), enabling trends in the community to be more readily discernible from conveniently small sample sizes (Moore and Bett, 1989). This property may be more significant in areas where impoverished macrofaunal populations exist, for example, in estuaries and exposed beaches. Nematodes are ubiquitous, with few documented cases in which their absence has been recorded (Vitellio and Vivier, 1974; Vivier, 1978; Powell *et al.*, 1982,).

It has been asserted that meiofaunal organisms respond more quickly, and are more sensitive, to chemical impacts than the macrofauna (McIntyre, 1977; Van Damme *et al.*, 1984), while remaining relatively unaffected by mechanical disturbance and destabilisation of the sediment (Austen *et al.*, 1989; Warwick *et al.*, 1990a and b). This may allow for differentiation between the potentially confounding influence of multiple impacts, thus aiding in the attribution of causal agents. In addition, the ecology of marine meiobenthos has received much attention (see Table 2 for summary of reviews), providing a baseline against which the effects of pollution on community composition can be gauged.

Despite the obvious advantages to monitoring the meiofauna, their routine use has been limited, and there are no well-established precedents to draw from regarding the procedures to be adopted for a field programme. One reason for their limited use is the cost of sample processing, which has been claimed to increase as the mesh size used to sieve sediment decreases (Kingston and Riddle, 1989; James *et al.*, 1995). Therefore, when a large number of samples need to be examined on a regular basis, investigation of the meiofauna has been assumed to be prohibitively demanding of resources.

As nematodes are generally highly diverse and abundant, the requirement for manageable densities of organisms necessitates the collection of small samples but, by only sampling a small proportion of the pool of organisms there is a danger of losing information about the area being characterised. However, sample pooling and repeated sub-sampling may offset the consequences of faunal patchiness (Somerfield and Warwick, 1995). High diversity coupled with chaotic taxonomy of meiofaunal taxa has, historically, proved to be a significant limiting factor in applications to pollution assessment. This difficulty has been ameliorated with the recent publication of taxonomic keys covering the major meiofaunal taxa (Platt and Warwick, 1983, 1988; Huys *et al.,* 1996; Somerfield and Warwick, 1996; Warwick *et al.*, 1998).

Table 2 - A summary of published reviews on the ecology of meiofauna

Reference	*Subject Area*
Swedmark (1964)	Interstitial sand fauna
McIntyre (1969)	Ecology of marine meiobenthos
Coull (1973)	Estuarine meiofauna, trophic relationships and microbial interactions.
Gerlach (1978)	Food chain relationships of meiofauna and bacterial productivity.
Fenchel (1978)	Ecology of micro- and meiofauna.
Coull and Bell (1979)	Ecology of marine meiofauna.
Platt and Warwick (1980)	Littoral nematodes.
Giere and Pfannkuche (1982)	Ecology of marine oligochaeta.
Heip, Vincx, Smol and Vranken (1982)	Systematics and ecology of marine nematodes.
Hicks and Coull (1983)	Ecology of marine harpacticoid copepods.
Thiel (1983)	Ecology of meiobenthos and nanobenthos of the deep sea.
Coull and Palmer (1984)	Field experimentation of meiofauna.
Heip, Vincx and Vranken (1985)	Ecology of marine nematodes.
Soyer (1985)	Mediterranean Sea meiofauna
Higgins and Thiel (1988)	Introduction to meiofauna.
Coull (1988)	Ecology of marine meiofauna.
Gee (1989)	Meiofauna as food for fish.
Coull (1990)	Meiofauna as food for higher trophic groups.
Giere (1993)	Introduction to meiofauna.

It has been argued in the past that, while the meiobenthos is known to be ubiquitous, abundant and diverse, there is little evidence to suggest that the group has any significant ecological and/or economic role to play (McIntyre, 1969; Marshall, 1970). However, recent evidence from fish stomach analysis has shown that components of the meiofauna, particularly harpacticoid copepods, are often the dominant food source for juvenile fish such as gobies (Gee, 1989; Coull, 1990). Copepods have also been documented as being important prey items in the diet of juveniles of several commercially exploited species, especially flatfish such as *Limanda limanda*, *Platichthys flesus* and *Pleuronectes platessa* (Gee, 1989). Hence, an assessment of the impact of anthropogenic perturbation on the meiobenthos in areas where juvenile fish are resident would seem to be highly appropriate.

Recent studies have highlighted the potential role of marine meiofauna in assessing biodiversity (Attrill *et al.*, 1996; Gee and Warwick, 1996). One such study, in the Thames estuary, found that the diversity of macrofauna and meiofauna was similar in terms of the number of species enumerated, yet the amount of sediment sorted for meiofauna was 550 times less than that for macrofauna (Attrill *et al.*, 1996), the implication being that, for the same amount of sediment, meiofauna are much more diverse. It would therefore appear that, in assessing the biodiversity of marine ecosystems, the meiofaunal component cannot afford to be ignored.

1.5 IMPACTS OF POLLUTION ON MEIOFAUINA

1.5.1 Organic pollution

Early published studies indicated that gross contamination by sewage results in a decline in copepods and an increase in the abundance of nematodes (McIntyre, 1977; Raffaelli and Mason, 1981). This led to the suggestion that a nematode/copepod ratio could be used as an index of organic pollution (Parker, 1975; Raffaelli and Mason, 1981). However, several authors have questioned the ability of such an index to adequately quantify responses of meiofauna to organic pollution in all habitats (Coull, *et al.*, 1981; Vidakovic, 1983; Lambshead, 1984; Gee *et al.,* 1985; Hodda and Nicholas, 1986; Moore and Pearson, 1986; Widbom and Elmgren, 1988). Nevertheless, Amjad and Gray (1983) found that the ratio matched their expectations in describing the organic loading of Oslo Fjord. Warwick (1981b) proposed a modification to the single figure index by suggesting that only those nematodes that feed in a similar way to harpacticoid copepods (the 2A feeding group:

epigrowth feeders) should be used in determining the ratio. In response to this, Raffaelli (1987) acknowledged that the original index could not be universally applied with success to all habitats (sand, mud, intertidal, subtidal) neither could it be considered robust to the responses of the different groups of harpacticoid copepods (epibenthic, interstitial, burrowing). He therefore qualified the original proposal of Raffaelli and Mason (1981), by advocating that the index be limited to use on sandy beaches exposed to organic pollution, and derived using counts only of interstitial copepods. The history of this index, and the controversy surrounding it, serves as a salutary lesson in the dangers of applying an unduly simplistic approach to pollution detection, despite the obvious attractions of single figure indices. Most field investigations of the effects of pollutants on meiofauna communities have reported densities (or biomass) of major taxa. However, density measures have led to difficulties in interpretation, as densities do not vary consistently, if at all, in response to organic enrichment (Coull and Chandler, 1992). With the one exception of Austen *et al.* (1989) field studies of the effects of sewage pollution on meiobenthic diversity have found that diversity is lower in polluted areas compared to reference conditions (Olsson *et al.,* 1973; Marcotte and Coull, 1974; Anger and Scheibel, 1976; Vitiello and Aissa, 1985; Arthington *et al.,* 1986; Keller, 1986; Moore and Pearson, 1986; Moore, 1987; Sandulli and Nicola - Guidici, 1990; Essink and Romeyn, 1994; Moore and Somerfield, 1997). Sources of organic pollution other than sewage have also been reported to cause a reduction in the diversity of meiofaunal communities (Henning *et al.,* 1983; Van Es *et al.,* 1980; Bouwmann *et al.,* 1984; Lorenzen *et al.,* 1987). In an investigation of a site with mild organic enrichment arising from sewage sludge disposal, Somerfield *et al.* (1993) observed only a slight effect on the diversity of the meiofaunal community. However, they did find an enhancement of some nematode species thought to be bacterial grazers.

Under conditions of gross enrichment the size separation between macrofaunal and meiofaunal organisms (Warwick, 1984) breaks down with the two size classes converging into a single mode (Warwick *et al.,* 1986). This is largely the consequence of flourishing numbers of small polychaetes and large copepods and nematodes. Perhaps the most notable change in communities in areas of gross organic enrichment is the appearance of dense aggregations of large oncholamid nematodes of the genus *Pontonema. Pontonema alaeospicula* has been reported in the vicinity of the Garroch Head sewage sludge disposal ground (Bett and Moore, 1988; Moore and Somerfield, 1997). Dense populations have also been observed close to a sewage outfall in the Firth of Forth and near an outfall from an alginate factory in Loch Creran, Scotland (Bett and Moore, 1988). A closely related species *P. vulgare* has also been recorded in dense mats underneath fish cages (Lorenzen *et al.,* 1987; Prien, 1988). *Pontonema* species and other oncholamid nematodes have been cited as potential "pollution indicators" (Bett and Moore, 1988). Although such characteristic patterns of species occurrences aid in the assessment of pollution impacts, further work is needed in order to understand why such meiofaunal species respond in this way.

Indicator species have also been proposed amongst the harpacticoid copepods, *Bulbamphiascus imus* (Brady) being the most often quoted example (Bodin and Le Moal, 1982; Moore and Pearson, 1986; Moore and Bett, 1989; Coull and Chandler, 1992). This species has also been reported in high densities in the vicinity of the Garroch Head disposal site (Moore and Bett, 1989; Moore and Somerfield, 1997) and in other enriched locations (Marcotte and Coull, 1974; Bodin and Le Moal, 1982; Keller, 1986; Sandulli and Nicola-Guidici, 1990).

A theoretical objection to the use of indicator organisms is that no marine species has evolved solely to exploit pollution, but rather to exploit certain natural ecological conditions. Intuitively, it might be expected that certain "indicator" organisms might respond to anthropogenic influences in the same manner as they would to comparable natural influences in pristine environments. Thus, on its own, the presence of an "indicator" organism is not proof of the presence of anthropogenic disturbance (Gray, 1981; Platt *et al.*, 1984).

1.5.2 Trace metal pollution

Unlike the wealth of literature on the impacts of organic pollution on the meiobenthos, there have been limited field studies where the toxic effect of sedimentary metals has been investigated (e.g. Tietjen, 1977,1980; Van Damme *et al.*, 1984; Somerfield *et al.*, 1994; Millward and Grant, 1995). Of these, few have demonstrated a clear "cause and effect" relationship because of confounding factors such as differences in sediment granulometry and organic burden of the sediments (e.g. Tietjen, 1980; Somerfield *et al.*, 1994).

Tietjen (1980) found a correlation between increased concentration of the heavy metals chromium, copper, lead and zinc and decreased nematode diversity in the medium sand fauna of the New York Bight Apex. This accords with the later results of Somerfield *et al.* (1994) where nematode diversity was also found to be depressed in areas within the Fal estuary and was associated with high sediment metal concentrations. Another key finding of the latter study was the occurrence of increased dominance and decreased evenness of nematodes with increasing metal concentration. However, no such association was demonstrated between metal concentration and copepod diversity.

1.5.3 Mixed pollutants

As with organic pollution, a reduction in the diversity of meiofaunal communities has been observed in studies where the source of disturbance is from mixed pollutants (Govaere *et al.*, 1980; Coull and Wells, 1981; Hennig *et al.*, 1983; Van Damme *et al.*, 1984; Heip *et al.*, 1988; Radziejewska and Drycimski, 1988, 1990; Newell *et al.*, 1990; Somerfield *et al.*, 1995).

These studies reflect a commonly encountered situation, in which benthic communities are exposed to multiple impacts arising from liquids and solids containing combinations of pollutants.

1.6 A COMPARISON OF MEIOFAUNAL AND MACROFAUNAL RESPONSES TO DISTURBANCE.

Warwick (1981a) has suggested that determinants of diversity may be different for meiofaunal and macrofaunal communities. Meiofauna are thought to maintain diversity through partitioning of species into specialised trophic groups whereas macrofauna may have less discriminating trophic preferences, but maintain diversity by spatial segregation of the species (Whitlatch, 1980). Thus, a comparison of the responses to pollution of the two components of the benthos sampled simultaneously in the field may provide insights into the underlying mechanisms by which different pollutants could affect community structure.

Comparatively few field studies have directly compared the responses of macrofauna and meiofauna to disturbance (e.g. Josefson and Widbom, 1988; Austen *et al.*, 1989; Warwick *et al.*, 1990b; Gee *et al.*, 1992; Somerfield *et al.*, 1995; Moore and Somerfield, 1997). Josefson and Widbom (1988) found the macrofauna and meiofauna exhibited differential responses to subtidal anoxia, with the macrofauna being more sensitive. Similarly, Warwick *et al.* (1990b) reported that the meiofauna were apparently unaffected at all localities investigated in Hamilton Harbour, Bermuda whereas the macrofaunal communities at two of their sampling stations were clearly impacted. This differential response was attributed to physical disturbance caused by the passage of large cruise liners, suggesting that the meiofauna consisting largely of motile forms were less sensitive than the macrofauna to dislodgement from the sediment.

In a study of a putative gradient of sewage pollution, physical disturbance was also implicated by Austen *et al.* (1989), as contributing to the disparity between benthic responses. They found that the spatial extent of impact on intertidal meiofaunal communities was less than that for the macrofauna along a gradient of sewage pollution. It was speculated that this result could be ascribed to increased sensitivity of the macrofauna to sediment disturbance caused by digging for shellfish rather than effects of the sewage discharge. By contrast, Moore and Somerfield (1997) found that whilst all macrofaunal community measures were strongly perturbed by sewage sludge disposal, the area of influence was less than that for the meiofauna. The meiofauna displayed a gradation of community change up to 3-4km away from the centre of disposal, but this could not be assigned to any particular aspect of sludge disposal. This was in contrast to the response of the macrofauna which exhibited a more severe reaction to disposal, being limited to within 1-2km of disposal, and which correlated with sedimentary carbon levels.

Gee *et al.* (1992) offered several possible explanations for the observed absence of any significant impact on the meiofaunal community, as opposed to that observed for the macrofauna, at a disused drilling platform in the North Sea. Firstly, they hypothesised that the meiofauna were insensitive to drilling activity. This theory was discounted in light of evidence from other studies, which had demonstrated that meiofaunal communities are sensitive to the effects of oil-based pollutants. Hence, a second explanation was offered which suggested that the time gap between the cessation of drilling and sampling (>2yr.) was sufficient to allow the complete recovery of the meiofaunal community. Finally, it was suggested that hurricane force storms that had crossed the area prior to sampling led to the deposition of a fresh layer of sediment (2-5cm thick) and may have diluted any differences in the surficial communities between stations.

Interestingly, Somerfield, *et al.* (1995) also found apparent differences in the time-mediated responses of macrofauna and meiofauna along a transect through a Liverpool Bay dredgings disposal ground. Nematodes appeared to be more sensitive to sediment structure, or to some factor correlated with it, and the ongoing disposal of dredgings i.e. short-term events. This was in contrast to the pattern observed for macrofauna, which seemed to correspond with concentrations of sedimentary metals and the historic disposal of dredgings.

It is difficult to draw any overall conclusions from such a limited number of studies. However, all of the investigations reviewed suggest that the meiofauna and macrofauna respond differently to perturbation, and furthermore when examined in parallel they may provide complementary information. Hence, it would seem advantageous to use both in marine pollution monitoring programmes and perhaps additional work will clarify in which circumstances they are both best utilised.

1.7 INTRODUCTION TO THE DISPOSAL OF DREDGED MATERIAL

As this study focuses on the impact of dredged material disposal on macrofaunal and nematode assemblages, it is useful at this stage to briefly review disposal practices and their likely biological consequences.

The disposal of dredged material into coastal waters can be divided into two types. Material arising from the periodic removal of silt and sand deposited by natural forces in channels, harbours and berthing areas are termed "maintenance" dredgings. This is in contrast to "capital" dredgings derived from "one-off" projects such as new port facilities or the initial deepening of navigation channels. This introduction will confine its discussion to the effects of the disposal of maintenance dredgings, since this activity was the subject of the present study. Figures 1 and 2 show the main disposal sites used in 1995 and 1996 respectively in UK waters and the quantities of both capital and maintenance dredgings deposited at each site.

A recent summary of dredged material disposal practices, and the biological consequences, is provided by the Marine Pollution Monitoring Management Group (M.P.M.M.G., 1996). The bulk of dredged material consists of silty sands but coarse sand and shingle can occur in maintenance dredging, and statutory control of its disposal at sea in the United Kingdom is provided by Part II of the Food and Environment Protection Act, 1985. Disposal occurs at designated sites where material is generally discharged instantaneously from the hulls of transporting vessels. Unless the sites are very deep or subject to exceptionally strong tidal currents, it has been estimated that 95% to 99% of the dredged material will sink directly to the sea-bed (see below). The total amount of dredged materials disposed of, the nature of the material and prevailing environmental conditions at the disposal site will all influence the nature and magnitude of disturbance to the benthic community. Moreover, the seasonal timing and regularity of disposal will also affect the intensity and the extent of influence. In seeking to assess the effects of the disposal of dredgings on the benthos, the history of the discharge will need to be established. At some of the larger disposal sites in the UK, the characteristics of dredged material will vary in time, both in sedimentological composition and in contaminant content, depending on the location of recent dredging campaigns. Thus, any field assessment of the effects of disposal must take into account such variability, as well as detailed information on the receiving environment.

1.8 PHYSICAL PROCESSES OF DREDGED MATERIAL DISPOSAL

To understand the ecological consequences of dredgings disposal it is essential to be aware of the physical processes involved in the disposal operation, as this determines the fate of the disposed material. The disposal process can be separated into three distinct transport phases defined on the basis of the physical processes that dominate during each period. These phases have been termed convective descent, dynamic collapse and pressure diffusion (Waterways Experiment Station, 1986). Figure 3 is a diagrammatic representation of the transport processes during sea disposal of dredged material. Following release from the hopper on the disposal barge, the material falls through the water column as a distinct jet. During the descent large volumes of water are entrained in the jet and fine material becomes separated from the jet and remains in the upper portion of the water column. This material persists as a near surface plume and is advected away from the point of discharge under the influence of currents. At the seabed, the descending jet collapses as a result of impact on the bed and the material which is not deposited on impact will move out radially under its own momentum. When sufficient energy has been dissipated material will begin to settle rapidly on the bed. Diffusive processes will then dominate and any remaining material will be mixed with the lower water column. The concentration of suspended solids will be lower and settling will take place at a much slower rate.

1.9 NATURE OF THE BIOLOGICAL EFFECTS OF DREDGED MATERIAL DISPOSAL

1.9.1 Effects beneath the discharge

Within the disposal site, it is to be anticipated that direct burial by the discharged dredged material will be the most evident impact on the indigenous benthic fauna. Maurer *et al.* (1981a and b; 1982) carried out laboratory experiments to examine the responses of selected macro-invertebrates to sediment overburden. They concluded that many motile epibenthic and infaunal animals could withstand an overburden of sediment (up to 90cm) especially when the overlying sediment was native to their habitat. They also found that increased depth and burial time caused greater mortality. In addition, mortality was linked to water temperature, such that mortality was greater during summer months than in the winter. Similar experiments conducted with nematode assemblages indicated that they were able to migrate through a sediment overburden of 10cm within a period of 2 weeks (Romeyn and Leiseboer, 1989). This result was obtained in treatments where both the original and deposited sediment was fine sand. However, the addition of muddy sediments over cores of sand was found to limit the migration of the resident nematodes to only a few cms. It therefore seems likely that those members of the benthic community that can tolerate the effects of rapid sedimentation may have the capacity to migrate upward to the new sediment surface providing burial is not too extensive (Maurer *et al.*, 1981a, b; 1982; Romeyn and Leiseboer, 1989). The sediment characteristics of the discharged material would also seem to be important in determining the impact of disposal on benthic communities.

Several studies have examined the effects of dredged material disposal on benthic communities in the field (Harrison, 1967; Flint, 1979; Van Dolah *et al.*, 1984; Wildish and Thomas, 1985; Rees *et al.*, 1992; Harvey *et al.*, 1998). Harrison (1967) reported a 71% reduction in the average number of benthic invertebrates at a disposal site in upper Chesapeake Bay 1-month after the cessation of disposal activities. In Liverpool Bay, Somerfield *et al.* (1995) found that the densities and range of copepod species were reduced within a dredged material disposal site, while the nematode community was dominated by species typical of muddier sediments such as *Sabatieria punctata*, *Sabatieria breviseta* and *Daptonema tenuispiculum* rather than a sandy complement of species, which were abundant outside. They attributed this largely to changes in the sediment structure, although a subsidiary influence of elevated heavy metal concentrations could not be discounted.

Detrimental effects of the disposal of dredged material on the benthic macrofauna were found to be minimal at a site in a South Carolina estuary (Van Dolah *et al.*, 1984). The absence of any gross effects of dredged material disposal on the benthos was attributed to the strong tidal currents in the area, which rapidly dispersed any accumulations of material away from the site. Rapid re-population of the disposal site by opportunistic species may also mask the immediate effects of disposal (Flint, 1979; Rees *et al.*, 1992; Somerfield *et al.*, 1995; Harvey *et al.*, 1998). Since some estuarine animals are able to withstand the process of dredging, the introduction of "exotic" species to an area may also be a consequence of disposal (Wildish and Thomas, 1985; Rees *et al.*, 1992).

Chemical effects associated with sediment overburden may also contribute to mortality of the benthic fauna in the receiving area. At the disposal site, reducing substances bound to the discharged sediment (e.g. organic matter, sulphides, and ammonium) may be released into the water column. In sheltered areas, where water movement is minimal, the release of these compounds may result in a reduction in the oxygen level of the seawater to concentrations that induce mortality in some the benthic organisms. In addition, the disposal of contaminated material may have sub-lethal toxicological effects.

1.9.2 Effects adjacent to the discharge

Proximal to the sediment mound (within the confines of the disposal site), the fauna may be affected by increased turbidity from dispersing fine material, and any contaminants bound to the fine particulates. Moore (1977) and Newcombe and MacDonald (1991) have reviewed the effect of suspended inorganic particles on aquatic marine life. Marine benthic invertebrates vary greatly in their tolerance to the amount and type of suspended solids (Newcombe and MacDonald, 1991). Organic matter associated with the dredged material would also be expected to modify the fauna. Such impacts arising from the input of organically-rich sediments are likely to be comparable to those observed at sewage sludge disposal grounds (see Pearson and Rosenberg, 1978) although of a milder nature as the amount of organic material would generally be much lower.

1.9.3 Effects beyond the disposal site.

A more "stable" community, akin to nearby unaffected locations, may persist on the outer margins of the site, providing they are seldom in direct receipt of dredged material. However, this community will be within the influence of dispersing material and as such may be slightly modified. Bordering the disposal site, dispersing particulates have been documented to cause a net enhancement of benthos (Zambriborsch *et al.*, 1982; Rees *et al.*, 1992). Possible explanations for this finding include the stabilising influence and nutritional property of the settling material.

1.10 STUDY SITES

Transect surveys of the macrofauna and nematode assemblages were conducted at four dredged material disposal sites: Tees Bay, Liverpool Bay, Lune Deep, and Swansea Bay. These sites were selected in order to investigate the responses of the communities to a range of dredged material varying both in sedimentological composition and contaminant burden. In addition, the selected sites are amongst the largest disposal operations in UK waters and represent a range of environmental conditions in which dredged material is disposed. Other more pragmatic considerations, which were taken account of during site selection, included the ease of obtaining quantitative samples for meiofaunal analysis both from stations within the disposal sites and outside. This criterion could only be met in areas where fine sediments predominate, as there is a requirement for undisturbed sediment samples for meiofauna analysis (see Chapter 2).

The environmental setting of each disposal site is set out in individual chapters (see Chapters 3, 4, 5, & 6). However, a brief description of the main environmental features of the sites and the characteristics of the dredgings disposed of is given below (see also Table 3). The Tees Bay disposal site is located at approximately 30m depth off the north-east coast of England (see Figure 4) and currently receives about 2Mt. wet weight annually of maintenance dredgings consisting predominantly of mud and sand from the industrialised Tees estuary. The zone around the disposal site itself is heterogeneous and contains high proportions of coarse sand (1-4mm) some of which may have been derived from the historic disposal of capital dredgings. Tidal currents are known to flow approximately parallel to the coastline and residual near-bed currents are south-easterly (M.A.F.F., 1965; Ramster, 1976).

The Liverpool Bay disposal site, located in shallow water of about 10m depth, also receives about 2Mt. wet weight of maintenance dredgings from the Mersey estuary and its approaches, and has been comparatively well studied in recent years (see Rowlatt *et al.*, 1986; Rees *et al.*, 1992; Somerfield *et al.*, 1995). The dredgings typically consist mainly of sands (70%), although muds (30%) contain the bulk of the trace metal contaminants (Rowlatt, 1982). However, on a shorter time-scale the sediment composition can vary greatly depending on where recent dredging has taken place. Fine particulates have the potential to disperse widely due to a net south-easterly residual current in the inner Bay and as a result of tidal currents running in an east-west direction at velocities up to 1.4kt (Admiralty data). The site is also exposed to wave action especially from winds with a north-westerly component.

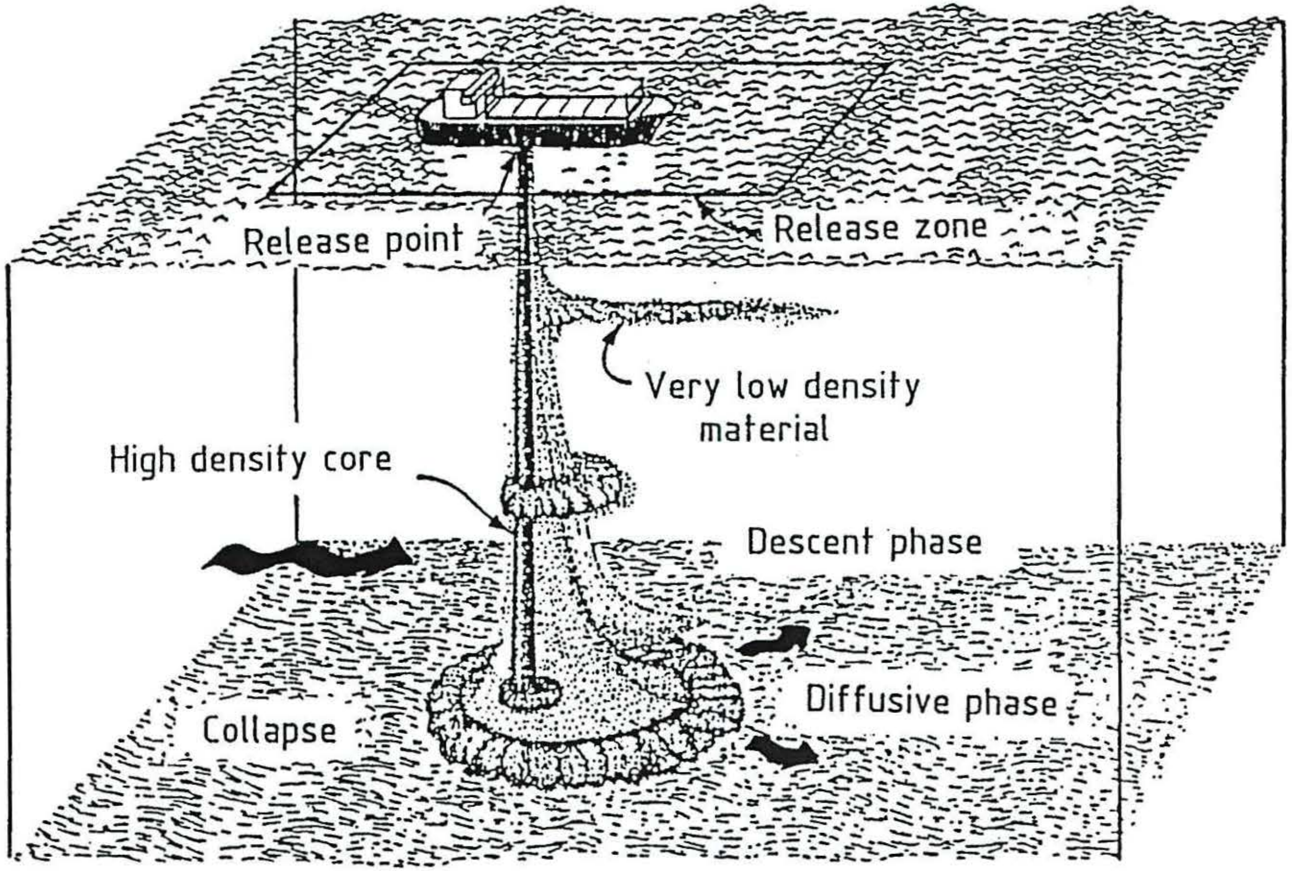
The Lune Deep site is located at about 35m depth within the greater Morecambe Bay area in the north-eastern Irish Sea and receives about 0.9Mt. wet weight of maintenance dredgings annually. At the south-western end of the Lune Deep, peak tidal velocities run parallel to the Deep with flood directed currents of 0.8Kt being slightly stronger than ebb directed currents. Sediments here are considered to represent a muddy-sand depositional area whereas further north, in the vicinity of the disposal site, sediments are coarser in nature (Rostron, 1992).

Swansea Bay, located on the northern coastline of the Bristol Channel, experiences one of the largest tidal ranges in the world (8.5m mean Spring Tides, 4.1mean Neap Tides). Maximum surface flood and ebb tidal current speeds have been recorded as 1.3 and 1.5kt at the site. Prevailing winds in the area are southwesterly and as the Bay is open to the southwest, long wavelength swell from the western Atlantic breaks upon the eastern coastline of the embayment. Thus, the combined influence of waves and tides creates a high-energy environment. The disposal site is located in shallow water of approximately 20m depth. It contains gravelly sand in the south-western sector while its eastern sector lies on the edge of a sand and mud area. Approximately 2Mt. wet weight of muddy maintenance dredgings taken from the approach channels of Swansea Docks and Port Talbot Harbour are disposed of annually at this site.

Table 3 A summary of the main environmental characteristics of the disposal sites investigated and the type of material disposed of.

Site	*Depth of site*	*Bottom Type*	*Tidal currents*		*Quantity of material disposed per annum*	*Description of dredged material*
			Ebb	*Flow*		
Tees Bay	30m	Mud, shell	0.9kt	1.2kt	2Mt	Sandy dredgings from the Tees Estuary and approach channels
Liverpool Bay	<10m	Sand, broken shell	1.4kt	1.1kt	2Mt	70% Sand and 30% Mud from the Mersey Estuary and approach channels
Lune Deep	35m	Fine sand, broken shell	1.8kt	1.7kt	0.9Mt	Muddy dredgings from the River Wyre and Fleetwood Docks and their approach channels
Swansea Bay	20m	Gravelly sand and Soft Mud	1.3kt	1.5kt	2Mt	Muddy dredgings from Swansea Docks and the Port Talbot Harbour and their approach channels

Figure 3 Transport processes during open water disposal of dredged material (after Waterways Experiment Station, 1986).



2. MATERIALS AND METHODS

2.1 INTRODUCTION

This chapter provides details of the field and laboratory procedures undertaken to compare the responses of meiofaunal and macrofaunal communities to dredgings disposal along transects through four UK dredged material disposal sites (see Figure 4).

As many meiofaunal workers have stressed the importance of obtaining representative "undisturbed" sediment samples for quantifying meiofaunal communities (Barnett *et al.*, 1984; Bett *et al.*, 1994; Somerfield and Clarke, 1997) initially it was important to identify an appropriate sampler, across a reasonable range of fine subtidal sediments.

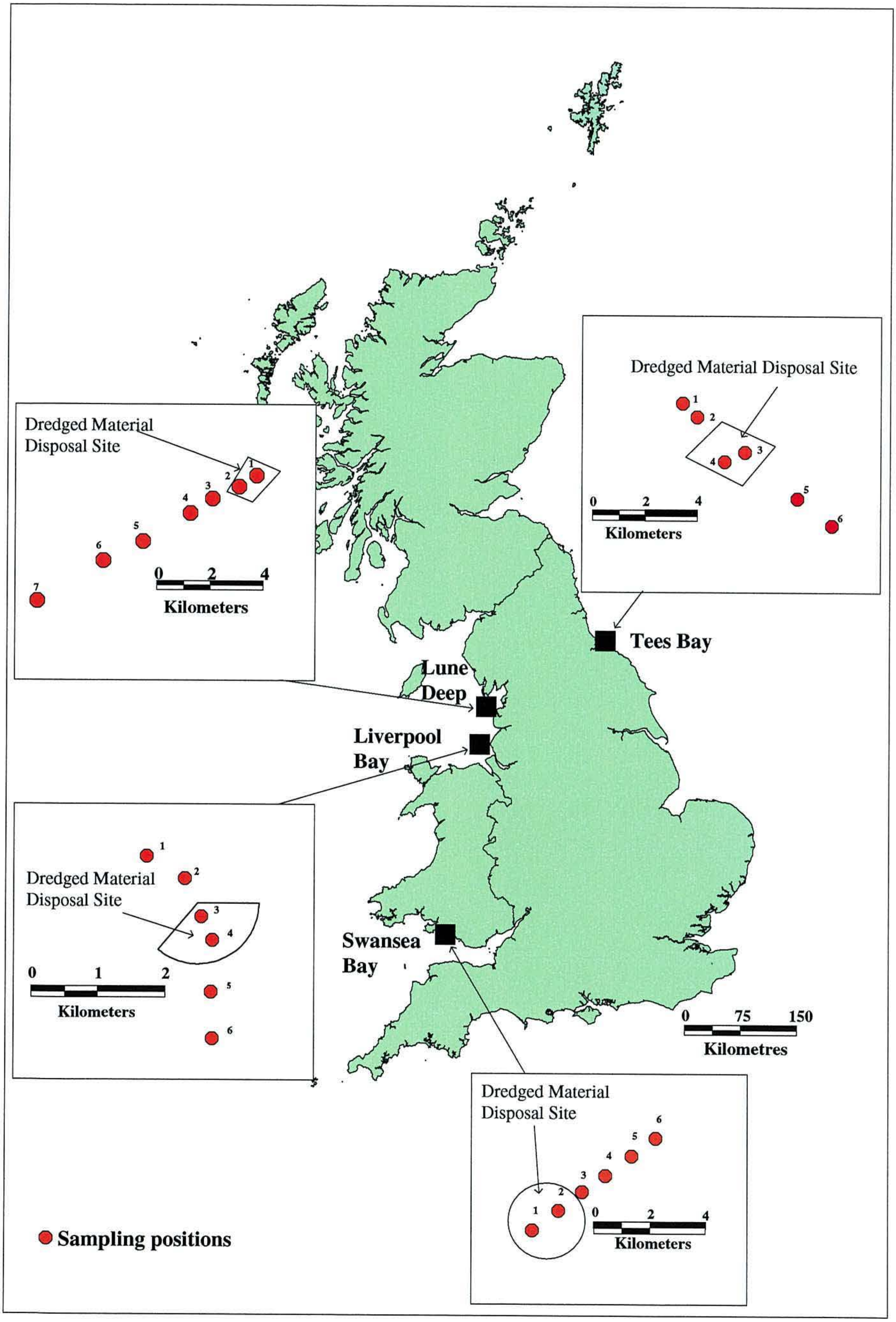
A final section describes the numerical methods adopted to summarise the biological and environmental data.

2.2 QUANTITATIVE SAMPLING AT DREDGED MATERIAL DISPOSAL SITES

2.2.1 Selection of sampler

A prerequisite in quantitative meiofaunal studies is for undisturbed sediments (Barnett *et al.*, 1984; Bett *et al.*, 1994; Somerfield and Clarke, 1997). With this goal foremost, a review was initiated to assess the most appropriate sampling device for collecting meiofauna samples at the offshore dredgings disposal sites. This review culminated in a comparison exercise between several sampling devices (Craib, Bowers and Connelly Multiple-corer, Institute of Oceanographic Sciences Box Corer and a Day Grab). During gear trials carried out on board the Jodalee in the River Crouch, Essex, the Bowers and Connelly Multiple-corer provided samples of undisturbed sediments.

Figure 4. The location of investigated dredged material disposal sites sampled around the UK coast.



A Bowers and Connelly Mini-Multiple corer is shown in Plate 1. This corer is supported by a stand and allows the unimpeded flow of water through the core tubes during its descent to the seabed. Sediment penetration by the core tubes does not commence until the device has come to rest on the seabed and it then proceeds slowly under the control of a hydraulic damper. These features of the corer should prevent the tilting of the corer on the seabed and limit the disturbance caused by the production of a pressure wave (Blomquist, 1985, 1991). In order to confirm this and to observe the sampling operation of the corer on a soft-bottom substrate an underwater video survey was carried out from the Prince Madog on 23 August 1995. A sandy mud substrate was chosen for this survey in an attempt to record any disturbance to soft surficial sediments due to the corer during sample collection. The video used was the Osprey Simrad Electronic "Cylops" Integrated colour TV system. This system consisted of a water corrected, wide angle CCD camera (OE1336) contained within a waterproof housing, connected to a surface control unit via a jacked cable. Light at the seabed was provided by a 300W waterproof lamp (see Plate 2). The surface control unit (OE1212) had an integral monitor, which allowed the operator to adjust focus and lighting levels as required and to view the images as they were produced. The images were recorded on to a VHS videotape for subsequent analysis. A series of photographic stills captured from the videotape are presented in Plate 3. It is apparent from the video footage and the stills presented here that visually there was very little disturbance caused by the action of the corer on the seabed both during its descent and during sediment penetration. The Bowers and Connelly Mini Multiple-corer was therefore judged to be suitable for obtaining quantitative meiofaunal samples from fine sediments. Modifications to the core tubes to improve sampling efficiency and precision over a wider range of substrates included the addition of stainless steel tips and the incorporation of an etched scale marked in centimetre intervals.

2.2.2 Field sampling

The corer was routinely deployed at a speed of approximately 1 metre per second and allowed to rest on the seabed for at least 15 seconds before retrieval. Care was taken to ensure the warp was slack whilst the corer was on the seabed. This involved paying out extra warp to compensate for any movement of the corer away from the ship. The corer was raised slowly off the seabed with recovery then taking place at up to 2 metres per second. Li *et al.* (1997) found that single cores (10cm^2) were insufficient to account for the variation in nematode diversity due to the aggregated distribution of subtidal nematodes. Therefore three replicate samples (23.76cm^2) were taken from each station in order to account for the within station variability. Multiple samples collected from one deployment of the corer are pseudo-replicates and cannot be considered as true replicates since they are not statistically independent entities, and as such do not increase the number of degrees of freedom available for formal significance testing (see Hurlburt, 1984 and Heffner *et al.*, 1996 for further details). Three replicate samples were therefore collected from separate deployments of the corer. Samples were discarded if the sediment surface appeared greatly disturbed, the sediment penetration depth was less than 5cm or the sediment core was not fully intact. Once a suitable sample had been retrieved, samples were placed in 2.5l sample buckets and a mixture of 7% formaldehyde in filtered seawater (filtered over a 63μm mesh) was added as a fixative. Samples were labelled inside (using standard M.A.F.F. plankton labels) and outside using permanent markers. "Rose Bengal," a vital stain, was routinely added to the fixative prior to its use.

Plate 1 Photograph of a Bowers and Connelly Multiple Corer.

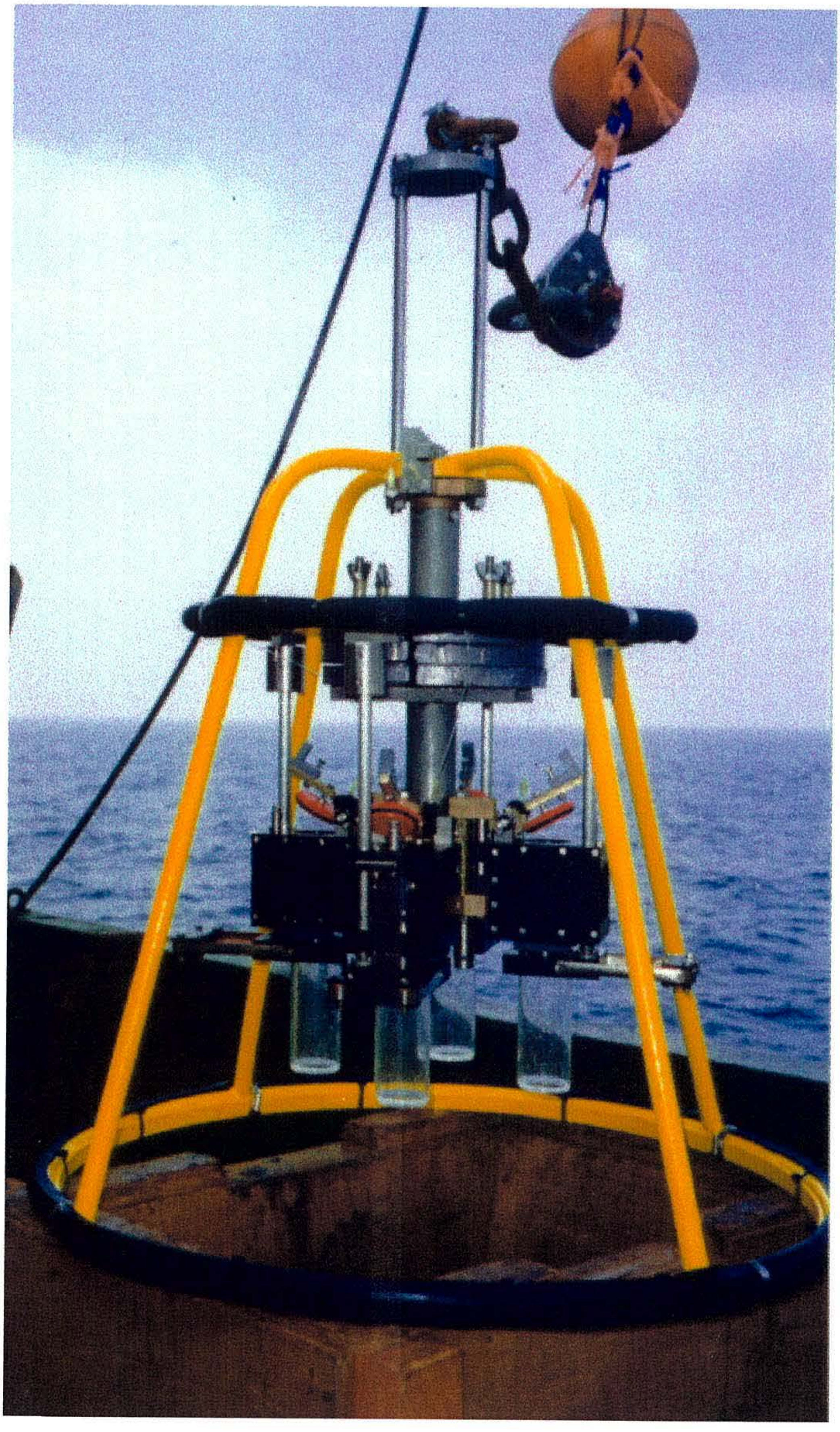


Plate 2 Photograph of the Multicorer with video camera and light source attached

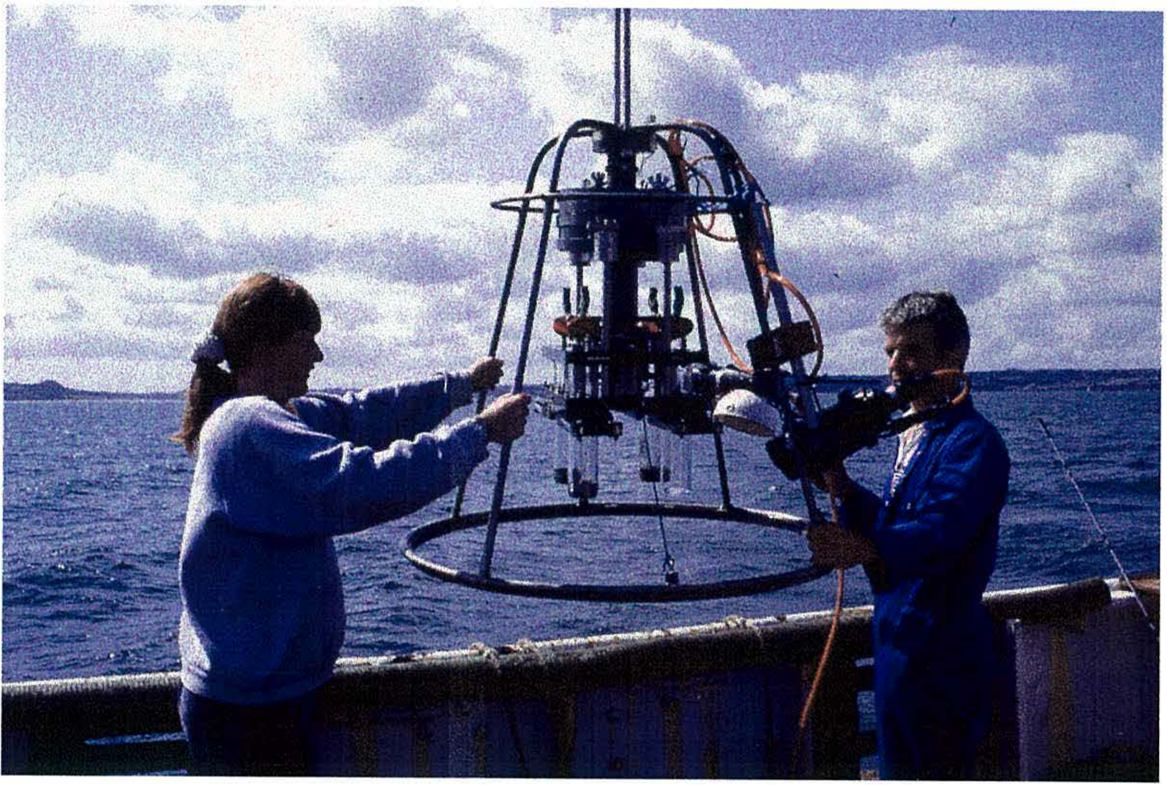
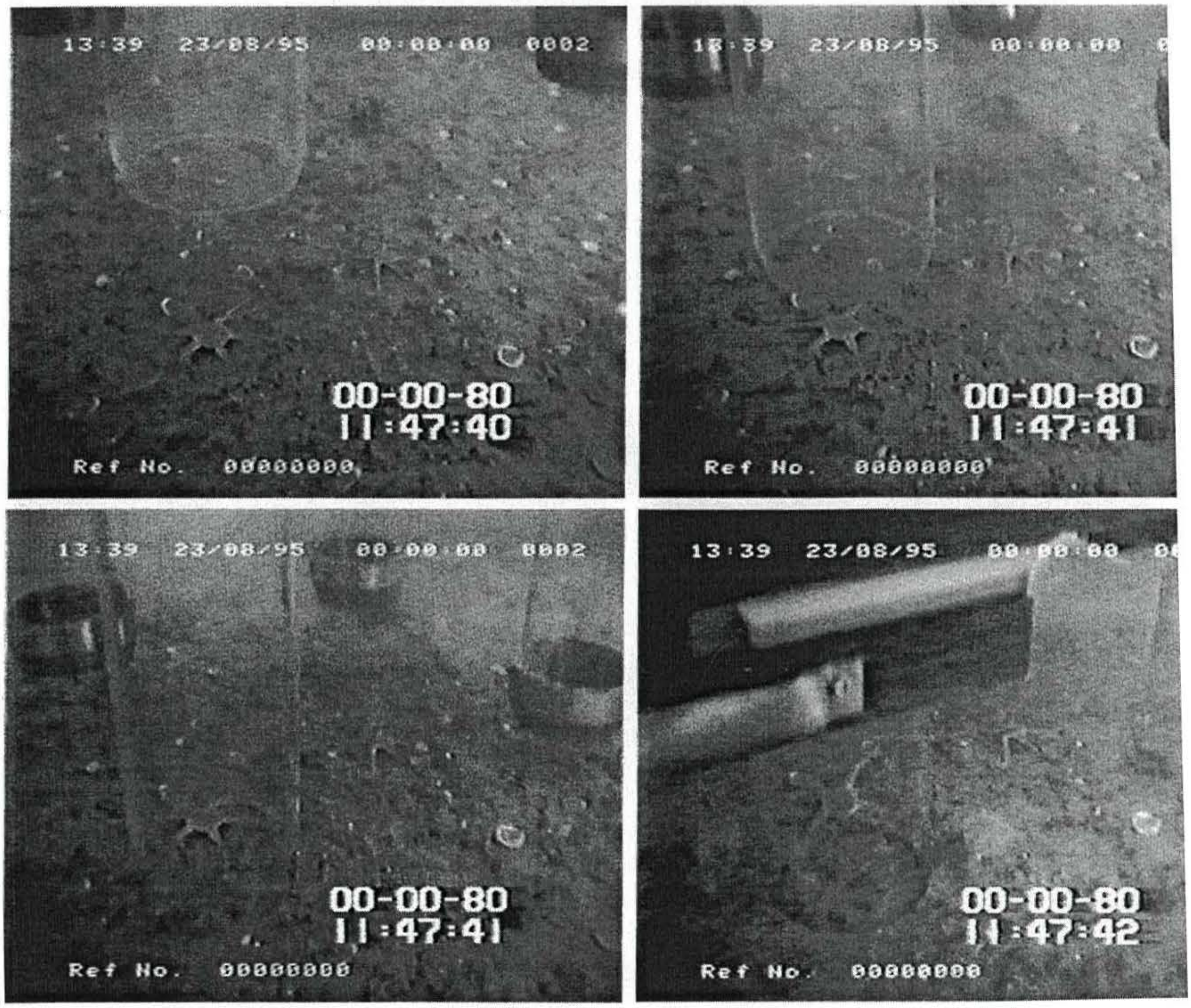


Plate 3 Sequence of captured video stills showing the sampling operation of the Multicorer



The sediment type, the depth of sediment penetration of cores retained and any artefacts indicative of disposal practices or large macrofaunal organisms visible within the core were recorded.

The top 5cm of sediment from an additional core from each successful deployment was also retained for particle size and trace metals analyses. Sediment samples were stored in a freezer at -20^{0}C in large sealable plastic bags placed in 1.25l labelled Tupperware pots pending further analysis.

Three replicate 0.1m^2 Day grab samples were also collected at each station along the transects for macrofauna analysis and a sub-sample (50ml syringe to a depth of 5cm) removed from each grab for particle size analysis. Surficial sediment from a further Day Grab at each station was retained for analyses of metal concentrations and organic carbon and nitrogen, and frozen at -20^{0}C pending analysis. Macrofauna samples were sieved on a 1 mm mesh prior to fixation in 7% buffered formalin.

Replicate sub-samples (50ml syringe to a depth of 5cm) were also taken at each station from separate macrofaunal Day grab deployments along the Tees and Swansea Bay transects for meiofaunal analyses and preserved in 7% buffered formalin. This was in order to compare the relative performance of the Multicorer and Day Grab in meiofauna sampling over a range of conditions.

A summary of the sampling details of surveys conducted at the 4 dredged material disposal sites is given in Table 4.

2.2.3 Sidescan survey at Liverpool Bay

A sidescan sonar survey was also carried out at the Liverpool Bay disposal site using an EG&G 260 sidescan with a towed 272TD dual frequency sensor in order to establish the location of deposited material. This was used in conjunction with slant range correction and water column removal to give true XY sonographs on thermal paper. Global Positioning

System (GPS), aerial location and GPS time were printed to paper every two minutes and on manual fixes. Navigational software used was the SEXTANT hydrographic survey package. Positional data were logged to disc every 50m along track whilst on-line. The position of the sidescan fish was logged using course made good information and manual playback entry to establish absolute position. The off-track display was used to continuously monitor deviation from the survey line and allow course corrections to be made.

Table 4 Summary of ship borne sampling at selected dredged material disposal sites.

Cruise	*Dates*	*Transect*	*Samples*
Corystes 6/95	May, 1995	Tees Bay	macrofauna meiofauna sub-samples (grab) particle size (grab) metals and organics (grab)
Corystes 6/95	May, 1995	Swansea Bay	macrofauna meiofauna sub-samples (grab) particle size (grab) metals and organics (grab)
Corystes 7/96	May, 1996	Tees Bay	meiofauna (multicores) particle size (multicores) metals and organics (multicores)
Cirolana 8b/96	June, 1996	Swansea Bay	meiofauna (multicores) particle size (multicores) metals and organics (multicores).
Prince Madog 1996	September, 1996	Liverpool Bay Site Z	macrofauna particle size (grab) metals and organics (grab) meiofauna (multicores) particle size (multicores) metals and organics (multicores).
Prince Madog 1996	September, 1996	Lune Deep	macrofauna particle size (grab) metals and organics (grab) meiofauna (multicores) particle size (multicores) metals and organics (multicores).

2.3 LABORATORY PROCEDURES

2.3.1 Meiofaunal sample processing and extraction.

The meiofaunal laboratory procedures adopted throughout the project are largely based on those described by Somerfield and Warwick (1996) in their meiofauna manual. Samples were washed through a 63µm sieve to remove the formalin and the silt fraction. Tap water filtered through a "Sartorius Sartopure" 1.2µm filter was used for all washings. Once the fine sediment fraction had been removed an aliquot of up to 100ml of the sieve residue was transferred to a 1L measuring cylinder where the material was subject to a process of elutriation and decantation in order to separate the meiofauna and lighter fractions of the sediment from the coarser material. This involved inverting the cylinder 5 times in order to distribute the material evenly throughout the volume. After allowing the heavier particles (mainly sand) to settle out the supernatant was decanted over a 63µm sieve. The decantation process was repeated 5 times. Further aliquots of the sieve residue were then processed in the above manner. The extraction efficiency was assessed for each survey prior to adopting this method. At least 96% of the Copepoda and 100% of other meiofaunal taxa including the Nematoda were extracted from sediment samples after removal of the silt fraction by a 63µm sieve. The decanted material was then transferred to a 250ml glass beaker and a solution of Ludox TM 40 with a specific gravity of 1.15 was added. Sufficient Ludox solution was added to the sample to ensure that at least 10 times the sample volume was obtained. Samples were stirred using a glass rod to evenly distribute the sample throughout the solution, covered and then left for 45 minutes to allow the heavier material to settle out. The supernatant was then gently poured through a 63µm sieve into a collecting jug. The Ludox solution was returned to the sample beaker and the process was repeated three times. The meiofauna extract was then washed with tap water and transferred to airtight jars containing a preservative solution of 70 % methanol (GPR) prior to sub-sampling.

As there may be statistical problems associated with estimating diversity based on analysing a set number of individual nematodes across all samples (Somerfield and Warwick, 1995), an alternative approach was adopted during this study whereby the total number of animals present in a constant proportion of the total sample was analysed. Sub-sampling of the sediment cores was achieved by using a sample splitter which was designed with reference to other examples in the meiofaunal literature, especially that of Jensen (1982).

The splitter consists of two cylindrical chambers: a mixing chamber and a splitting chamber (see Figure 5 and Plate 4). The mixing chamber is simply a cut-down funnel. Its central aperture (7mm cross sectional diameter) leads on to the splitting chamber and is closed from above with a rubber bung with an attached metal handle. The mixing chamber fits tightly on top of the splitting chamber and together they are placed upright on top of a tripod. A spirit level was used to ensure that the splitter was fitted together correctly and horizontally. The splitting chamber has a central rod with a conical tip and is divided by radial compartments with 64mm high walls. Each compartment has a drainage nipple at its base on to which a rubber tube is attached. The tubing is closed off by means of metal screw clips.

Extracted sample material was washed from each sample jar into the mixing chamber. Once all the material from the sample jar had been removed the contents were gently mixed with a glass rod to evenly suspend the sample. In practice, it was found that the material was already evenly suspended. The rubber bung was then removed allowing the material to pass through the funnel aperture and on to the cone below, splitting the sample evenly into the 8 compartments. Replacing the rubber bung allowed any remaining sample material to be washed with a small volume of water from the sides of the mixing chamber. When the bung was removed this material became evenly divided amongst the splitting compartments. A 1/8th sub-sample was removed by randomly selecting a splitting compartment and draining the contents into a receiving beaker. A jet of water was then used to rinse the compartment and remove any remaining material. This method of sub-sampling was validated by "splitting" a known sample containing 676 nematodes and assessing the variation in the number of nematodes in each chamber. A two way ANOVA indicated that there was no significant difference ($p>0.05$) between the numbers of nematodes recorded in each splitting compartment over three different occasions (see Table 5). A single sub-sample from each replicate core was analysed further. Grab sub-samples were extracted and analysed without further sub-sampling.

Table 5 The results of trials to investigate the performance of the sample splitter.

	Numbers of Nematodes		
Chamber	*Trial 1*	*Trial 2*	*Trial 3*
1	96	75	69
2	97	81	99
3	71	91	105
4	89	102	81
5	57	79	96
6	78	71	89
7	102	86	81
8	86	91	56
Total	676	676	676

Sub-samples from both cores and grabs were then placed in cavity blocks containing a solution of 5% glycerol, 30% ethanol and 65% tap water. Cavity blocks were covered with a clearly labelled coverslip, leaving a small gap to allow evaporation and were placed into a desiccator.

Figure 5 A diagram of the Jensen sample splitter in longitudinal and cross section (redrawn after Jensen, 1982).

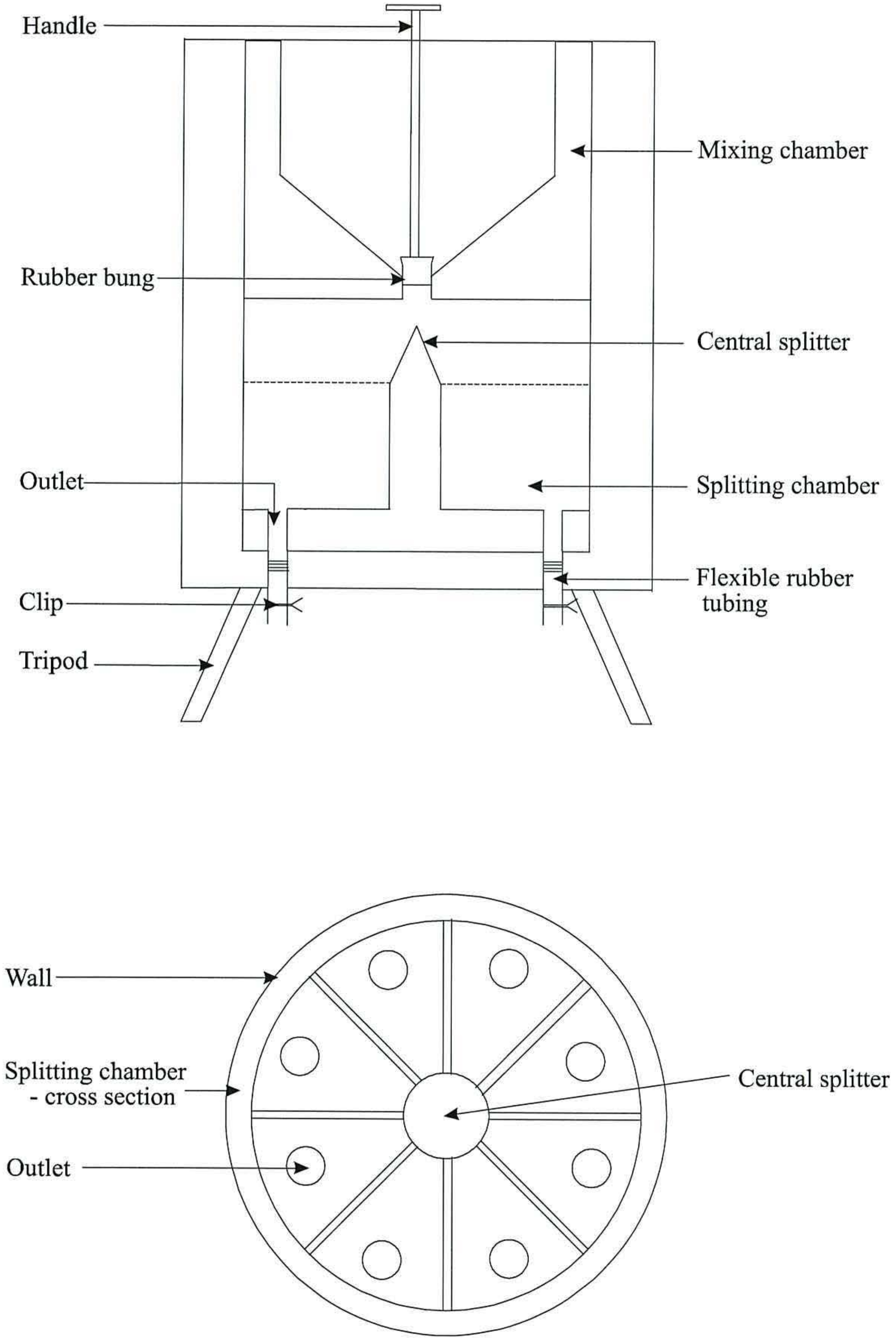
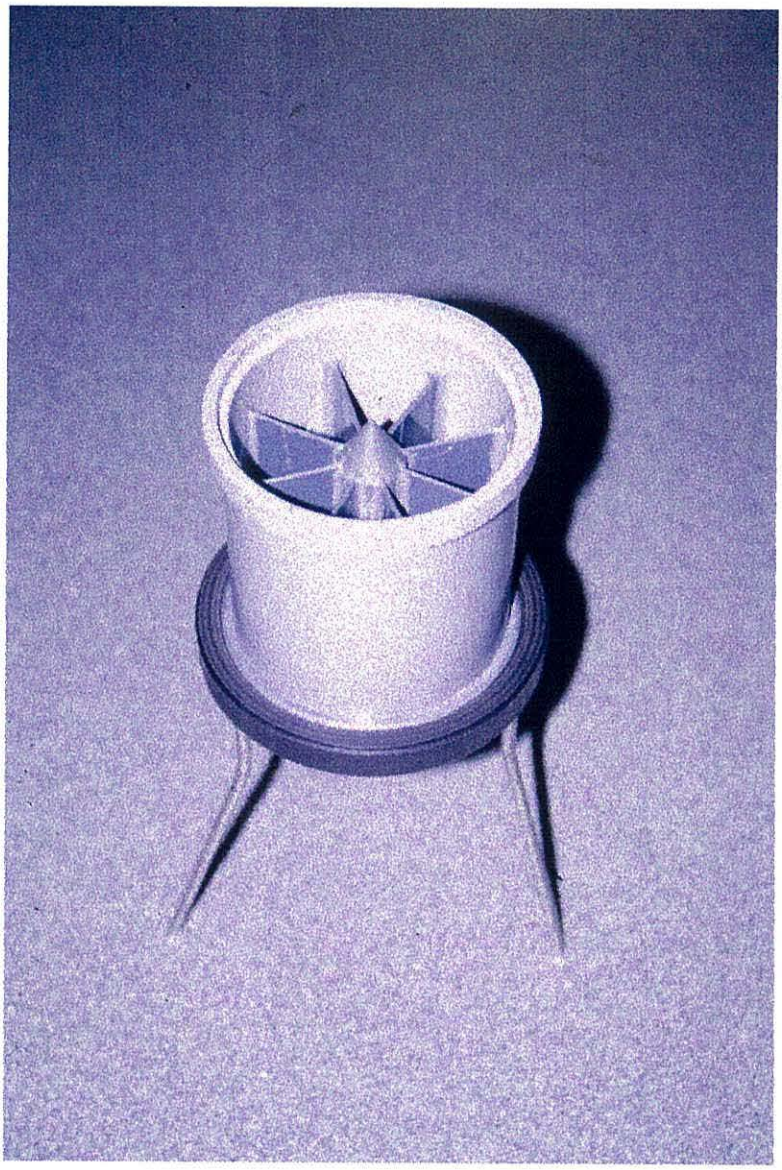


Plate 4 Photograph of the splitting chamber of the modified "Jensen" sample splitter



After a period of several days the animals were present in anhydrous glycerol. Meiofauna samples were then mounted on mass slides and sealed initially with paraffin wax and then ringed with two coats of Bioseal Mountant No. 2. Identification and enumeration of nematodes was conducted using a compound microscope with Nomarski interference contrast illumination. Wherever possible, nematode specimens were identified to species level using the keys for free-living marine Nematoda (Platt and Warwick, 1983, 1988; Warwick *et al.*, 1998). A reference collection was established cataloguing the slide co-ordinates of representative specimens for each species encountered. For certain problematic specimens and the confirmation of an undescribed species consultation was sought from the Natural History Museum, London.

2.3.2 Macrofaunal sample processing and extraction

Each macrofauna sample was elutriated over a 1mm mesh sieve to remove the formalin and to separate the coarse and fine material. Specimens present in the decanted fine fraction were placed into petri-dishes containing a preservative mixture of 70% methanol (GPR), 10% glycerol and 20% tap-water. The coarser fraction was placed on plastic trays and examined for any remaining animals such as bivalves not recovered in the decanting process, which were then added to the petri dishes. The fauna was then sorted and identified to the lowest possible taxon, usually species, and enumerated. Representative specimens were retained as part of a curatorial reference collection and named according to the nomenclature of Howson and Picton (1997).

2.3.3 Sediment processing and analysis.

After thawing, sediment samples were first wet - sieved on a 63μm sieve to provide an estimate of the silt and clay fraction (<63μm). This fraction was dried at 100^0C and then weighed. The coarser fraction (sand and gravel) was also oven dried for 12hrs at a temperature of 100^0C and analysed by sieving over a series of geometric test sieves (BS6580) with 0.5 phi intervals ranging from -6 phi (6300 microns) to +4 phi (63 microns). The sieve residues on individual sieves were weighed on a Sartorius top pan balance with a precision of ± 0.01g.

Organic carbon and nitrogen concentrations were determined in the <63μm fraction using a Perkin Elmer 240 CHN analyser, after removal of carbonates with 8% HSO_3 (Shaw, 1959). The concentrations of a range of sedimentary metals were determined in an *aqua regia* extract of the fine sediment fraction by flame atomic absorption spectrophotometry (Harper *et al.,* 1989; Jones and Laslett, 1994). This method partially extracts metals from the sediment, and has been used at the Burnham-on-Crouch Laboratory for many years providing comparability between recent and historic data. However, one of the limitations of this method of digestion is that it does not break down the more refractory matrices such as silicates, nor does it dissolve some refractory minerals such as chromite (Jones and Laslett, 1994).

Chlorobiphenyl concentrations were determined for Swansea Bay core sediments by established methodology (Allchin *et al.,* 1989*)* with some modifications. In essence, samples were air dried at ambient temperature until constant weight, passed through a 2000μm stainless steel sieve and then ground with an agate pestle and mortar. Sub-samples (10g dry weight) were mixed with anhydrous sodium sulphate and then Soxhlet extracted with acetone/hexane for six hours. Sulphur removal was aided by the addition of copper turnings to the Soxhlet flask. A suitable aliquot of the extract was taken and subjected to clean up and class fractionation by alumina and silica chromatography. Chlorobiphenyl residues were determined by high resolution gas chromatography using a 50m x 0.2mm capillary column coated with 0.33 μm 5% phenyl methyl silicone and operated under optimised conditions. Quantification was by a multi-level internal standard procedure.

2.4 DATA ANALYSES

2.4.1 Univariate measures of benthic community structure

The trophic grouping of each nematode species was determined using the generic key of mouthpart morphology as defined by Wieser (1953). The 4 groupings are as follows: 1A buccal cavity absent or minute, no teeth; 1B - conical or cup-shaped buccal cavity, teeth absent or minute; 2A - medium sized buccal cavity, small to medium teeth; 2B - large buccal cavity, large teeth or well developed cuticularised structures. Although Wieser's classification has been revised on a number of occasions, most recently by Moens and Vincx (1997), modifications to the original scheme are supported by very few actual observations of the feeding behaviour of nematodes. It has also been suggested that some species may alter their mode of feeding in response to the availability of food (Moens and Vincx, 1997). Therefore, in this study, Wieser's approach was retained, but as a method to assess the numbers of a particular morphological group which may have some ecological relevance, rather than as a classification of feeding types. It has been shown that perturbation (organic enrichment) may result in a proportional reduction in the 2A feeding type with a concomitant rise in the 1B feeding group (Lambshead, 1986). Therefore, the ratio of 1B/2A may have some indicator value as a measure of disturbance caused by an increase in the organic loading of the sediments.

The limitations of single-figure diversity indices for describing ecological data have been stated by many authors (e.g. Green, 1979); however their use in the present study is justified as a method to facilitate the comparison of samples within sites where natural environmental variation was minimal. Univariate measures calculated included: total abundance, number of species, and the following indices: Shannon-Wiener diversity (H'), Margalef's species richness (d) and Pielou's evenness (J). In order to statistically compare macrobenthic and nematode communities from different stations, each univariate measure was calculated for all three replicates. The equations used to calculate these indices are presented in Table 6. A one-way ANOVA was used to test the significance of differences between stations for each site at the 95% confidence level as estimated using Fisher's least significant difference (LSD) procedure.

Table 6 Equations for univariate indices used to assess nematode and macrobenthic community structure.

Index	*Symbol*	*Equation*	*Reference*
Total abundance	A	$\log(1+A)$	
Number of species	S	$\log(1+S)$	Poole (1974)
Shannon-Wiener	H'	$H' = -\Sigma_i p_i (\log_2 p_i)$	Shannon and Weaver(194
Pielou's evenness	J'	$J' = H'(\text{observed}) / H'\text{max}$	Pielou (1966)
Margalef's richness	d	$d = (S-1) / \log A$	Margalef (1958a and b)

p_i = Proportion of the *i*th species in the assemblage

H'max = The maximum possible diversity which would be achieved if all species were equally abundant.

Diversity indices were also calculated from data pooled across sample replicates from each station. Inter-relationships between the following environmental variables and diversity indices were examined using Pearson product moment correlation co-efficients:

% (silt and clay), % organic carbon, % total carbon, % organic nitrogen, cadmium, chromium, copper, mercury, nickel, lead, and zinc. All variables used in the analysis were log (1+x) transformed to reduce skewness of the data.

2.4.2 Multivariate measures of benthic community structure.

The two stage approach advocated by Field *et al.* (1982) for analysing multivariate data has been followed. This involves exploring the sample and species associations and then comparing the findings with the environmental information in order to offer an environmental interpretation of the community patterns. Such a strategy separates the analysis of biotic and environmental data and therefore makes no prior assumptions about causality. However, it does rely on the environmental and community data being distributed identically. The validity of this assumption has been questioned in ecological investigations (Rossi *et al.*, 1992). However the above approach is justified in the current study as there was very little information on the biological consequences of dredged material disposal and the causal environmental factors (other than the immediate physical impact following discharge) were not readily appreciated (M.P.M.M.G, 1996). Therefore the direct integrated use of environmental data was not deemed appropriate until after "letting the species tell their story" (Day *et al.*, 1971).

A range of non-parametric multivariate techniques included in the PRIMER[1] package was therefore applied to the species/sample matrices in order to summarise the faunal community data at each dredged material disposal site. This involved initially constructing a lower triangular similarity matrix from the transformed biotic data matrices using the Bray-Curtis similarity co-efficient. This index is considered appropriate for marine ecological community data as, unlike other similarity indices, it is not affected by joint absences which tend to be a feature of such data sets (Field *et al.*, 1982). When applied as a quantitative index for comparing samples it gives greater weight to abundant species than to rarer ones. The Bray Curtis distance index takes the form:

Equation 1

$$\delta_{jk} = \frac{\sum_{i=1}^{S} \left| Y_{ij} - Y_{ik} \right|}{\sum_{i=1}^{S} \left(Y_{ij} + Y_{ik} \right)}$$

Bray and Curtis (1957)

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[1] Plymouth Routines In Multivariate Ecological Research.

which can be converted to a % similarity using the similarity complement:

Equation 2 $$S_{jk} = 1 - \delta_{jk}$$

where Y_{ij} is the score for the *i*th species in the *j*th sample; Y_{ik} is the score for the *i*th species in the *k*th sample and δ_{jk} is the dissimilarity between the *j*th and *k*th samples summed over all species.

Transformations were chosen on a site specific basis (see individual Chapters for details) in order to limit the contributions to similarity by the most dominant species, and therefore allow the rarer species to influence the analyses (Elliot, 1977). The similarity co-efficients were then grouped using group average linkage cluster analysis (Lance and Williams, 1967), a hierarchical classification technique, and the results displayed as dendrograms. Although dendrograms may be an effective method of displaying sample groupings when one main gradient of community variation exists, hierarchical classification techniques are less able to convey the sample sequence when several gradients are present in the data set (Gauch and Whittaker, 1981). Most benthic communities are probably intrinsically defined by several gradients and thus dendrograms may not always faithfully reflect the sample groupings. However, ordination methods are effective with such data sets and therefore complement clustering methods. Accordingly, the Bray-Curtis similarity matrix was further employed to produce non - metric multidimensional scaling (MDS) ordinations of the inter- sample relationships (Kruskal and Wish, 1978). Ordination methods serve to summarise community data by producing a “map” or configuration in a two dimensional space in which similar species or samples are close together and dissimilar entities are further apart. The non-metric solution seeks, for a given dimension, an ordination that minimises the stress value. When the stress value is large it indicates that the configuration or "map" for a particular dimension poorly represents the sample dissimilarities. Stress values can therefore be viewed as a measure of the goodness of fit of an ordination diagram in representing the similarity values (Clarke and Green, 1988) and are calculated as follows:

Equation 3 $$Stress = \sum_j \sum_k \left(d_{jk} - \hat{d}_{jk}\right)^2 / \sum_j \sum_k d_{jk}{}^2$$

where $\hat{d}_{jk}$ is the distance predicted from the fitted regression line corresponding to the dissimilarity δ_{jk}.

As a basic aim of this study is to provide an empirical basis for describing the effects of dredged material disposal on benthic communities, it was important to establish whether "indicator" taxa characterise stations within the dredged material disposal sites. Therefore, similarities percentage analyses (SIMPER) were performed on the species-sample matrices to elucidate characteristic faunal groupings and to determine which species contribute to the Bray - Curtis dissimilarity between stations (Clarke, 1993). Such an analysis involves calculating the average dissimilarity $\bar{\delta}$ between all pairs of inter-group samples (i.e. every sample replicate from station 1 paired with every replicate from station 2). This average is then separated into the contributions from each species to $\bar{\delta}$. For example, if the Bray-Curtis dissimilarity between any two samples is δ_{jk} (see above) which is a function of the overall species values, then the contribution from the *i*th species can be considered as $\delta_{jk,}$ (*i*). Taking $\delta_{jk,}$ (*i*) and then averaging over all sample pairs (*j*, *k*), with *j* samples from the first group (i.e. station 1) and *k* samples from the second group (i.e. station 2), gives the average contribution $\bar{\delta}_i$ from the *i*th species to the overall average dissimilarity $\bar{\delta}$ between groups 1 and 2. However, it is not only $\bar{\delta}_i$ which is important in distinguishing characteristic species but also the consistency with which a species contributes to $\bar{\delta}_i$ from all the sample pairs which is defined by the standard deviation (S.D.) of δ_i. A good discriminating species will therefore have a large $\overline{\delta}_i$ and a small S.D.δ_i. The ratio of $\overline{\delta}_i / S.D.\delta_i$ thus provides a useful index for ranking discriminating species.

The variation in species composition between replicate samples will reflect differences in the physical and chemical environment. Therefore, to extract the underlying pattern in the biotic data and to gain insight into the effects of dredged material disposal on community structure it was often helpful to average sample replicates for each station. Similarity matrices were therefore constructed based on averaged meiofaunal and macrofaunal data. These were then subsequently compared to test whether the responses of the communities were in broad agreement. Concordancy in the patterns of response would suggest the existence of "real" trends that can be examined for their causality, in this case with particular reference to dredgings disposal. One method of comparing the agreement between ordinations would be to conduct a Procrustes analysis (Gower, 1971). This type of analysis views ordinations as configurations of points which can be moved in space as a whole to fit another configuration. However, it is dependent on the dimensionality chosen to view the ordinations. Alternatively, if two ordinations are defined in only one dimension the correlation of their ranks can be used as a measure of their agreement. This latter method was the one adopted in this study and was conducted by means of the RELATE routine. This procedure calculates Spearman rank correlations between each of the corresponding similarity matrices, the significance of which is then ascertained through a permutation procedure (Clarke and Ainsworth, 1993).

Warwick and Clarke (1993) consider that increased variability in community composition among replicates from a station can be indicative of community stress. This was examined using the relative index of multivariate dispersion (r.IMD; Somerfield *et al.*, 1993); an increase in the value implies increased disturbance. This index compares the average rank dissimilarities within samples with the average rank between all samples. It takes a value of

1 for a sample when the average rank dissimilarity between replicates equals the average rank dissimilarity over all station comparisons. A value of greater than 1 is obtained if a replicate sample is more variable than average. In contrast a value lower than 1 is achieved if a replicate is less variable.

The second stage in analysing the multivariate data is to test whether the community patterns found at each site relate to environmental gradients. A correlation-based principal component analysis (PCA) was therefore used to ordinate the environmental variables, the data points having previously undergone a log (1+X) transformation. A lower triangular matrix based on Euclidean distance was then constructed from the environmental data obtained from grabs. Interpretation of the relationships between the macrofaunal data and environmental data obtained from grabs was then facilitated by directly comparing the ordinations derived from the environmental data and the averaged macrobenthic data by means of the RELATE routine. A Spearman rank correlation was computed between the corresponding matrices, as described previously. As only one sample was taken from each grab station for the determination of metals and organics, averaging of these data was not required. The meiofaunal data, both from grab sub-samples and cores, were similarly compared with the corresponding environmental data from cores.

Relationships between environmental measures and biological variation were further explored using the method of Clarke and Ainsworth (1993) and employing the BIO-ENV routine contained within the PRIMER suite of programs. This approach detects patterns of variation in the species data that can be explained "best" by the observed environmental variables (see Clarke and Ainsworth, 1993). A rank correlation coefficient (e.g. *pw,* weighted Spearman co-efficient) is calculated between all elements in the biotic and abiotic (dis)similarity matrices with environmental variables taken singly, 2 at a time, 3 at a time, etc. This procedure tests which combination of variables give the best match to the biotic pattern.

Additional variables when added to the optimum combination would be expected to impair the match and hence would have a lower rank correlation. A weighted Spearman rank correlation co-efficient (*pw*) was chosen for this analysis as this gives weighting to the calculated dissimilarities and tends not to be overdominated by the larger dissimilarities. The highest few co-efficients at each level of complexity have been tabulated, allowing the extent of improvement or deterioration in the match to be traced as further variables are added. The following environmental variables were examined: % (silt and clay), % organic carbon, % total carbon, % organic nitrogen and a range of concentrations of sedimentary metals. All variables used in the analysis were log (1+x) transformed to reduce skewness of the data. Pearson product moment correlation analyses were performed to establish whether any of the above transformed environmental variables at each site were collinear ($r>0.95$) prior to their inclusion in the BIO-ENV routine. On discovering mutual correlation between the environmental variables, a single variable was used as a representative of the correlated variables in the analysis.

At the Lune Deep site, the nematode data were further analysed by employing the recently proposed measure of taxonomic diversity Δ (Warwick and Clarke, 1995). This index is empirically related to Shannon - Wiener diversity (H') but also includes an additional component of taxonomic separation. The theoretical basis for developing this index and its derivation is described elsewhere e.g. Clarke and Warwick (1995) and Hall and Greenstreet (1998). However, in essence, this method assumes that in grossly perturbed environments benthic communities are maintained at an early successional stage with limited numbers of species that are closely related. Conversely, relatively diverse communities with a range of distinct species, belonging to many orders would be predicted in unperturbed environments. Furthermore, Warwick and Clarke (1995) suggested that Δ might be better used to detect changes in species composition in communities subjected to moderate levels of anthropogenic disturbance compared with other more conventional measures of diversity.

2.4.3 Physical procedures.

Sediment particle size analyses were conducted according to the Udden Wentworth Phi classification:

Equation 4 Phi (θ) = $-\log_2 d$

where d = the particle size in mm.

3. A COMPARISON OF THE RESPONSES OF MEIOFAUNAL AND MACROFAUNAL COMMUNITIES AT A TEES BAY DREDGED MATERIAL DISPOSAL SITE.

3.1 INTRODUCTION

The disposal site under investigation is located at approximately 30m depth in the Tees Bay off the north-east coast of England, and currently receives about 2 Mt. annually of dredged material consisting predominantly of mud and sand from the industrialised Tees estuary (see Figure 6). Two disposal sites are used for the disposal of dredgings in Tees Bay; however, it is the inshore of the two which is considered in this chapter. Historically, this disposal site was used for the disposal of capital dredgings, but since 1990 the site has been used exclusively for the disposal of maintenance dredgings (see Figure 7).

The sediments and macrofaunal communities in the vicinity of the disposal site were examined in 1984, as part of a general survey of the Bay to investigate the suitability of sites for the disposal of sewage sludge (Pomfret and Garlick, 1989). This investigation revealed a complex distribution of faunal communities, which reflected the variable substrates in the area. In summary, there were silty areas to the north and south of the disposal site, which supported an assemblage dominated by *Diastylis rathkei*, *Mysella bidentata* and *Amphiura filiformis*. Further offshore there was a progression from fine sand in the north to very mixed sediments in the south-east. The zone around the disposal site itself was found to be heterogeneous and contained areas of hard substrate and high proportions of coarse material (1-4mm) some of which might have been derived from the disposal of capital dredgings. Corresponding with this zone of coarse sediment was a community characterised by *Melinna cristata*, *Lumbrinereis gracilis*, *Mya* sp. and Ophiuroidea.

Metal levels in the sediments across the Bay have been found to be generally low, (Pomfret and Garlick, 1989), although a survey of the chemical quality of sediments around the disposal site in 1988, did reveal a slight elevation of metal concentrations that was attributed to the dredgings disposal operation. (M.A.F.F., 1991).

Inshore of the disposal site the macrofauna has also been the subject of a long-term benthic monitoring programme since 1969 to assess the effect of the outflow of the River Tees (Lewis, 1990). An analysis of the data from the period 1973-1985 (Shillabeer and Tapp, 1990) concluded that the Bay had a stable benthic macrofauna and that there had been no long-term changes in abundance or diversity. Studies of biomass and the growth rate of *Fabulina fabula* did, however, reveal an impact close to the mouth of the estuary.

In 1986, a survey was carried out at the disposal site to investigate the physical processes involved during the open-water disposal from barges of silty dredged material removed from the upper part of the Tees estuary (Delo and Burt, 1987). Through an examination of both the silt content and metal concentrations of seabed sediments prior to and subsequent to disposal, it was shown that dispersal of material could be detected up to 250m away from the point of disposal due to the propagation of a bed wave. Current velocity was found to influence the passage of this wave at a distance of 125m from the disposal point, but had no effect at a distance of 50m. This was ascribed to the fact that at 50m the material was in the collapse phase where momentum effects were still evident whilst at 125m the bed wave was in the diffusion phase and therefore susceptible to advection (see Figure 3). Delo and Burt (1987) also documented the presence of a near surface plume approximately 80m in width where peak concentrations of suspended solids reached 200ppm. This was estimated to comprise 0.5-2% of the dry weight of material discharged from the hopper. Unfortunately, there was no attempt to quantify the longitudinal axis of the plume, although the existence of a well-defined plume in terms of its cross section concentrations was recorded approximately 140m down current from the disposal position. Admiralty data (Chart 2567 Tidal diamond

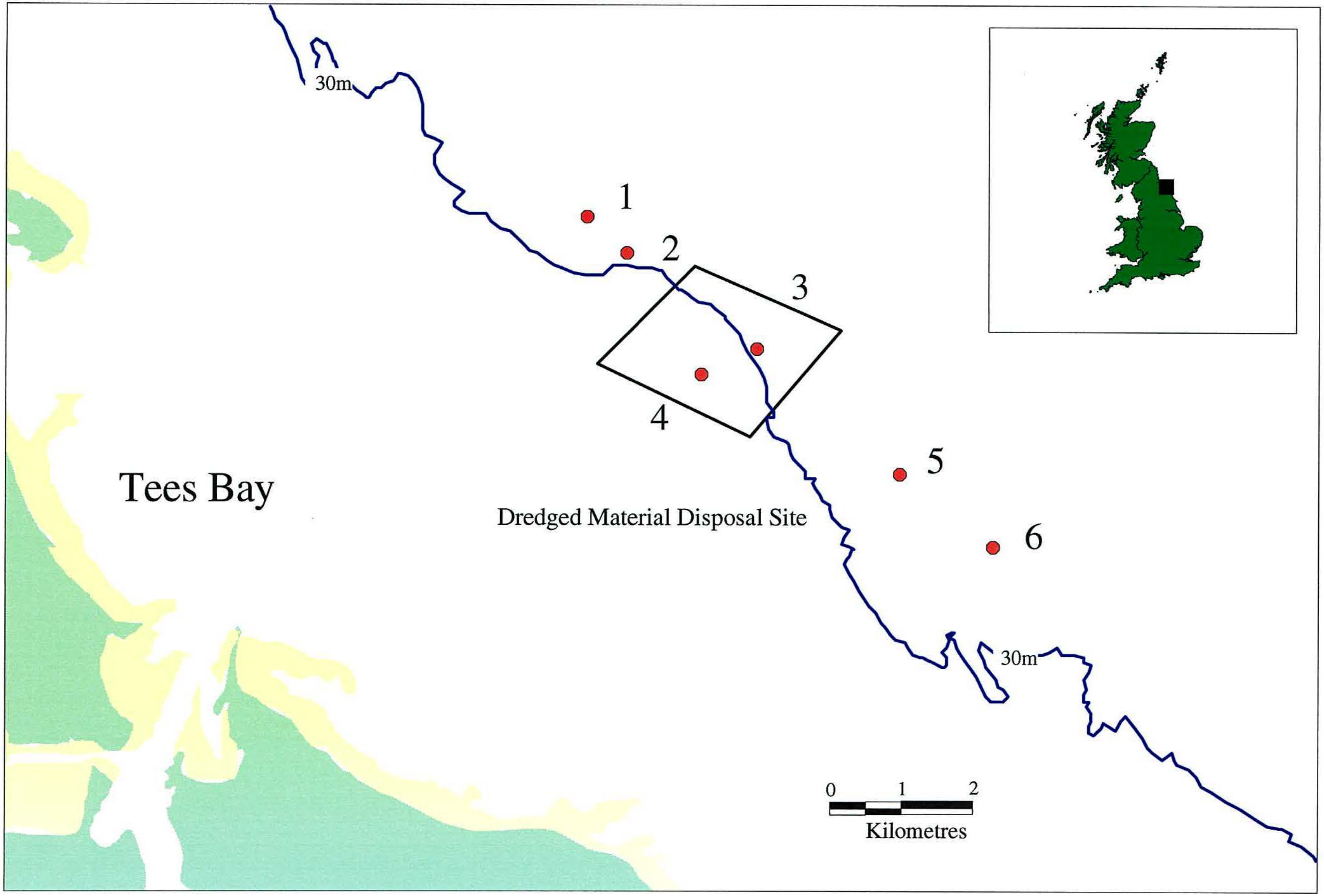
C) indicates that material carried in a surface plume in this area could be expected to travel approximately 2km away from the point of disposal during spring tides.

3.1.1 Sampling design.

Six stations were sampled in total, of which five of these (stations 1, 2, 3, 5 and 6) were located along an approximately north - south transect through the disposal site (Figure 6). A further station (station 4) was positioned inshore of the transect within the confines of the licensed disposal site. Thus stations 3 and 4 are located within the disposal site and would be expected to be directly impacted by the disposal operation. The sampling design was chosen to take into account the tidal and near bed residual currents in the area. Tidal currents are known to flow approximately parallel to the coastline and residual near bed currents are south-easterly (M.A.F.F., 1965; Ramster, 1977). Such a design also minimised the effects of depth in subsequent analyses, which varied from 27 to 33m.

In May 1995, three replicate 0.1m^2 Day grab samples were collected for macrofauna analysis from stations 1-5, with sub-samples of sediment (50ml syringe to a depth of 5cm) removed from each grab for analysis of silt and clay content. Replicate sub-samples of sediment were also taken for meiofaunal analyses at each station from separate Day grab deployments. Owing to the deteriorating weather conditions at station 6, only two replicate grab samples were collected for macrofaunal, meiofaunal and particle size analyses. Surficial sediment from a further Day Grab at each station was retained for analyses of metal concentrations and organic carbon and nitrogen.

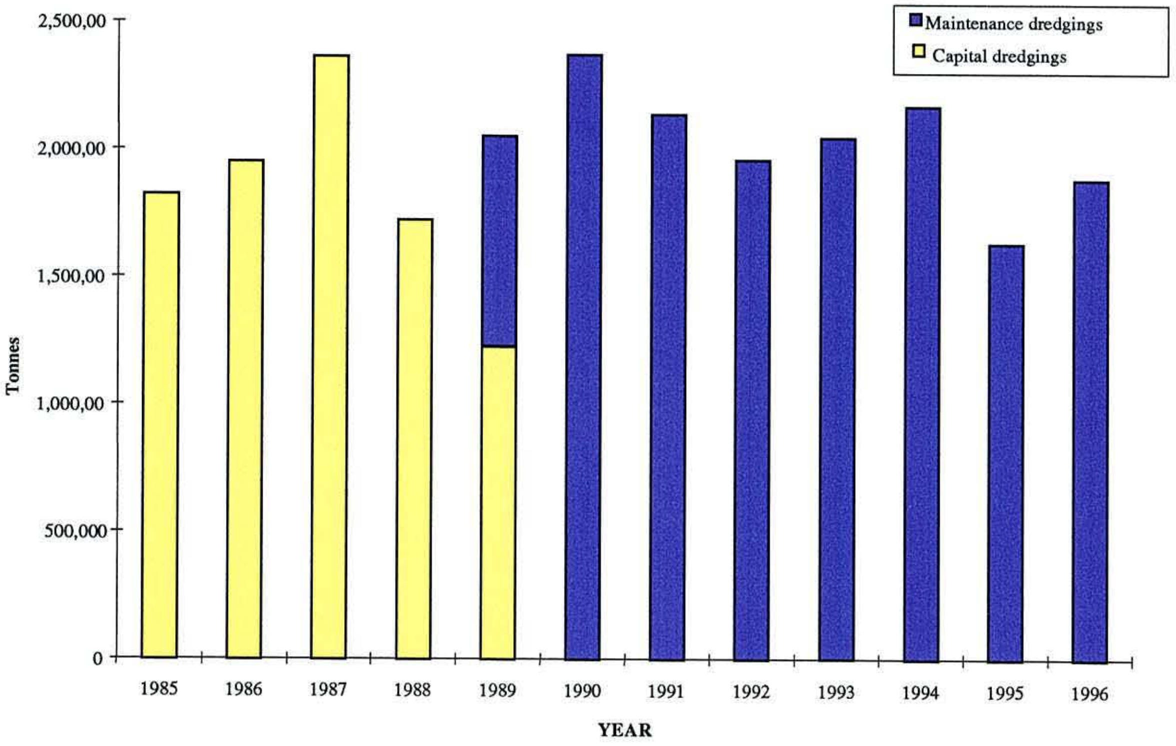
Figure 3 The location of the sampling stations in relation to the Tees Bay dredgings disposal site.



The stations were revisited in the following year (May 1996) and 3 replicate sediment cores were collected at each station from separate deployments of a Bowers and Connelly Multiple Mini-Corer (see Chapter 2 for field sampling procedures).

Although the macrofaunal grab samples and meiofaunal core samples were taken in consecutive years, the quantity and nature of dredgings disposed of at the site during this interval remained relatively constant (K. Simpson, *pers. comm.*; see also Figure 7). Furthermore, since Somerfield *et al.* (1995) have suggested that macrofaunal communities reflect long-term changes in the disposal of dredged material there is no reason to suppose that the macrofaunal community at the Tees Bay site will have substantially altered between May 1995 and 1996.

Figure 7 The quantity of dredged material disposed of into a Tees Bay dredged disposal site.



3.2 RESULTS

3.2.1 Univariate measures of community structure.

Nematode "feeding types".

Table 7 and 8 show the percentage abundance of nematode feeding types from grab sub-samples and cores respectively. It can be seen that the inshore disposal station (station 4) is dominated by 1B nematodes (Figure 8 and 9) and this is largely a consequence of elevated numbers of *Sabatieria pulchra* group at this station (Figure 10 and 11). The ratio of 1B/2A also appears to provide a useful summary of the distribution of feeding groups along the transect (Figure 12 and 13). Furthermore, high values of this ratio at the inshore disposal station (station 4) might suggest that the nematode community at this station is perturbed (see Chapter 2).

Diversity measures.

Although univariate measures of diversity (H') derived from the macrofaunal data appear to be reduced within the disposal site (stations 3 and 4) compared to outside (stations 1, 2, 5 and 6), this difference was not significant (Figure 14). However, the pattern of impact is more apparent when the univariate measures derived from nematode data obtained from grabs are examined. Significantly different values occur within the disposal site at station 4 for all measures excepting abundance (Figure 15). Analyses of univariate nematode data from cores revealed a similar pattern of impact to the sub-samples from grabs with highly significant variation in values of diversity (H'), evenness (J), richness (d), abundance (A) and number of taxa (S) along the transect (Figure 16)

Excepting abundance which was found to be lowest at the offshore disposal station (station 3), all other univariate measures derived from nematode core samples were lower at the inshore disposal station (station 4).

Table 7 The percentage abundances of the 4 nematode feeding types for replicated (a, b and c) and pooled (a-c) Day grab sub-samples at each station.

Station	**Nematode group**				
	1A	*1B*	*2A*	*2B*	*1B/2A*
1a	11	71	13	5	5.39
1b	11	58	25	6	2.29
1c	20	58	10	13	5.75
1a-c	12	64	18	6	3.61
2a	10	63	18	8	3.45
2b	5	47	40	8	1.16
2c	7	35	56	2	0.62
2a-c	7	41	48	4	0.87
3a	2	47	44	8	1.08
3b	0	52	30	18	1.73
3c	4	67	25	4	2.67
3a-c	2	55	34	8	1.61
4a	0	96	3	1	28.88
4b	0	94	6	1	16.88
4c	0	88	9	3	10.21
4a-c	0	93	6	1	16.51
5a	15	40	38	7	1.04
5b	12	44	42	3	1.05
5c	19	42	27	13	1.58
5a-c	15	42	36	7	1.16
6a	15	65	17	3	3.94
6b	8	75	15	2	5.11
6a-c	12	70	16	3	4.44

Table 8 The percentage abundances of the 4 nematode feeding types for replicated and pooled core samples at each station.

Station	**Nematode group**				
	1A	*1B*	*2A*	*2B*	*1B/2A*
1a	4	69	18	10	3.85
1b	5	92	3	0	30.00
1c	6	73	16	6	4.57
1a-c	5	76	14	6	5.58
2a	9	48	35	8	1.36
2b	8	49	35	7	1.39
2c	8	60	29	3	2.11
2a-c	8	53	33	6	1.64
3a	4	52	36	8	1.44
3b	4	47	44	4	1.07
3c	11	54	25	11	2.16
3a-c	6	51	36	7	1.42
4a	1	93	5	1	18.75
4b	0	87	10	2	8.38
4c	0	94	6	0	15.91
4a-c	0	91	7	1	13.09
5a	8	46	37	9	1.24
5b	15	44	36	5	1.24
5c	8	58	29	6	2.00
5a-c	11	49	34	7	1.43
6a	6	78	9	6	8.33
6b	14	60	19	7	3.12
6c	2	91	5	3	19.89
6a-c	7	78	11	4	7.21

Figure 8 Mean distribution of nematode feeding groups from grab sub-samples along Tees Bay transect

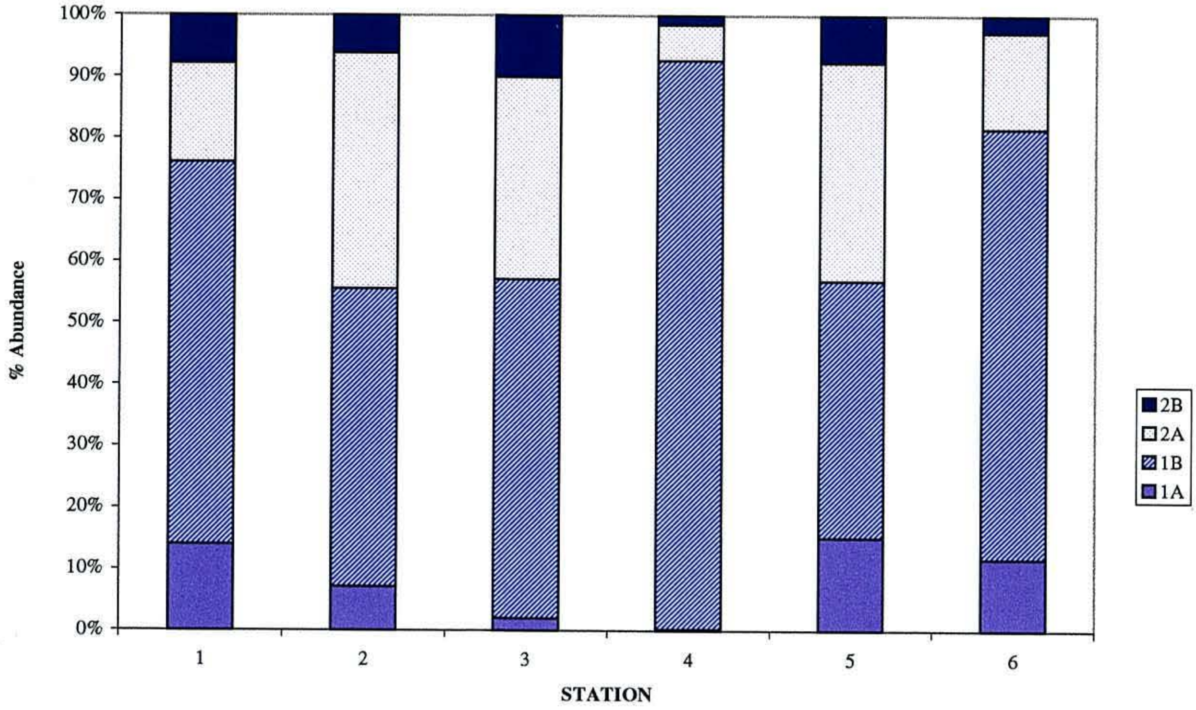


Figure 9 Mean distribution of nematode feeding groups from cores along Tees Bay transect

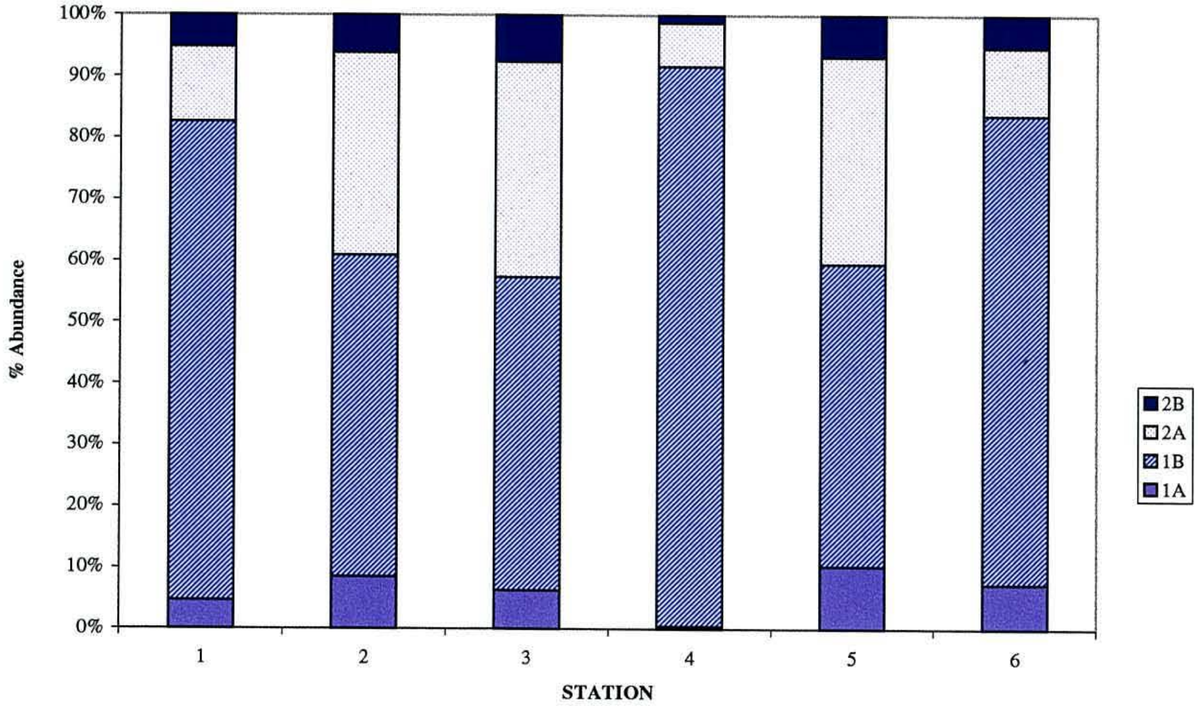


Figure 10 Distribution of A) *Sabatieria pulchra* group and B) *Daptonema tenuispiculum* along Tees Bay transect from grab sub-samples during 1995 (means and 95% Least significant intervals).

A)

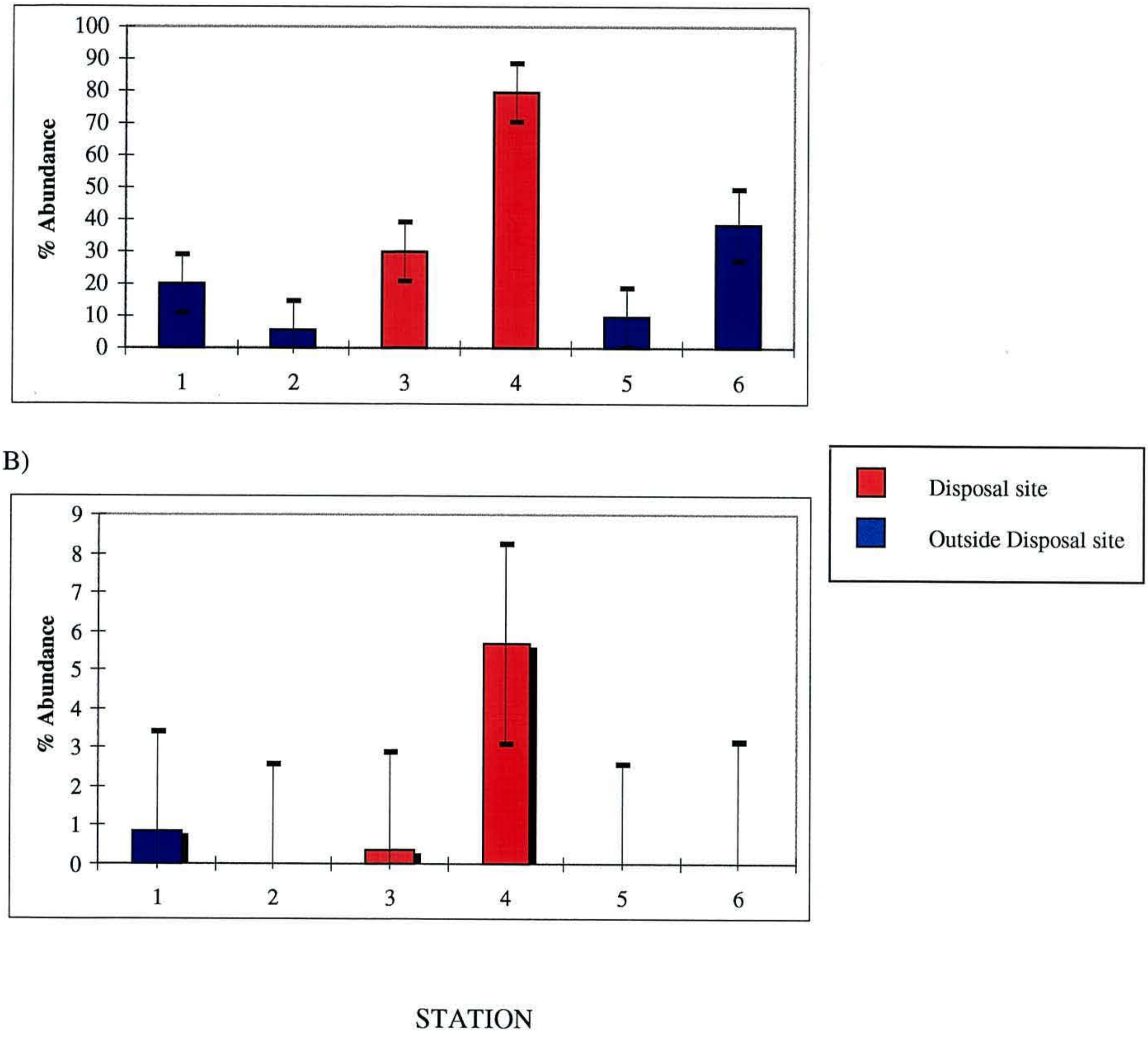


Figure 11 Distribution of A) *Sabatieria pulchra* group and B) *Daptonema tenuispiculum* along Tees Bay transect from cores during 1996 (means and 95% Least significant intervals).

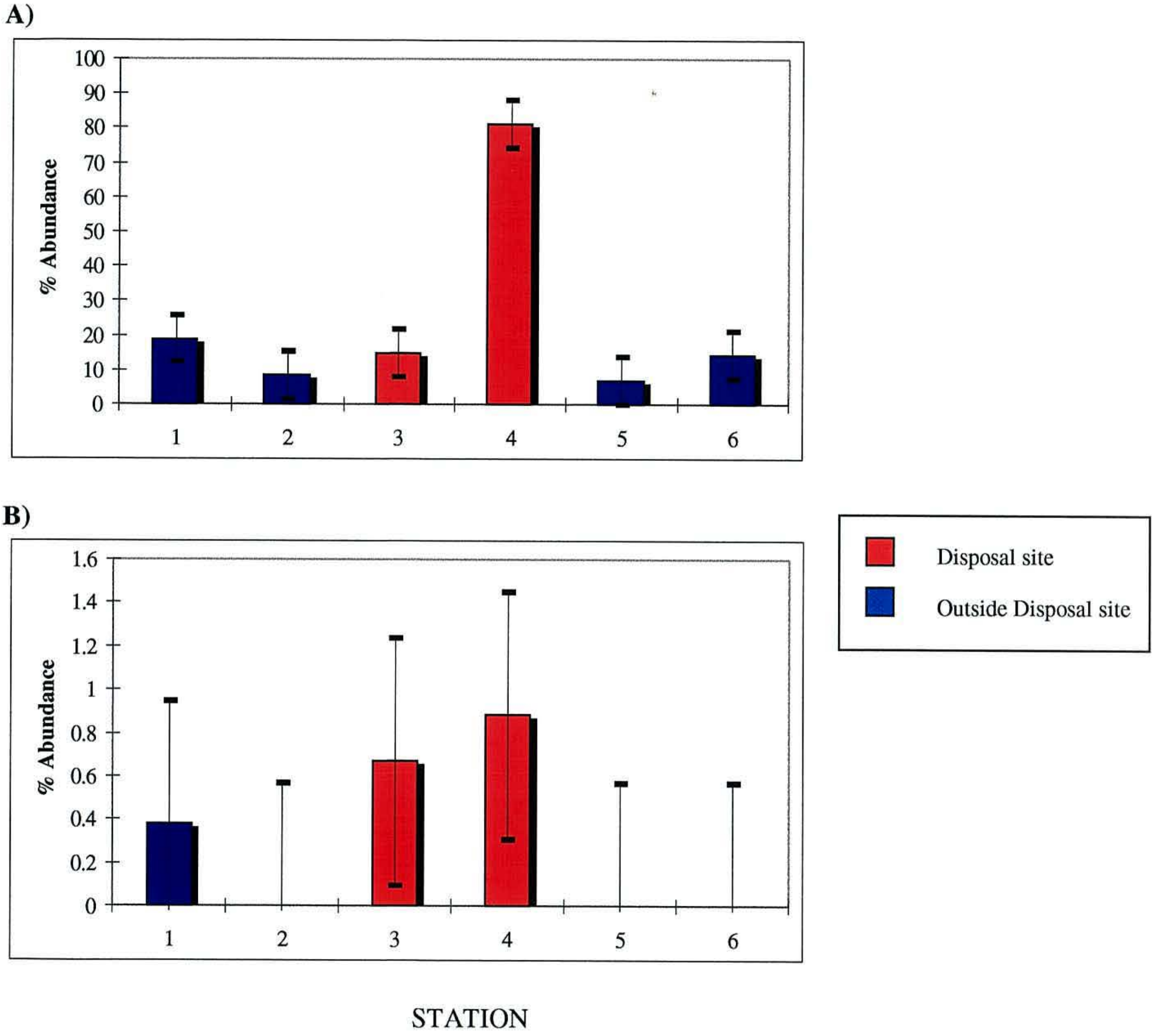


Figure 12 Distribution of the ratio of 1B/2A nematode groups from grab sub-samples (means and 95% Least significant intervals) along the Tees Bay transect.

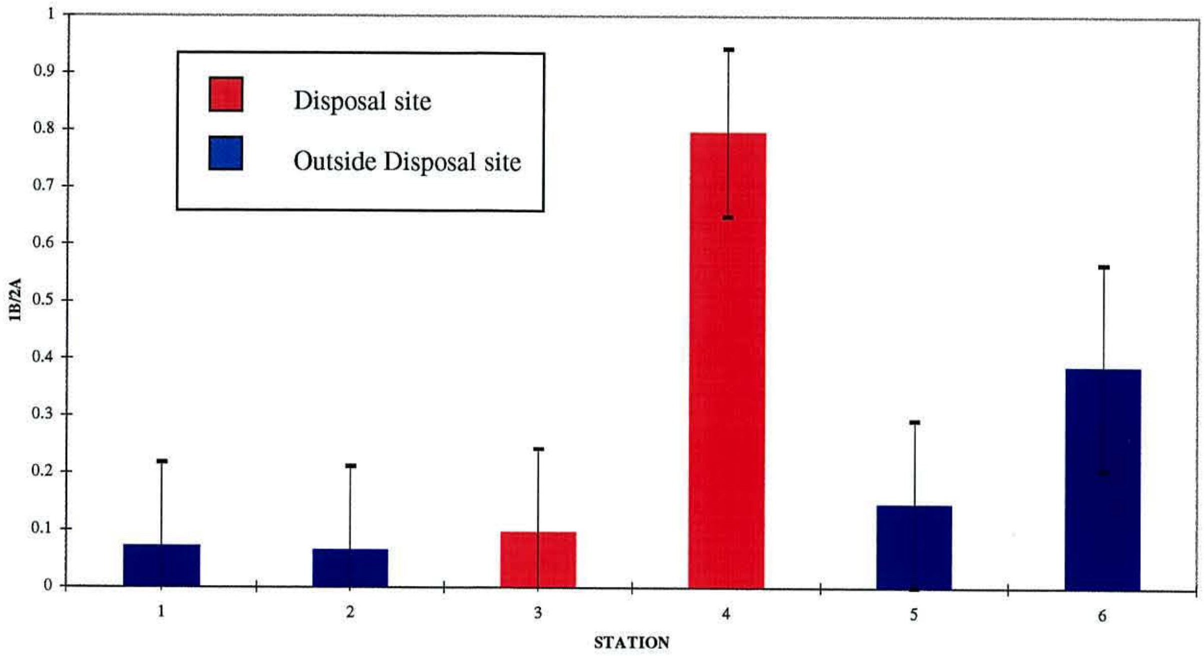


Figure 13 Distribution of the ratio of 1B/2A nematode groups from cores (means and 95% Least significant intervals) along the Tees Bay transect.

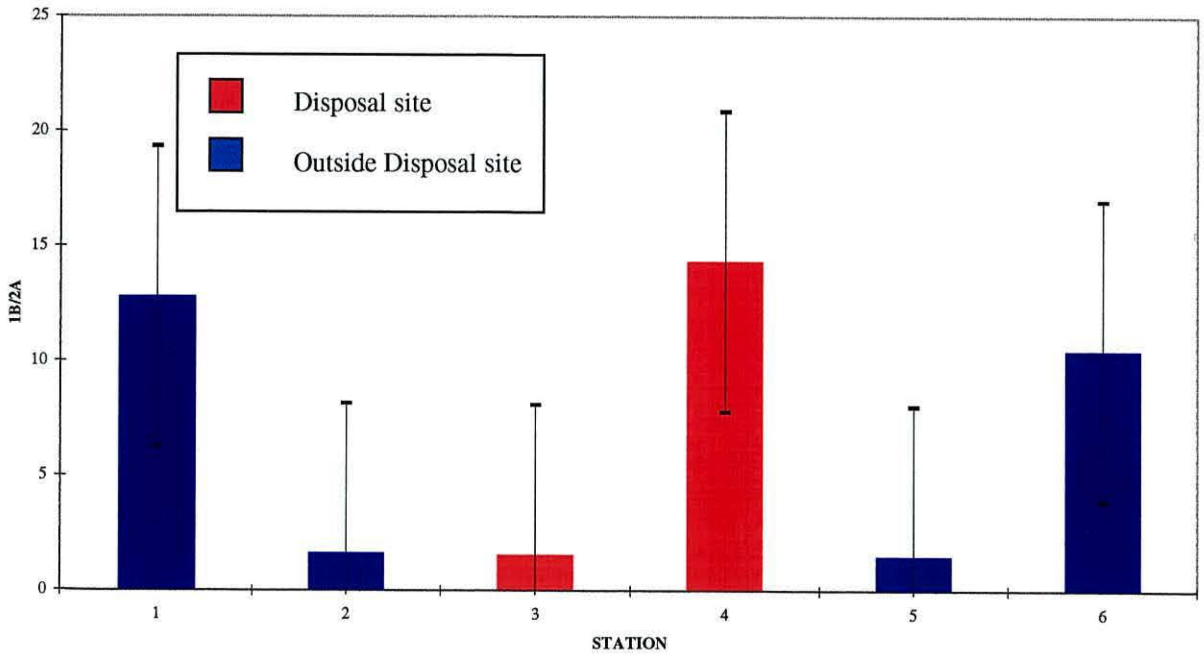


Table 9 F-ratios and significance levels (from $F_{5,11}$ for grabs and from $F_{5,12}$ for cores) from 1-way ANOVA tests for differences in various univariate measures of community structure between stations.

Univariate Measure	*Macrofauna (Grabs)*		*Nematodes (Grabs)*		*Nematodes (Cores)*	
	F	p	F	p	F	p
Log (1+S)	3.07	0.0565	5.90	<0.05	4.64	<0.05
Log (1+A)	2.30	0.1158	2.26	0.1205	8.73	<0.05
d	2.43	0.1021	14.15	<0.05	7.55	<0.05
H'	1.41	0.2939	14.75	<0.05	14.95	<0.05
J	0.40	0.8376	8.56	<0.05	26.44	<0.05

Macrofaunal diversity (H') is significantly correlated with trends in several trace metal concentrations (Table 10). Furthermore, the negative association between these concentrations and diversity is suggestive of an adverse effect of dredgings disposal. There is also significant correlation between the abundance of macrofaunal individuals and % silt and clay. The outcome of correlation analyses therefore suggests that dredgings disposal may be affecting macrobenthic populations, mediated through both a change in particle size characteristics and an increase in the concentration of a range of trace metals.

There are also relatively strong ($p<0.05$) correlations between diversity indices derived from pooled nematode data from grab sub-samples and several trace metal concentrations sampled from grabs (Table 11). Trends in nematode diversity (H') in 1995 appear to be best explained by variation in trace metal concentrations, or some other factors associated with this variation. There were no significant ($p>0.05$) relationships between nematode diversity derived from core samples and a range of trace metal concentrations from core sediments (Table 12). However, variation in the numbers of nematodes from cores was negatively correlated with trace metal concentrations from core sediments (Table 12).

Table 10 Pearson product moment correlations between each pair of log-transformed (1+N) variables from grabs (based on 6 pairs of observations). Diversity indices are derived from pooled macrofaunal data. Values highlighted in bold type indicate significant correlation ($p<0.05$).

	log(1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	0.5179	0.5927	0.3567	0.0405	0.4050
%OrgC	0.3600	0.5347	0.1669	0.1597	0.4096
%N	**0.8226**	0.6852	0.7373	-0.0911	0.5216
%s/c	0.7483	**0.8826**	-0.5293	-0.0672	0.6047
%S	-0.4250	-0.6765	-0.2011	-0.0963	-0.3865
%G	-0.4136	-0.5022	-0.2570	-0.5766	-0.7589
Cd	-0.3751	0.1034	-0.5610	-0.6578	-0.7225
Cr	-0.6957	-0.1806	**-0.8679**	-0.1268	-0.5540
Cu	-0.4518	0.0305	-0.6207	-0.7738	**-0.8807**
Hg	-0.5406	-0.1618	-0.6521	-0.6023	**-0.8194**
Ni	-0.3857	0.1469	-0.6286	-0.1195	-0.3289
Pb	-0.6322	-0.1806	-0.7917	0.1491	-0.3056
Zn	-0.5596	-0.1654	-0.6534	-0.7252	**-0.9304**

Table 11 Pearson product moment correlations between each pair of log-transformed (1+N) variables from grabs (based on 6 pairs of observations). Diversity indices are derived from pooled nematode data from grab sub-samples. Values highlighted in bold type indicate significant correlation ($p<0.05$).

	log (1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	0.3571	-0.0743	-0.0743	0.1430	0.2377
%OrgC	0.1699	-0.1743	0.2318	0.0971	0.1486
%N	0.7245	0.1455	0.1455	0.2759	0.2377
%s/c	0.4343	0.1476	0.1476	0.1773	0.2759
%S	-0.0551	0.0487	0.0487	-0.1074	-0.0999
%G	-0.1917	0.3810	0.3810	-0.4320	-0.4336
Cd	-0.4305	0.5854	-0.6057	**-0.9543**	**-0.9195**
Cr	-0.7999	-0.1050	-0.7818	-0.6270	-0.7467
Cu	-0.5274	0.5427	-0.6969	**-0.9800**	**-0.9774**
Hg	-0.5331	0.2243	-0.5720	-0.7915	**-0.8129**
Ni	-0.6175	-0.1266	-0.6059	-0.4950	-0.5852
Pb	-0.7690	-0.3906	-0.6706	-0.3443	-0.4989
Zn	-0.5609	0.5322	-0.7285	**-0.9308**	**-0.9497**

Table 12 Pearson product moment correlations between each pair of log-transformed (1+N) variables from cores (based on 6 pairs of observations). Diversity indices are derived from pooled nematode data from cores. Values highlighted in bold type indicate significant correlation (p<0.05).

	log (1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	-0.5710	-0.2673	-0.5836	-0.3528	-0.4396
%OrgC	-0.3965	-0.1717	-0.4292	-0.2427	-0.3127
%N	-0.7085	-0.2917	-0.7101	-0.4341	0.0535
%s/c	0.0308	-0.1111	-0.0022	0.1067	0.0665
%S	0.2678	0.3191	0.2632	0.0323	0.1124
%G	-0.7801	-0.2030	-0.7321	-0.5948	-0.6449
Cd	-0.1600	**-0.8372**	0.0080	0.4035	0.2889
Cr	-0.2080	-0.7266	-0.0186	0.2853	0.2041
Cu	-0.4307	-0.0083	-0.4116	-0.3664	-0.3779
Hg	-0.2803	**-0.8468**	-0.1206	0.2948	0.1703
Ni	-0.4597	-0.0110	-0.5273	-0.3960	-0.4502
Pb	-0.1794	-0.6283	-0.0121	0.2666	0.1947
Zn	-0.3446	-0.6527	-0.1939	0.1459	0.0535

3.2.2 Multivariate measures of community structure.

Clustering.

Cluster analysis of square-root transformed macrobenthic data revealed 2 major groups, those samples outside the licensed disposal site (stations 1, 2, 5 and 6) and those within (stations 3 and 4) (Figure 17A). These groups further subdivide at higher similarity levels, with assemblages from each of the disposal stations clustering separately. An essentially similar pattern was obtained with the nematode fauna from grab sub-samples (Figure 17B). Cluster analysis of nematode data from the cores revealed that the community at the inshore disposal station (station 4) was clearly different from all other assemblages (Figure 17C). Nematode core sample replicates were also grouped by station along the north-south transect through the disposal ground. One exception was a replicate from the most northerly station (station 1) which clustered with a station to the south (station 6).

Figure 14 Means and 95% LSD intervals for univariate measures of MACROFAUNA community structure along the TEES BAY transect.

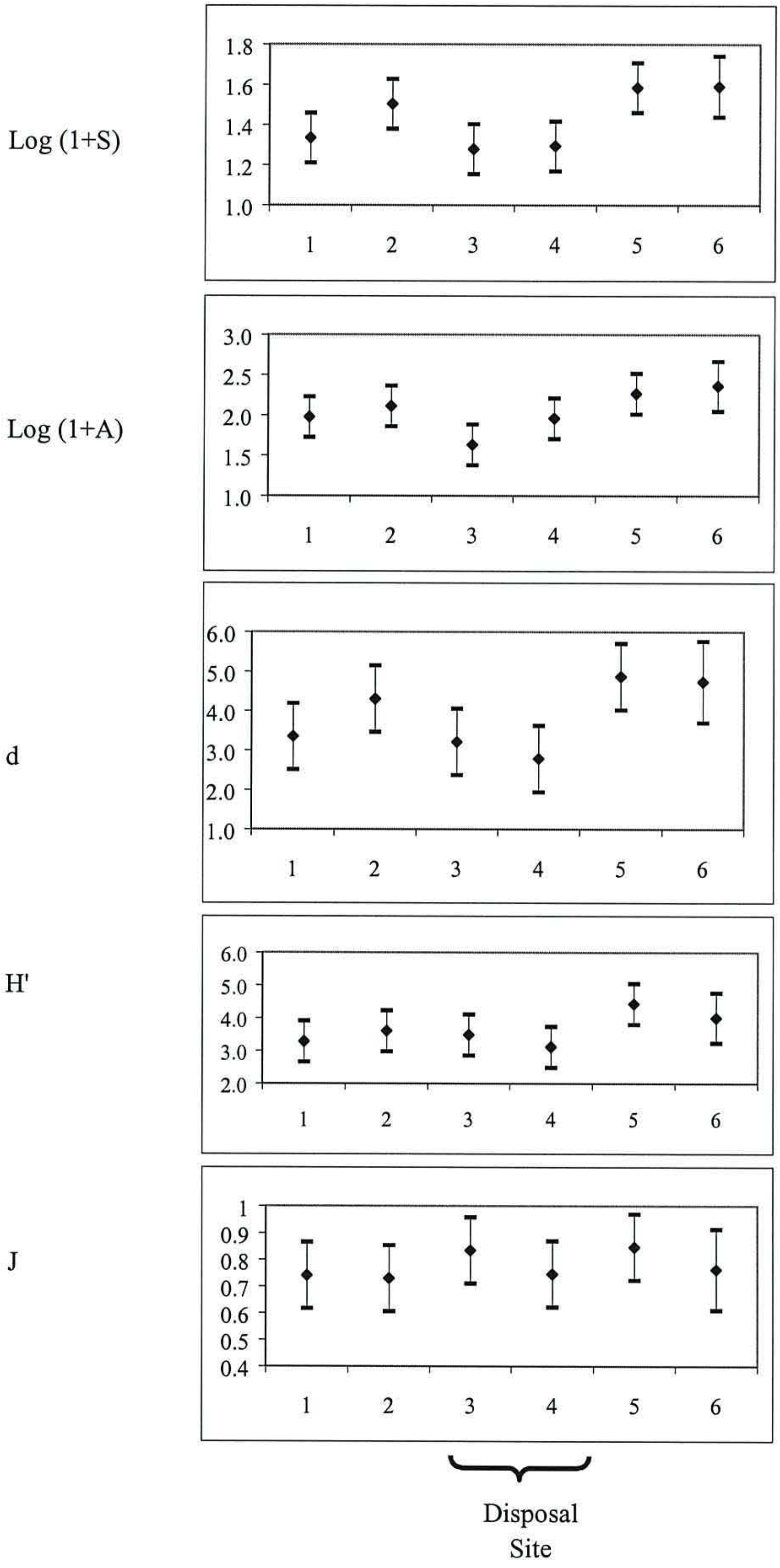


Figure 15 Means and 95% LSD intervals for univariate measures of NEMATODE community structure from grab sub-samples along the TEES BAY transect.

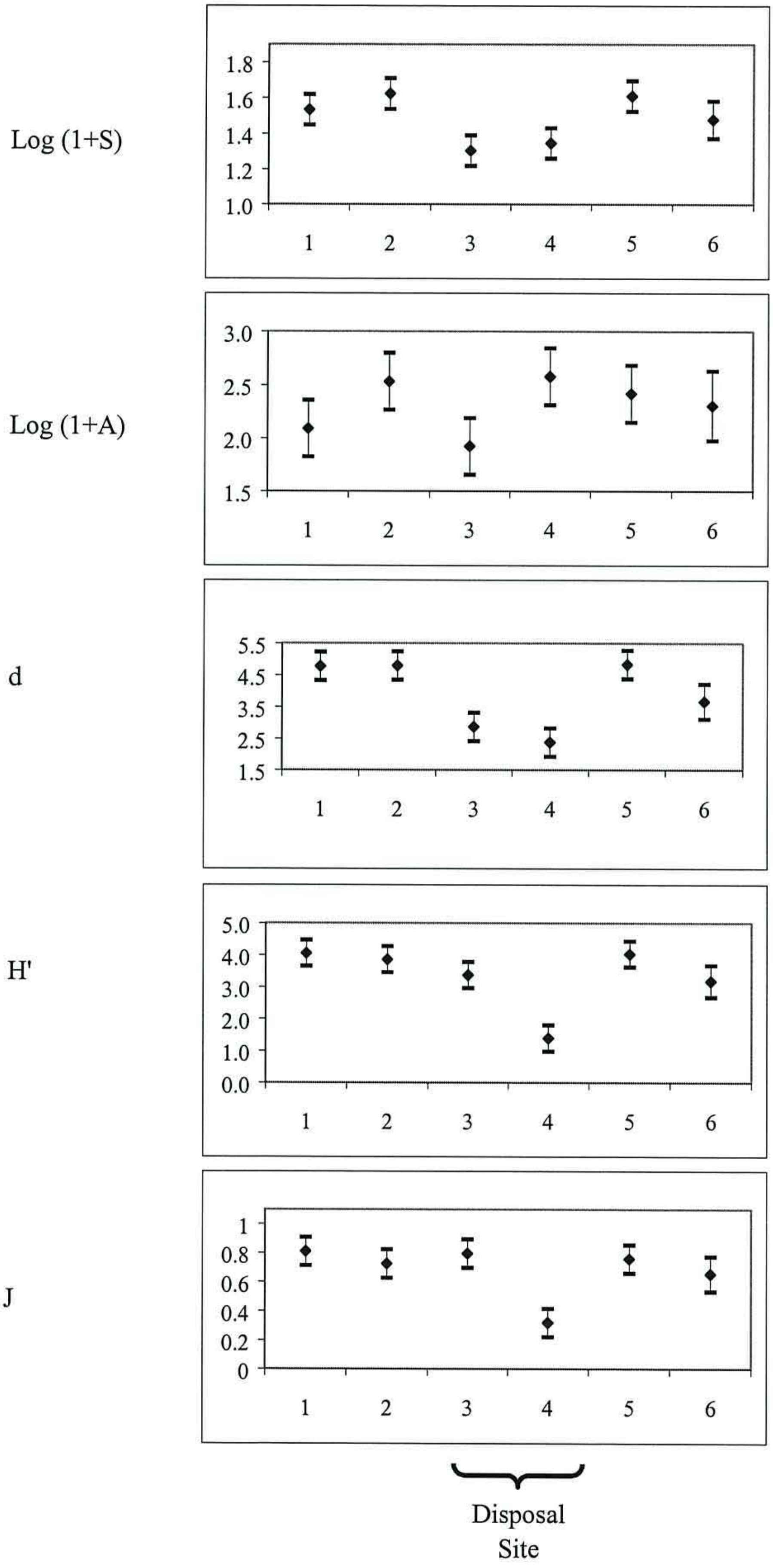
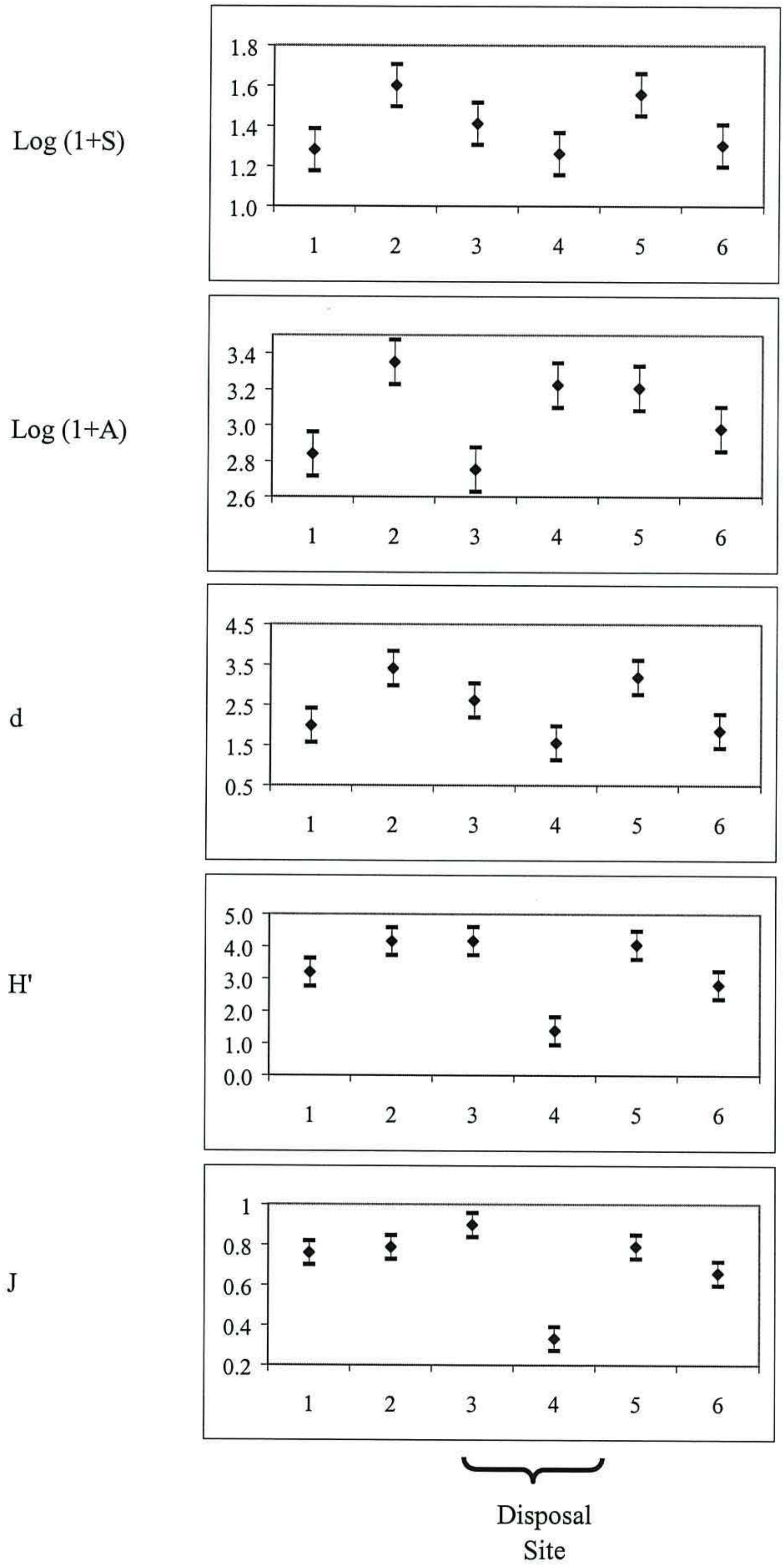


Figure 16 Means and 95% LSD intervals for univariate measures of NEMATODE community structure from cores along the Tees Bay transect.



Stations (2 and 5), in the immediate vicinity of the disposal site, i.e. north and south of the site also clustered together.

Ordination.

MDS ordinations of square-root transformed macrobenthic data also indicated separation of samples within the disposal site (stations 3 and 4) from those to the north and south (station 1, 2, 5 and 6) (Figure 18A). Similarly, configurations resulting from square-root transformed nematode data indicate that both grab sub-samples and core samples from outside the disposal site are clustered and clearly separated from those within (Figure 18B and C). Furthermore, ordinations of nematode data also discriminate between the 2 groups of samples within the disposal site, with the offshore disposal station occupying an intermediate position between the inshore disposal station and the stations outside the zone of significant impact (Figure 18B and C). Ordinations of averaged square-root transformed biotic data are very similar with the offshore disposal station (station 3) again occupying an intermediate position between the inshore disposal station and stations (1, 2, 5 and 6) outside the licensed site. When the similarity matrices were compared, nematode and macrobenthic communities were found to be significantly correlated ($p<0.05$) (Figure 19A, C and D; Table 13).

Table 13 Pairwise Spearman rank correlations between similarity matrices derived from averaged square-root transformed abundance data. *$p<0.05$ by a permutation test.

	Macrofauna	Nematodes (Cores)
Nematodes (Grab sub-samples)	0.886^{*}	0.879^{*}
Nematodes (Cores)	0.868^{*}	

Figure 17 Dendrograms for group average clustering of Bray-Curtis similarities based on square-root transformed data from TEES BAY for stations 1-6.

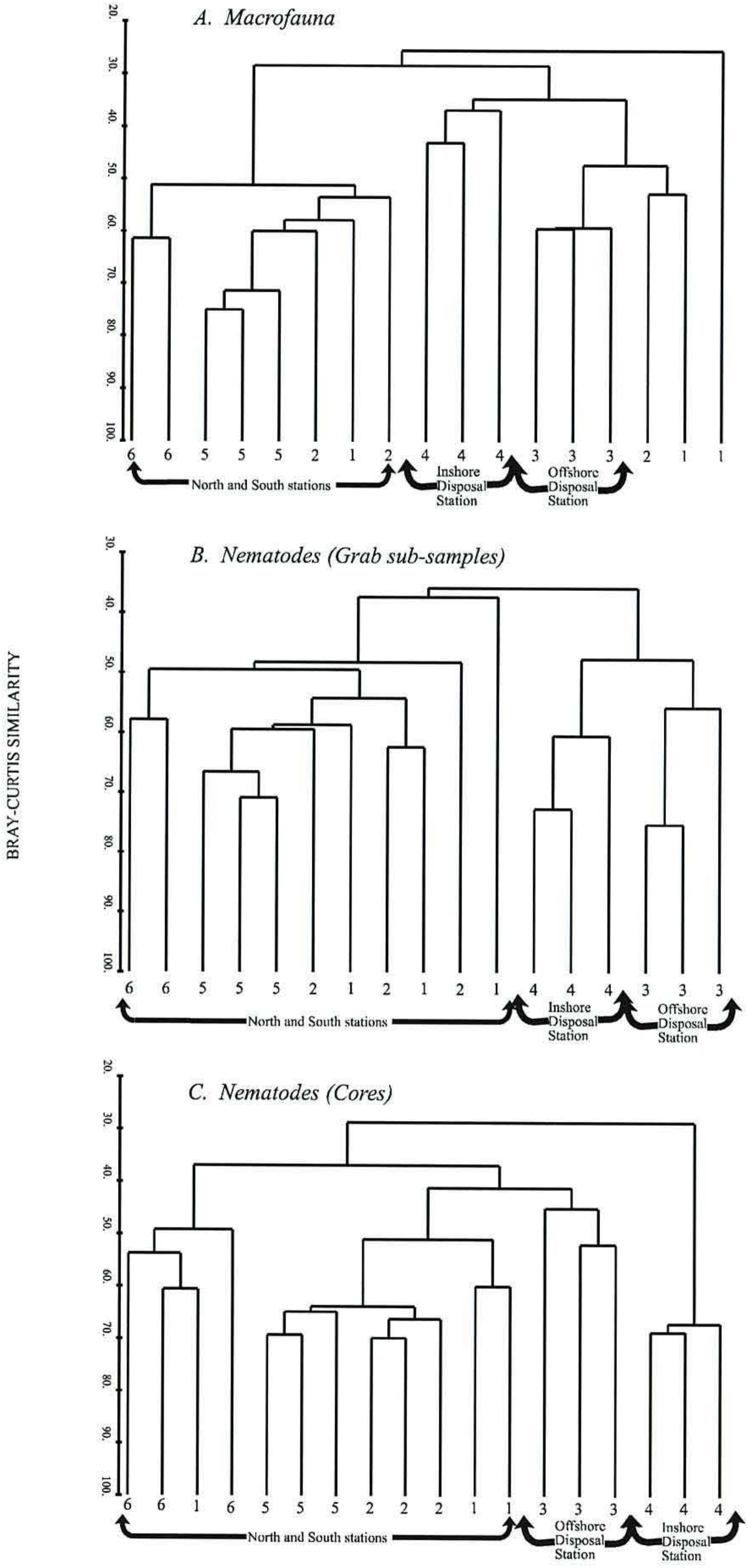
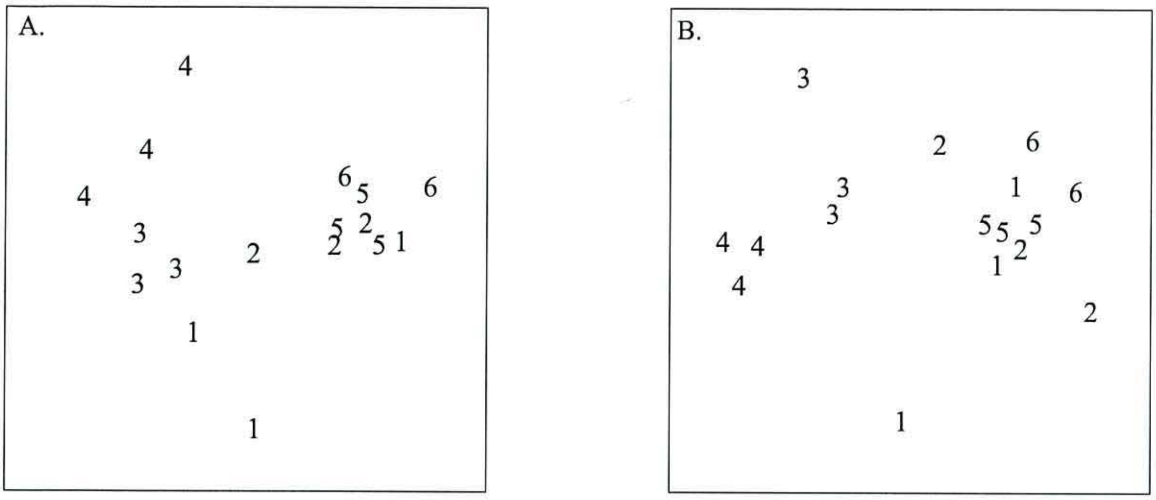
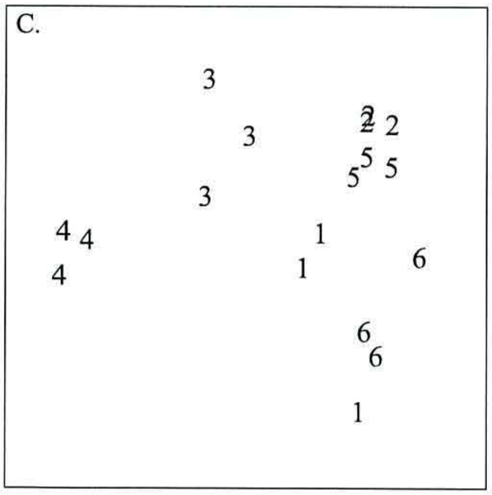


Figure 18 Multidimensional scaling ordinations of square-root transformed biotic data.



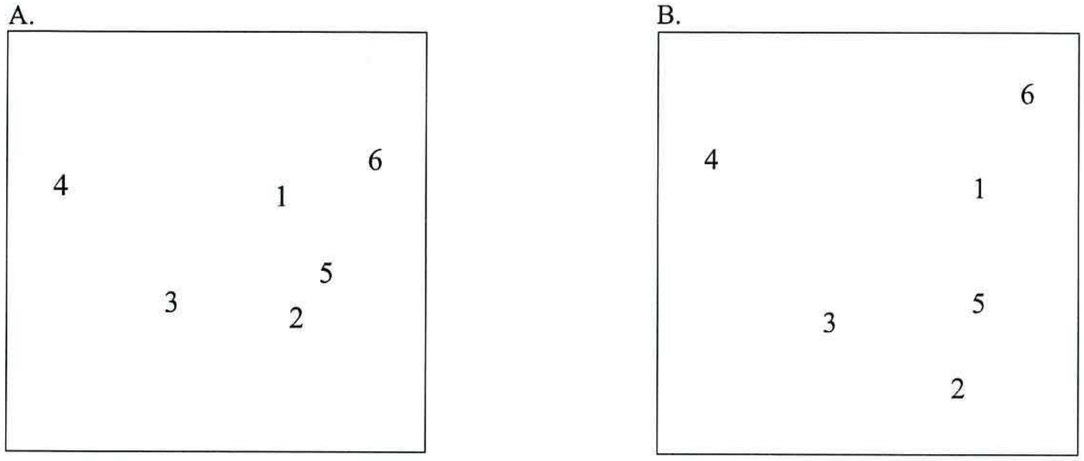
Macrofauna, stress = .14

Nematodes, (Grab sub-samples), stress = .13



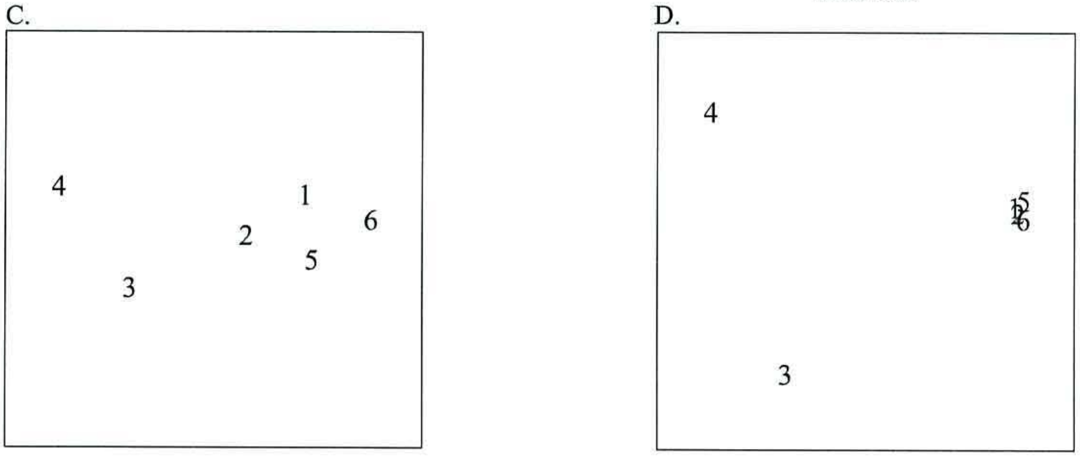
Nematodes (Cores), stress = .10

Figure 19 Ordinations by PCA of environmental variables, and by MDS of averaged abundances from stations 1 to 6. Environmental variables log transformed, nematodes and macrofauna square-root transformed.



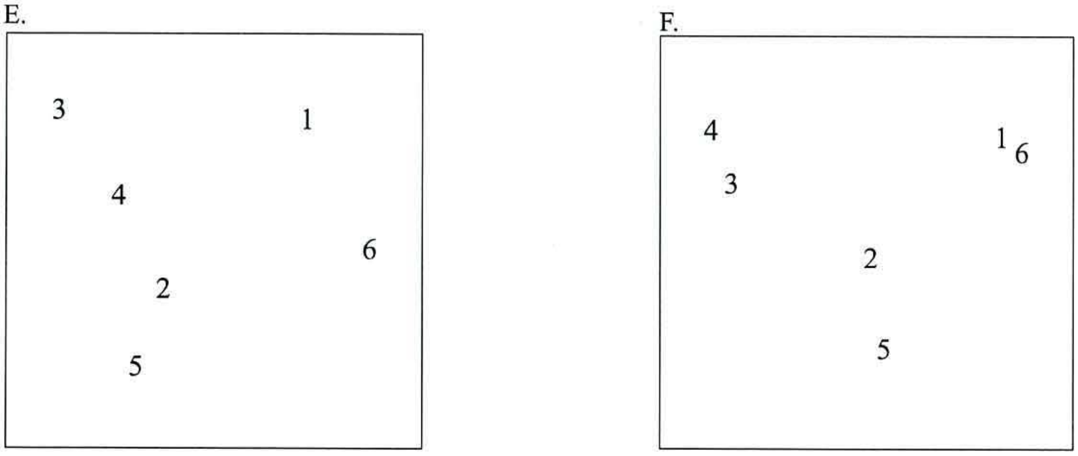
Nematodes (Cores), stress 0.01

Environmental variables (Grabs) log (x+1) transformed stress 0.01



Macrofauna, (Grabs) stress 0.01

Nematodes, (Grab sub-samples) stress 0.01



Environmental variables (Cores) log (x+1) transformed stress 0.01

Sediment parameters (Cores) log (x+1) transformed stress 0.01

Species analyses.

SIMPER (Similarities percentages analyses) performed on square-root transformed macrofauna and nematode abundances indicated which predominant species contributed to the Bray-Curtis dissimilarities between stations. The macrofaunal organisms important in characterising the inshore disposal station comprised *Polydora ciliata* (agg.), *Capitella* sp., *Tubificoides benedii, Mytilus edulis* (juveniles), *Nephtys hombergii, Ophryotrocha* sp. and *Tubificoides pseudogaster* (Table 14). The bivalves *Nucula nitidosa*, *Nuculoma tenuis,* and *Chamelea gallina,* together with the polychaetes *Prionospio fallax* and *Chaetozone setosa* *(*agg.) were important in defining macrofaunal components of the stations outside the disposal site. The bivalve *Thyasira flexuosa* was also an important component of samples in stations to the south but less so to the north in contributing to the dissimilarity of samples from the inshore disposal station and those from stations outside the disposal site. Nematode species present in the inshore disposal station but occurring in lower numbers or absent to the north and south of it include *Sabatieria pulchra* grp., *Daptonema tenuispiculum*, *Chaetonema riemanni*, *Paracanthonchus heterodontus, Eumorpholaimus* sp. and *Odontophora longisetosa* (Table 15 and 16). Species that occur to the north and south of the disposal site but are reduced in numbers or absent from the inshore disposal station comprised *Sabatieria ornata, Daptonema normandicum, Tripyloides marinus*, *Aponema torosa*, and *Terschellingia longicaudata.*

The nematode communities of the two disposal stations also differ in their abundance of S*abatieria pulchra* grp., *Chaetonema riemanni*, *Paracanthonchus heterodontus* and *Daptonema tenuispiculum*, these species being more numerous at the inshore disposal station (station 4). Although numbers of harpacticoid copepods were generally low, they were nevertheless absent or reduced in number from samples from disposal site stations compared with stations outside the disposal site.

3.2.3 Biotic and environmental relationships

The results of metals and particle size analyses of the grab and core sediments are given in Table 17. Environmental variables from the core sediments were averaged and the results are given in Table 19. Ordinations by PCA of the environmental data from grabs (Figure 19B) show that the inshore disposal station (station 4) is separate from stations outside the disposal site, and also that the offshore disposal station (station 3) occupies an intermediate position between these groups of stations. This configuration represents a general trend of increasing metal concentrations from sediment samples at the ends of the transect to samples within the disposal site (Table 16). MDS ordinations of averaged biotic data also conform to this pattern (Figure 19A, C, D). Moreover, correlations between the environmental variables and biotic matrices underlying the ordinations in Figure 19 were significantly related ($p<0.05$) (Table 20). The arrangement of stations produced by the PCA ordination of environmental variables from cores is slightly different from the pattern given by the PCA ordination of environmental variables from grabs, with the two disposal site stations being transposed (Figure 19E). However, a clear gradient of change from stations in the disposal site to stations at the ends of the transect is produced when only sediment parameters from cores are used to derive the PCA ordination (Figure 19F). This also represents a trend towards increasing % silt and clay from within the disposal site to stations to the north and south (Table 18).

Table 14 Breakdown of average dissimilarity between the station 4 and all other stations into contributions from each macrofaunal species from grabs; species are ordered in decreasing contribution (cut-off at 60% average dissimilarity).

Station 4, 1	$\bar{\delta}_i/S.D.\delta_i$
***Polydora ciliata* (agg.)**	**1.80**
Diastylis rathkei typica	0.91
Nucula nitidosa	1.23
Nephtys hombergii	**1.45**
***Capitella* sp.**	**0.86**
***Mytilus edulis* (juveniles).**	**1.80**
Tubificoides benedii	**2.26**
Chaetozone setosa (agg.)	1.28
Abra alba	1.07
Nephtys caeca	**1.39**
***Ophryotrocha* sp.**	0.63
Nuculoma tenuis	1.25
Spiophanes bombyx	**2.14**
Tubificoides pseudogaster	**0.64**
Fabulina fabula	**1.11**
Leucon nasica	1.03
Chamelea gallina	1.31
Prionospio fallax	1.28

Average dissimilarity between 4 & 1 =77.32

Station 4,2	$\bar{\delta}_i/S.D.\delta_i$
Nucula nitidosa	2.79
***Polydora ciliata* (agg.)**	**1.10**
Prionospio fallax	2.57
Chaetozone setosa (agg.)	1.69
Chamelea gallina	1.55
***Capitella* sp.**	**0.88**
Nephtys hombergii	**1.81**
Nuculoma tenuis	5.99
Tubificoides benedii	**2.77**
Dosinia sp.	2.23
Abra alba	**1.27**
Scoloplos armiger	1.43
***Ophryotrocha* sp.**	**0.66**
***Mytilus edulis* (juveniles)**	**1.45**
Thayasira flexuosa	1.19
Tubificoides pseudogaster	**0.66**
Arctica islandica	4.27
Amphiura filiformis	0.99

Average dissimilarity between 4 & 2 =73.96

Station 4,3	$\bar{\delta}_i/S.D.\delta_i$
***Polydora ciliata* (agg.)**	**1.18**
Chaetozone setosa (agg.)	1.33
***Capitella* sp.**	**0.91**
***Mytilus edulis* (juveniles)**	**2.24**
Abra alba	**1.27**
Nucula nitidosa	1.09
Nephtys hombergii	**2.07**
***Ophryotrocha* sp.**	**0.67**
Tubificoides pseudogaster	**0.67**
Chamelea gallina	1.10
***Nephtys* spp. (juveniles)**	**4.15**
Fabulina fabula	1.09

Average dissimilarity between 4 & 3 =61.60

Station 5,4	$\bar{\delta}_i/S.D.\delta_i$
***Polydora ciliata* (agg.)**	**1.08**
Nucula nitidosa	3.52
Arctica islandica	3.70
Thyasira flexuosa	4.42
Prinospio fallax	4.03
Chamelea gallina	2.15
Amphiura filiformis	6.59
Anobothrus gracilis	6.00
Nuculoma tenuis	3.47
Chaetozone setosa	1.75
Dosinia sp.	2.63
***Capitella* sp.**	**0.88**
Nephtys spp. (juveniles)	1.46
Mysella bidentata	1.81
Paracucumaria hyndmani	3.82
Tubificoides benedii	**2.70**
***Mytilus edulis* (juveniles)**	**2.30**
Ampelisca macrocephala	3.20

Average dissimilarity between 5 & 4 =75.32

Station 6,4	$\bar{\delta}_i/S.D.\delta_i$
***Polydora ciliata* (agg.)**	**1.05**
Abra alba	4.61
Thyasira flexuosa	6.96
Amphiura filiformis	1.77
Mysella bidentata	1.55
Diastylis rathkei typica	1.72
Pholoe minuta	3.73
Nuculoma tenuis	6.36
Nucula nitidosa	2.04
Cylichna cylindracea	1.83
***Capitella* sp.**	**0.85**
Leptosynapta inhaerens	1.78
Nephtys hombergii	**1.63**
Nephtys caeca	**2.64**
Paracucumaria hyndmani	4.76
Tubificoides benedii	**2.66**
Chaetozone setosa	1.45
Eudorella truncatula	5.25

Average dissimilarity between 6 & 4 =77.76

Highlighted taxa are more numerous at station 4

Table 15 Breakdown of average dissimilarity between the station of station 4 and all other stations into contributions from each nematode species from Day grab sub-samples; species are ordered in decreasing contribution (cut-off at 60% average dissimilarity).

Station 4, 1	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**1.56**
Daptonema tenuispiculum	**2.36**
Paracanthonchus heterodontus	**1.89**
Sabatieria ornata	3.54
***Eumorpholaimus* sp.**	**2.11**
Aponema torosa	2.83
Tripyloides marinus	1.08
Terschellingia longicaudata	2.24
Halalaimus longicaudatus	3.51
Richtersia sp.	2.55
Chaetonema riemanni	**3.12**
Odontophora longisetosa	**2.65**
Oxystomina elongata	3.51
Daptonema furcatum	3.75
Prochromadorella ditlevseni	1.16
Cobbia trefusiaeformis	0.66
Microlaimus turgofrons	2.06
Thalassomonhystera sp.	1.47

Average dissimilarity between 4 & 1
=68.72

Station 4,2	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**1.83**
Aponema torosa	0.98
Sabatieria ornata	2.92
Daptonema tenuispiculum	**2.48**
Daptonema normandicum	1.77
Richtersia sp.	1.42
Paracanthonchus heterodontus	**1.41**
Tripyloides marinus	4.11
Oxystomina elongata	4.00
***Eumorpholaimus* sp.**	**2.56**
Terschellingia longicaudata	3.36
Spirobolbolaimus sp.	0.75
Microlaimus turgofrons	1.73
Leptolaimus elegans	1.14
Mesacanthion diplechma	1.46
Calomicrolaimus sp.	1.06
Odontophora longisetosa	**1.41**
Cobbia trefusiaeformis	1.20
Chaetonema riemanni	**4.34**

Average dissimilarity between 4 & 2
=69.58

Station 4,3	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**2.10**
Daptonema tenuispiculum	**2.31**
Paracanthonchus heterodontus	**1.84**
Calomicrolaimus sp.	1.28
Axonolaimus helgolandicus	2.82
Aponema torosa	1.19
Spirobolbolaimus sp.	1.18
***Eumorpholaimus* sp.**	**1.05**

Average dissimilarity between 4 & 3
=52.29

Station 5,4	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**1.97**
Aponema torosa	2.50
Sabatieria ornata	4.93
Daptonema tenuispiculum	**2.89**
Terschellingia longicaudata	4.24
Paracanthonchus heterodontus	**2.00**
Marylynnia complexa	2.62
Cyartonema sp.	5.22
Paralongicyatholaimus minutus	2.25
Halalaimus isaitshikovi	2.50
***Eumorpholaimus* sp.**	**3.04**
Mesacanthion diplechma	1.79
Linhomoeus elongatus	2.58
Leptolaimus elegans	1.31
Chaetonema riemanni	**8.73**

Average dissimilarity between 5 & 4
=68.17

Station 6,4	$\bar{\delta}_i/S.D.\delta_i$
Sabatieria pulchra grp.	**1.34**
Sabatieria ornata	2.09
Daptonema tenuispiculum	**2.77**
Microlaimus turgofrons	2.82
Paracanthonchus heterodontus	**2.04**
Leptolaimus elegans	4.10
Terschellingia longicaudata	3.20
Eumorpholaimus sp.	**2.75**
Daptonema normandicum	1.25
Linhomoeus elongatus	6.30
Chaetonema riemanni	**6.78**
Halalaimus longicaudatus	3.40
Odontophora longisetosa	**3.37**
Thalassomonhystera sp.	7.38
Amphimonhystrella sp.	3.71

Average dissimilarity between 6 & 4
=65.59

Highlighted taxa are more numerous at station 4.

Table 16 Breakdown of average dissimilarity between the station 4 and all other stations into contributions from each nematode species from Cores; species are ordered in decreasing contribution (cut-off at 60% average dissimilarity).

Station 4, 1	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**3.89**
Sabatieria ornata	2.32
Daptonema normandicum	1.57
Chaetonema riemanni	**4.08**
Tripyloides marinus	1.23
Paracanthonchus heterodontus	**4.01**
Odontophora longisetosa	**1.89**
Thalassomonhystera sp.2	6.00
Terschellingia longicaudata	3.11
Aponema torosa	2.78
Axonolaimus helgolandicus	**1.11**
Linhomoeus elongatus	2.56

Average dissimilarity between 4 & 1 =70.19

Station 4,2	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**4.58**
Aponema torosa	8.50
Tripyloides marinus	3.63
Sabatieria ornata	3.50
Metalinhomoeus filiformis	1.06
Prochromadorella ditlevseni	4.48
Microlaimus sp.2	3.11
Richtersia sp.	3.05
Mesacanthion diplechma	2.55
Leptolaimus elegans	6.01
Oxystomina elongata	4.00
Dichromadora cucullata	4.94
Chaetonema riemanni	**4.92**
Paracanthonchus heterodontus	**4.44**
Diplopeltula incisa	10.04
Cobbia trefusiaeformis	2.71
Paralongicyatholaimus minutus	1.87

Average dissimilarity between 4 & 2 =74.49

Station 4,3	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**5.39**
Chaetonema riemanni	**1.96**
Microlaimus sp.2	5.88
Paracanthonchus heterodontus	**1.65**
Tripyloides marinus	1.79
Chitwoodia sp.	3.97
Dichromadora cucullata	1.21
Calomicrolaimus sp.	1.60
Aponema torosa	9.22
Axonolaimus spinosus	1.00
***Richtersia* sp.**	**1.17**
Theristus sp.4	1.39
Mesacanthion diplechma	1.21
Axonolaimus helgolandicus	**1.06**

Average dissimilarity between 4 & 3 =62.91

Station 5,4	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**5.10**
Aponema torosa	5.63
Tripyloides marinus	5.83
Sabatieria ornata	2.49
Daptonema normandicum	3.19
Cobbia trefusiaeformis	1.99
Leptolaimus elegans	2.46
Chaetonema riemanni	**5.30**
Paracanthonchus heterodontus	**4.77**
Terschellingia longicaudata	3.01
Mesacanthion diplechma	1.89
Axonolaimus spinosus	3.36
Sphaerolaimus spp.(juveniles)	12.16
Daptonema setifer	4.26
Marylynnia complexa	3.03
Sabatieria praedatrix	1.32
Oxystomina elongata	3.88

Average dissimilarity between 5 & 4 =73.88

Station 6,4	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**4.39**
Sabatieria ornata	3.81
Daptonema normandicum	1.30
Chaetonema riemanni	**4.84**
Paracanthonchus heterodontus	**4.64**
Terschellingia longicaudata	3.65
***Richtersia* sp.**	**2.17**
Odontophora longisetosa	**4.56**
Linhomoeus elongatus	6.49
Axonolaimus helgolandicus	**1.03**
Axonolaimus spinosus	6.61
Daptonema tenuispiculum	**1.23**

Average dissimilarity between 6 & 4 =74.96

Highlighted taxa are more numerous at station 4.

Table 17 Concentrations (mg. kg^{-1} dry weight) of heavy metals and values of other environmental variables in sediments taken from Day grabs at Stations 1 to 6. Org. C%: organic carbon; %C: Total carbon; N %: organic nitrogen; %G :average % gravel; %S: average % sand; %s/c :average % (silt + clay).

Station	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*	*Org.C*	*C%*	*N%*	*%G*	*%S*	*% sc*
1	<0.220	61	39	0.49	34	97	125	6.08	7.13	0.23	0.11	72.25	27.65
2	<0.210	38	43	0.35	25	47	147	3.75	5.36	0.18	1.14	77.59	21.27
3	<0.210	68	42	0.43	32	106	148	3.86	4.94	0.08	0.74	90.50	8.76
4	0.440	94	87	0.74	39	119	206	4.55	5.59	0.12	0.92	84.16	14.92
5	<0.240	53	36	0.26	29	75	131	4.65	5.64	0.15	0.12	65.64	34.24
6	<0.220	64	46	0.42	39	106	135	5.84	6.84	0.21	0.00	25.98	74.02

Table 18 Concentrations (mg. kg^{-1} dry weight) of heavy metals and values of other environmental variables in sediments taken from cores at Stations 1 to 6. C%: total carbon; Org. C :total organic carbon; N%: organic nitrogen; % s/c: % silt/clay; %S: % sand; %G: % gravel.

Station	*% s/c*	*% S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*	*Org. C*	*C%*	*N%*
1A	52.21	46.94	0.86	<0.24	50	40	0.30	28	73	126	3.24	4.85	0.15
1B	49.75	49.68	0.57	<0.24	76	58	0.60	35	99	162	5.04	6.09	0.23
1C	41.23	58.19	0.58	0.56	118	73	1.50	35	121	216	5.31	6.47	0.22
2A	11.56	88.23	0.22	<0.20	64	50	0.38	27	89	145	3.83	4.95	0.16
2B	26.10	73.60	0.30	0.24	61	70	0.32	31	89	149	4.51	5.39	0.18
2C	22.47	77.13	0.41	0.22	79	58	0.59	34	109	164	3.66	5.13	0.17
3A	16.11	83.67	0.22	0.31	72	51	0.47	24	107	169	3.34	4.65	0.15
3B	2.68	93.39	3.93	0.36	84	59	0.70	26	120	179	4.48	5.84	0.23
3C	1.45	98.32	0.23	<0.21	118	69	0.67	33	113	164	3.24	4.73	0.12
4A	8.16	91.31	0.53	0.21	86	61	0.53	30	108	166	3.93	5.59	0.19
4B	4.98	90.10	4.91	<0.20	52	61	0.25	20	84	125	3.93	5.32	0.19
4C	2.30	96.14	1.56	0.23	90	78	0.55	42	114	182	3.97	5.19	0.20
5A	18.83	81.09	0.09	<0.22	62	43	0.38	26	89	125	3.49	4.75	0.14
5B	21.40	78.58	0.03	0.19	92	59	0.67	33	121	166	4.42	5.67	0.18
5C	6.93	93.90	0.18	<0.21	51	38	0.20	29	92	121	3.63	5.03	0.12
6A	34.44	65.42	0.14	<0.24	79	52	0.60	38	108	146	5.33	6.41	0.24
6B	57.80	42.03	0.17	<0.24	53	45	0.44	34	93	141	4.07	5.58	0.21
6C	70.23	28.45	1.32	<0.24	64	53	0.59	39	106	153	5.18	6.36	0.25

Table 19 Summary of the data in Table 18. Mean Concentrations (mg. kg^{-1} dry weight) of heavy metals and mean values of other environmental variables from cores at Stations 1 to 6. C%: total carbon; Org. C :total organic carbon; N%: organic nitrogen; % s/c: % silt/clay; %S: % sand; %G: % gravel.

	%s/c	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*	*Org.C*	*C%*	*N%*
1	47.60	51.75	0.65	0.35	81	57	0.80	33	98	168	4.53	5.80	0.20
2	18.96	80.75	0.29	0.22	68	59	0.43	31	96	153	4.00	5.16	0.17
3	6.05	92.80	1.15	0.29	91	60	0.61	28	113	171	3.69	5.07	0.17
4	5.88	91.76	2.36	0.21	76	67	0.44	31	102	158	3.94	5.37	0.19
5	15.97	83.94	0.09	0.21	68	47	0.42	29	101	137	3.85	5.15	0.15
6	50.97	49.23	0.48	0.24	65	50	0.54	37	102	147	4.86	6.12	0.23

Table 20 Rank correlations (ρ) between the Euclidean distance matrices derived from environmental variables (log (1+X) transformed) from grabs and cores and similarity matrices derived from square-root transformed biotic data.

	Environmental variables (Grab)	Environmental variables (Cores)
Nematodes (Grabs)	0.771*	0.107
Macrofauna	0.686*	0.393
Nematodes (Cores)	0.918*	0.154

*$p<0.05$ by a permutation test.

Determination of Pearson correlation coefficients for all the environmental variables measured in sediments taken from grabs (Appendix XIX) revealed the relationship between percentage carbon and organic carbon to be collinear ($r>0.95$). In view of such a relationship the values of % organic carbon were omitted from the BIO-ENV procedure (being represented by % carbon). Values of % gravel were also excluded from the analyses as only a limited number of samples contained any material of this size fraction. The remaining 11 abiotic variables in sediments from grabs were used in the BIO-ENV search in separate runs to identify the most appropriate combinations of variables to explain the square-root transformed data derived from macrofauna, nematodes (grab sub-samples), and nematodes (cores) (Table 21-23). The BIO-ENV procedure revealed that the highest correlation of square-root transformed macrofauna data was 0.950 with a combination of 6 variables; Cd, Hg, Zn, C%, N% and % silt and clay (Table 21). However, with the nematode data from grab sub-samples, the highest correlation value is 0.943, with an 8 variable combination of Cd, Cr, Hg, Pb, Zn, N%, %S and % silt and clay (Table 22). A similar pattern emerges with the nematode data from cores and results in the highest correlation of 0.982 with Cd, Hg, Pb, Zn, % carbon, %S and % silt and clay (Table 23). These results indicate that both sedimentary parameters and metal concentrations are important in influencing macrobenthic and nematode communities in the Tees Bay.

In Appendix XXI Pearson product moment correlations are given for log (1+x) transformed averaged environmental variables measured in sediment samples from cores. The results indicate that Hg and Cd are significantly related (r>0.95) and that the relationships between % organic carbon and % carbon, % sand, and % N are collinear (r>0.95). Thus both Hg and % organic carbon were omitted from the BIO-ENV procedure. Repeating the BIO-ENV searches using the values of environmental variables measured from the cores reveals that the biotic data from all groups show the highest correlations with sedimentary measures (Table 24-26).

Table 21 Spearman rank correlations between square - root transformed macrofauna data and log (1 + x) transformed environmental data derived from grabs. Lower correlations omitted from the table.

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	Zn	0.664
2	Zn, %s/c	0.914
3	Zn, %N, %s/c	0.914
4	Hg, Zn, %N, %s/c	0.943
5	Cd, Zn, C%, %N, %s/c	0.946
6	**Cd, Hg, Zn, C%, %N, %s/c**	**0.950**

Table 22 Spearman rank correlations between square-root transformed nematode data from Day grab sub-samples and log (1+X) transformed environmental data derived from grabs. Lower correlations omitted from the table.

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	Zn	0.589
2	Zn, %s/c	0.832
3	Cr, Zn, %s/c	0.911
4	Cr, Cu, N%, %s/c	0.932
5	Cd, Cr, Cu, N%, %s/c	0.939
6	Cd, Hg, Pb, Zn, N%, %s/c	0.932
7	Cd, Cr, Cu, Pb, N%, %S, %s/c	0.932
8	**Cd, Cr, Hg, Pb, Zn, N%, %S, %s/c**	**0.943**

Table 23 Spearman rank correlations between square-root transformed nematode data from cores and log (1+X) transformed environmental data derived from grabs. Lower correlations omitted from the table.

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	Zn	0.718
2	Cu, %s/c	0.896
3	Ni, Zn, %s/c	0.950
4	Cr, Cu, C%, %s/c	0.943
5	Cd, Cr, Zn, C%, %s/c	0.957
6	Cd, Hg, Pb, Zn, C%, %s/c	0.954
7	**Cd, Hg, Pb, Zn, C%, %S, %s/c**	**0.982**

Table 24 Spearman rank correlations between square - root transformed macrofauna data and log (1 + x) transformed environmental data derived from cores. Lower correlations omitted from the table.

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	%s/c	0.664
2	**%s/c, %G**	**0.839**
3	%s/c, %S, %G	0.757

Table 25 Spearman rank correlations between square - root transformed nematode data (grab sub-samples) and log (1 + x) transformed environmental data derived from cores. Lower correlations omitted from the table.

Number of variables	*Best variable combination*	*Correlation (pw)*
1	%s/c	0.639
2	**%s/c, %G**	**0.721**
3	%s/c, %G, Cr	0.643

Table 26 Spearman rank correlations between square - root transformed nematode data (cores) and log (1 + x) transformed environmental data derived from cores. Lower correlations omitted from the table.

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	%s/c	0.539
2	**%s/c, %G**	**0.657**
3	%s/c, %G, %S	0.604

Table 27 Relative Index of Multivariate dispersion (r.IMD.) for A) macrofauna, B) nematodes from grab sub-samples and C) nematodes from cores for stations 1 to 6. The stations have been placed in the order of increasing r.IMD.

A)

Station	*r.IMD*
5	0.24
6	0.47
3	0.71
2	1.06
4	1.41
1	1.76

B)

Station	*r.IMD*
5	0.47
4	0.59
3	0.78
6	1.06
2	1.45
1	1.69

C)

Station	*r.IMD*
4	0.46
2	0.56
5	0.56
6	1.26
1	1.47
3	1.68

3.3 DISCUSSION

3.3.1 The meiofaunal community

The nematode community outside the dredged material disposal site is characterised by species such as *Sabatieria ornata, Daptonema normandicum, Tripyloides marinus, Aponema torosa*, and *Terschellingia longicaudata*. These species are typical inhabitants of sublittoral muddy sand communities and would be expected to occur in sediments from this area (Warwick and Buchanan, 1970; Platt and Warwick, 1983, 1988; Warwick *et al*., 1998).

In contrast, the nematode community at the inshore disposal site station is dominated by *Sabatieria pulchra* grp. and to a lesser extent the nematodes *Chaetonema riemanni, Paracanthonchus heterodontus,* and *Daptonema tenuispiculum*.

Somerfield *et al.* (1995) have noted that *Daptonema tenuispiculum* and *Sabatieria pulchra* grp. were numerically abundant at the "Site Z" dredgings disposal site in Liverpool Bay (see Chapter 4). They further suggested that the latter species and other members of the *Sabatieria pulchra* grp. might have indicator value as, although they are found in unperturbed situations, they often persist as the dominants of impoverished meiofaunal communities. In this study, elevated counts of both *Daptonema tenuispiculum* and of the *Sabatieria pulchra* grp. also contributed to the peak in the ratio of 1B/2A nematodes in sediments at the inshore disposal station. However, this index is not robust to changes in sediment type, which influences the proportions of each nematode "feeding type." Thus subtle changes in the nematode community due to dredgings disposal could not be readily discerned using this measure from the background noise associated with varying sediment types.

In general, nematode species more typical of sandy substrates, such as *Chaetonema riemanni* and *Eumorpholaimus* sp. (Platt and Warwick, 1983; Warwick *et al.*, 1998) appear to have replaced a muddy sediment assemblage at the Tees Bay disposal site. Their presence at the disposal site correlates with the presence of a coarser component to the sediment that has probably been derived from the disposal of sandy dredgings. The presence of significant numbers of the nematode *Paracanthonchus heterodontus* at the disposal site suggests that the nematode community is disturbed, as a species of this complex has been reported to be abundant close to the Garroch Head sewage sludge disposal ground (Somerfield *et al.,* 1993). Whether disturbance of the community is due to the effects of contaminants or organic enrichment (both of which can be associated with dredged material from certain locations), or due to physical perturbation from the disposal operation could not be established in this study. The species composition of the offshore disposal site station, however, comprised elements of both the assemblage of the inshore disposal site station and stations outside the licensed site. Densities of other meiofaunal organisms such as the harpacticoid copepods, ostracods and kinorhynchs indicated an impact at the disposal site but their low overall abundances at all stations precluded their use for assessment purposes at this site.

3.3.2 The macrofaunal community

Several macrofaunal organisms important in distinguishing the inshore disposal site station from stations outside the disposal site included *Polydora ciliata* (agg.), *Tubificoides benedii*, *Capitella* sp., *Mytilus edulis* juveniles, *Nephtys hombergii* and, to a lesser extent, the oligochaete *Tubificoides pseudogaster*. All these species have been documented as among those characterising the fauna of an intertidal sand community at Seal Sands at the mouth of the Tees Estuary (Alexander *et al.*, 1935; Gray, 1976; Kendall, 1979) and have also been reported as commonly occurring throughout most of the Tees Estuary (Hall *et al.*, 1996). Indeed, *Capitella capitata*, *Tubificoides benedii and Polydora ciliata* have been documented as typifying an abundant zone of subtidal fauna in the middle reaches of the River Tees estuary (Shillabeer and Tapp, 1990; Tapp *et al.,* 1993). Although the exact location of dredging campaigns carried out prior to the sampling dates are unknown, the entire length of the Tees Estuary is dredged frequently (Mr. K. Simpson, *pers. comm.*) and sediments both in the vicinity of Seal Sands and in the middle reaches of the estuary are likely to be among those disposed of at the site. It is therefore probable that at least some of these animals were transported to the disposal site along with the dredged material and have been introduced to the area as exotic species. This is in accordance with the findings of Wildish and Thomas (1985) who observed that *Capitella capitata* was conveyed in dredged material and appeared to survive at a Canadian disposal site in the absence of any nearby populations to sustain recruitment (see also Rees *et al.*, 1992). The oligochaete *Tubificoides pseudogaster* is considered to be more typical of estuarine conditions than marine. Its presence at the disposal site in a fully marine environment and its absence to the north and south of the disposal ground also suggests that this animal was transported to the disposal site via this route. The related oligochaete *Tubificoides benedii* has also been documented to occur in polluted estuaries (Wharf, 1977; Hunter and Arthur, 1978; Birtwell and Arthur, 1980) and can tolerate anaerobic conditions when oxygen and/or sulphide become limiting (Dublilier *et al.*, 1994,1995) apparently without incurring an oxygen debt (Birtwell and Arthur, 1980). This ability, together with a low metabolic rate, may also favour its survival during transport to the site. Many nematode species are similarly adapted to sediments of low oxygen content (Wieser and Kanwisher, 1961; Ott and Schiemer, 1973), although their introduction to marine environments along with dredged material is undocumented. Nevertheless, *Sabatieria pulchra* grp. and *Paracanthonchus heterodontus*, two of the nematode taxa abundant within the disposal site, occur in substantial numbers in the Tees Estuary, the source of the deposited dredged material (Trett, 1996).

The reproductive strategies of the macrofaunal organisms may also explain the distribution of organisms in the vicinity of the disposal site. Although the larvae of *Polydora ciliata* are long-lived they are also benthic (Dorsett, 1961). The Tubificidae similarly exhibit benthic development and have been observed in laboratory cultures to reproduce by simple fission. *Capitella capitata* also has no pelagic development with the larvae occurring in the tube of the parent. Such reproductive strategies would be advantageous for recolonising new areas, following relocation via dredged material.

3.3.3 Comparison of the effects of disposal on both communities

Comparison of the responses of the nematode and macrofaunal Tees Bay communities reveals that the general pattern of impact of dredgings in the area is not dissimilar. This is reassuring, considering that the core samples were taken a year later than the grabs, and justifies a closer inspection of any observed differences between the communities that may be related to disposal activities. The general pattern is also evident with the environmental variables taken from grabs, but it is not apparent with an analysis of environmental variables obtained from the cores. While this disparity between environmental variables obtained from grabs and cores may be due to samples being taken a year apart, the fact that the biotic data from grabs and cores are significantly related implies that the method of sampling is likely to be more critical for environmental variables. A surface scrape of sediment was taken from grabs whereas the top 5cm of sediment from cores was used for determining trace metal concentrations. Measuring the deeper sedimentary layers of cores may not have provided an indicator of conditions within the surface layers and may have led to the anomalous result. The limited surface area available from core samples, 23.75cm^2 compared to a maximum area of 0.1m^2 from grabs may have also contributed to the differing pattern, with the smaller surface area not adequately sampling the patchy distribution of contaminants in the disposal site.

Analyses of nematode community data clearly indicated marked changes in community structure in response to the disposal operation. The community at the inshore disposal site is less diverse than both the offshore disposal site station and the stations outside. Multivariate analyses separate both stations inside the disposal site from the remainder of the sampling stations, but there is also evidence of a differential impact of dredgings between the two disposal site stations. This implies that dredgings are not uniformly distributed within the licensed site. As the community structure of the inshore station is substantially modified it may be inferred either that disposal most frequently occurs in this area or that the bulk of disposed dredgings are being transported as a bed wave to this region (Delo and Burt, 1987). These authors recorded a peak concentration of 2000ppm for suspended solids in the bottom 2m of the water column in association with a bed wave of discharged material at this disposal site. Interestingly, the nematode community from the offshore disposal site station obtained from cores is not as altered as that from the inshore disposal site station, yet it exhibits greater sample variability (Table 27C). This may be a sampling artefact with lower numbers of individuals being sampled effectively; or it reflects a sparse and patchy fauna as a consequence of disturbance (Warwick and Clarke, 1993; Lambshead and Hodda, 1994) due to dredgings disposal. Support for the latter is provided by an understanding of the distribution of deposited material on the seabed. In regularly used disposal sites such as that at Tees Bay, deposited material is likely to exist as discrete mounds rather than a uniform covering over the whole of the site (Rowlatt and Limpenny, 1987; M.P.M.M.G., 1996). As a consequence, the fauna is likely to reflect this patchiness with the production of a mosaic of communities occupying different stages in the recolonising process (for review see Hall *et. al.*, 1992). Hence, sampling is likely to reveal a high degree of variability. Although the macrofaunal community is also affected by the disposal of dredgings, the pattern of disposal is not as clear as with the nematode data. This finding may be a direct consequence of the different sensitivities of these two groups of organisms to disturbance but it could also be a function of variability in the individual patch sizes occupied by species and the extent to which these have been sampled adequately. For example, the spionid *Spiophanes bombyx* has been reported to occur in irregular and patchy settlements in this area (Shillabeer and Tapp, 1990).

There is also some evidence for a local enrichment effect immediately outside the disposal site that may be associated with dispersing dredged material (Zambriborsch *et al.*, 1982; Rees *et al.*, 1992), most probably from the settlement of fines entrained in the near surface plume (Delo and Burt, 1987). The effect is most pronounced with the nematode data from the cores. In fact, the statistical output derived using nematode core data was generally less ambiguous than that obtained using macrofaunal data. This was primarily due to the higher degree of precision observed with the nematode data.

An important finding from this study is the close agreement between the nematode data obtained with grabs and cores and this will be further explored in Chapter 6. Changes in the macrofaunal and nematode community also clearly reflect changes in both the sediment grain size and the environmental variables. Perturbed faunal communities were found within the disposal site and their presence accorded with coarser substrates and elevated sedimentary metal concentrations that may be attributed to the disposal of sandy dredgings.

4. A COMPARISON OF THE RESPONSES OF MEIOFAUNAL AND MACROFAUNAL COMMUNITIES AT A LIVERPOOL BAY DREDGED MATERIAL DISPOSAL SITE.

4.1 INTRODUCTION

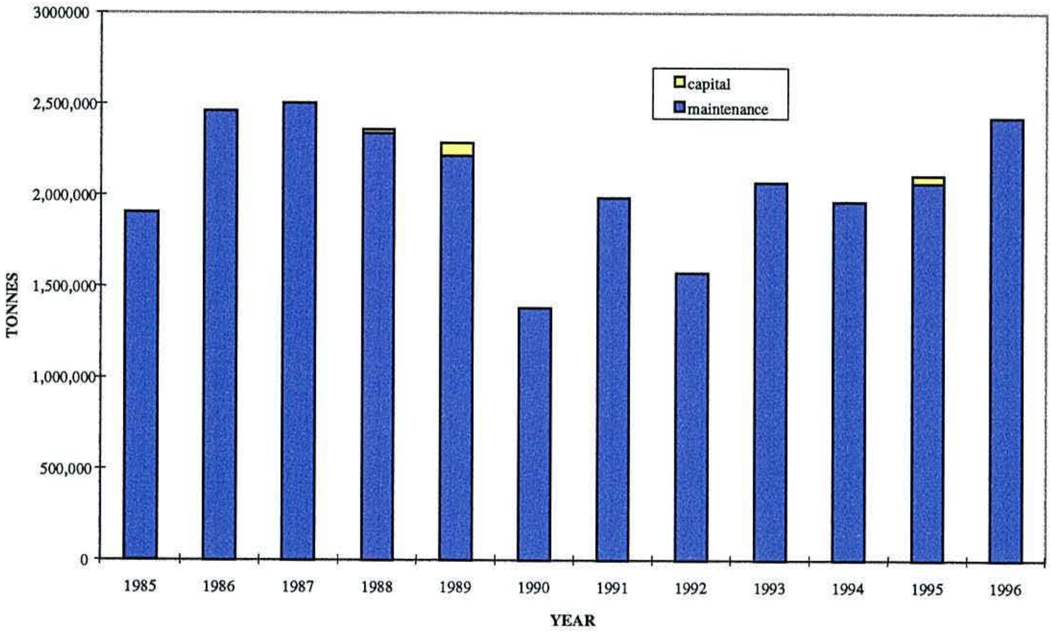
Liverpool Bay is one of the most thoroughly investigated regions of the Irish Sea (see Taylor and Parker, 1993; Barne *et al.*, 1996, for general reviews of the region). Sewage sludge disposal has received particular attention with a considerable amount of survey and monitoring effort directed towards establishing its fate and effect in the Bay (DOE, 1972a,b, 1973, 1976; Norton *et al.*, 1984; Rowlatt, 1986; Rees and Walker, 1991).

Dredged material has also been disposed of at various locations in Liverpool Bay since as early as 1874. Disposal commenced at "New Site Z" off the Mersey in 1982 following the shoaling of a nearby site, probably due to the accumulation of sandy dredgings (Rees *et al.*, 1992). About 2 million wet tonnes of sediment arising from the dredging of the Mersey estuary and its approaches have been disposed of annually at this site since 1985 (see Figure 20). It is located in a shallow (<10m in the centre) dispersive environment with tidal currents of up to 0.8m s^{-1} running in an approximately east-west direction. In a typical year, the dredgings consist mainly of sands (70%), although muds (30%) contain the bulk of the trace metal contaminants (Rowlatt, 1988). However, on a shorter time-scale, the sediment composition can vary greatly depending on where recent dredging has taken place and the composition of the dredged material. For example, the proportion of "fines" in the dredged material decreases in the order docks > lock entrances > sea channels > Eastham channel (Rowlatt, 1988). As would be expected, the contaminant burden of the dredgings also varies (see Table 28). Although the site is used mainly for the disposal of maintenance dredgings, the site has also been used occasionally (in 1988, 1989 and 1995) for the disposal of small quantities of capital dredgings (Figure 20).

Table 28 Mean metal concentrations (mg/kg wet weight) of dredgings from various areas within the River Mersey and Liverpool Docks system. Source – Unpublished M.A.F.F. Data.

Dredged area	*Date*	*No of sites sampled*	*% Solids*	*As*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
Mersey Docks	05/03/97	4	43.3	8.50	0.295	40	23	0.533	16	46	135
Tranmere Oil Stages	16/05/96	3	58.2	15.00	0.865	45	38	1.260	15	60	229
East Float	05/03/97	2	47	10.85	0.411	50	34	0.695	19	52	164
Camell Lairds Frontage	22/03/96	2	57.6	9.75	0.430	37	24	0.620	13	41	152
Eastham Channel and Lock approaches	24/02/94	4	52.9	-------	0.270	25	16	0.510	9	27	125

Figure 20 The quantity of dredged material disposed of at "Site Z" in Liverpool Bay.

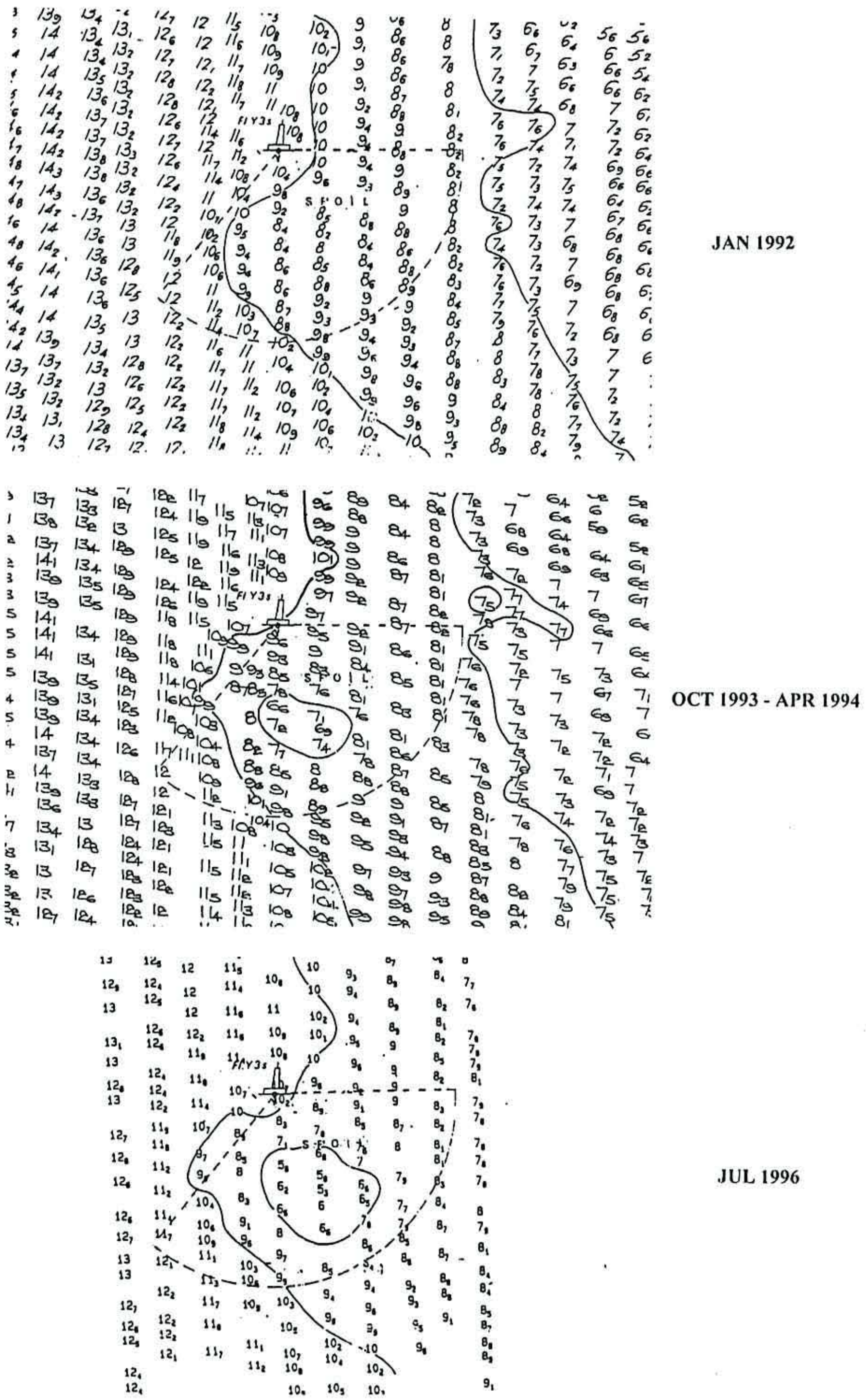


In a survey in 1984 of the distribution of sediment types in the general vicinity of "Site Z", it was noted that the area appeared to be dispersive with respect to fines but that there was potential for sands to accumulate (Rowlatt *et al.*, 1986). Elevated concentrations of certain trace metals were also reported at the site compared with offshore areas (Rowlatt *et al.*, 1986), although the imprint of muddy dredgings was difficult to isolate from a mobile mud patch associated with the mouth of the Mersey. Recent evidence from bathymetric surveys carried out by the Mersey Port Authority for the period January 1992 to July 1996

(Figure 21) tend to confirm that sediments are accumulating in the centre of "Site Z". As a result of these findings, in November 1996 the site was extended to the west to ameliorate shoaling of the site.

The macrobenthic fauna of this area of Liverpool Bay is comparatively well studied with both the spatial and temporal distribution of the large dominant species (animals retained on sieve meshes ranging from 1 - 5mm) having previously been investigated (Rowlatt *et al.*, 1986; Rees *et al.*, 1992). Relatively short - lived, fast growing deposit feeders such as *Lagis koreni* and *Abra alba* have been recorded as characterising muddy stations inshore and to the south of the disposal site. This accords well with the presumed transport of dredged material by the net south-easterly residual current (Ramster and Hill, 1969) coupled with wave-driven sediment movement from north-westerly winds. The enhanced abundances of these two "indicator" taxa (*Lagis* and *Abra*) close to the disposal site were thought to be the result of a local enrichment effect associated with dispersing dredged material (Rowlatt *et al.*, 1986; Rees *et al.*, 1992). Evidence in support of the existence of such an effect was also provided by the enhanced counts of predatory epibenthic species to the south of the dredged material disposal site together with elevated levels of organic carbon within the disposal site (Norton *et al.*, 1984). However, the possibility that the deposited material helped to provide a temporary stabilising substratum promoting the survival of colonisers could not be discounted. Furthermore, as no evidence was found that the colonising fauna appeared not to be prohibited from settling in surface sediments surrounding the disposal site, any contaminant effects were considered negligible at least for the dominant species.

Figure 21 Evidence of shoaling at Site Z Dredged material disposal site (MDHC Bathymetric Surveys). No shoaling is apparent in January 1992 but by 1993/1994 and 1996 the depth of water had decreased from 8m to 6 and 5 m respectively. The distances shown in A-C are similar but the font sizes of the depths are different.



In 1985, a study of the vertical distribution of macrofauna down a core from the centre of the disposal site showed that live animals were restricted to the surface layers of the sediment. However, at a depth of 12cm moribund specimens of “estuarine” species were recorded suggesting the transport of animals via dredgings disposal (Rees *et al.*, 1992). More recently, Somerfield *et al.* (1995) compared the meiofauna and the macrofauna communities along a transect through the disposal site using a suite of multivariate analyses and correlation statistics. They observed the presence of a distinct nematode community within the disposal site. The distinction was mainly due to the dominance of several non-selective deposit-feeding nematodes (*Sabatieria pulchra* group and *Daptonema tenuispiculum*) and the absence of a large number of “sandy” species common to stations outside the disposal site. Macrofaunal species important in distinguishing "Site Z" from nearby sediments included both the polychaete *Lagis koreni* and the bivalve *Mysella bidentata*. The sediments along the transect were similar to those previously recorded in the region, with the active region of disposal containing sediments with an 80% silt and clay content. An elevation of several trace metals was also recorded within the disposal site. When Somerfield *et al.* (1995) compared patterns in community structure with the environmental data, they showed that macrofaunal community correlated with contaminant levels whereas the nematode community reflected the variation in sediment types. This led Somerfield *et al.* (1995) to infer that the macrofaunal community may reflect longer-term trends in the chemical quality of the dredged material, in contrast to the nematode community which may reveal shorter-term changes in its physical nature.

4.1.1 Sampling design

The sampling design used in the present study was similar to that used in the survey conducted in September 1991 by Somerfield *et al.* (1995) in which a transect of stations running in an approximately north - south direction was sampled (Figure 22). Six out of the seven stations were chosen from the original transect, the most northerly station was disregarded as the data from the station appeared to add little to the analysis and there was some concern that this station was being influenced by other disposal activities in the area. These stations were sampled using a Day Grab and a Multicorer (see Methods and Materials - Chapter 2) in September 1996. This enabled a direct comparison to be made with the results of the earlier survey at a site where, given the variable nature of the dredged material, there is the potential for significant temporal changes in the benthic community.

4.2 RESULTS

4.2.1 Univariate measures of community structure.

Nematode "feeding types"

Trends in the abundance of the 4 nematode "feeding" groups along the transect show a peak in the percentage abundance of 1B non-selective deposit feeders within the disposal site (stations 3 and 4) and immediately to the south of the disposal site (station 5) (Figure 23). This peak is largely due to elevated counts of the nematodes *Daptonema tenuispiculum* and *Sabatieria pulchra* group (Figure 24A and B). It has been shown that perturbation (organic enrichment) may result in a proportional reduction in the 2A feeding type with a concomitant rise in the 1B feeding group (Lambshead, 1986). Therefore, the ratio of 1B/2A may have some indicator value as a measure of disturbance caused by an increase in the organic loading of the sediments. There is significant variation in this index between stations ($p<0.01$) with a peak in the ratio within the disposal site itself, at station 4, and elevated levels both at station 3, also within the disposal station, and at station 5, some 300m south of the disposal site. Thus the ratio 1B/2A appears to provide a useful summary of the distribution of feeding groups along the transect and may also reflect disturbance from dredgings disposal (Figure 25).

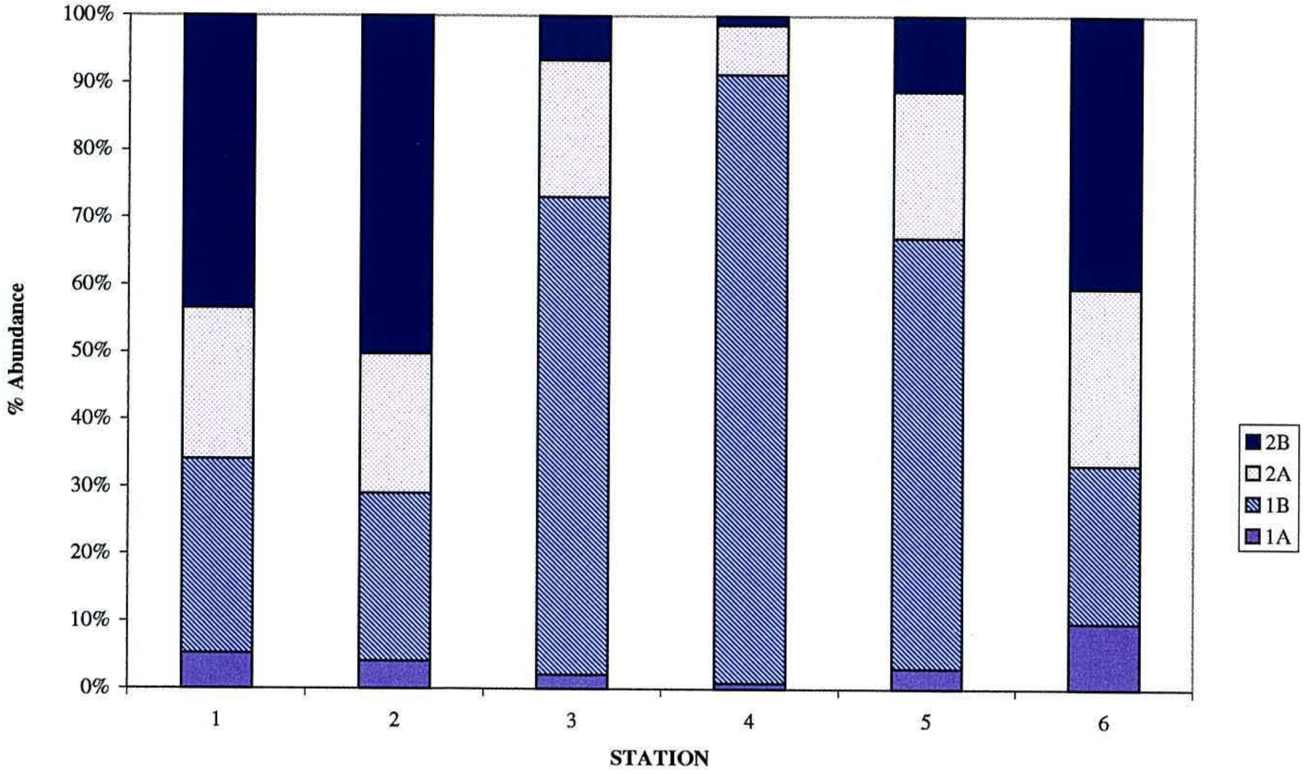
Diversity measures.

Univariate measures of macrofaunal data for numbers of taxa (S), abundance (A) and Maragalef's richness (d) show a general upward trend of values away from the disposal site (Figure 26). This trend is reversed for evenness values (J), with the highest values occurring within the disposal site and corresponding to the least populated stations. Such a pattern suggests that the frequency of disturbance at the centre of disposal activity is too great to favour even the more "tolerant" species, thereby causing a more equitable distribution of individuals amongst the reduced complement of surviving species. Indeed, taxa such as *Lagis koreni*, *Lanice conchilega*, *Mysella bidentata* and juvenile *Spisula subtruncata*, which are characteristic inhabitants of sediment in the inner Liverpool Bay area, were numerically dominant only at the northern and southern ends of the transect. No clear trends were discernible in values of the Shannon-Wiener diversity index (H') derived from the macrofaunal data, although the highest diversity was observed at a station to the south of the disposal site (station 5). This might suggest that at station 5 the community is slightly enriched, possibly as a result of dispersing dredged material providing a rich food source.

A plot of the number of log-transformed nematode species (S) (Figure 27) indicates clear differences between stations along the transect, with the lowest numbers of nematode taxa occurring within the disposal site (Stations 3 and 4) and reduced numbers found outside (c.f. 2 and 5) when compared with the northern and southern extremes. This appears to indicate an effect of dispersing dredged material moving away from the disposal site.

Figure 22 The location of the sampling stations in relation to the "Site Z" dredgings disposal site.

Figure 23 Mean distribution of nematode feeding groups along "Site Z" transect.



A similar gradient is evident with values of Margalef's richness (d) (Figure 27). Differences in the total counts of nematodes are less distinct, although the general trend is similar, with abundances reduced within the disposal site and immediately to the south. Reduced values of Shannon-Wiener diversity (H') and Pielou's evenness (J) occurred within the disposal site at station 4, although these were not significant. Such a reduction in diversity may indicate a shift towards greater dominance by one or a few species.

Table 29 The percentage abundances of the 4 nematode feeding types for replicated and pooled core samples at each station.

Station	**Nematode group**				
	1A	*1B*	*2A*	*2B*	*1B/2A*
1a	7	44	29	20	1.53
1b	6	20	23	51	0.89
1c	3	22	16	60	1.39
1a-c	5	25	20	50	1.25
2a	3	21	17	59	1.26
2b	6	43	36	15	1.19
2c	3	11	9	77	1.16
2a-c	3	16	14	67	1.19
3a	2	79	16	3	4.98
3b	3	69	23	4	2.99
3c	1	65	22	12	2.98
3a-c	2	71	20	6	3.50
4a	2	91	7	0	12.13
4b	1	90	7	2	13.14
4c	0	91	8	1	11.63
4a-c	1	91	7	1	12.17
5a	2	64	20	14	3.23
5b	4	66	23	7	2.87
5c	4	61	23	13	2.71
5a-c	3	64	22	11	2.91
6a	9	16	14	61	1.18
6b	14	31	33	22	0.92
6c	6	24	32	38	0.76
6a-c	11	24	26	40	0.93

Figure 24 Distribution of A) *Sabatieria pulchra* group and B) *Daptonema tenuispiculum* along "Site Z" transect (means and 95% Least significant intervals).

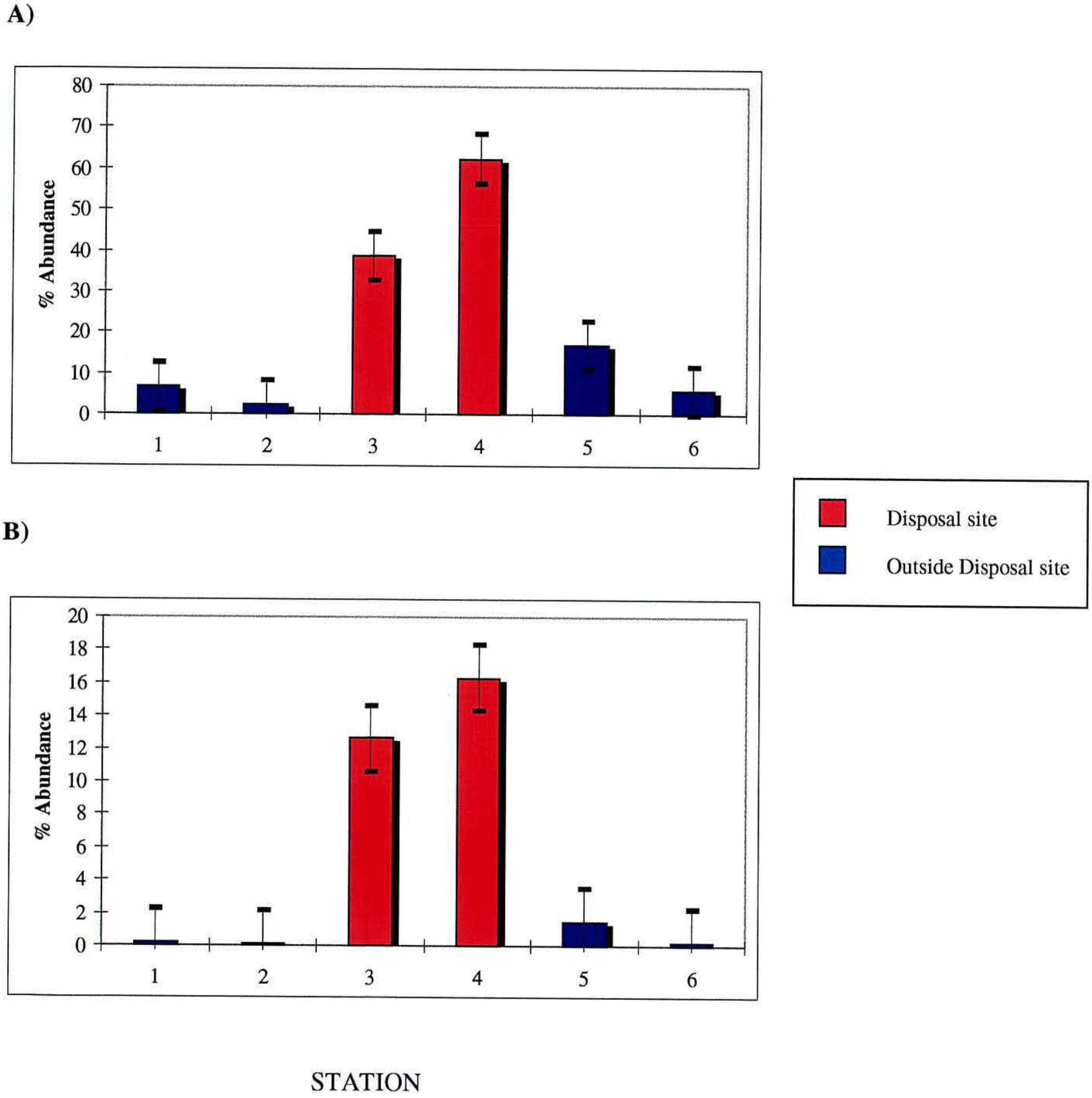
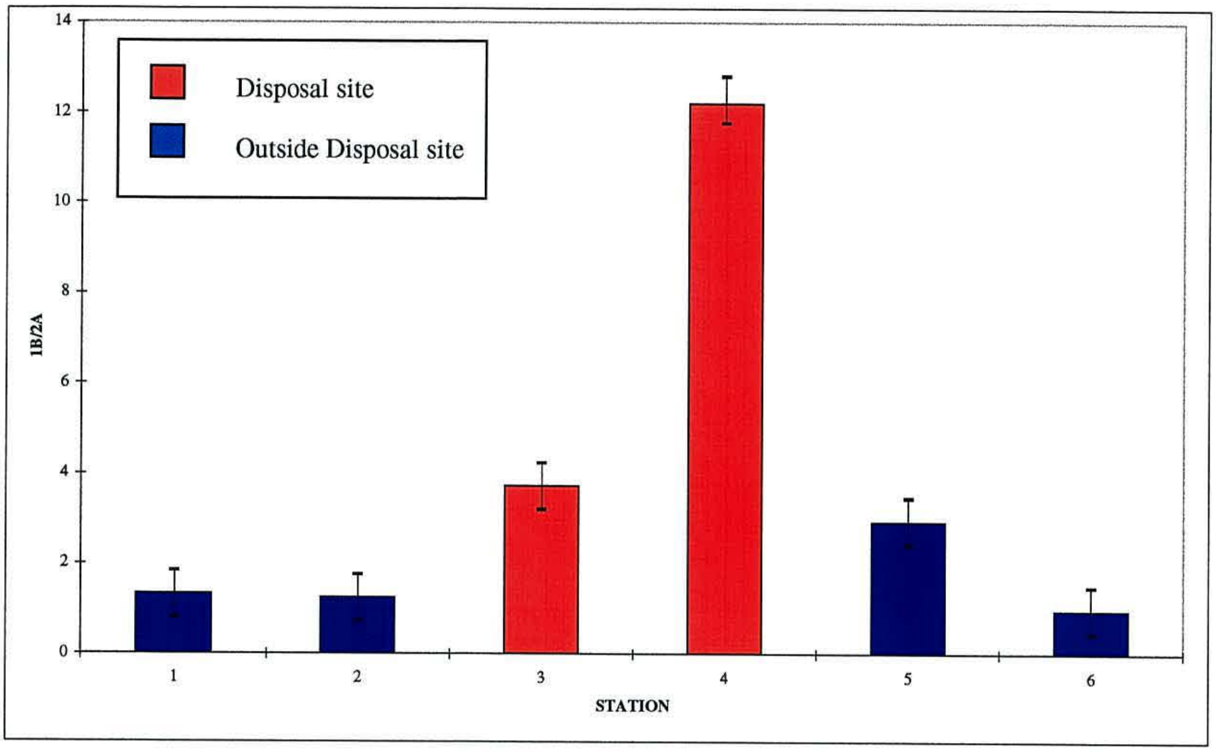


Figure 25 Distribution of the ratio of 1B/2A nematode groups (means and 95% Least significant intervals) along the "Site Z" transect.



A comparison of a range of environmental variables from sediments taken from Day grabs with univariate measures derived from pooled macrofaunal data indicate that trends in macrofaunal individuals are best explained by the distribution of Zn values (Table 31). The distribution of Cd also seems to account, at least in part, for variability in the numbers of macrobenthic taxa (S) along the transect. However, values of macrofaunal richness (d) are negatively correlated ($p<0.05$) with both Hg and Zn concentrations.

Table 30 F-ratios and significance levels (from $F_{5,12}$) from 1-way ANOVA tests for differences in various univariate measures of community structure between stations.

Univariate Measure	*Macrofauna (Grabs)*		*Nematodes (Cores)*	
	F	p	F	p
Log (1+S)	22.36	<0.01	37.91	<0.01
Log (1+A)	19.65	<0.01	6.29	<0.01
D	12.95	<0.01	86.54	<0.01
H’	10.10	<0.01	2.85	0.0639
J	33.32	<0.01	1.69	0.2118

Thus, some aspects of macrofaunal community structure appear to be influenced by sedimentary metal levels along the transect. Zn concentrations are also significantly related ($p<0.05$) to the number of nematode taxa and nematode species richness (Table 32). There is a lack of significant correlation ($p>0.05$) between sedimentary grain size and univariate measures derived from both macrobenthic and nematode data. This may imply that the dredged material is similar in terms of its particle size distribution to sediments naturally present in the area. It might be anticipated, therefore, that recently deposited dredged material may have originated from the outer reaches of the Mersey estuary where sediments are sandy in nature.

4.2.2 Multivariate measures of community structure

Cluster analysis

The effects of dredgings disposal at “Site Z” are evident from cluster analysis of 4th root transformed macrofaunal data, with the disposal site stations (3 and 4) clearly separated from all other stations at the 55% similarity level (Figure 28). Furthermore, the variability between replicates is greatest at station 3 within the disposal site (Table 33A). A gradient of change is also discernible, with greater similarity between the stations located at the northern and southern ends of the transect (stations 1 and 6) than stations adjacent to the disposal site (stations 2 and 5).

Table 31 Pearson product moment correlations between each pair of log-transformed (1+N) variables from grabs (based on 6 pairs of observations). Diversity indices are derived from pooled macrofaunal data. Values highlighted in bold type indicate significant correlation ($p<0.05$).

	log(1+S)	*log(1+A)*	*d*	*J*	*H'*
%C	-0.4414	-0.3346	-0.5785	0.1993	-0.0610
%OrgC	-0.4649	-0.3314	-0.6072	0.1794	-0.1150
%N	-0.3435	-0.1724	-0.5077	-0.0132	-0.2982
%s/c	0.3498	0.2674	0.3176	-0.3524	-0.1852
%S	-0.2947	-0.2204	-0.2628	0.3360	0.2078
%G	0.5913	0.6175	0.5674	-0.4898	-0.2064
Cd	**-0.8174**	-0.6893	-0.8018	0.4582	-0.0661
Cr	-0.5827	-0.4505	-0.7127	0.2212	-0.1595
Cu	-0.6639	-0.5642	-0.7723	0.3854	-0.0148
Hg	-0.7701	-0.6744	**-0.8584**	0.4956	0.0809
Ni	-0.5549	-0.4827	-0.6621	0.3726	0.0988
Pb	-0.5370	-0.3863	-0.6747	0.1993	-0.1532
Zn	-0.8089	**-0.8146**	**-0.8204**	0.7910	0.4862

Table 32 Pearson product moment correlations between each pair of log-transformed (1+N) variables from grabs (based on 6 pairs of observations). Diversity indices are derived from pooled nematode data. Values highlighted in bold type indicate significant correlation ($p<0.05$).

	log (1+S)	*log(1+A)*	*d*	*J*	*H'*
%C	-0.2931	-0.1081	-0.3537	-0.1358	-0.2465
%OrgC	-0.3132	-0.0525	-0.3997	-0.2998	-0.3969
%N	-0.1409	0.1490	-0.2461	-0.3580	-0.3910
%s/c	0.3953	0.1298	0.4395	0.5184	0.5689
%S	-0.3225	-0.1288	-0.3387	-0.3458	-0.3908
%G	0.4076	0.4829	0.3043	-0.4457	-0.2720
Cd	-0.6315	-0.2186	-0.6848	-0.6189	-0.7301
Cr	-0.3710	-0.0991	-0.4446	-0.2728	-0.3863
Cu	-0.5088	-0.2660	-0.5657	-0.2253	-0.3895
Hg	-0.6362	-0.3511	-0.6965	-0.3179	-0.5088
Ni	-0.4851	-0.2805	-0.5486	-0.2213	-0.3852
Pb	-0.3681	-0.0444	-0.4687	-0.4207	-0.5182
Zn	**-0.8807**	-0.6782	**-0.9116**	-0.2828	-0.5555

From cluster analysis of 4th root transformed nematode community data it can be seen that samples are grouped according to their respective stations. Furthermore, two main clusters can be distinguished at the 55% level of similarity (Figure 28), stations within (3 and 4) and just to the south of the disposal site (station 5), and stations to the north and at the southern end of the transect (stations 1, 2 and 6). This pattern suggests that the effects of dredgings disposal on the nematode community are discernible some 300m south of the confines of the disposal operation. It is also interesting to note that sample variability is greatest between nematode samples within the disposal site (Table 33B). This may be ascribed to greater habitat heterogeneity as a consequence of dredgings disposal with communities representing different stages in the "recovery" process. In contrast, faunal similarity at the station immediately to the south of the disposal site (station 5), is relatively high, which implies greater uniformity in the effects of dispersing dredged material at this station (Table 33B).

A sidescan sonar survey conducted at the time of sampling (see Chapter 2 for Methods) indicated that dredged material is fairly widespread in the disposal site itself and to the west of the site, which corresponds, with the direction of tidal flow (see Figure 29). However, at and near to station 5, south of the disposal site, discrete patches of material were identified, possibly representing a zone of secondary deposition arising from transport away from the site by residual currents or individual barge loads which have been disposed of short of the licensed site (Figure 29). Although some useful information can be gained on the distribution of dredged material from an examination of sonographs, clearly such observations only relate to visible "relief". The dispersal of unconsolidated fine material as uniform layers (cm or mm thick) would not be detectable with sidescan sonar.

Figure 26 Means and 95% LSD intervals for univariate measures of MACROFAUNA community structure along "Site Z" transect.

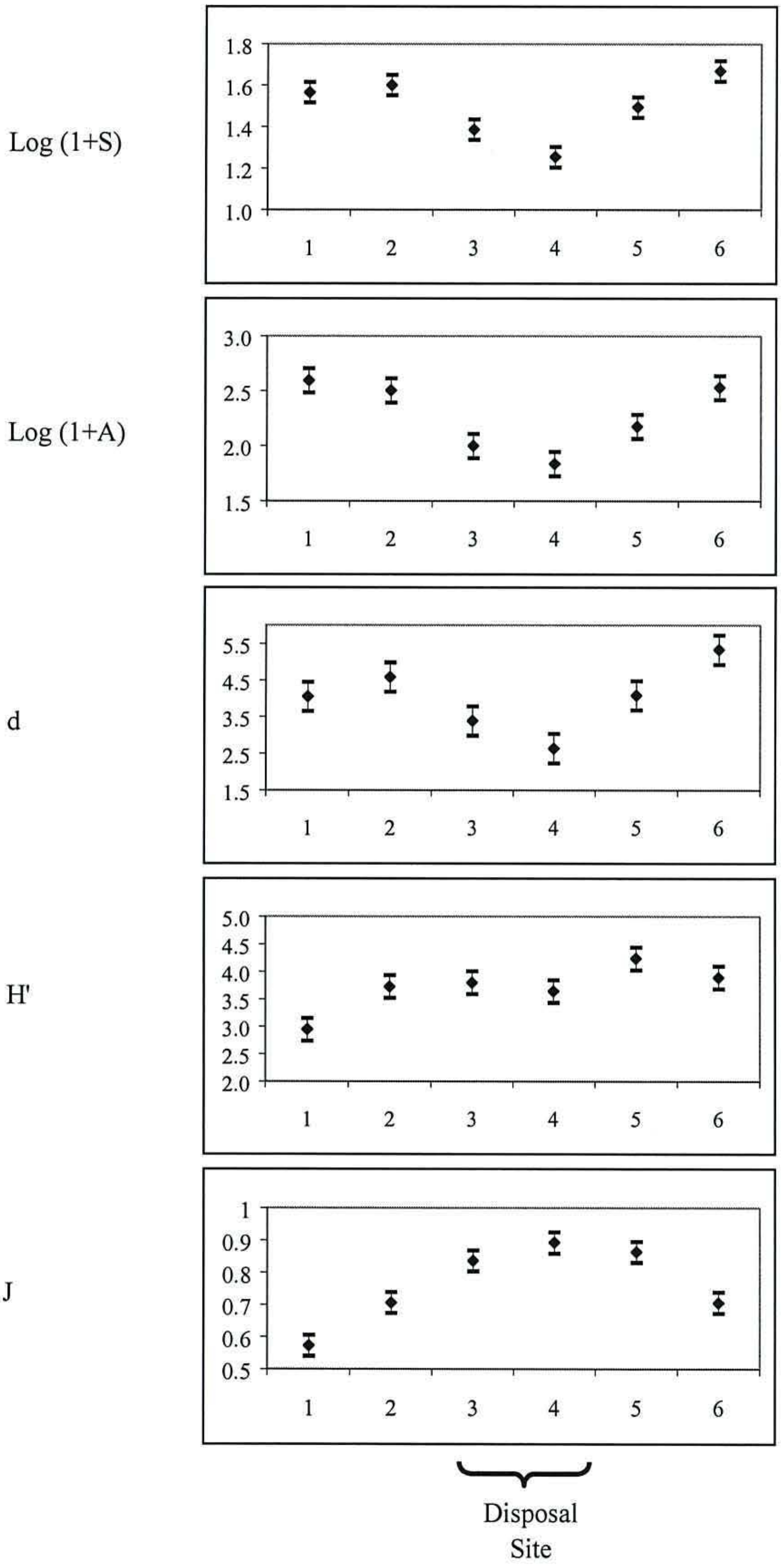


Figure 27 Means and 95 % LSD intervals for univariate measures of NEMATODE community structure along "Site Z" transect.

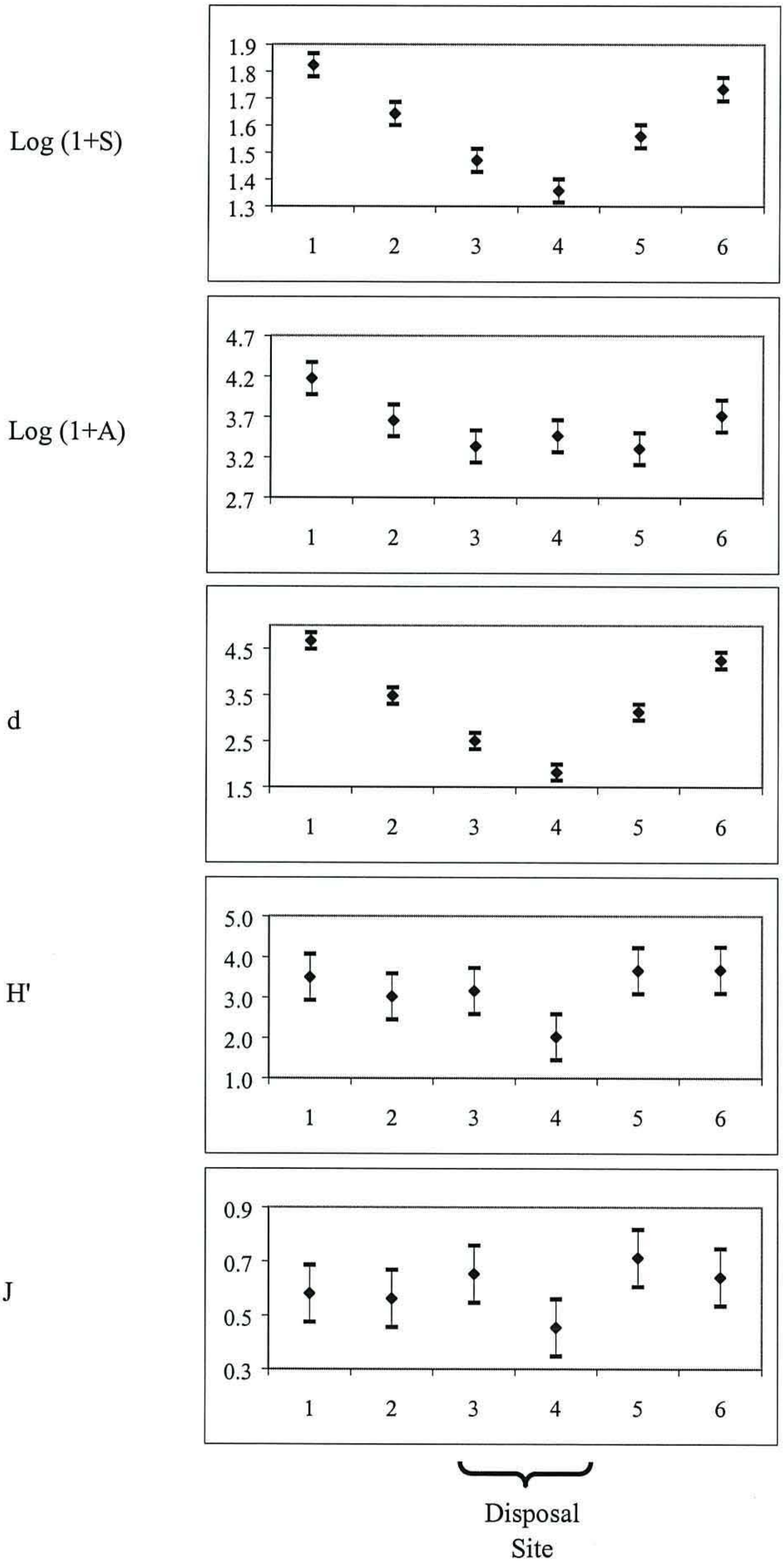
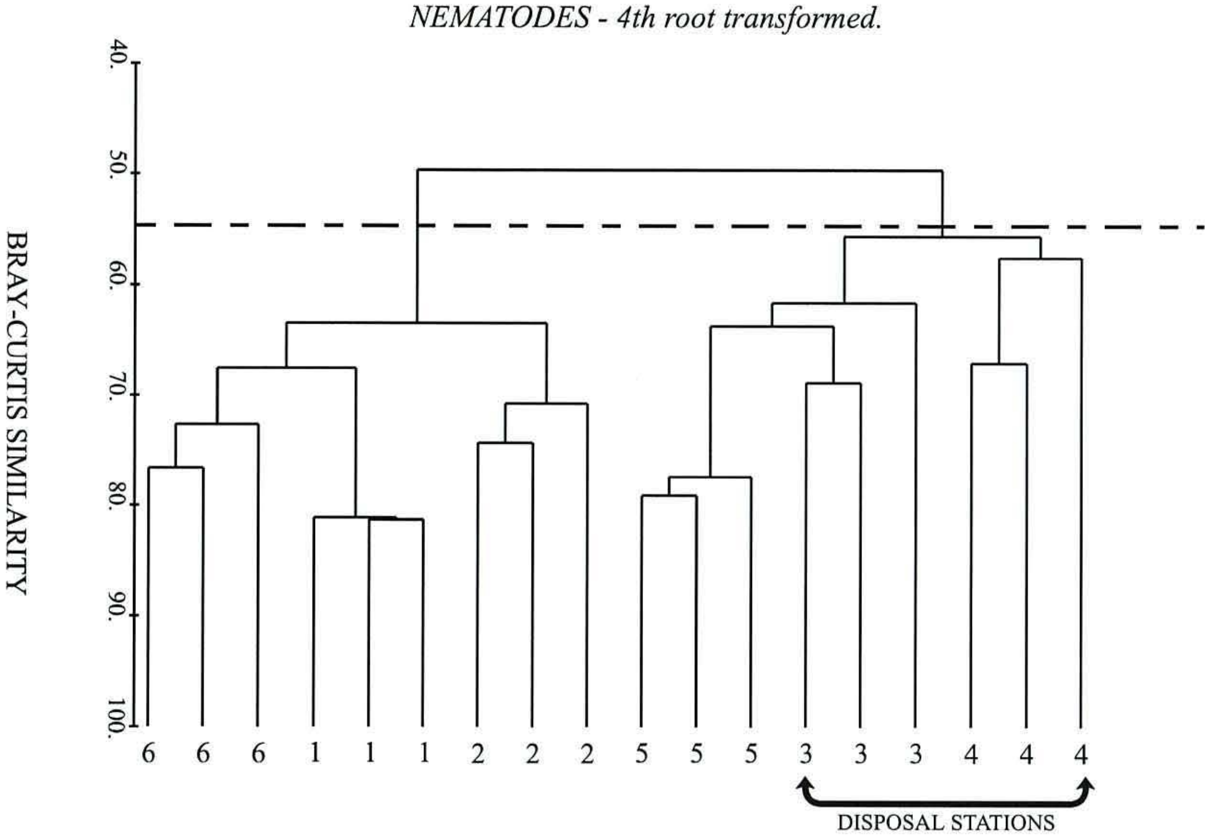


Figure 28 Cluster analysis of 4th root transformed nematode and macrofauna data for stations 1 to 6.



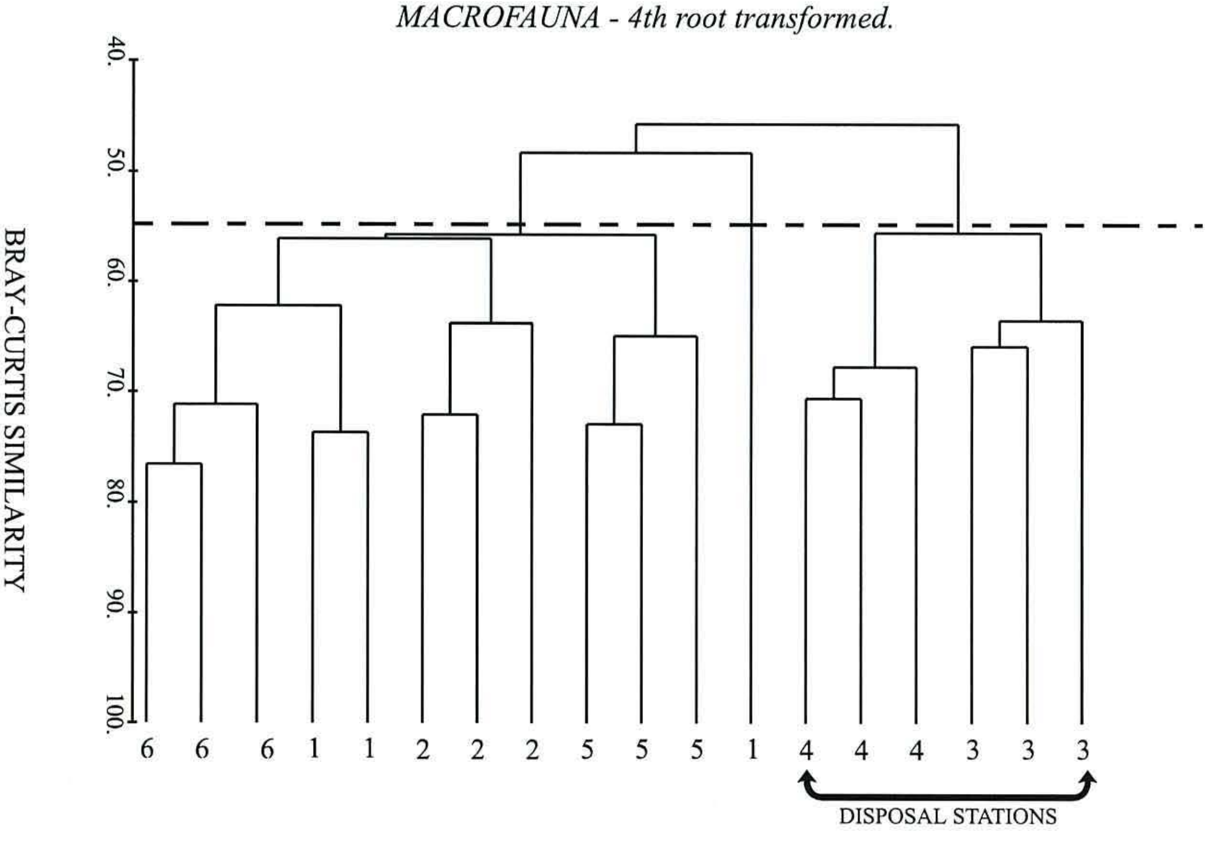


Figure 29 The location of dredged material along site Z transect as inferred from side-scan sonar records.

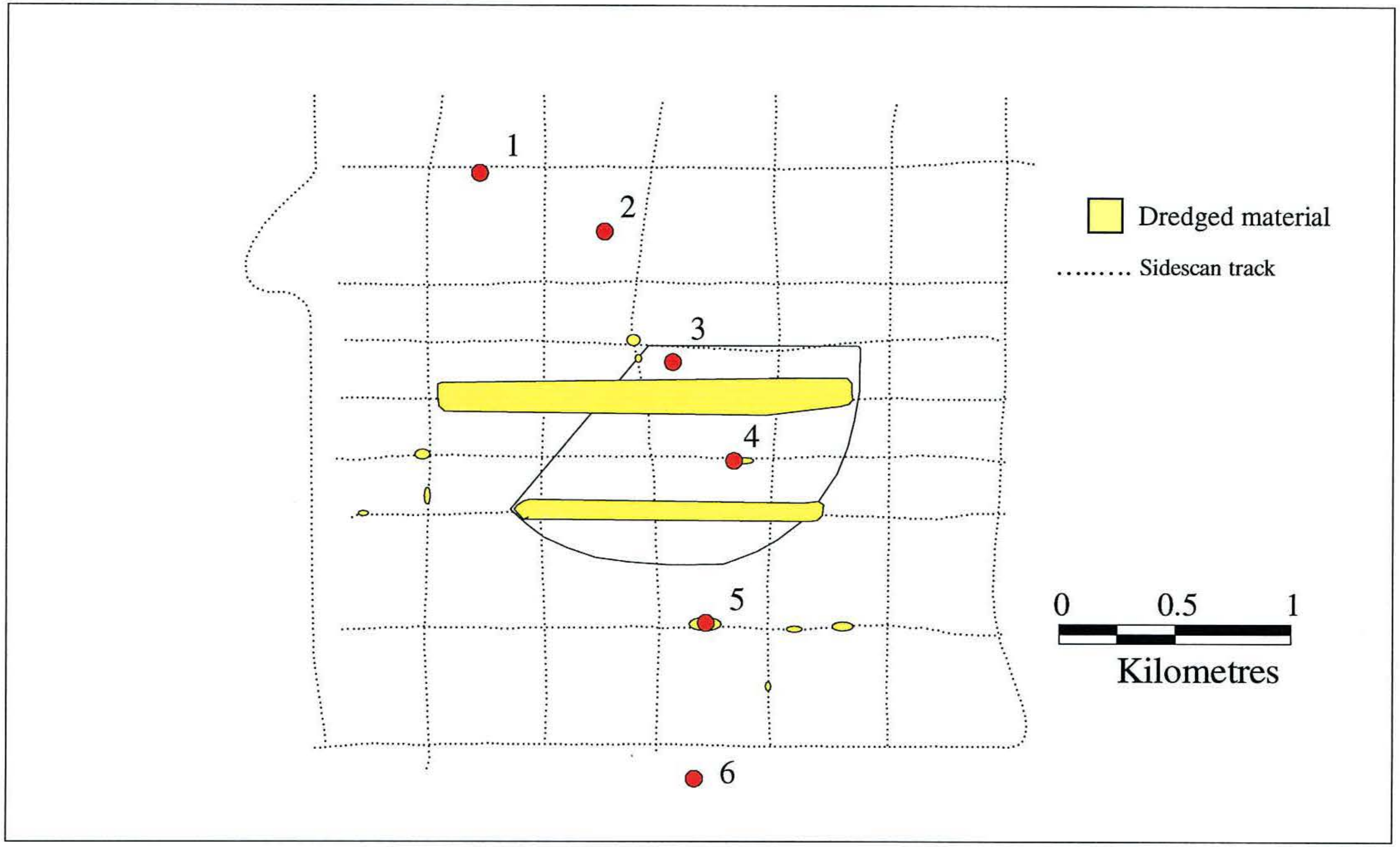


Table 33 Relative Index of Multivariate Dispersion for A) macrofaunal grab samples and B) nematodes from cores for stations 1 to 6. The stations have been placed in the order of increasing r.IMD.

A)

Station	*r.IMD*
6	0.42
4	0.88
5	0.98
2	1.05
1	1.26
3	1.40

B)

Station	*r.IMD*
1	0.21
5	0.56
6	0.88
2	1.09
3	1.58
4	1.68

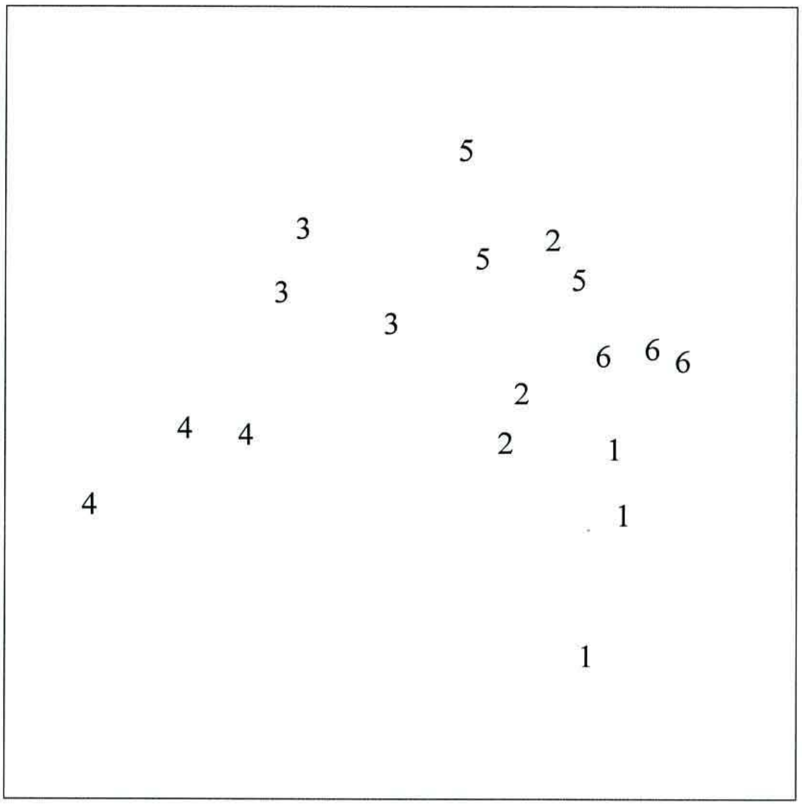
Ordination

Ordinations of 4th root transformed macrofaunal community data indicate a gradient of change with samples ordered according to distance away from the disposal site (Figure 30). However, this pattern is slightly obscured due to the "arching" of the sample configuration (Figure 30). Commonly, this "arching" effect occurs in ordinations when a single, strong environmental gradient exists. In such circumstances as here, the samples at opposing ends of the gradient have few species in common, and dissimilarity levels close to 100% are therefore obtained.

Ordinations of 4th root transformed nematode data also conform to the gradient described above, although the pattern is clearer due to the absence of any "arching" (Figure 30). Samples from a station to the south of the disposal site (station 5) are also more closely associated with replicates from a station (3) within the disposal site. This also provides further evidence that the effects of dredgings disposal are not confined to within the licensed boundary of the disposal site. Ordinations of averaged 4th root transformed biotic data also bear out the existence of a gradient of effect emanating from the disposal site (Figure 31). When these ordinations were compared they were found to be significantly correlated ($p<0.05$)(Table 34).

Figure 30 Multidimensional scaling ordinations of 4th root transformed biotic data.

MACROFAUNA - 4th root transformed, Stress = .13



NEMATODES - 4th root transformed, Stress = .10

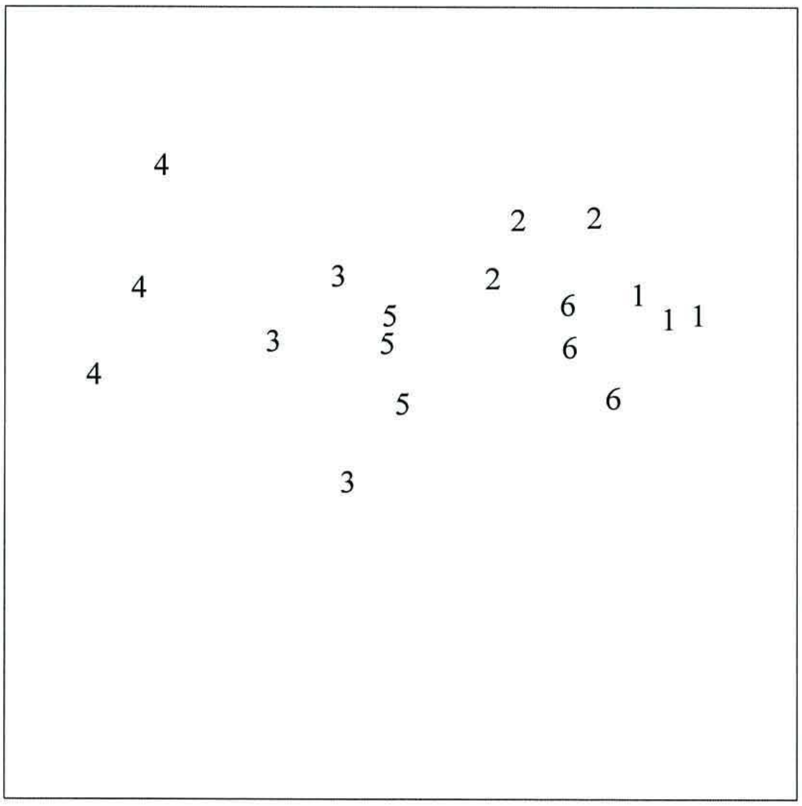
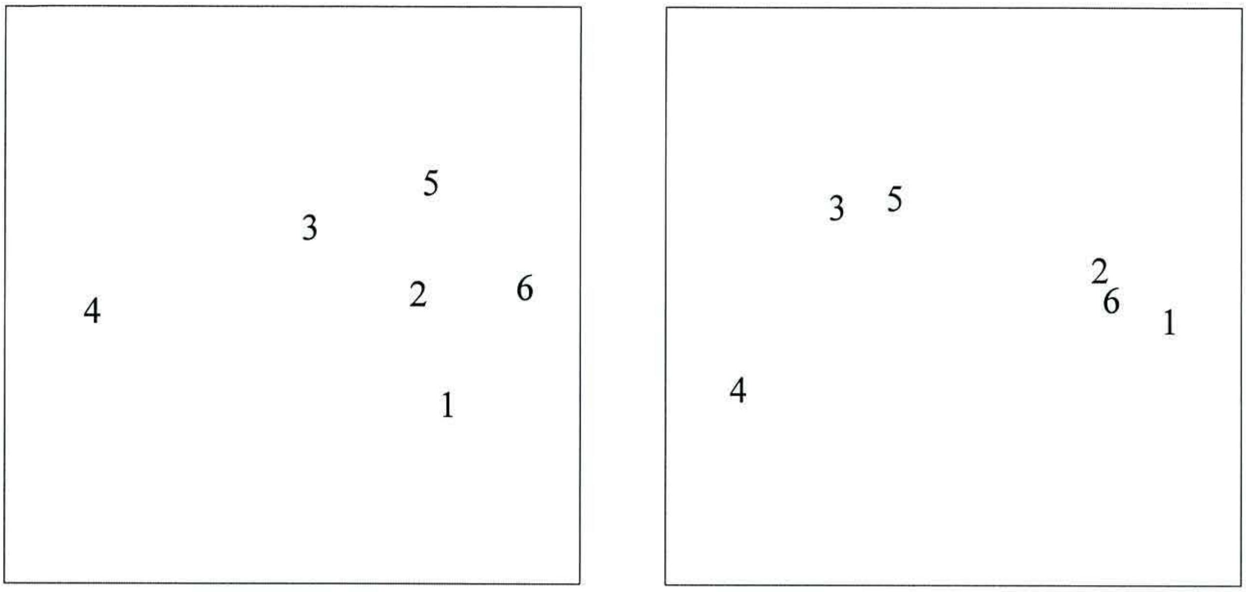


Figure 31 Ordinations by PCA of environmental variables, and by MDS of averaged abundances from stations 1 to 6. Environmental variables log (1 + N) transformed, nematodes and macrofauna 4th root transformed.

MACROFAUNA - 4th root transformed, Stress = .05

NEMATODES - 4th root transformed, Stress = .01



ENVIRONMENTAL VARIABLES FROM GRABS
Stress = .01

ENVIRONMENTAL VARIABLES FROM CORES
Stress = .01

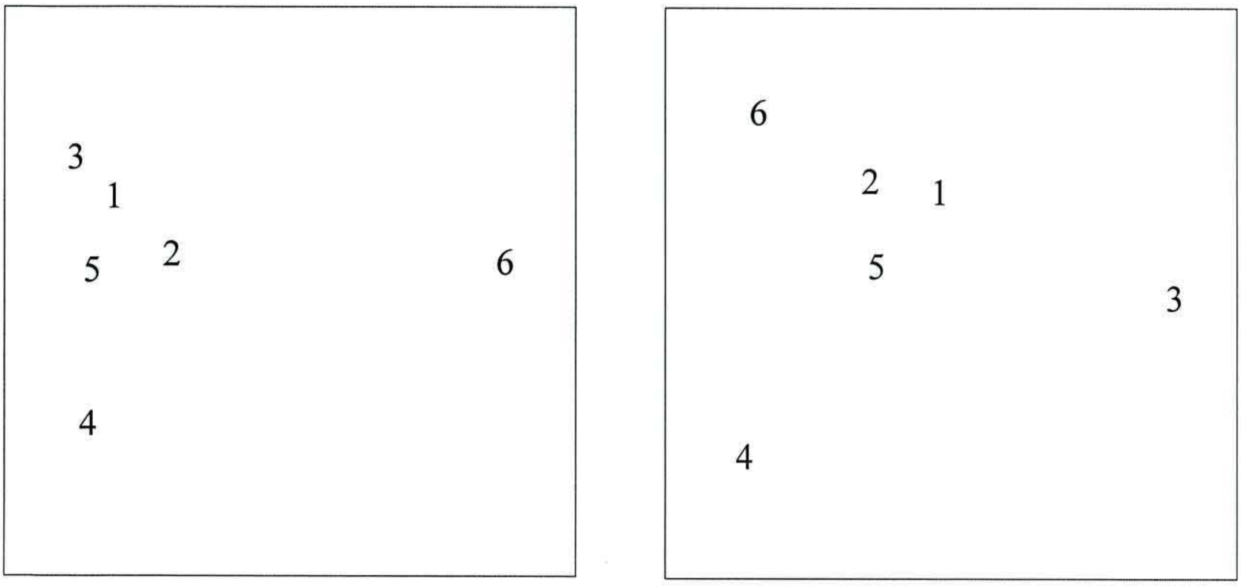


Table 34 Pairwise Spearman rank correlations between similarity matrices derived from averaged fourth-root transformed abundance data. *p<0.05 by a permutation test.

	Macrofauna
Nematodes (Cores)	0.793*

Species analyses.

The impact of dredgings disposal on the macrofaunal community appears to cause a reduction in the abundance of a range of taxa such as *Lanice conchilega*, juvenile *Spisula subtruncata* and *Polinices pulchellus*, which were usually common nearby (see Appendix VIII). Populations of the suspension-feeder *Lanice* with its long ramifying tubes have been shown to promote short-term sediment stability and permit diversification (Eagle, 1975). Thus the elimination of populations of *Lanice* at station 4 (within the disposal site), presumably as a result of the disposal operation, may also limit the scope for successful colonisation by other species. It is also of interest to note the slight elevation in the numbers of the polychaete *Magelona mirabilis* within and immediately to the north of the disposal site. This species is typical of sandy sediments and is thought to be able to tolerate regular or intermittent disturbance at the seabed. The disposal site did not show a proliferation of classical macrofaunal indicators of disturbance or pollution, such as the polychaete *Capitella;* however it is interesting to note enhanced counts of the oligochaete *Tubificoides pseudogaster* at station 5, to the south of the disposal site. This species is more typical of estuarine conditions and may have been derived from populations from within the Mersey estuary transported along with the deposited dredgings (Wildish and Thomas, 1985; Rees *et al.*, 1992). Table 35 shows the breakdown of the average dissimilarity between the station of active disposal (station 4) and all other stations into contributions from each macrofaunal species, with species being ranked in terms of their contribution to the average dissimilarity. Relatively few macrofaunal taxa are more numerous within the disposal station compared to outside (see highlighted taxa within Table 35) and these taxa are different for each station inter-comparison. It can also be seen that the stations located at the ends of the transect (stations 1 and 6) are more dissimilar in terms of their species complement to station 4 than stations closer by (stations 2, 3 and 5). The ratio of $\overline{\delta}_i / S.D.\delta_i$ is also produced in Table 35 for selected macrofaunal species and gives an indication of whether a particular species is a good "discriminator" between samples derived from station 4, compared to samples from other stations along the transect (see Chapter 2 - Methods and Materials). These data indicate that *Polinices pulchellus* appears to be useful in discriminating conditions at stations located at the ends of the transect (stations 1 and 6) from the particular conditions within the disposal site, whereas *Phoronis* sp. discriminates stations to the south of the transect.

Disposal site stations also differed from the others due to the elimination or reduced abundance of a range of nematode species including *Metoncholaimus scanicus*, *Chionolaimus papillatus* and *Spirinia parasitifera* (see Appendix III). Many of the recorded nematode taxa play some part in determining the dissimilarity between the station of active disposal (station 4) compared to those outside the disposal site (Table 36). The most striking effect of dredgings disposal, however, is the proliferation of the non-selective deposit feeders *Daptonema tenuispiculum* and *Sabatieria pulchra* grp. within the disposal sites which consistently contributed to the dissimilarity of the disposal site stations compared with those stations outside (Table 36). Furthermore, a comparison of the faunal assemblage from station 4 (within the disposal site) with stations on the periphery (stations 2 and 5), also identified enhanced numbers of the nematodes *Paracanthonchus c.f. platti* and *Daptonema normandicum* at the disposal site.

Table 35 Breakdown of average dissimilarity between the station of active disposal and all other stations into contributions from each macrofaunal species; species are ordered in decreasing contribution to the average dissimilarity (cut-off at 60% average dissimilarity).

Station 4,1	$\bar{\delta}_i/S.D.\delta_i$	Station 4,2	$\bar{\delta}_i/S.D.\delta_i$	Station 4,3	$\bar{\delta}_i/S.D.\delta_i$	Station 5,4	$\bar{\delta}_i/S.D.\delta_i$	Station 6,4	$\bar{\delta}_i/S.D.\delta_i$
Chaetozone setosa	4.54	*Spisula subtruncata* (juv.)	12.05	*Echinocardium cordatum*	4.94	*Phoronis*	21.77	*Lanice conchilega*	18.93
Pholoe minuta	7.61	*Nephtys hombergii*	1.77	***Ophiura* (juv.)**	**4.99**	*Lanice conchilega*	8.10	*Pholoe minuta*	9.21
Phaxas pellucidus	9.86	*Spisula subtruncata*	23.81	*Lanice conchilega*	5.68	*Pseudopolydora pulchra*	6.33	*Phaxas pellucidus*	8.95
Eteone longa	5.71	*Lanice conchilega*	2.89	*Tellimya ferruginosa*	1.33	*Nucula nitidosa*	2.65	*Tellimya ferruginosa*	4.03
Nucula nitidosa	2.15	*Eteone longa*	10.43	*Nephtys hombergii*	1.98	***Abra alba***	**4.72**	*Amphiura brachiata*	9.07
Spisula subtruncata (juv.)	1.85	*Mactra stultorum*	2.34	*Pseudopolydora pulchra*	1.33	ACTINIARIA	3.13	*Nucula nitidosa*	2.57
Polinices pulchellus	12.53	*Pharus legumen*	1.59	***Diastylis bradyi***	**1.25**	*Eumida bahusiensis*	6.74	ACTINIARIA	8.58
Spisula subtruncata	5.71	*Phaxas pellucidus*	1.31	*Pharus legumen*	1.55	*Pharus legumen*	1.87	*Lagis koreni*	3.48
Ampelisca brevicornis	6.51	*Nucula nitidosa*	1.66	***Perioculodes longimanus***	**1.33**	*Liocarcinus (juv.)*	27.02	***Magelona mirabilis***	**2.33**
Lutraria sp. (juv.)	10.05	ACTINIARIA	1.32	***Abra alba***	**1.14**	*Abludomelita obtusata*	8.46	*Lutaria* sp.(juv.)	5.99
Glycera tridactyla	**1.89**	*Lutraria* sp. (juv.)	1.30	***Synchelidium maculatum***	**1.33**	***Lagis koreni***	**1.35**	*Echinocardium cordatum*	5.83
Spio decorata	6.48	*Spio decorata*	4.25	Amphiuridae (juv.)	1.33	*Nephtys hombergii*	1.48	*Abludomelita obtusta*	4.22
Pharus legumen	1.70	*Phoronis* sp.	1.33	*Mactra stultorum*	1.16	*Pholoe minuta*	1.28	*Polinices pulchellus*	20.42
Lanice conchilega	1.33	*Spiophanes bombyx*	1.32	*Sigalion mathildae*	1.05	*Tubificoides pseudogaster* (agg.)	1.33	*Harmothoe lunulata* (agg.)	7.17
Magelona mirabilis	**1.20**	*Fabulina fabula*	5.19	***Bathyporeia guilliamsoniana***	**0.67**	*Balanus crenatus*	1.28	*Eumida bahusiensis*	7.36
Nephtys hombergii	1.10	*Pseudopolydora pulchra*	1.22	*Pholoe minuta*	0.67	*Chaetozone setosa* (agg.)	1.19	*Phoronis* sp.	26.89
Mysella bidentata	1.59	*Polinices pulchellus*	1.32	***Magelona mirabilis***	**1.35**	*Polinices pulchellus*	1.32	*Pseudopolydora pulchra*	6.95
Gyptis helgolandica	1.25	***Mysella bidentata***	**1.45**			*Fabulina fabula*	4.97	*Mysella bidentata*	2.20
Harmothoe lunulata	1.33	***Diastylis bradyi***	**1.22**			*Lutraria* sp. (juv.)	1.33	*Pharus legumen*	1.86
Ensis arcuatus	1.33	*Poecilochaetus serpens*	1.18					*Liocarcinus* (juv).	6.31
Amphiura brachiata	1.28	*Pholoe minuta*	1.31					*Chamelea gallina*	14.98
Corbula gibba	1.32	*Glycinde nordmanni*	1.31					*Spisula subtruncata* (juv.)	15.21
Chamelea gallina	1.32	*Ensis ensis*	1.31					*Conopeum reticulum*	26.89
		Elminius modestus	0.95					*Gattyana cirrosa*	26.89
		Sigalion mathildae	1.42						
		Eteone picta	1.43						

Average dissimilatity between 4 & 1
= 58.84

Average dissimilatity between 4 & 2
= 56.54

Average dissimilatity between 4 & 3
= 44.46

Average dissimilatity between 5 & 4
= 57.50

Average dissimilatity between 6 & 4
= 62.64

Highlighted taxa are more numerous at station 4.

Table 36 Breakdown of average dissimilarity between the station of active disposal and all other stations into contributions from each nematode species; species are ordered in decreasing contribution to the average dissimilarity (cut-off at 60% average dissimilarity).

Station 4,1	$\bar{\delta}_i/S.D.\delta_i$	Station 4,2	$\bar{\delta}_i/S.D.\delta_i$	Station 4,3	$\bar{\delta}_i/S.D.\delta_i$	Station 5,4	$\bar{\delta}_i/S.D.\delta_i$	Station 6,4	$\bar{\delta}_i/S.D.\delta_i$
Metoncholaimus scanicus	3.40	*Metoncholaimus scanicus*	1.85	*Chonolaimus papillatus*	8.37	*Chonolaimus papillatus*	8.93	*Metoncholaimus scanicus*	3.73
Dichromadora cucullata	4.24	***Daptonema tenuispiculum***	2.94	*Paralongicyatholaimus minutus*	13.45	***Daptonema tenuispiculum***	4.41	*Polysigma fuscum*	3.71
Spirinia parasitifera	3.89	***Sabatieria pulchra grp.***	5.86	*Spirinia parasitifera*	1.86	***Sabatieria pulchra grp.***	3.29	*Spirinia parasitifera*	2.91
Chonolaimus papillatus	14.34	*Polysigma fuscum*	7.10	*Paracanthonchus longicaudatus*	1.31	*Neochromadora spp.*	6.37	*Calomicrolaimus honestus*	3.35
Prochromadorella attenuata	5.24	*Microlaimus conothelis*	4.98	***Paracanthonchus c.f platti***	1.31	*Sphaerolaimus balticus*	7.69	***Daptonema tenuispiculum***	2.63
Microlaimus conothelis	13.88	*Neochromadora spp.*	7.34	*Chromaspirinia sp*	1.71	*Mesacanthion diplechma*	1.75	*Metalinhomoeus filiformis*	4.05
Chromaspirina sp.	3.64	*Chonolaimus papillatus*	11.34	***Thalassoalaimus tardus***	1.84	*Odontophora sp.2*	1.87	*Microlaimus conothelis*	6.6
Leptolaimus luridus	8.94	*Spirinia parasitifera*	2.63	*Microlaimus sp.4*	1.32	*Microlaimus conothelis*	13.66	*Dagda bipapillata*	7.99
Desmodora c.f communis	3.48	*Desmodora c.f. communis*	3.07	***Ascolaimus elongatus***	1.31	*Chromadorita c.f. nana*	13.66	*Neochromadora spp.*	14.36
Paracanthonchus longus	9.33	*Enoplolaimus sp.*	9.28	***Cricolaimus elongatus***	1.18	*Leptolaimus sp.3*	13.66	*Leptolaimus sp.3*	14.79
Pomponema debile	2.74	*Paralongicyatholaimus minutus*	6.65	*Prochromadorella attentuata*	1.32	*Marylynnia complexa*	1.76	***Sabatieria pulchra grp.***	2.25
Prochromadorella ditlevseni	6.02	*Molgolaimus sp.*	12.04	*Neochromadora spp.*	1.32	*Viscosia elegans*	1.89	*Chromaspirina sp.*	2.46
Sabatieria celtica	2.61	*Pomponema debile*	2.02	***Sabatieria pulchra grp.***	1.32	*Paracanthonchus longicaudataus*	2.40	*Molgolaimus sp.*	6.01
Metalinhomoeus filiformis	3.60	*Mesacanthion diplechma*	1.80	*Microlaimus turgofrons*	0.97	*Sabatieria celtica*	1.58	*Sphaerolaimus balticus*	19.98
Mesacanthion diplechma	2.72	*Chromadorina sp.*	8.37	*Dichromadora cucullata*	0.97	*Spirinia parasitifera*	1.30	*Leptolaimus luridus*	1.32
Richtersia sp.	5.68	*Viscosia elegans*	1.88	*Desmodora c.f.communis*	0.96	***Paracanthonchus c.f. platti***	1.43	*Paralongicyatholaimus minutus*	20.12
Microlaimus sp.4	16.86	*Leptolaimus sp.3*	1.31	***Sabatieria ornata***	0.90	*Viscosia abyssorum*	1.53	*Desmodora c.f. communis*	2.46
Leptolaimus sp. 3	15.41	***Paracanthonchus c.f platti***	1.37	***Daptonema normandicum***	0.89	*Richtersia sp*	2.30	*Cyartonema elegans*	5.59
Eumorpholaimus sp.	14.02	*Paracanthonchus longicaudatus*	2.38	*Neochromadora munita*	0.89	*Cricolaimus elongatus*	1.33	*Rhabdocoma americana*	8.38
Polysigma fuscum	5.02	*Leptolaimus luridus*	1.33	*Pseudonchus deconincki*	0.88	***Daptonema normandicum***	1.92	*Microlaimus sp.4*	10.3
Daptonema tenuispiculum	6.37	*Calomicrolaimus honestus*	1.65	*Odontophora sp.2*	0.84	*Metalinhomoeus longiseta*	1.32	*Theristus denticulatus*	8.17
Viscosia elegans	2.64	*Metalihomoeus filiformis*	1.33	*Viscosia elegans*	0.78	*Campylaimus sp.*	1.32	*Paracanthonchus longus*	17.14
Paralongicyatholaimus minutus	4.60	*Chromadorita tentabunda*	1.31	***Sabatieria celtica***	0.75			*Mesacanthion diplechma*	1.63
Sphaerolaimus balticus	6.04	***Daptonema normandicum***	1.20					*Metalinhomoeus longiseta*	1.3
Chromadorina sp	6.63							*Viscosia elegans*	1.36
Paracanthonchus longicaudatus	1.72							*Pomponema debile*	1.67
Cobbia trefusiaeformis	3.45							*Paracanthonchus longicaudatus*	2.39
Oxystomina asetosa	7.54							*Richtersia sp.*	3.14
Rhabdodemania major	2.25								
Chromadorita tentabunda	5.48								
Chromadorita nana	1.32								
Average dissimilatity between 4 & 1 = 63.46		Average dissimilatity between 4 & 2 = 57.52		Average dissimilatity between 4 & 3 = 42.47		Average dissimilatity between 5 & 4 = 46.48		Average dissimilatity between 6 & 4 = 60.68	

Highlighted taxa are more numerous at station 4.

4.2.3 Biotic and environmental relationships

Table 37 shows the concentrations of trace metals and other environmental variables from Day grab samples taken along the transect. There appears to be very little variation in sediments between stations. Vertical stratification of the sediments in the disposal site presents some difficulties in quantifying the physico-chemical nature of the benthic habitat (Table 40). Rees *et al.* (1992) reported that the macrofauna from this area are generally confined to the oxic surface layers and hence sediment sub-samples taken from grabs from the upper 5cm should allow realistic comparisons with the fauna. Some caution is also required in relating the biotic data to the trace metal levels that were determined from sediments from a separate grab sub-sample. For chromium, copper, nickel, lead and organics, from sediments taken from grabs there is no evidence to suggest levels at the disposal site are proportionately enriched compared with those nearby. However, for cadmium, mercury and zinc there does appear to be a slight enhancement in their concentrations in sediments from the disposal site station 4, which may be accounted for by recently deposited dredged material from the Mersey estuary. Analysis of the core samples indicates local patchiness in both the physical nature and trace metal levels of the sediments (Table 38) although, generally, sediments from station 3 have enhanced levels of a range of trace metals (Table 39).

The presence of tomato seeds (albeit in low numbers) and other artefacts were also noted at some of the sampling stations, indicating the potential for wide dispersal of particulates within the inner Bay (see Table 40). Possible sources include sewage-sludge disposal from ships to the west of the sampling area, pipeline discharges and the disposal of sewage-contaminated sediments dredged from within the estuary.

Table 37 Concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 6 from Day Grab samples.

Station	*%C*	*%OrgC*	*% N*	*% s/c*	*% S*	*% G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
1	3.79	2.51	0.34	8.62	91.05	0.33	<0.20	101.92	48.39	0.85	38.47	129.04	142.76
2	3.56	2.17	0.27	5.85	92.44	1.72	<0.19	84.80	38.62	0.74	38.72	108.06	238.40
3	3.74	2.28	0.26	11.74	88.21	0.05	<0.20	101.27	55.28	1.12	41.72	111.84	291.38
4	3.59	2.21	0.26	3.48	96.43	0.09	0.31	96.55	51.82	1.22	38.86	123.30	329.87
5	3.79	2.38	0.27	6.10	93.84	0.06	<0.19	93.44	51.46	1.01	41.06	109.66	288.96
6	2.96	0.87	0.07	6.65	92.89	0.47	<0.19	57.14	18.16	0.10	27.05	31.90	101.90

Table 38 Concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 6 from replicated core samples.

Station	*% C*	*% OrgC*	*% N*	*% G*	*% S*	*% s/c*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
1A	3.41	2.13	0.39	0.10	93.03	6.87	<0.18	73.4	47.0	1.06	36.20	109	264
1B	3.06	1.96	0.39	1.07	90.48	8.45	<0.21	51.9	29.9	0.61	27.50	68	166
1C	3.27	2.14	0.38	0.63	96.19	3.17	<0.22	69.5	44.8	1.08	33.30	101	226
2A	2.35	1.64	0.19	0.24	96.34	3.42	0.26	66.7	48.8	1.19	26.90	109	256
2B	3.44	2.33	0.34	3.11	93.61	3.28	<0.19	62.3	36.6	0.75	31.30	86	193
2C	3.06	1.93	0.24	2.95	94.06	2.99	0.20	73.2	36.0	0.17	32.12	91	224
3A	3.99	2.76	0.37	0.01	90.87	9.12	0.16	79.4	56.2	0.32	30.10	106	271
3B	2.71	2.31	0.26	0.14	92.72	7.14	0.38	80.3	59.2	0.20	32.90	112	290
3C	3.2	2.29	0.27	0.06	91.04	8.90	0.27	86.1	57.6	1.35	33.80	110	290
4A	5.19	1.96	0.24	0.04	96.73	3.23	<0.22	79.9	43.9	0.94	27.90	82.7	251
4B	2.94	1.63	0.21	0.03	98.12	1.85	<0.17	56.0	34.2	0.74	22.10	61.3	182
4C	3.19	2.16	0.25	0.03	97.46	2.51	<0.18	86.9	49.6	1.26	31.80	96.2	265
5A	3.1	2.12	0.25	0.00	96.37	3.63	<0.23	65.2	37.6	0.70	26.30	69.7	203
5B	3.19	2.05	0.24	0.10	95.00	4.90	<0.21	67.2	40.6	0.80	31.40	74.2	207
5C	3.81	2.61	0.42	0.10	96.14	3.76	0.27	66.8	41.6	0.75	32.70	69.9	217
6A	2.98	1.95	0.24	1.08	95.45	3.47	<0.20	53.2	34.4	0.66	24.70	66.2	181
6B	3.25	2.18	0.28	0.49	93.26	6.25	<0.21	55.0	33.6	0.59	27.20	68.3	181
6C	2.97	1.99	0.25	0.73	94.84	4.43	<0.23	60.5	37.7	0.45	32.70	43.2	200

Table 39 Mean trace metal concentrations (mg kg^{-1}dry weight) of mean trace metals and other environmental variables at Stations 1 to 6 from core samples

Station	*% C*	*% OrgC*	*% N*	*% G*	*% S*	*% s/c*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
1	3.25	2.08	0.39	0.68	93.38	5.94	0.20	64.93	40.57	0.92	32.33	92.7	219
2	2.95	1.97	0.26	2.58	94.12	3.31	0.22	67.40	40.47	0.70	30.11	95.3	224
3	3.30	2.45	0.30	0.10	92.18	7.72	0.27	81.93	57.67	0.62	32.27	109.3	284
4	3.77	1.92	0.23	0.03	97.39	2.57	0.19	74.27	42.57	0.98	27.27	80.1	233
5	3.37	2.26	0.30	0.07	95.85	4.08	0.24	66.40	39.93	0.75	30.13	71.3	209
6	3.07	2.04	0.26	0.81	94.62	4.57	0.21	56.23	35.23	0.57	28.20	59.2	187

Table 40 Field sediment descriptions and observations on the occurrence of artefacts derived from Day Grab samples from stations 1 to 6. The estimated depth of grab sample collected is given.

Station	*Depth of Grab (cm)*	*Sediment description*	*Material >1mm*	*Material < 1mm*	*Tomato seeds*
1A	6.0	Muddy sand		Coal, clinker, wood	
1B	6.5	Muddy sand	Organic detritus	Clinker, brick, wood	
1C	8.5	Muddy sand with shell		Clinker, coal, brick, wood	
2A	5.0	Muddy sand	Brick	Clinker, coal, brick, wood	1
2B	6.0	Muddy sand	Brick, stones	Clinker, coal, brick, wood	
2C	6.0	Muddy sand with fine gravel	Stones	Clinker, coal, brick, wood	
3A	5.0	Muddy sand over anoxic mud	Brick, sanitary liner	Wood, seeds	
3B	5.0	Muddy sand over mud		Wood, organic detritus	1
3C	6.5	Muddy sand over mud		Clinker, coal, brick, wood	
4A	5.5	Muddy sand			
4B	6.0	Fairly clean sand over muddy sand and mussel shells			
4C	8.0	Fairly clean sand over muddy sand			
5A	7.0	Muddy sand		Clinker, coal, brick, wood	
5B	5.0	Shelly muddy sand			1
5C	7.0	Muddy sand			2
6A	10.0	Muddy shelly sand		Coal, brick, wood	
6B	7.0	Muddy shelly sand		Coal, brick, wood	
6C	10.0	Muddy shelly sand		Coal, brick, wood	

PCA ordinations of log-transformed environmental variables from sediments taken from grabs revealed that the most southern station (station 6) along the transect was isolated from all other stations (Figure 31). This is due to the lower concentrations of metals found in the sediments from this station. The ordinations derived from PCA of log-transformed environmental variables from cores showed a slightly different spatial arrangement of the stations, with the disposal site stations separated from all other stations (Figure 31). However, when the similarity matrices derived from the environmental data were compared with the biotic similarity matrices they were not found to be significantly related ($p>0.05$).

Table 41 Rank correlations (ρ) between the Euclidean distance matrices derived from environmental variables (log (1+X) transformed) in sediments taken from grabs and cores and similarity matrices derived from square-root transformed biotic data.

	Environmental variables (Grab)	Environmental variables (Cores)
Macrofauna	-0.018	0.443
Nematodes (Cores)	0.039	0.379

Appendix XXII shows Pearson product moment correlations between each of the environmental variables from sediments sampled using grabs. It can be seen that many of the environmental variables are significantly correlated ($p<0.05$). Where $r>0.95$ a variable was chosen arbitrarily as a proxy for the correlated variables in BIO-ENV analyses. Thus, % silt and clay was omitted from the analyses being represented by % sand, and Cu replaced Cr, Hg, Ni, Pb, Org.C and %C.

Table 42 Spearman rank correlations between macrofauna and environmental similarity matrices derived from grabs.

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	**Cd**	**0.752**
2	%S*,Cd	0.732
3	%S*,Cd, Zn	0.689

* is a proxy for % silt and clay.

Table 43 Spearman rank correlations between nematode (cores) and environmental similarity matrices (grabs).

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	Cd	0.496
2	Cd,Zn	0.696
3	**%G,Cd,Zn**	**0.743**

The output from BIO-ENV using environmental data determined from sediments taken from grab samples suggests that macrofaunal community structure is determined by Cd or some other unmeasured but correlated factor (Table 42); sediment type is also influential in combination at slightly lower correlation levels. Nematode community structure is related to a 3 variable combination of Cd, Zn and % gravel (Table 43).

Appendix XXIII shows Pearson product moment correlations between each of the environmental variables from sediments sampled using cores. After removing Zn values because of the significant correlation with Cr (r>0.95), the BIO-ENV procedure was repeated using environmental data from core sediments. The results indicate that both the macrofauna and nematode data are related to the C and N content of sediments, to the sedimentary parameters and certain sedimentary metal concentrations (see Table 44 and 45).

Table 44 Spearman rank correlations between macrofauna and environmental similarity matrices derived from cores.

Number of variables	*Best variable combination*	*Correlation (pw)*
1	%S	0.461
2	%C,Cd	0.711
3	%C, %S,Cd	0.775
4	**%C,%N,%S,Cd**	**0.825**
5	%C,%N,%G,Cd,*Cr	0.739

* Cr is a proxy for Zn

Table 45 Spearman rank correlations between nematode (cores) and environmental similarity matrices (cores).

Number of variables	*Best variable combination*	*Correlation (pw)*
1	%G	0.654
2	%C,*Cr	0.682
3	%C,%S,Cd	0.732
4	%G,%S,Cd,Hg	0.739
5	**%C,%OrgC,%N,%G,*Cr**	**0.768**
6	%C,%OrgC,%N,%G,Cd	0.732

* Cr is a proxy for Zn

4.3 DISCUSSION

Dredgings disposal at this site appears to cause an increase in the dominance of nematode non-selective deposit feeders, thereby shifting the balance of feeding groups from that typical of sandy sediment to that resembling a muddy sediment. This increase was largely attributable to the dominance of *Daptonema tenuispiculum* and *Sabatieria pulchra* group. These taxa were also recorded as dominating the nematode fauna at this site in 1991 (Somerfield *et al.*, 1995). Such a consistent response is somewhat surprising in light of the appreciable change to the sediment type that has occurred within the disposal site between survey dates. In 1991 Somerfield *et al.* (1995) recorded a mean % silt and clay content of >82% from station 4 (station 5 in Somerfield's paper) as derived from sub-samples from grabs. Analyses of sediments sampled in the same way at this station in 1996 during this study revealed a markedly lower proportion of fines. Indeed, the mean % silt and clay content was recorded as only 3%. This considerable shift in the sediment type at the disposal site is probably the result of a difference in the nature of the material deposited in the period preceding each survey. Prior to the 1996 survey, effort had been apparently directed towards dredging the sandbanks in the outer reaches of the Mersey estuary (N. Gilbert, M.A.F.F. *pers. comm*). Despite this difference, it would appear that sediment type, expressed in terms of the proportion of fines, is not the most important environmental factor responsible for causing the observed enhancement of these nematode taxa at the disposal site. Variation in the nature of the deposited material as well as the natural variability in the prevailing sediment type at the seabed (see Introduction, this Chapter) inevitably complicate the identification of cause and effect relationships. However, *Sabatieria pulchra* and *Daptonema* sp. are recognised as typical thiobiotic species capable of surviving in anoxic sediment (Jensen, 1987; Jensen *et al.*, 1992; Hendelberg and Jensen, 1993 and references therein; Dando *et al.*, 1995). It is conceivable therefore that these taxa are able to flourish within the disposal site due to changes to the sediment associated with the strongly reducing conditions that prevail just below the sediment surface. Although measurements of Eh were not undertaken in the current study, previous surveys have recorded reduced Eh values close to the surface from cores of sediment taken from within the disposal site. Further sampling would be necessary to test whether such taxa flourish as a consequence of the chemical changes to the sediment associated with the development of anoxia within silty deposits and the concomitant reduction in competition and predation pressure.

The output from BIO-ENV using environmental data from grabs indicated that a combination of sedimentary metal concentrations and gravel content were important factors for determining the structure of the nematode community along the transect in 1996. That gravel content is among one of the combination of variables found to "best" explain the nematode distribution may be a response to the small amount of capital dredgings deposited at the site in 1995. If this were the case, this would seem to provide further evidence that nematode communities reflect the short-term consequences of dredgings disposal (Somerfield *et al.*, 1995).

Components of the macrofaunal community in the disposal site have, however, changed since the 1991 survey, with the dominant deposit feeder *Lagis koreni* being replaced by another deposit feeder *Magelona mirabilis*, which is more adapted to life in sands. Previously, Rees *et al.* (1992) found that both *L. koreni* and *A. alba* were useful indicators of dispersing fines from dredgings disposal operations in Liverpool Bay. This is in contrast to the findings of the current study where both these taxa were found to be reduced in areas thought to be influenced by dispersing particulates. Marked annual fluctuations are a feature of *Lagis* dominated assemblages and this has been assumed to be a consequence of variations in recruitment success, adult mortality through storm events (Nicolaidou, 1983) and oxygen deficiency (Nichols, 1977) as well as the feeding activities of the animals themselves (Eagle, 1975). Therefore, the reduced dominance of this species at the disposal site may not necessarily be the direct result of changes in the quality of the deposited dredgings. This emphasises the dangers of relying on "indicator taxa" for conclusively demonstrating the effects of anthropogenic disturbance. Although the numerical dominants of the macrofaunal community from the disposal site have altered between surveys, the principal environmental factors i.e. sedimentary metal concentrations governing the distribution of the macrofaunal community as a whole, remain the same. Of course, this does directly imply that contaminant effects from these particular metals are responsible for regulating the macrofaunal community at this site. Metal concentrations may simply be correlated with some other unmeasured property also reflecting the long-term fate of deposited material (see Clarke and Ainsworth, 1993). For example high levels of TBT from within Liverpool Docks have been recorded and disposed of at the site in recent years (M.A.F.F. unpublished data).

Trends in the nematode community identified both by univariate and multivariate analyses revealed that stations within (stations 3 and 4) and to the south of the disposal site (station 5) were most affected by dredgings disposal. Disturbance peripheral to the site is most likely due to the transport of material as bed load. Advection by residual currents and wave driven movement from north-westerly winds are suggested as the factors responsible for transport of material to this station. A gradient of effect emanating from the disposal site was also demonstrated with macrofaunal community analyses, though effects to the south of the disposal site arising from the transport of dispersing particulates were not so pronounced. It has been suggested that the nutritional quality of dispersing material may contribute to an enrichment effect (Zambriborsch, 1982; Rees *et al.*, 1992). Thus, differences in the severity of impacts from the settlement of fines may be related to the differential response that both communities exhibit to an enhanced food supply. Nematodes are known to have highly specialised feeding preferences (Moens and Vincx, 1997 and references therein) and hence the nature of the food supply is likely to be an important factor governing the diversity of this group (Warwick, 1981a). Indeed, the ratio of nematode feeding groups appeared to be a useful index of disturbance at this site. In contrast, food supply may have a lesser role in maintaining the diversity of the macrofaunal community with, for example, competition for space being more critical (Whitlach, 1980).

This study demonstrates the need for temporal studies at large dredgings disposal sites as "one-off" studies fail to address the variability associated with alterations in dredging practices or changes in environmental conditions. Equally it is apparent that when licences are being granted for the disposal of dredgings greater effort should be directed towards quantifying the physical nature and organic content of the material being disposed of, not just the contaminant burden.

5. A COMPARISON OF THE RESPONSES OF MEIOFAUNAL AND MACROFAUNAL COMMUNITIES AT THE LUNE DEEP DREDGED MATERIAL DISPOSAL SITE.

5.1 INTRODUCTION

The Lune Deep is located within the greater Morecambe Bay area in the north-eastern Irish Sea. Approximately 0.9MT of maintenance dredgings are disposed of annually at a site located at 35m depth in the northern end of the Lune Deep (Figure 32). The material arises from the dredging of navigable channels in the River Wyre and Fleetwood Docks and disposal can occur up to several times each month. In 1996 as part of a M.A.F.F. licence condition, eight samples of dredged material were analysed for contaminants, and the levels were found to be low (see Table 46). Particle size analysis was also undertaken on the samples and the results showed the material to be on average 95% sand and 5% silt and clay. However, it is likely that both the particle size and contaminant burden of the dredgings will vary to some extent depending on the location of dredging.

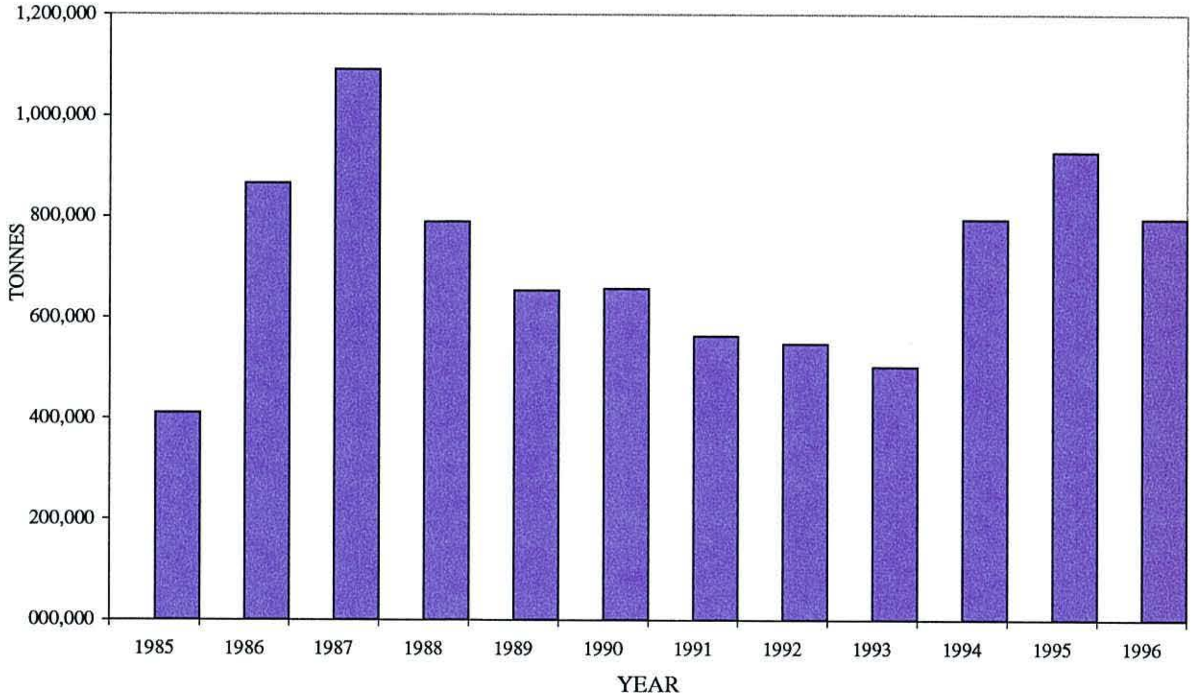
At the south-western end of the Lune Deep, tidal currents run parallel to the Deep with flood directed currents of 0.8kt being slightly stronger than ebb directed currents. Sediments here are considered to represent a muddy-sand depositional area whereas further north, in the vicinity of the disposal site, sediments are coarser in nature (Rostron, 1992). Sediment transport patterns follow constant counter-clockwise circulation and result in a highly mobile sediment on the seabed (McLaren, 1989) (see Figure 33). Most of the Lune Deep is protected from wave action, with seabed interaction only likely to occur about 9% of the time in water depths of 30m (Pringle, 1987). In Morecambe Bay, sedimentary trace metal concentrations have been found to be positively correlated with the percentage fines, although this relationship breaks down in sediments that are predominately sand (Rostron, 1992).

Whilst several studies have examined environmental impacts in the Morecambe Bay area, most have been concerned with monitoring the effects of gas field developments on the benthos and seabed geochemistry (Law *et al.*, 1989; Rees, 1994). Previous marine biological studies within the Lune Deep itself have been less numerous. Using diving techniques Emblow (1992) investigated the cobble and boulder habitat of the borders of the Lune Deep. A more widespread survey of benthic communities over the whole of Morecambe Bay, which included stations located within the Lune Deep, was carried out by the Joint Nature Conservation Committee (J.N.C.C.) (Rostron, 1992). The aim of the J.N.C.C. survey was to characterise the habitats and benthic communities of the area and attempt to relate benthic faunal distributions to sediment transport information and contaminant data. Rostron (1992) identified 16 benthic "communities" in the Morecambe Bay area using cluster analysis, though the species assemblages identified suggested that most were variations of the "*Amphiura*", "*Abra*" and shallow "*Venus*" communities recognised by other workers (Petersen, 1924; Jones, 1950; Buchanan, 1963). Day grab samples collected from stations at the south-west end of the Lune Deep were distinguished by species such as *Lagis koreni*, *Nucula nitidosa*, *Mysella bidentata* and *Nephtys hombergii* with lower densities of *Abra alba* and *Ophiura ophiura*. This group of stations was considered to resemble a classical "*Abra*" community and is known to occur in small localised patches in embayments throughout the Irish Sea (Jones, 1950). Sampling stations located within the central parts of the Lune Deep were found to have a lower species diversity, although in terms of relative abundance the overwhelming feature of samples from this area was the numerical dominance of *Lagis koreni*, with densities of >3000 per m^{-2}. *Mysella bidentata* also occurred in large numbers. However, there was an abrupt decline in all population densities in the northern part of the Deep, from a line just south of the dredged material disposal site.

Table 46 Mean metal concentrations (mgl^{-1}wet weight) of dredgings from areas within the River Wyre and Fleetwood Docks. Source – Unpublished M.A.F.F. Data.

% solids	*As*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
75.3	6.1	0.12	15.1	4.5	0.08	8.1	13.2	40.4

Figure 32 The quantity of maintenance dredged material disposed of annually between 1985 and 1996 into the Lune Deep disposal site.



5.1.1 Sampling design

Three replicate Day grab and core samples were collected at 7 stations from a transect through the Lune Deep dredged material disposal site in line with the prevailing tidal currents. Two of the stations (1 and 2) were located within the dredged material disposal site whereas stations 3 and 4 were located on the periphery (~0.5 km and 1.5 km respectively) of the site and stations 5, 6 and 7 were more distant (3.5, 5.6, 8.3 km respectively) (see Figure 34). Bedrock was found to the north of the disposal site and therefore no samples could be taken in this area. Collected samples were processed according to the procedures described in

Chapter 2. Due to difficulties in obtaining enough intact cores from the coarse sediments within the disposal area for meiofauna analyses, only one core was available from station 1 and two from station 2 for trace metals analysis.

5.2 RESULTS

5.2.1 Univariate measures of community structure

Nematode "feeding types"

Non-selective deposit feeders (1B) are the most numerically dominant feeding type recorded, accounting for, on average, >50% of nematodes at all stations (Table 47). Moreover, the disposal site stations supported the highest densities of this group of animals and, with the exception of station 7, their relative importance tended to decrease with distance away from the disposal area (Figure 35). Dominance of the 1B group of nematodes within the disposal site is primarily due to the abundance of *Sabatieria pulchra* group and *Daptonema tenuispiculum* (Figure 36). Relatively high numbers of *S. pulchra* grp. also occur at the southernmost station (7) which is characterised by a significantly higher silt-clay content than the others. Unlike counts of *S. pulchra* grp., numbers of *D. tenuispiculum* are not elevated at the southernmost station yet are numerically dominant within the disposal site. This suggests that the latter species may be better suited as an "indicator" of disturbance from dredgings disposal at this site. In addition, the ratio of non-selective deposit feeders to epigrowth feeders (1B/2A) appeared to be a useful indicator of the effects of dredged material disposal, since significantly higher ratios were recorded within the disposal site (**Figure 37**).

Figure 33 The pattern of sediment transport within Morecambe Bay (After Rostron, 1992).

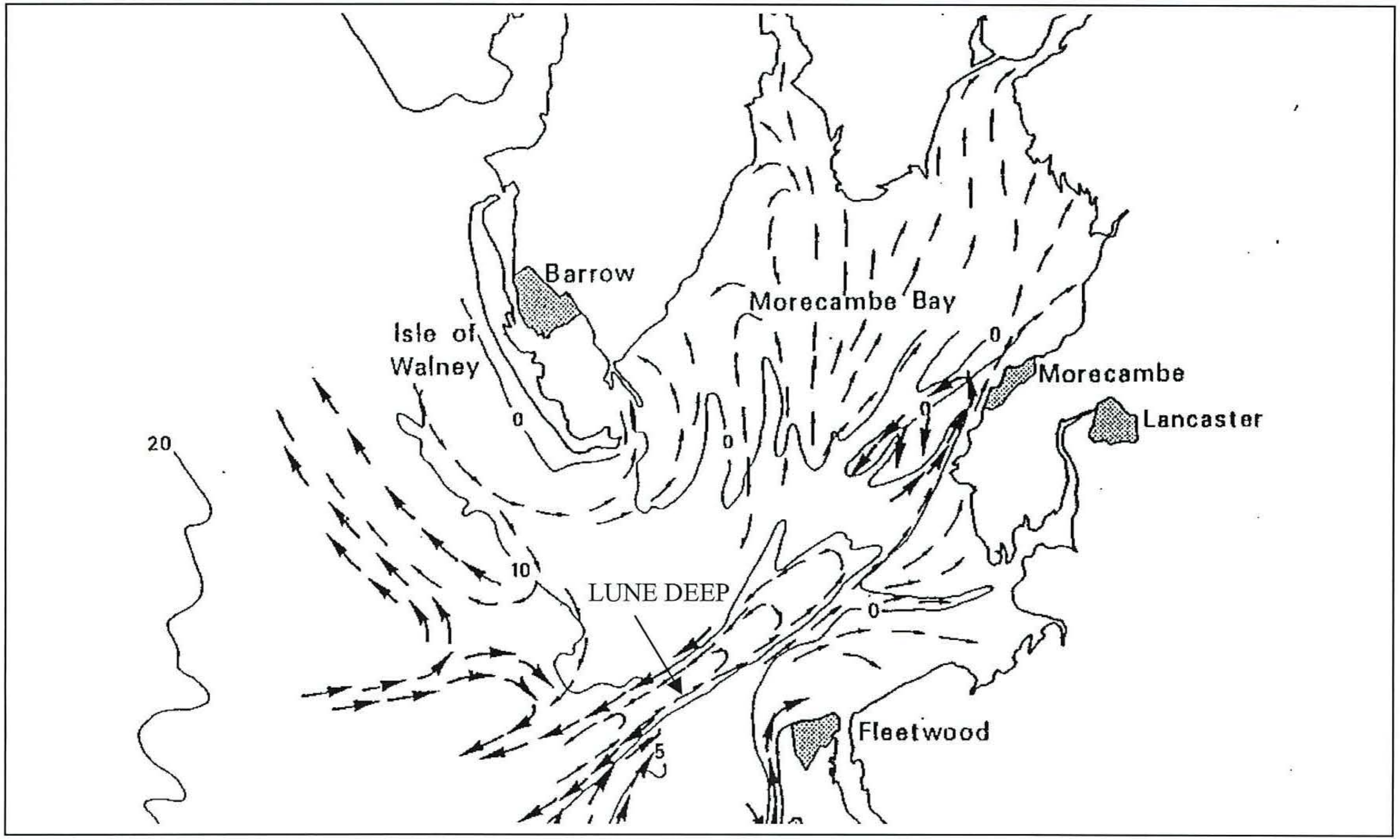
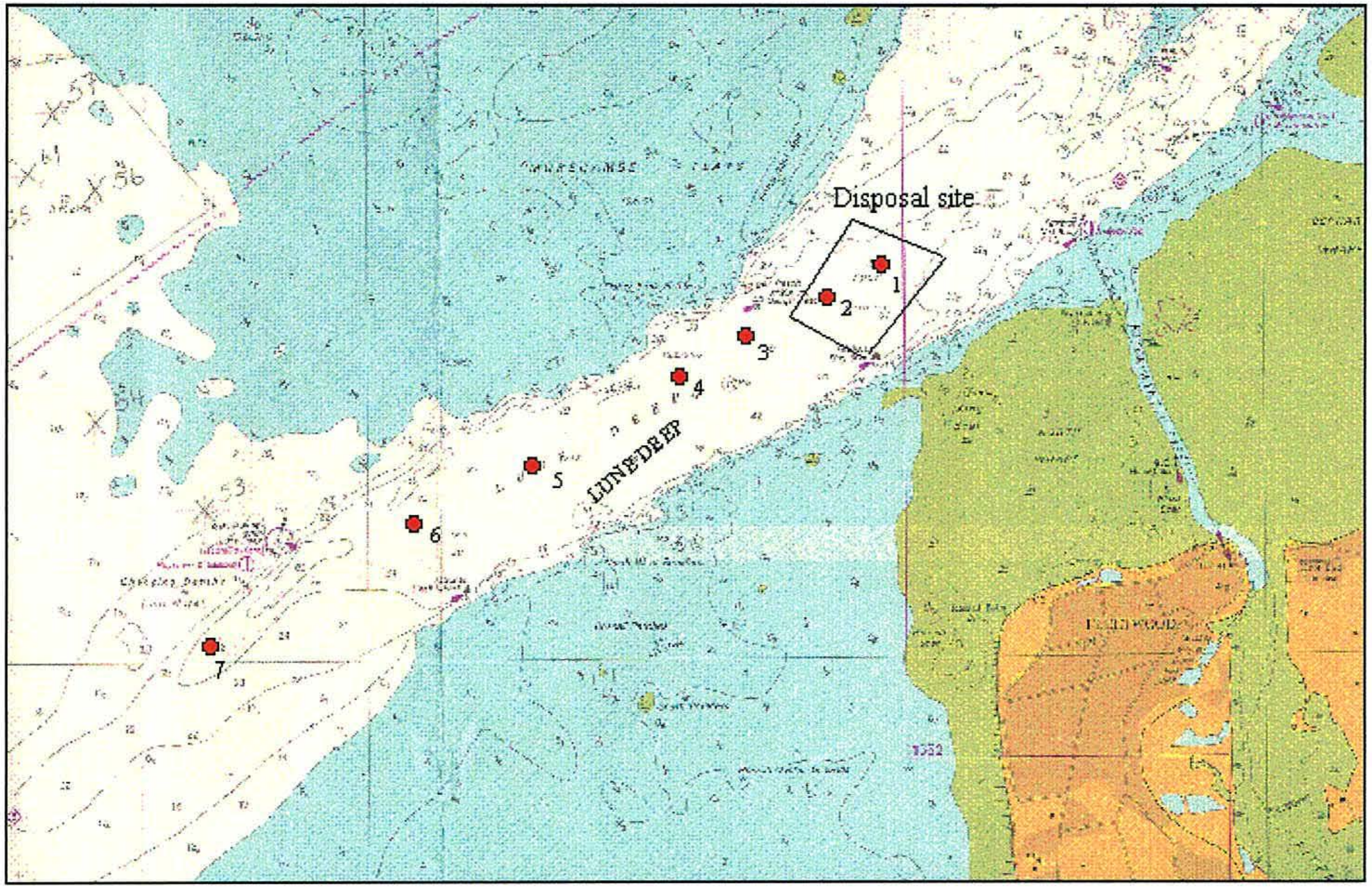


Figure 34 The location of the sampling stations (1 to 7) in relation to the Lune Deep dredgings disposal site (box).



Diversity Measures

Adverse effects of dredgings disposal on the macrofaunal assemblages were not detectable from estimates of the numbers of species (log 1+S) or species richness (d). Indeed, estimates of these parameters showed that station 1 within the Lune Deep disposal site was the richest in terms of its species complement (Figure 38). Evenness (J) was also reduced at this station compared to adjacent stations (Stations 2, 3, and 4). The lowest estimates of diversity and evenness were recorded at station 5 several km away from the dredgings disposal site and were due to the dominance of *Nucula nitidosa* at this station. The pattern of disturbance from dredgings disposal was more clearly discernible with univariate descriptors derived from nematode data, with significantly reduced values ($p<0.05$) of numbers of taxa (S), species richness (d), and diversity being recorded within the disposal site at stations 1 and 2 (Table 48, Figure 39). Trends in taxonomic diversity (Δ) were also found to mirror those observed in the Shannon - Wiener (H') diversity index (Figure 40). However, the pattern of disturbance was more clearly discernible with Δ than H', probably as a result of the insensitivity of the former measure to variations in the numbers of individuals between samples. This recently proposed taxonomic diversity index (Warwick and Clarke, 1995) therefore appears to provide a useful summary of the effects on nematode communities of disturbance from dredgings disposal. The lack of sensitivity in the counts of nematodes (Log 1+A) can be attributed to the elevations of *Sabatieria pulchra* group and *Daptonema tenuispiculum* within the disposal site, which mask reductions in the abundance of many other taxa.

Figure 35 Mean distribution of nematode feeding groups along the Lune Deep transect.

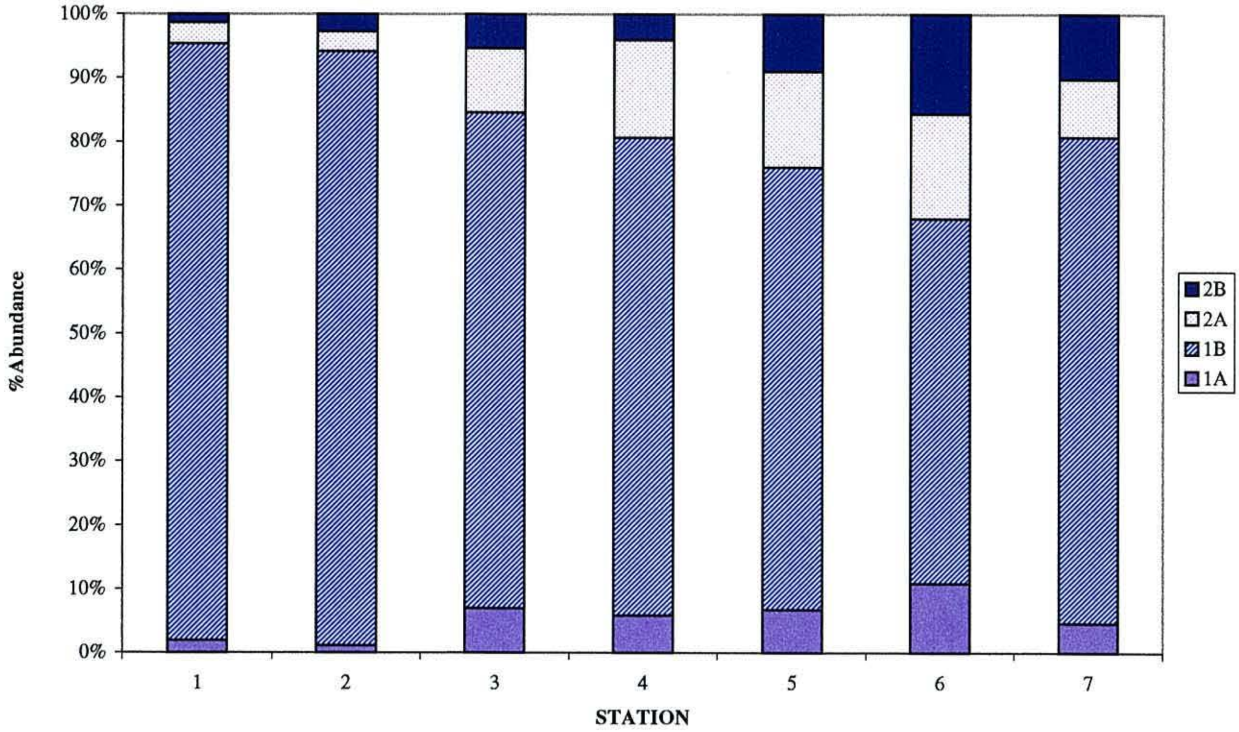


Figure 36 Distribution of A) *Sabatieria pulchra* group and B) *Daptonema tenuispiculum* along the Lune Deep transect (mean percentage abundance and 95% Least Significant Intervals).

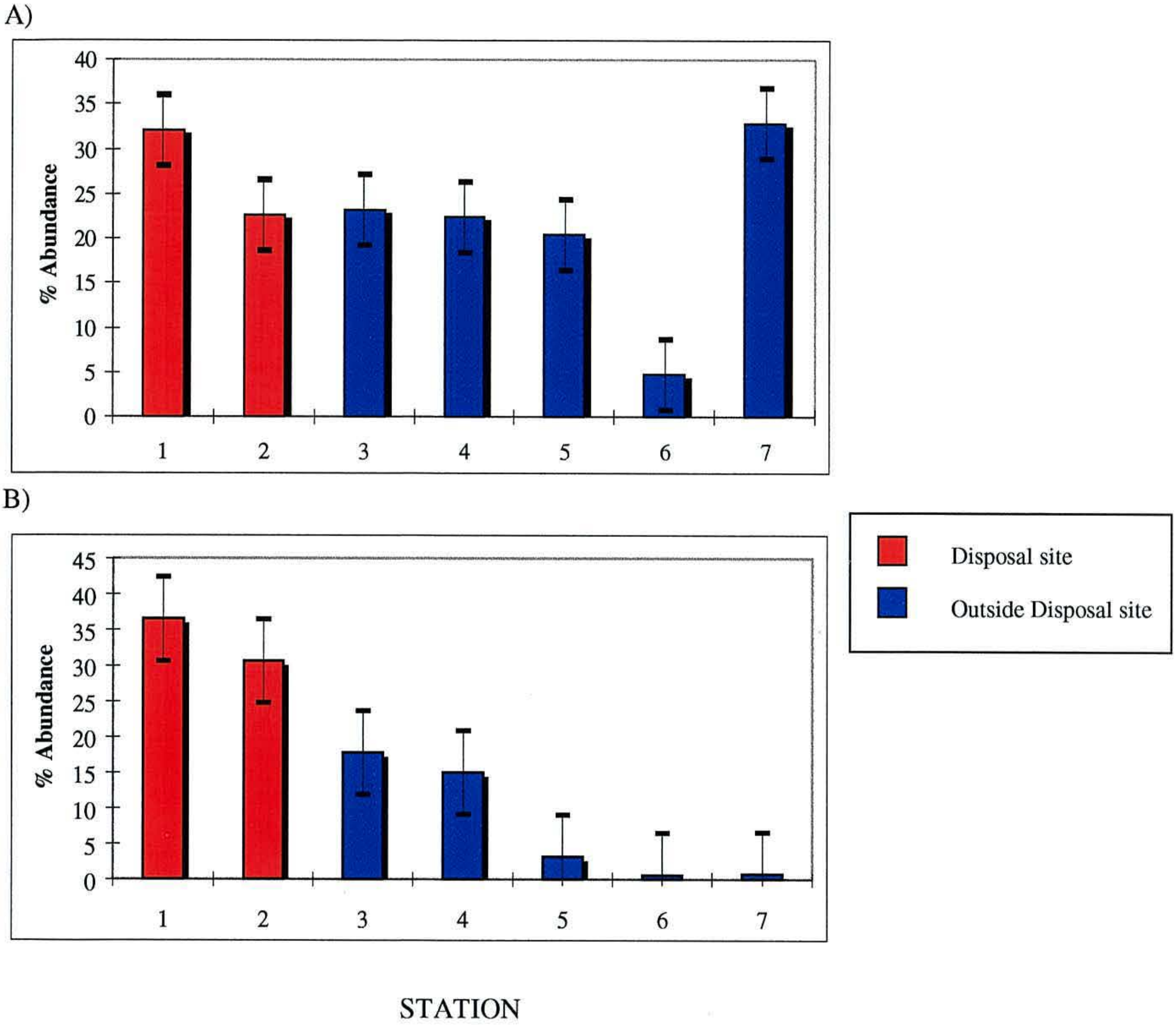


Figure 37 Distribution of the ratio of 1B/2A nematode groups (means and 95% Least significant intervals) along the Lune Deep transect.

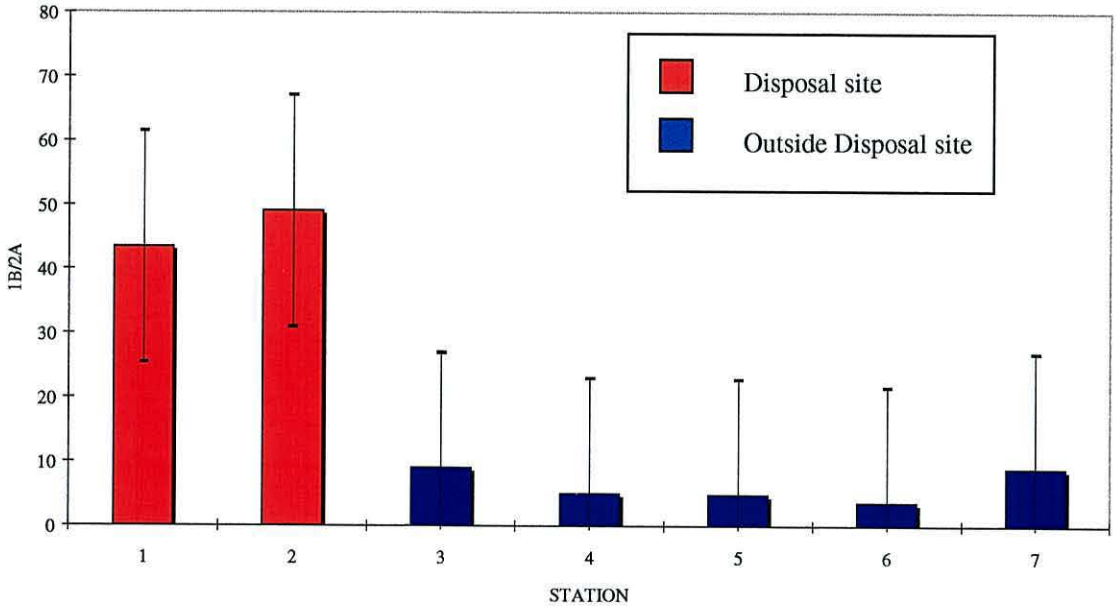


Table 47 The percentage abundance of the 4 nematode feeding types for replicated and pooled core samples at each station.

Station	Nematode group				Ratio
	1A	1B	2A	2B	1B/2A
1a	4	93	2	1	37.25
1b	2	90	7	1	13.75
1c	0	98	1	1	79.25
1a-c	2	93	3	1	27.81
2a	1	90	6	4	15.00
2b	2	96	1	1	97.00
2c	1	93	3	3	35.00
2a-c	1	93	3	3	27.46
3a	10	69	14	7	5.08
3b	3	83	11	4	7.45
3c	8	81	6	6	14.43
3a-c	6	79	10	5	7.95
4a	6	71	18	5	3.85
4b	6	78	13	3	6.25
4c	5	76	15	4	5.00
4a-c	6	74	16	4	4.77
5a	13	62	19	5	3.25
5b	3	74	13	9	5.65
5c	4	71	13	12	5.56
5a-c	7	69	15	9	4.56
6a	14	59	13	13	4.38
6b	8	59	20	13	3.00
6c	10	53	16	21	3.38
6a-c	11	57	16	16	3.61
7a	4	80	7	9	12.05
7b	7	71	11	12	6.70
7c	3	78	10	10	7.91
7a-c	5	77	9	10	8.75

Table 48 F-ratios and significance levels (from $F_{5,12}$) from 1-way ANOVA tests for differences in various univariate measures of community structure between stations.

Univariate Measure	*Macrofauna (Grabs)*		*Nematodes (Cores)*	
	F	p	F	p
Log (1+S)	3.95	0.02	6.47	<0.05
Log (1+A)	22.0	<0.01	5.96	<0.05
D	2.53	0.07	5.31	<0.05
H'	13.79	<0.01	10.49	<0.05
J	27.99	<0.01	11.97	<0.05

Table 49 Pearson product moment correlations between each pair of log-transformed (1+N) variables from grabs (based on 7 pairs of observations). Diversity indices are derived from pooled macrofauna data. Values highlighted in bold type indicate significant correlation (p<0.05).

	Log (1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	-0.0456	0.2879	-0.2402	-0.4574	-0.4679
%OrgC	-0.1863	0.0059	-0.2584	-0.1891	-0.2180
%N	-0.2565	-0.0237	-0.3243	-0.1584	-0.2053
%s/c	0.5826	**0.9551**	0.2124	-0.5532	-0.4120
%S	-0.5093	**-0.8462**	-0.1589	0.3587	0.2224
%G	0.7612	0.4065	**0.7765**	-0.4456	-0.2688
Cd	0.0214	0.0886	-0.1249	0.2213	0.2769
Cr	0.5627	0.5757	0.3294	-0.4205	-0.2276
Cu	0.6029	0.7148	0.3455	-0.7505	-0.5825
Hg	0.4520	0.0699	0.1818	**-0.8018**	-0.6872
Ni	0.5413	0.7103	0.3124	-0.6734	-0.5147
Pb	0.7395	0.5951	0.5513	-0.7072	-0.5003
Zn	0.3976	0.6417	0.1028	-0.6372	-0.5149

Table 49 presents the matrix of Pearson product moment correlations that were calculated between the biological descriptors derived from macrofaunal data and environmental variables from sediments sampled with grabs. It can be seen that the abundance of macrofaunal individuals (log 1+A) is positively related (p<0.05) to the quantities of fines (%s/c) present and hence negatively related (p<0.05) to the proportion of sand (%S) in the sediment. However, trends in macrofaunal richness (d) along the transect are positively related ($p<0.05$) to the gravel (%G) content of the sediments. Thus, the results of these correlation analyses indicate that both the fine and coarse components of the sediment or some correlated but unmeasured factor influence the structure of the macrobenthic community along the Lune Deep transect.

Table 50 Pearson product moment correlations between each pair of log-transformed (1+N) variables from cores (based on 7 pairs of observations). Diversity indices are derived from pooled nematode data.

	Log (1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	0.3076	0.5005	0.1934	0.0763	0.1723
%OrgC	-0.0353	0.4050	-0.1420	-0.2301	-0.1831
%N	0.2668	0.3813	0.1903	0.1325	0.1899
%s/c	0.0142	0.0362	-0.1753	-0.6383	-0.4526
%S	0.0456	0.0109	0.2157	0.6524	0.4822
%G	-0.4685	0.0155	-0.5338	-0.6107	-0.6107
Cd	-0.3711	-0.2676	-0.4055	-0.5680	-0.5506
Cr	-0.2078	0.2377	-0.3108	-0.4624	-0.4167
Cu	0.1365	0.2838	0.0613	0.1318	0.1413
Hg	-0.0757	0.3824	-0.1886	-0.3932	-0.3053
Ni	0.1517	0.2097	0.0582	-0.2365	-0.1016
Pb	0.0848	0.3728	-0.0234	-0.1239	-0.0561
Zn	-0.1546	0.2355	-0.2583	-0.6329	-0.4985
As	-0.5893	0.3294	-0.6871	-0.4218	-0.5470

Conversely, trends in other environmental variables such as sedimentary metals do not appear to be significant in determining the structure of the macrofaunal community along the transect, except Hg which is negatively correlated ($p<0.05$) to values of evenness (J). No significant correlation ($p>0.05$) was observed between diversity indices derived from pooled nematode data and environmental variables from core sediments (Table 50).

Figure 38 Means and 95% LSD intervals for univariate measures of MACROFAUNA community structure along the LUNE DEEP transect.

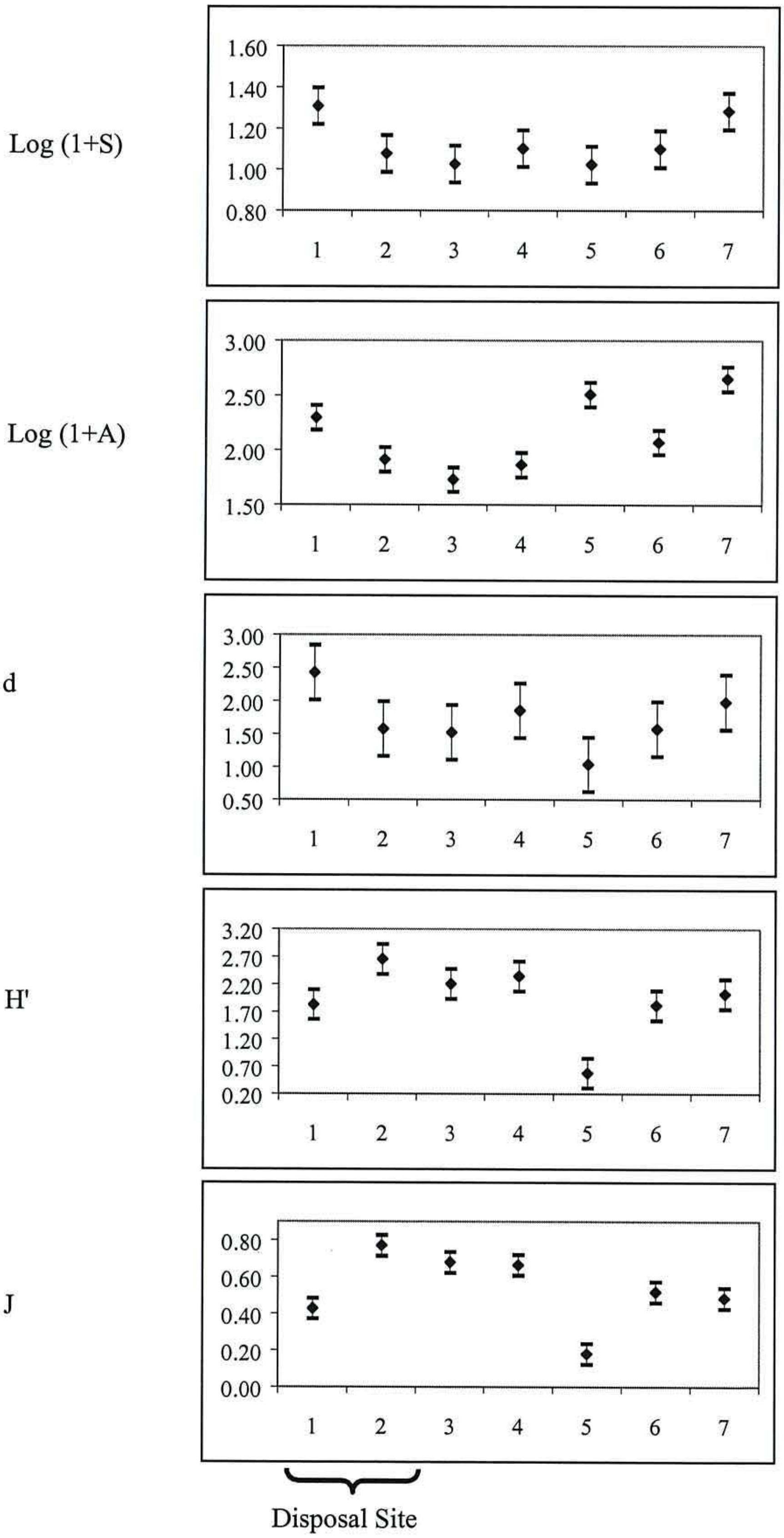


Figure 39 Means and 95 % LSD intervals for univariate measures of NEMATODE community structure along the LUNE DEEP transect.

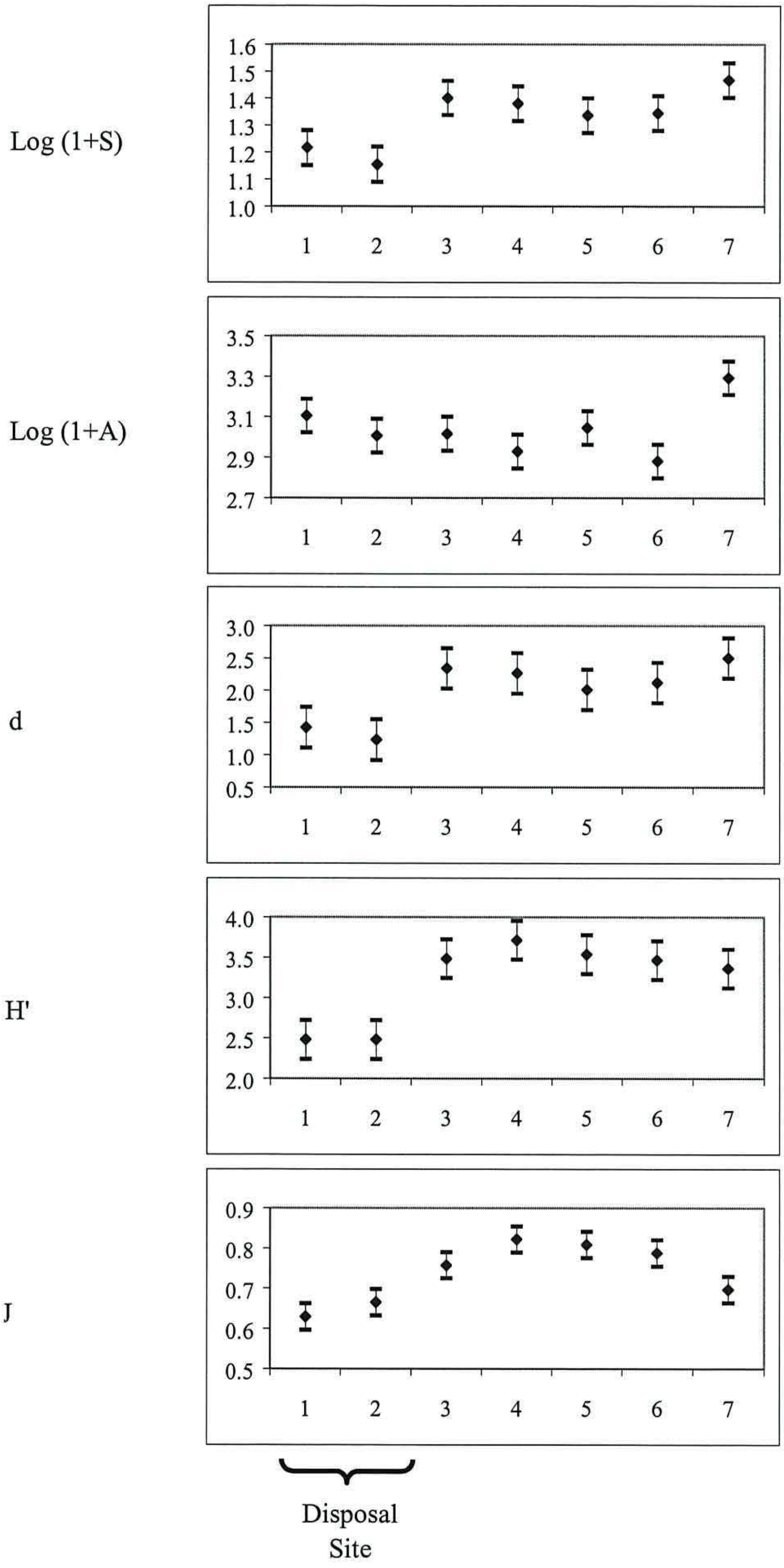
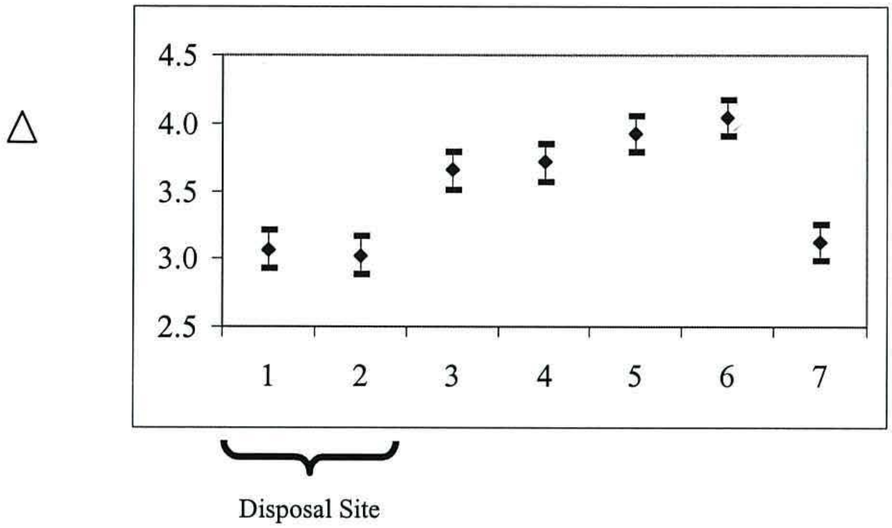


Figure 40 Means and 95 % LSD intervals for taxonomic diversity (Δ) derived with nematode data from along the LUNE DEEP transect.



5.2.2 Multivariate measures of community structure

Clustering

Cluster analysis of the macrofaunal assemblages show there are several clusters at the 50% Bray Curtis similarity level. On the left hand side of the dendrogram (Figure 41) there is a loose affinity between station 1, within the disposal site, and the most south-western station (7). The overwhelming feature of these two stations is the numerical dominance of the opportunistic taxa *Lagis koreni* and *Mysella bidentata* (Appendix IX). The second major cluster is more complex, and consists of a group of stations (2, 3, 4 and 6) which were typified as having a predominately sandy sediment containing a relatively sparse fauna. The low density of macrofauna was probably due to frequent disturbance of the sandy sediment by tidal currents. In a number of cases, sample replicates from the same station appeared in different clusters. It should be noted, however that, with such an impoverished fauna, species represented by very few individuals can have a marked influence on the clustering pattern.

Station 5 is distinct from this main group of stations; its separation probably results from the large numbers of *Nucula nitidosa* and corresponds with slightly muddier sediment.

The dendrogram derived from square-root transformed nematode data revealed the presence of several major clusters (Figure 41). The disposal site stations (1 & 2) formed a distinct grouping that was linked with stations (3 & 4) adjacent to the site. A further cluster consisted of stations (5, 6, & 7) located at the southern end of the transect. Thus the arrangement of stations is suggestive of a gradual change in nematode species composition as a function of distance from the disposal operation. Patterns in the distribution of nematode assemblages are therefore consistent with the effects of disposal activity, both at the site itself, and peripherally in the direction of the prevailing tidal current. Observed changes in the faunal composition away from the disposal site may arise from the physical consequences of a relatively high near-bed suspended load generated by the disposal of the finer components of dredgings deposited at the site.

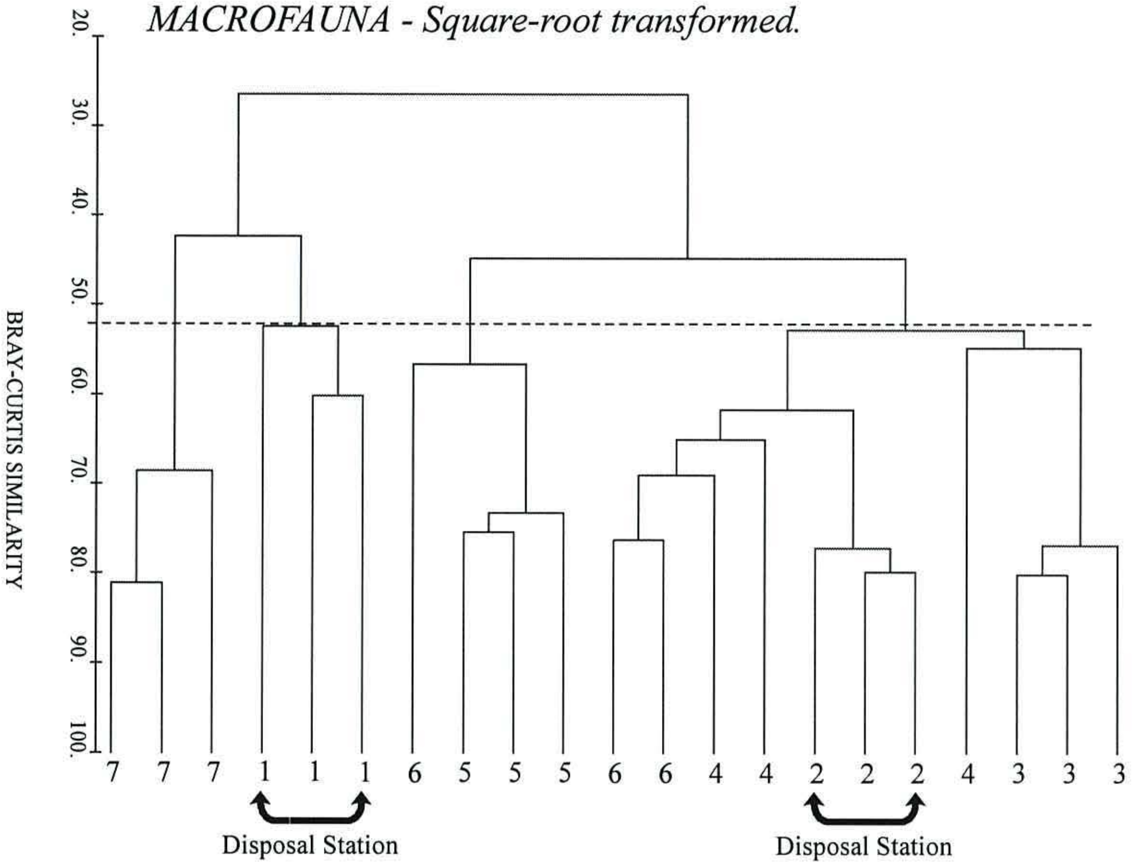
Ordination

There is a marked difference between the ordinations of the macrofaunal and nematode species abundance data (Figure 42). Whilst macrofaunal composition appears to be grossly modified within the disposal site at station 1, the impact is limited in extent, with station 2 (also within the site) only slightly affected by the disposal operation. By contrast, there is a clear gradient of change in nematode species composition that appears to be related to distance from the discharge and extends far beyond the margins of the licensed site. It is also of interest to note the separation of station 7 in both macrofaunal and nematode species ordinations from the other sampled stations. While the macrofaunal structure of station 7 is similar to that of station 1, (within the disposal site) the nematode composition of station 7 shows greater affinity with stations 5 and 6, located to the south of the disposal site. Stations 1 and 7 are characterised by a higher silt and clay content than stations to the south and north respectively. This may explain the apparent similarity of the macrofaunal assemblages at these stations. In contrast, distance from the disposal site appears to be the overriding factor responsible for structuring the nematode community. The outcome of MDS ordinations of pooled biotic data for each station is shown in Figure 43. For macrofaunal data, the loose affinity of stations 1 and 7 in terms of their species complement is reaffirmed, these stations being clearly separated from the others. MDS ordination of pooled nematode data shows a very different spatial arrangement, which again corresponds to distance from the disposal site (Figure 43). As might be anticipated from Figure 43, when the similarity matrices underlying these ordinations are compared there is no significant correlation ($pw = 0.165$, $p>0.05$).

Species analyses

Characterising numerical dominants within the disposal site are the polychaetes *Lagis koreni* and *Pholoe minuta*, and the bivalve mollusc *Mysella bidentata* (Table 52). However, it is also interesting to note the presence within the disposal site of a number of epifaunal species such as the barnacle *Balanus crenatus*, the hydroid *Lovenella clausa* and bryozoans e.g. *Electra pilosa* and *Bugula plumosa*. These epifaunal taxa have a ubiquitous distribution around the UK coast in habitats where suitable surfaces for attachment such as stones or shells occur (Mackie *et al.*, 1995). Presence of species such as *Magelona mirabilis*, *Fabulina fabula*, and *Nephtys hombergii* at stations 2, 3, 4, 5 and 6 reflected the predominant sandy environment. Station 7 had a community more characteristic of a muddy sand depositional environment and was characterised by species such as *Abra alba*, *Mysella bidentata* and *Lagis koreni*.

Figure 41 Cluster analysis of square- root transformed macrofauna and nematode data for stations 1-7 along the LUNE DEEP transect.



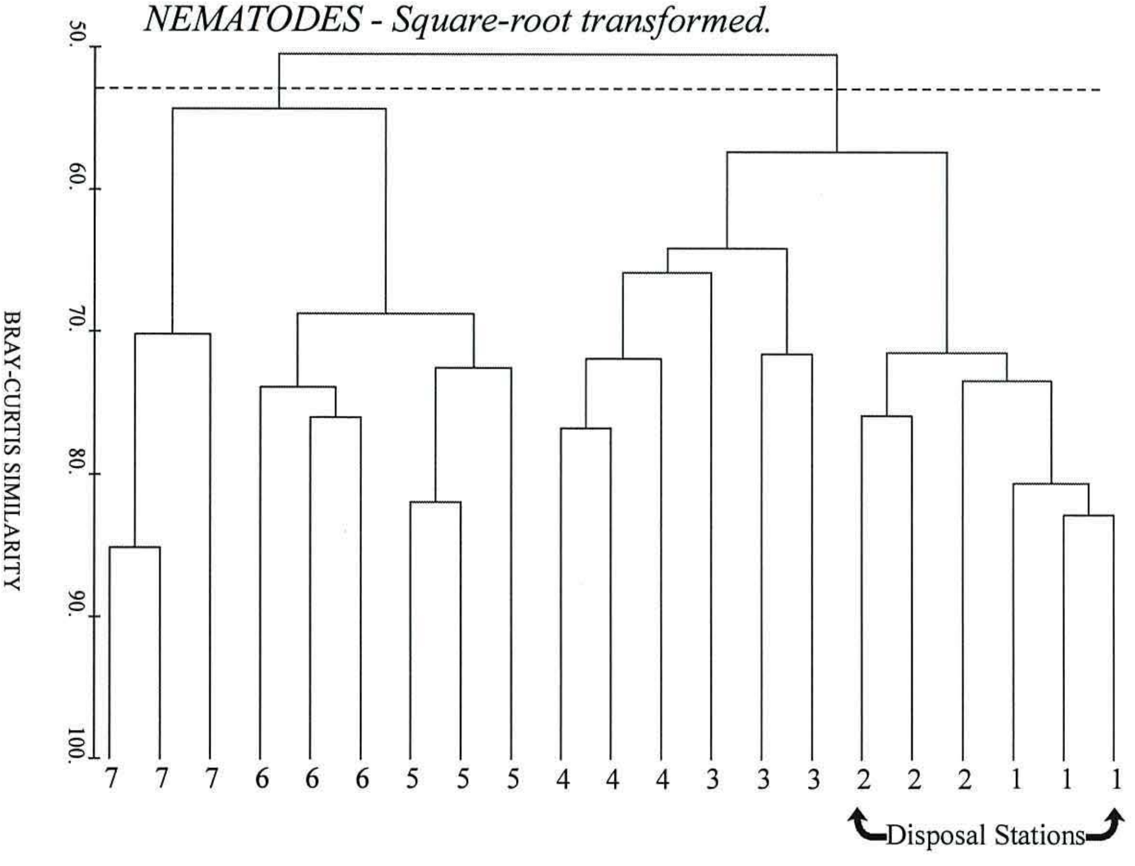
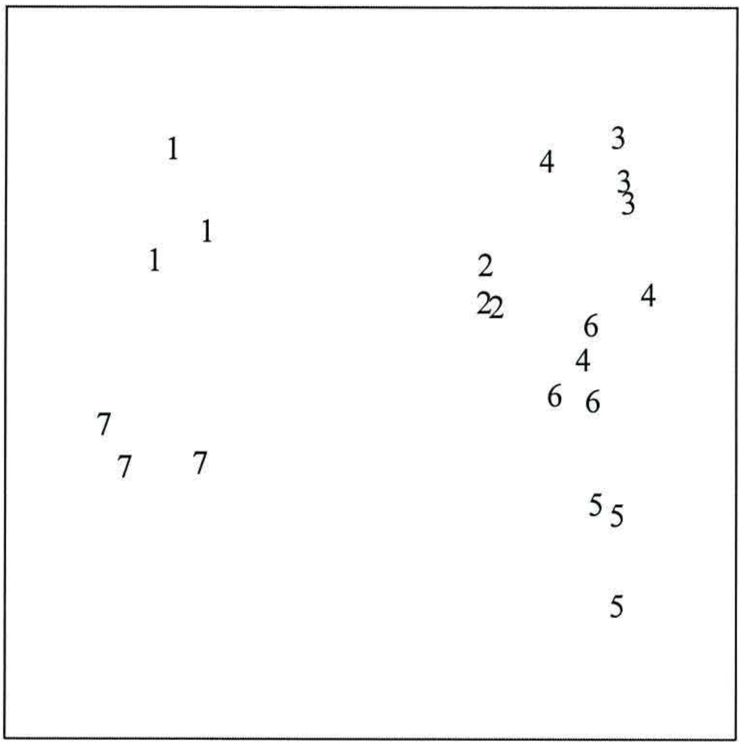


Figure 42 Multidimensional scaling ordinations of square-root transformed biotic data for stations 1 to 7.

MACROFAUNA Square-root transformed - Stress = .10



NEMATODES Square-root transformed - Stress = .14

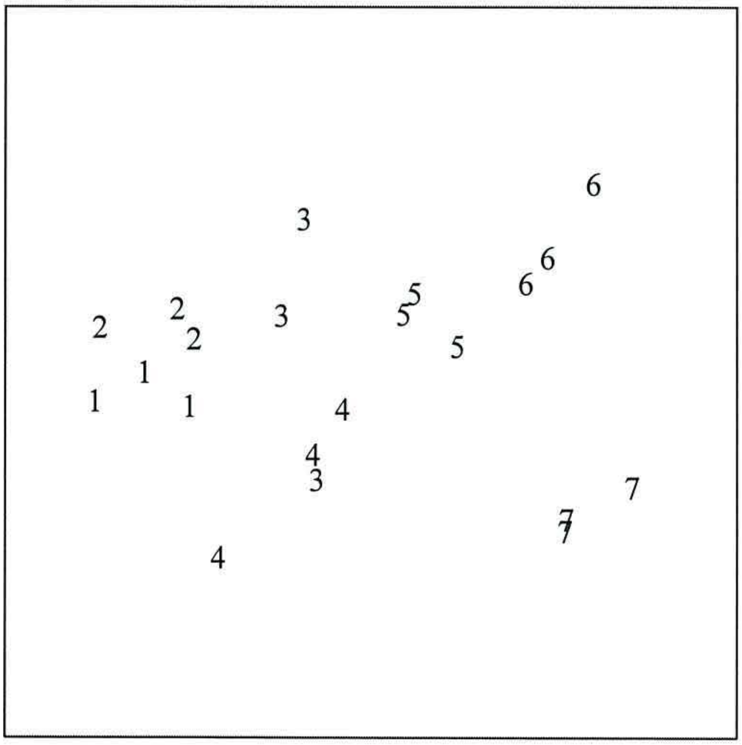
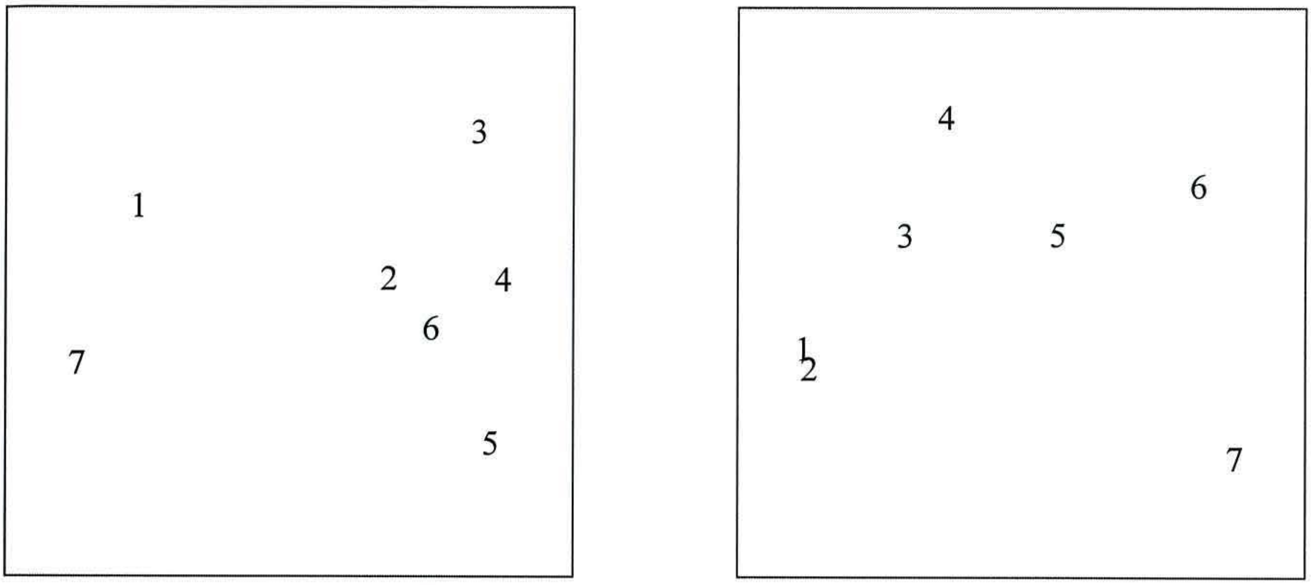


Figure 43 Ordinations by PCA of environmental variables, and by MDS of averaged abundances from stations 1 to 7. Environmental variables log (1 + *N*) transformed, nematodes and macrofauna Square - root transformed.

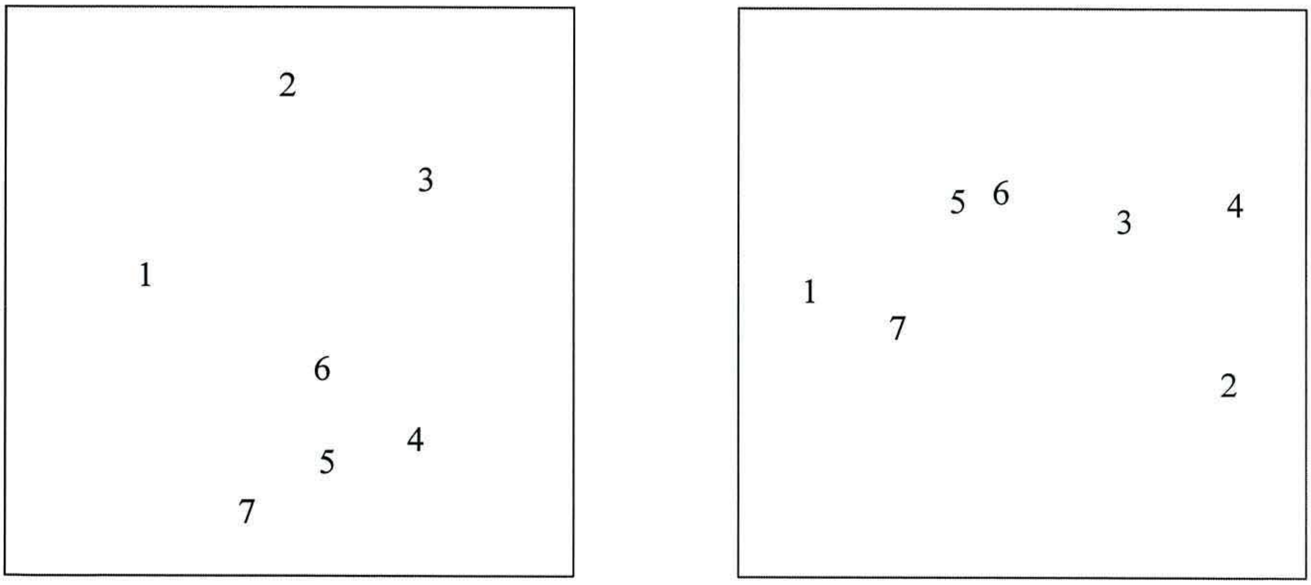
MACROFAUNA - Square-root transformed,
Stress= .04

NEMATODES - Square-root transformed,
Stress= .04



ENVIRONMENTAL VARIABLES (GRABS)
Log transformed

ENVIRONMENTAL VARIABLES (CORES)
Log transformed



A feature of the nematode community within the disposal site is the prevalence of the non-selective deposit feeders *Sabatieria pulchra* grp. and *Daptonema tenuispiculum* (Table 53). These species were amongst the highest ranked, in terms of their average dissimilarity, in all inter-station comparisons with a disposal site station (1). Furthermore, stations outside the disposal site possessed a large number of taxa typical of sandy sediments that were absent or reduced within the disposal site e.g. *Chitwoodia warwicki*, *Camacolaimus tardus*, *Cyartonema germanicum* and *Ascolaimus elongatus*.

Within station variability in macrofaunal community composition, determined by the relative index of multivariate dispersion (r.IMD), was highest at a disposal site station (1) (Table 51a). This accords with the hypothesis of Warwick and Clarke (1993) that increasing variability in faunal composition is a symptom of community stress. In the case of nematode data, however, faunal composition at station 1 was the most consistent of all sampled stations (Table 51B). Interestingly, the variability in nematode species composition between replicates was highest at intermediate distances from the disposal site (at stations 3 and 4).

Table 51 Relative Index of Multivariate Dispersion for A) macrofaunal grab samples and B) nematodes from cores for stations 1 to 7. The stations have been placed in the order of increasing r.IMD.

A)

Station	*r.IMD*
2	0.42
3	0.48
7	0.79
5	0.88
6	1.24
4	1.52
1	1.67

B)

Station	*r.IMD*
1	0.33
6	0.82
5	0.91
7	0.94
4	1.09
2	1.21
3	1.70

5.2.3 Biotic and environmental relationships

Most of the sediments sampled consisted of slightly muddy sands, except a station in the disposal site (station 1) and in the southwest of the survey area (station 7) where there was an increase in the proportion of fines (Table 54 - 56). Core sediments from the disposal site were seen to have an underlying anoxic muddy layer, but there was no evidence for the transport of material (in the form of clay lumps or black mud) to stations adjacent to the site. A single core retrieved from station 1 within the disposal site had slightly enhanced levels of Zn and Hg compared with sediments retrieved from other stations (Table 54). For trace metals from grab sediments, there is no evidence to suggest that levels at the disposal site are proportionately enriched compared with those nearby (Table 56). The trace metal content of sediments is commonly found to be positively associated with the amount of silt and clay present (Rowlatt, 1988). However, no significant relationship ($p>0.05$) between the fines content (%s/c) and trace metal burden of grab sediments could be discerned (see Appendix XXIV). In contrast, a positive association ($p<0.05$) between silt and clay and several trace metals was found with the core sediments, although the correlation coefficients (see Appendix XXV) were not particularly high when compared with the findings from similar studies in other areas (e.g. Rowlatt, 1988). The absence of a significant correlation with grab samples may partly reflect the lack of replicate measurements taken for quantifying concentrations of trace metals. Discrepancies between grab and core sediments may also be accounted for by the variation in the depth of sediment retained for trace metal and particle size analyses. Unlike the analysis of the cores, surface scrapes (~3-5mm) of sediment from grabs for the estimation of sedimentary contaminants would not have penetrated the deeper anoxic muddy layer observed in sediments from within the disposal site, yet may be a better indication of recent disposal activity.

Table 52 Breakdown of average dissimilarity between the station of active disposal and all other stations into contributions from each macrofaunal species; species are ordered in decreasing contribution (cut-off at 60% average dissimilarity).

Station 2,1	$\bar{\delta}_i/S.D.\delta_i$
Mysella bidentata	**3.26**
Fabulina fabula	8.08
Lagis koreni	**1.85**
Magelona mirabilis	2.96
Nucula nitidosa	2.02
Pholoe minuta	**2.63**
Abra alba	1.60
Balanus crenatus	**0.67**

Average dissimilatity between 1 & 2
= 61.81

Station 3,1	$\bar{\delta}_i/S.D.\delta_i$
Mysella bidentata	**5.58**
Magelona mirabilis	8.62
Lagis koreni	**2.15**
Fabulina fabula	4.01
Pholoe minuta	**2.63**

Average dissimilatity between 1 & 3
= 73.44

Station 4,1	$\bar{\delta}_i/S.D.\delta_i$
Mysella bidentata	**4.17**
Lagis koreni	**2.60**
Fabulina fabula	5.33
Magelona mirabilis	2.28
Nucula nitidosa	1.59
Pholoe minuta	**2.62**
Abra alba	**1.14**

Average dissimilatity between 1 & 4
= 73.55

Station 5,1	$\bar{\delta}_i/S.D.\delta_i$
Nucula nitidosa	10.16
Mysella bidentata	**4.42**
Lagis koreni	**2.56**
Fabulina fabula	2.75

Average dissimilatity between 1 & 5
= 78.10

Station 6,1	$\bar{\delta}_i/S.D.\delta_i$
Mysella bidentata	**3.73**
Nucula nitidosa	7.86
Lagis koreni	**2.26**
Fabulina fabula	3.58
Magelona mirabilis	1.73
Pholoe minuta	**2.56**

Average dissimilatity between 1 & 6
= 71.51

Station 7,1	$\bar{\delta}_i/S.D.\delta_i$
Abra alba	7.07
Mysella bidentata	**1.24**
Nephtys hombergii	3.18
Nucula nitidosa	2.15
Lagis koreni	1.22
Spisula subtruncata	6.97
Phyllodoce groenlandica	2.90
Pseudopolydora pulchra	2.95

Average dissimilatity between 1 & 7
= 57.65

Highlighted taxa are more numerous at Station 1.

Table 53 Breakdown of average dissimilarity between the station of active disposal and all other stations into contributions from each nematode species; species are ordered in decreasing contribution (cut-off at 60% average dissimilarity).

Station 2,1	$\bar{\delta}_i/S.D.\delta_i$
***Sabatieria pulchra* grp.**	**1.55**
Daptonema tenuispiculum	**1.82**
Paramonhystera riemanni	1.73
***Odontophora* sp.**	**2.10**
Leptolaimus elegans	13.91
Metalinhomoeus filiformis	13.91
Trefusia zostericola	**1.33**
***Spirinia* sp.2**	**1.17**
Setosabatieria hilarula	**1.23**
Microlaimus turgofrons	**0.90**

Average dissimilatity between 1 & 2
= 27.93

Station 3,1	$\bar{\delta}_i/S.D.\delta_i$
Daptonema tenuispiculum	**2.81**
Daptonema normandicum	1.13
***Sabatieria pulchra* grp.**	**1.46**
Chitwoodia warwicki	4.27
Paramonhystera riemanni	**3.87**
Metoncholaimus scanicus	3.87
Leptonemella aphanothecae	4.27
Prochromadorella attentuata	4.73
Comesa cuanensis	8.46
Cyartonema germanicum	14.35
Richtersia sp.	1.34
Trefusia zostericola	**1.33**
Eleutherolaimus stenosoma	**1.45**
Mesacanthion diplechma	3.46
Camacolaimus tardus	1.29

Average dissimilatity between 1 & 3
= 41.43

Station 4,1	$\bar{\delta}_i/S.D.\delta_i$
Daptonema tenuispiculum	**7.62**
***Sabatieria pulchra* grp.**	**3.80**
Paramonhystera riemanni	**4.72**
Paracanthonchus heterodontus	2.49
Daptonema normandicum	2.17
Richtersia sp.	3.47
Cyartonema germanicum	21.15
Comesa cuanensis	4.62
Sabatieria longispinosa	1.76
Sabatieria celtica	**2.14**
Ascolaimus elongatus	1.42
Cobbia trefusiaeformis	1.73
Microlaimus turgofrons	1.63

Average dissimilatity between 1 & 4
= 44.54

Station 5,1	$\bar{\delta}_i/S.D.\delta_i$
Daptonema tenuispiculum	**28.02**
Ascolaimus elongatus	4.47
Mesacanthion diplechma	2.80
Camacolaimus tardus	14.47
Chitwoodia warwicki	6.00
Paramonhystera riemanni	2.40
***Sabatieria pulchra* grp.**	**3.15**
Dichromadora cucullata	10.81
Daptonema normandicum	1.96

Average dissimilatity between 1 & 5
= 47.12

Station 6,1	$\bar{\delta}_i/S.D.\delta_i$
Daptonema tenuispiculum	**6.35**
***Sabatieria pulchra* grp.**	**4.83**
Ascolaimus elongatus	7.07
Paramonhystera riemanni	**4.24**
Mesacanthion diplechma	4.57
Chitwoodia warwicki	4.97
Camacolaimus tardus	3.51

Average dissimilatity between 1 & 6
= 57.25

SStation 7,1	$\bar{\delta}_i/S.D.\delta_i$
Daptonema tenuispiculum	**14.82**
Sabatieria celtica	5.96
Mesacanthion diplechma	6.10
Richtersia sp.	6.51
Microlaimus turgofrons	2.49
Paramonhystera riemanni	**3.50**
Spirinia parasitifera	2.67
Setosabatieria hilarula	1.33
Sphaerolaimus balticus	3.86
Sabatieria pulchra	2.24
Paracanthonchus heterodontus	2.83
Chitwoodia warwicki	12.39

Average dissimilatity between 1 & 7
= 54.58

Highlighted taxa are more numerous at Station 1.

However, deeper sections (~5cm) sampled by grab for particle size analyses and all physico-chemical determinants from cores may have retained some of the underlying muddier material.

Ordinations by PCA of environmental data indicate separation of grab sediments taken from within the disposal site (stations 1 and 2) from those collected towards the southern end of the transect (Figure 43). It is arguable, however, whether their separation indicates an effect of disposal as sediments from these stations were found to have the lowest concentrations of trace metals (Table 56). The pattern produced with ordinations of core sediments showed stations 1 and 7, located at either end of the transect, clustering separately (Figure 43). MDS ordinations of averaged abundance data do not conform to either of the configurations produced with the environmental data and when the underlying similarity matrices were compared no significant relationships ($p>0.05$) were identified (Table 57). The lack of correlation between the environmental and biotic similarity matrices suggests that overall there are no strong gradients, which indicates only a limited impact of dredged material disposal in this area.

Further insights into the nature of the responses of nematode and macrofaunal assemblages to disturbance may be obtained by an examination of the outcome of the BIO-ENV procedure, which relates the patterns observed in ordinations of the biotic data with those of the environmental data. Sand, silt and clay, and gravel are the variable combinations identified as "best" explaining the macrofaunal MDS ordinations (Table 58). By contrast, the addition of sedimentary metal concentrations in the procedure produces lower rank correlations indicating a lesser role of trace metals in grab sediments in determining macrofaunal species patterns. The highest correlation coefficients at the Lune Deep are less than 0.8, which Clarke and Ainsworth (1993) deem as corresponding with a close match. However, the results obtained from this study broadly agree with those produced with correlation analyses using univariate measures, in that the physical nature of the sediment rather than any contaminant effects appeared to be more significant in influencing the macrofaunal distributions. Thus the results can be viewed with a reasonable degree of confidence.

Table 54 Concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 7 from replicated core samples.

Station	*% C*	*% OrgC*	*% N*	*% G*	*% S*	*% s/c*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*	*As*
1A	2.31	1.51	0.12	7.95	59.07	32.99	0.27	58	29	0.64	39	75	170	13
2A	2.22	1.55	0.16	0.02	87.19	12.79	0.46	76	30	0.44	32	62	117	12
2B	1.41	0.37	0.02	0.00	88.32	11.68	<0.21	21	6	0.08	10	14	51	n/a
3A	1.71	0.98	0.08	0.01	93.65	6.34	<0.12	16	7	<0.02	13	10	28	2
3B	2.31	1.22	0.15	0.09	87.68	12.23	0.32	79	32	0.36	43	74	178	11
3C	2.08	1.05	0.09	0.01	83.83	16.15	0.20	46	22	0.38	32	54	126	9
4A	1.91	0.91	0.10	0.00	91.66	8.34	0.21	40	23	0.33	30	48	114	9
4B	2.14	1.33	0.13	0.01	89.41	10.58	0.28	50	27	0.33	27	53	86	10
4C	1.92	0.40	0.04	0.00	94.51	5.49	<0.12	28	18	0.14	15	35	25	7
5A	2.32	1.19	0.14	0.55	85.42	14.03	0.22	52	28	0.49	31	63	108	12
5B	2.36	1.45	0.11	0.17	78.97	20.86	0.21	52	26	0.44	29	62	99	13
5C	2.34	1.50	0.13	0.79	83.57	15.64	0.27	52	28	0.49	31	64	107	12
6A	2.50	1.65	0.20	0.06	91.04	8.89	0.46	63	39	0.52	38	70	78	14
6B	2.28	1.44	0.13	0.03	89.70	10.27	0.19	55	26	0.39	31	65	102	11
6C	1.97	1.05	0.09	0.09	92.37	7.54	0.20	49	21	0.23	24	49	68	9
7A	2.41	1.48	0.13	0.27	52.42	47.31	0.41	56	26	0.48	34	66	111	12
7B	2.59	1.40	0.15	0.15	65.48	34.37	0.41	62	33	0.56	36	78	147	13
7C	2.18	1.25	0.11	0.38	62.05	37.57	0.32	49	23	0.37	28	54	86	11

Table 55 Mean concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 7 from core samples.

Station	*%C*	*%OrgC*	*% N*	*% s/c*	*% S*	*% G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*	*As*
1	2.31	1.51	0.12	32.99	59.07	7.95	0.27	58	29	0.64	39	75	170	13
2	1.82	0.96	0.09	12.30	87.69	0.01	0.46	48	18	0.26	21	38	84	12
3	2.03	1.08	0.11	12.46	87.5	0.04	0.26	47	20	0.37	29	46	111	7
4	1.99	0.88	0.09	8.44	91.55	0.01	0.25	39	23	0.27	24	45	75	9
5	2.34	1.38	0.13	14.38	85.11	0.51	0.23	52	27	0.47	30	63	105	12
6	2.25	1.38	0.14	8.8	91.14	0.06	0.28	56	29	0.38	31	61	83	11
7	2.39	1.38	0.13	38.51	61.22	0.27	0.38	56	27	0.47	33	66	115	12

Table 56 Concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 7 from Day Grab samples.

Station	*%C*	*%OrgC*	*% N*	*% s/c*	*% S*	*% G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
1	1.86	0.74	0.05	16.63	82.66	0.71	<0.17	56.98	20.03	0.36	23.19	46.83	64.76
2	1.67	0.71	0.06	10.06	89.90	0.04	<0.20	52.49	10.98	0.11	12.36	21.21	38.20
3	2.39	1.24	0.12	4.30	95.70	0.00	0.17	45.69	12.82	0.22	16.14	26.93	44.08
4	2.50	1.56	0.17	6.19	93.77	0.04	<0.19	69.26	22.97	0.45	29.71	45.48	136.77
5	2.65	1.31	0.14	18.75	81.11	0.14	<0.18	62.43	25.19	0.58	30.31	44.77	163.56
6	2.50	1.04	0.09	8.52	91.38	0.10	<0.21	61.64	20.04	0.34	31.43	44.43	130.00
7	2.60	1.24	0.12	43.92	55.97	0.10	<0.20	69.24	25.58	0.51	32.03	48.67	183.87

Table 57 Rank correlations (ρ) between the Euclidean distance matrices derived from environmental variables (log (1+X) transformed) from grabs and cores and similarity matrices derived from square-root transformed biotic data.

	Environmental variables (Grab)	Environmental variables (Cores)
Macrofauna	0.058	0.243
Nematodes (Cores)	0.235	0.138

Table 58 Spearman rank correlations between macrofauna and environmental similarity matrices (grabs).

Number of variables	*Best variable combination*	*Correlation (pw)*
1	%S	0.635
2	%S,%G	0.745
3	**%S,%s/c,%G**	**0.792**

Table 59 Spearman rank correlations between nematodes and environmental similarity matrices (cores).

Number of variables	*Best variable combination*	*Correlation (pw)*
1	*%sc	0.244
2	**%N, *%s/c**	**0.387**
3	%N, %sc, Zn	0.362

* %S is significantly correlated (r>0.95) to %s/c and was therefore excluded from the BIO-ENV procedure.

Table 60 Spearman rank correlations between nematodes and environmental similarity matrices (grabs).

Number of variables	*Best variable combination*	*Correlation (pw)*
1	Zn	0.240
2	%C,%S	0.610
3	%C,%S, Cd	0.665
4	**%C,%S, Cd, Zn**	**0.687**

Correlations were generally poor when the ordinations derived from nematode and environmental data from cores were compared (Table 59). Nevertheless, substrate type, expressed in terms of %silt and clay (which is inversely correlated to %S) was the single most influential factor explaining the spatial variability in the distribution and abundance of the nematode community. Based on the results of BIO-ENV with grab sediments, however, it appears metal concentrations may also contribute to the observed patterns in nematode species composition (Table 60).

5.3 DISCUSSION

In general, the Lune Deep possessed an impoverished macrofaunal community, the composition of which appeared indicative of an area subject to physical disturbance. This accords well with the findings of Rostron (1992) and, overall, macrofaunal assemblages were similar to those previously identified for the area. Interestingly, the values of diversity recorded along the entire Lune Deep transect are considerably lower than those recorded in comparable inshore sandy habitats in the Irish Sea (Mackie *et al.*, 1995). These observations suggest that the area may be naturally subjected to disturbance, possibly from tidal action. The nature of sediments has often been cited as a major factor influencing the distribution of macrofaunal organisms (e.g. Jones, 1950; Thorson, 1957; Hartnoll, 1983). It is interesting to note that when measures of macrofaunal diversity were correlated with environmental variables both the finest and coarsest sediment particles were identified as being important. That macrofaunal species richness is positively associated with the gravel content along the transect is perhaps not surprising. The interstices and crevices of coarse sediment particles provide more niches for colonisation and their exposed surfaces for the attachment of epifauna. The epifauna in turn increases the available niche space. Of particular interest is that, of all the sampled stations, one of those within the disposal site had the greatest number of macrofaunal taxa for which several possible explanations exist. The disposal of dredgings may have increased the range of sediment types within the disposal area leading to the diversification of microhabitats and thereby providing opportunities for colonisation by a wider range of species (M.P.M.M.G, 1996). In addition, the disposal of cohesive muddy or coarse sediments in high-energy environments such as the Lune Deep may confer a degree of temporary stability in the receiving area, and hence increase the potential for colonisation by opportunistic taxa such as *Lagis koreni* and *Mysella bidentata*. It has also been suggested that newly deposited dredged material may provide an enhanced food supply, particularly if the material is organically enriched (Rees *et al.*, 1992; Harvey *et al.*, 1998).

Rhoads *et al.* (1978) discussed the potential benefits of managing dredged material disposal in such a way as to maximise benthic productivity in order to improve local fisheries. Although dredgings disposal appears to have increased the numbers of macrofaunal taxa at one of the stations within the disposal site, there are also elevated levels of some trace metals in sediments at this station. Thus even if benthic productivity could be improved to the benefit of local fisheries, through effective management of the disposal site, there is also increased potential for the uptake of contaminants by local fish populations. Indeed, during dredging operations sediments can become oxidised (Fernandes *et al.*, 1994) which may lead to the release and subsequent increase in the bioavailability of trace metals in recently deposited sediments (Miller, 1986; Darby *et al.*, 1986), but there is no evidence from this study that this is occurring at the Lune Deep site.

It is useful to compare the macrobenthic assemblage at disposal site station 1 with station 7 located at the south-west end of the Lune Deep. These communities appeared to be very similar and were characterised by *Lagis koreni* and *Mysella bidentata* with lower densities of *Pholoe minuta*. The community at station 7 was characteristic of a muddy sand depositional environment. Conditions at the southernmost station (station 7) may therefore be similar to those found in disposal areas where muddy dredgings are dispersing. In both cases the conditions are amenable, in the short-term, to opportunistic colonisation by *L. koreni* and *M. bidentata.* Equally, the fauna from these stations is vulnerable to gross physical disturbance at unpredictable intervals, either by deposited dredged material or storm-induced sediment movements. Stations 1 and 7 were also found to be similar in terms of the numerical dominance of the non-selective deposit feeder *S. pulchra* grp. In previous Chapters (3 and 4), it has been demonstrated that the nematodes *S. pulchra* grp. and *D. tenuispiculum* are useful indicators of disturbance, as they appear to flourish in response to dredgings disposal. However, the dangers of relying on universal indicators of pollution and disturbance (Gray, 1981; Platt *et al.*, 1984) are highlighted at this location, where station 7, that was apparently undisturbed, was also found to have substantial numbers of *S. pulchra* grp. Further work is therefore needed to clarify why such nematode taxa respond in this way.

Effects on the macrofaunal community that could be attributed to the disposal of dredged material were localised and only marked with multivariate species analyses. This is in contrast to nematode data, where effects of disposal were evident up to several km beyond the disposal site and could be discerned using both descriptive statistics and multivariate analyses. This accords with the findings of Moore and Somerfield (1997) that, whilst the macrofaunal community was strongly perturbed by sewage sludge disposal at Garroch Head, the area of influence was less than that for nematodes. With both studies, stations adjacent to the disposal sites had modified nematode assemblages, which it can be assumed arise as a result of dispersing material from the disposal operations. However, as in the current study, the variation in nematode composition at Garroch Head, which could be explained by a range of measured abiotic variables, was low. Therefore, in both studies it was difficult to conclusively assign any particular aspect of disposal to account for alterations in the distribution and composition of the nematode fauna. This is in contrast to the pattern observed with the macrofauna, which seemed to correspond in this study with substrate type along the Lune Deep transect and with sedimentary carbon levels at the Garroch Head sewage sludge disposal site (Moore and Somerfield, 1997).

Dredged material disposed of at the Lune Deep site is only slightly contaminated and therefore it is likely that the most significant impact of dredgings disposal within the disposal site is a result of physical disturbance rather than contaminant effects. The disparity in responses between benthic macro- and meio-fauna to physical disturbance has previously been reported by Warwick *et al.* (1990b), and Austen *et.al.* (1989), and is considered further in Chapter 7.

Evidence for the existence of metal accumulation within sediments sampled from the disposal site was slight. Furthermore, gross effects of dredged material disposal on faunal assemblages were not apparent. This is probably a consequence of the strong tidal currents in the area, which rapidly disperses the dredgings. Overall, these findings point to the continued acceptability of this disposal operation at current levels of input, although far-field effects of disposal are discernible and should be monitored periodically.

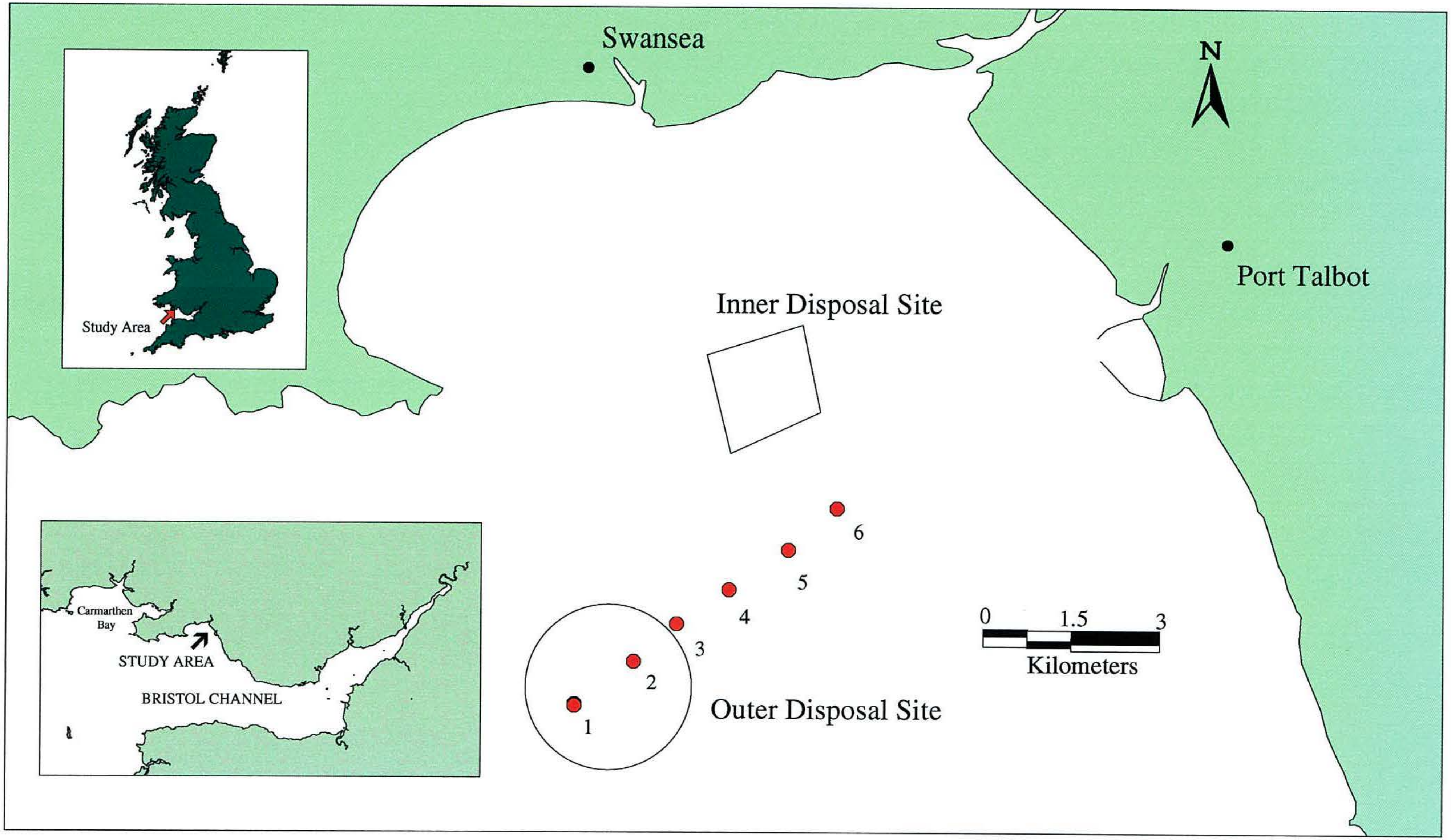
6. A COMPARISON OF THE RESPONSES OF MEIOFAUNAL AND MACROFAUNAL COMMUNITIES AT A SWANSEA BAY DREDGED MATERIAL DISPOSAL SITE

6.1 INTRODUCTION

Swansea Bay is located on the northern coastline of the Bristol Channel (Figure 44) and within the Bay there are two dredged material disposal sites: an inner and outer site. Until 1974, maintenance dredgings from all Swansea Bay Ports were deposited in the Inner disposal site. However, after tracer studies revealed that deposited material returned directly to Port Talbot Channel (Jackson and Norman, 1980), the disposal of maintenance dredgings was moved to the present Outer site. It is this latter site which is considered in the present Chapter. Approximately 2Mt wet weight of maintenance dredgings taken from the approach channels of Swansea Docks and Port Talbot Harbour have been disposed of annually at this site (Figure 45). Material is disposed of regularly throughout the year, resulting in an almost continuous discharge (M.A.F.F. unpublished data). Historically, the site also received capital dredgings during construction of the Port Talbot Tidal Harbour from 1967-69 (McGarey and Fraenkel, 1970) and more recently in 1996 approximately 6Mt of capital dredgings have been disposed of at the site during the deepening of the Port Talbot Harbour channel (Unpublished M.A.F.F. data). This recent large arising was disposed of after the surveys carried out as part of the current study.

As an embayment of the Bristol Channel, Swansea Bay experiences a large tidal range, locally affected by prevailing meteorological conditions (Collins *et al.*, 1979). Tidal dynamics of the Bristol Channel exhibit both standing and progressive wave characteristics; however, within Swansea Bay the standing wave oscillatory effects predominate (Collins *et al.*, 1979).

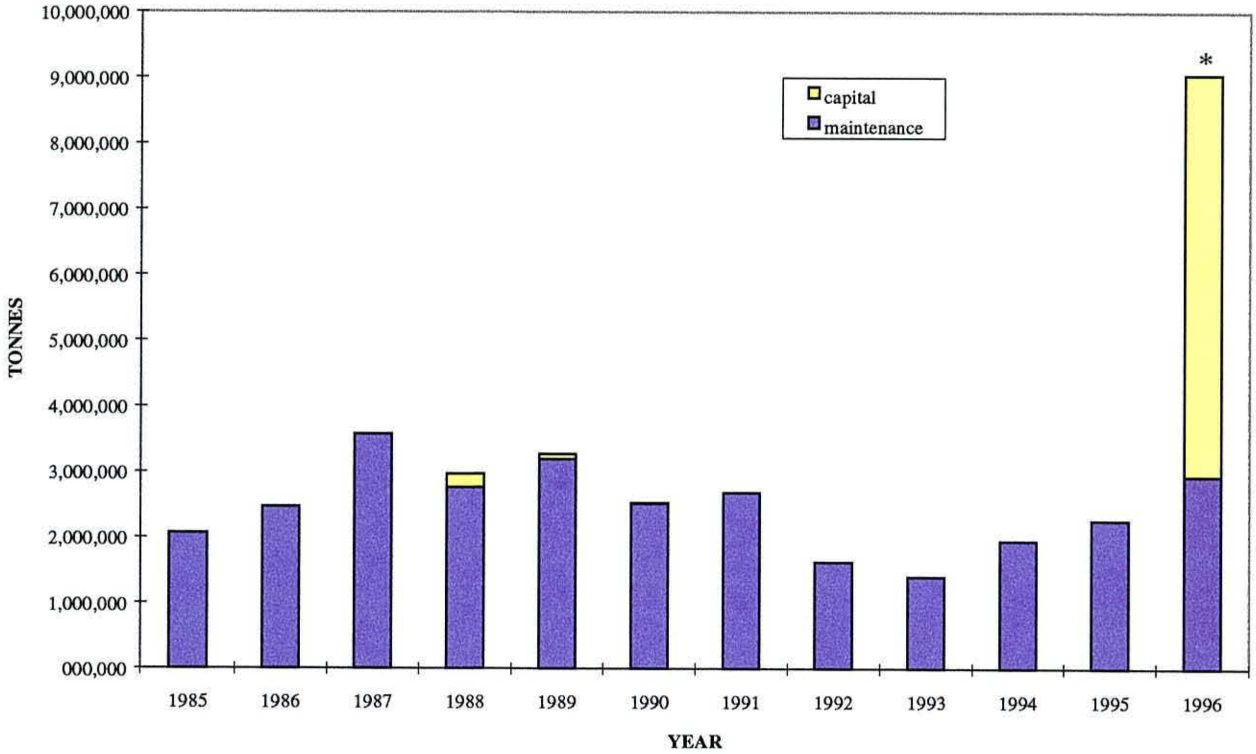
Figure 44 The location of the sampling stations in relation to the Outer Swansea Bay dredgings disposal site.



Tidal hydrodynamics have been considered in detail by Davies (1974), Collins *et al.* (1979) and Heathershaw and Hammond (1979). In the vicinity of the Outer disposal site, maximum surface flood and ebb current speeds have been recorded as 0.8 and 1.2m/s, respectively, on a 10m-range spring tide whilst, at the seabed, maxima were found to be only 0.5 m/s on both the flood and ebb tides (BTDB, 1976). The predominant flood direction is east-north-easterly while ebb direction is westerly. From radioactive tracer studies Heathershaw and Hammond (1980) demonstrated that the initial spread of fine-grained material extended approximately 2.4km to the east (in the direction of the flood current) to a width of 0.8km. Seven days later the tracer had travelled 6.5km to the east of the disposal site and had dispersed about 1km in lateral extent. However, movement of material after this initial dispersive phase was limited, with only a small proportion of the total quantity being deposited further afield. In the longer-term, bottom currents are strong enough to remobilise deposited fines at peak flows. The net movement of material is likely to occur in the direction of the residual drift which has been shown to be generally west to south-west near the disposal site (Collins *et al.*, 1980; Rigler and Collins, 1980; Pattiaratchi, 1981) but eastwards about 2km south of the licensed area (Heathershaw and Hammond, 1979). A recent Acoustic Doppler Current Profiler (ADCP) survey of the site indicated that during spring tides the plume created during disposal moved just north of east during the flood before turning south prior to the ebb (ABP Research, 1996). The overall plume width was also found to be dependent on the tidal range and was recorded as 2-3km wide with an eastward extent of at least 5-6km (see also Figure 46).

The geography of Swansea Bay dictates that waves from the approximate alignment of the Swansea Channel eastward are dominated by swell waves generated over a fetch of 6000km from the Atlantic Ocean. Prevailing south-westerly winds will further superimpose locally generated waves particularly during the winter months.

Figure 45 The quantity of dredged material disposed of to the Outer Swansea Bay site (M.A.F.F. unpublished data).



*The capital dredgings deposited in 1996 occurred subsequent to the 1996 surveys of the disposal site.

The distribution of sediment types in Swansea Bay has been described previously by Blackley (1978) and Collins *et al.* (1979) and is related to the combined effects of waves and tides. For the Inner Bay, as tidal induced flow speeds are generally low, the predominant influence on sediment movement, particularly in the eastern half of Swansea Bay, is storm waves. This is supported by results of the 1973 radioactive tracer test at the Inner disposal site which showed the main direction of movement was aligned with the prevailing wave direction (Jackson and Norman, 1980). In the western section of the Bay the tidal influence is thought to be more dominant, being sheltered from the south-westerly storms. The rotary tidal patterns in the vicinity of the Swansea Approach Channel (Figure 46) assists the formation of an anticlockwise circulation in this section of the Bay. Further studies were undertaken by the British Transport Docks Board (BTDB) which indicated that wave-induced flows during storms are aligned along the Port Talbot Approach Channel (see Figure 46), and a very dense near-bed turbidity layer can move up the channel into the harbour causing siltation (Jackson and Norman, 1980). This would account for the infilling of the channel by the equivalent of one year's annual maintenance dredging after a single storm event in 1974. The supply of sandy material to the west side of Swansea Bay appears to be related to storm activity from the south-east which resuspends and transports sediments in the eastern half of the Bay that have been deposited by south-westerly storms. This process explains the intermittent periods of very heavy siltation within the Swansea Approach Channel and the change in material types dredged.

The actual origin of the muds and sandy muds in the central and eastern part of the Bay has been a matter of some speculation. While the data of Chubb *et al.* (1980) indicate that rivers and streams are the major source of suspended solids, Collins *et al.* (1979) consider fluvial inputs to the sediment budget to be minimal. The latter authors also discount contributions from the erosion of local relict deposits except under extreme weather conditions. A certain amount of material may have been derived from the historical disposal of sewage sludge in the Bay (Murray *et al.*, 1980). However, several authors have concluded that the most significant source of material results from the reworking and recycling of material from both capital and maintenance dredging activities (Davies, 1974; Shackley, 1979; Collins *et al.*, 1980; Price and Brooks, 1980). This was a view supported by Shackley (1982) and thought to account for the impoverished macrofaunal communities found in the Inner Bay. Her supposition was that, before dredging disposal, the seabed of the Inner Bay consisted of exposed relict sediments (mixed gravel, stones, mud and sand) supporting a rich epifauna, but that the re-distribution of the dredged material led to the creation of the present substrata of muds, sandy muds and muddy sand. She further proposed a mechanism to explain the composition of the present day fauna (Shackley and Collins, 1984). Redistribution of species such as *Abra* and *Nucula* was thought to be the result of dredging activities, while the presence of *Spisula* which is atypical for this environment is attributed to sporadic incursions of sand from the sandwave zone of the south west.

Conneely (1988) identified 4 discrete groupings of stations from a large-scale survey of Swansea Bay macrofaunal populations. These groupings were similar to those distinguished previously by Warwick and Davies (1977) for the Bristol Channel. A "*Venus*" community was associated with fine to medium sands and consisted primarily of species which are adapted to high-energy environments, such as *Nephtys cirrosa*, *Gastrosaccus spinifer*, *Urothoe brevicornis* and *Bathyporeia pelagica* (Britton and Britton, 1980; Tyler and Shackley, 1980). In contrast, the "*Modiolus*" community was restricted to areas where the substrata contained quantities of gravel. This community was the richest of the faunal groupings in terms of its species complement, which was attributed to the greater variety of microniches available in the coarser substrate. Collins *et al.* (1979) viewed these gravelly regions to be areas of balance between erosional forces and ephemeral deposition. This would account for the presence of finer material intermixed with the gravels observed by Conneely (1988). Occupying the greater part of the central and eastern sectors of the Bay was an "*Abra*" community that was associated with muddier sediments (Conneely, 1988). This community appeared to be an extension of the "*Abra*" community described by Warwick and Davies (1977) from the Bristol Channel. Distinguishing species from this group included *Nephtys hombergii*, *Nucula turgida*, *Diastylis rathkei*, *Spisula elliptica*, *Abra alba*, and *Spiophanes bombyx*.

Warwick and George (1980) examined the faunal assemblage at a single station thought to be representative of the "*Abra*" community in Swansea Bay over the course of a year, in order to estimate production of the major component species. Owing to the instability of the local environment the numbers of individuals were found to be highly variable, both between months and between samples taken in the same month. However, the species composition did not alter significantly during the period of study. In winter and spring, nearly all species were present in low numbers, with increasing numbers found in summer and autumn and declining numbers observed again in winter. This pattern was assumed to be the result of strong currents causing an influx and subsequent re-establishment of benthic communities from remote areas of the Bay and, as a result, cast doubt on the validity of calculating production levels in this area. Excepting *Abra alba*, the robust nature of the recorded taxa gave further support to this hypothesis. These findings are in agreement with those of Conneely (1988) who also noted increasing densities of the dominant taxa during the summer months from three sites representing the major facies of an "*Abra*" community. However, Conneely (1988) was unable to establish a causal mechanism, as the effects of recruitment could not be separated from those due to changes in substrata type. Of the dominant species, both *Nephtys hombergii* and *Nucula turgida* were largely indifferent to all but gross changes in grain size. Furthermore, *Nucula turgida* was found to exhibit different characteristics according to the environment it inhabits. In muddy sediments, the rate of growth is slow with low mortality and recruitment (Warwick and George, 1980; Conneely, 1988). In sands, the initial rate of growth is rapid but, while recruitment is high, the population suffers heavy mortality. *Diastylis rathkei* exhibited an increase in abundance due to recruitment during the summer months, but also showed a clear affinity for muddy sediments. In contrast, *Spisula elliptica* and *Spiophanes bombyx* appeared to be associated with increased quantities of sand. Warwick and Davies (1977) suggested reduced salinity levels as a possible causative factor for the impoverished fauna in Swansea Bay. Conneely

(1988) disputed this, as stations having an impoverished fauna did not appear to have significantly depressed salinities compared with stations elsewhere.

The area bordering the Bay is heavily industrialised and there are a number of domestic sewage inputs discharging over 100,000m^3 of sewage into Swansea Bay daily (consented dry weather flow) at the time of the survey (Crumpton and Goodwin, 1995). A considerable amount of data on the composition of the inputs from these sources up until 1979 is presented in Chubb *et al.* (1980) with more recent information given in NRA (1995). Furthermore, the NRA reported that, during 1991, Swansea Bay received the second highest annual loading of zinc from discharges in the UK (NRA, 1995).

Table 61 Mean metal concentrations (ppm wet weight) of dredgings from various areas within the Swansea and Port Talbot Dock Systems. Source – Unpublished M.A.F.F. Data.

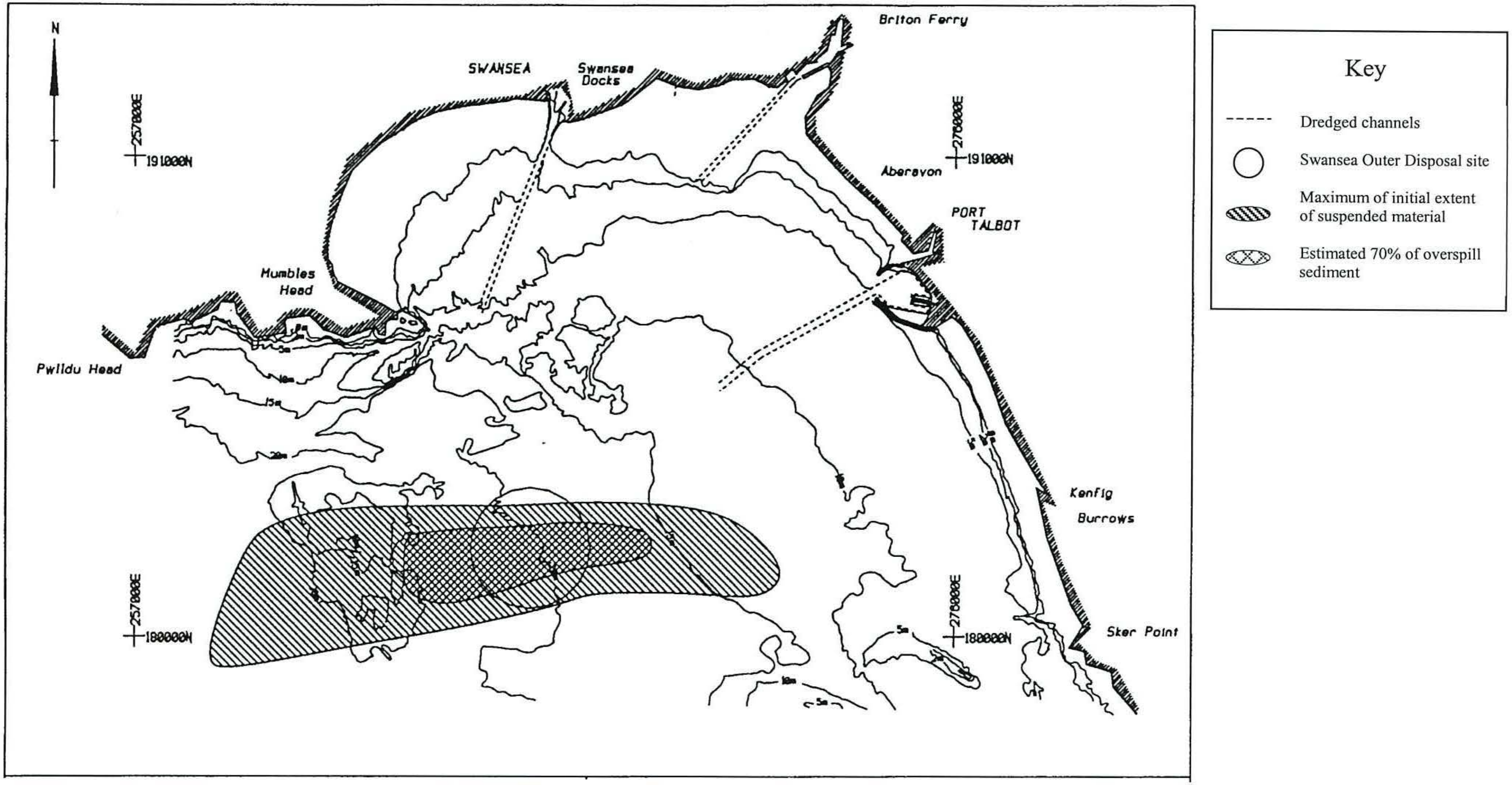
Source of material	*Date*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Solids (%)*	*Zn*
Neath Estuary	Dec-95	<0.040	7.9	6.5	<0.020	7.4	12.9	85.0	55.0
Swansea Approach Channel	Oct-94	0.83	26.0	22.7	0.46	14.3	59.7	42.4	100.3
Port Talbot Dock	Aug-97	0.30	28.1	17.0	0.22	16.0	37.1	55.41	91.1

6.1.1 Sampling design

The Outer disposal site is located in shallow water of approximately 20m depth. It contains gravelly sand in the south-western sector while its eastern sector lies on the edge of a sand and mud area. Although it has been predicted that 70% of sandy mud deposited at the disposal site will accumulate over 5km in an east-west direction centred around the site (ABP, 1997; see also Figure 46), a south-westerly aligned transect was adopted for sampling purposes. Such a design corresponds with the direction of predicted wave induced sediment transport (Collins *et al.*, 1979). This design was selected in order to establish changes in the faunal communities attributable to dredgings disposal rather than to quantify the totality of effects associated with the disposal operation. Two benthic surveys were carried out, the first in June 1995 and the second a year later. In 1995, three replicate 0.1m^2 Day Grab samples were collected from each of six stations along a transect emanating from within the Outer Swansea Bay disposal site (Figure 44). Two stations (1 and 2) were located within the disposal site; a third station was positioned on the margins of the site and further stations (4, 5 and 6) were located at increasing distance shoreward from the site. Samples to the south of the disposal site could not be obtained due to the coarse nature of the seabed in this area. Sub-samples of sediment were taken from the grabs for particle size and nematode analyses, with the remaining material preserved separately for later macrofaunal analysis (see Chapter 2 for Methods). A surface scrape of sediment was also collected from an additional grab at each station for the estimation of a range of organic and trace metal contaminants.

The stations were revisited in June 1996 and replicate core samples were collected for nematode analysis employing the Bowers and Connelly Multiple Mini-Corer. Triplicate core samples were also obtained at each station for the assessment of environmental variables. In addition, the surface layer from a single core at each station was collected for analysis of polychlorinated biphenyls (PCBs).

Figure 46 The extent of sediment dispersion during disposal, at the Outer disposal site in Swansea Bay, predicted from numerical models (reproduced from ABP, 1997).



6.2 RESULTS

6.2.1 Univariate measures of community structure

Nematode "feeding types"

The distribution of nematode "feeding types" expressed as % contribution of selective deposit feeders (1A), non-selective deposit feeders (1B), epigrowth grazers (2A) and predators (2B) shows that, with the exception of the northernmost stations (5 and 6), the non-selective deposit feeders (1B) formed the greatest proportion of the nematode groups encountered in both core and grab sediments (Figure 47A and B; see also Table 62 and 63).

An examination of the distribution of the "indicator" taxa *Sabatieria pulchra* grp. and *Daptonema tenuispiculum* revealed significant differences between stations (Figure 48A & B and 49A & B). However, only the distribution of *S. pulchra* grp. from core sediments could be related to any effect of dredgings disposal (Figure 49A), with elevations of this taxon observed within and on the periphery of the disposal site. No trend could be discerned in the ratio of 1B/2A feeding groups calculated from nematode data from grab sub-samples (Figure 50A). In contrast, consideration of this measure derived from nematode data from core sediments taken in 1996 revealed a broad trend of decreasing values away from the disposal site, although the differences were not significant (Figure 50B).

Diversity Measures

Changes in univariate measures derived from macrofaunal community data provide no evidence of an effect of dredgings disposal (Figure 51). For example, Shannon-Wiener diversity (H'), evenness (J) and macrofaunal species richness (d) decrease northwards away from the disposal site.

Figure 47 Mean distribution of nematode feeding groups along the Swansea Bay from A) grab sub-samples and B) cores.

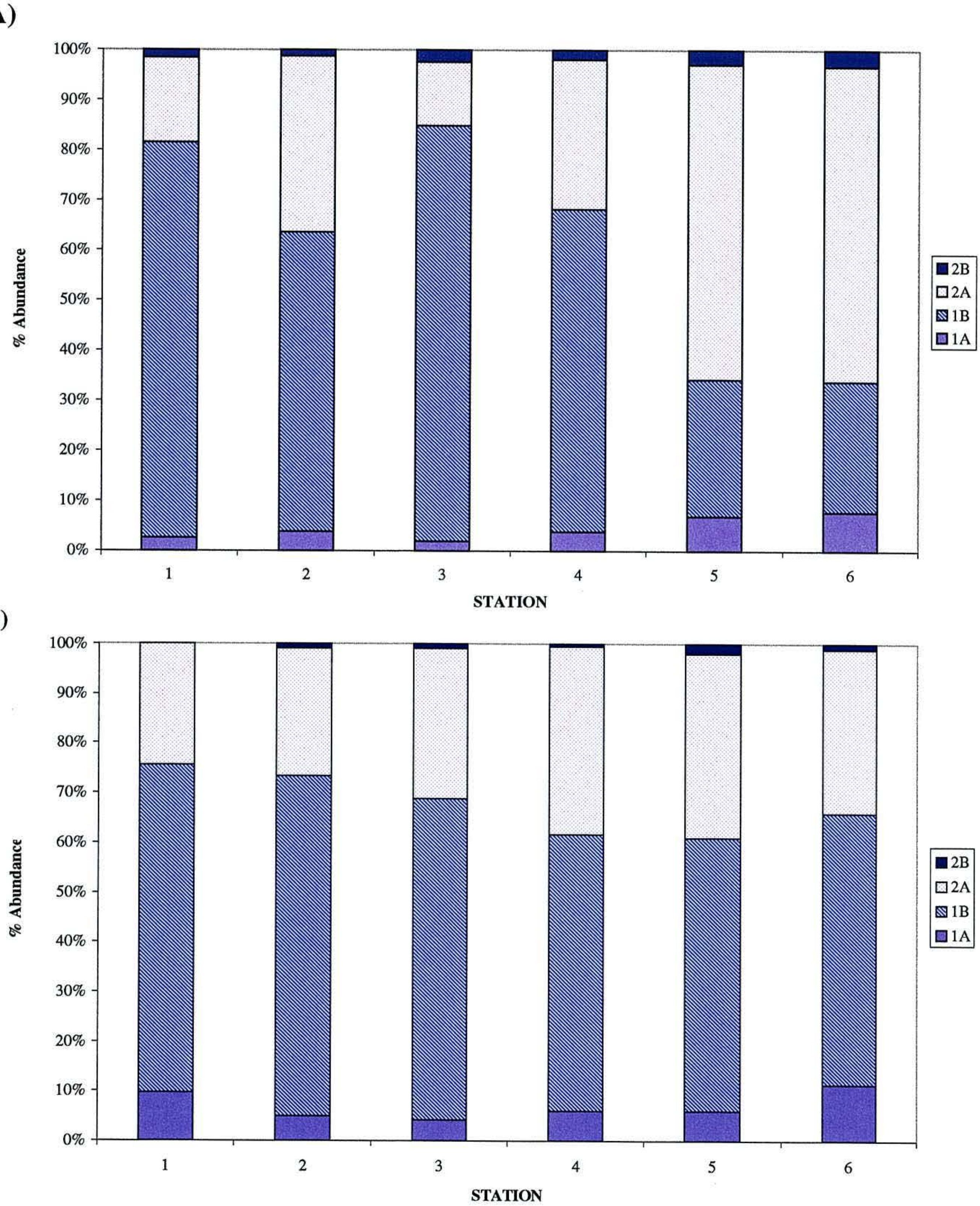


Figure 48 Distribution of the percentage abundance of A) *Sabatieria pulchra* group and B) *Daptonema tenuispiculum* from grab sub-samples along the Swansea Bay (means and 95% Least Significant Intervals).

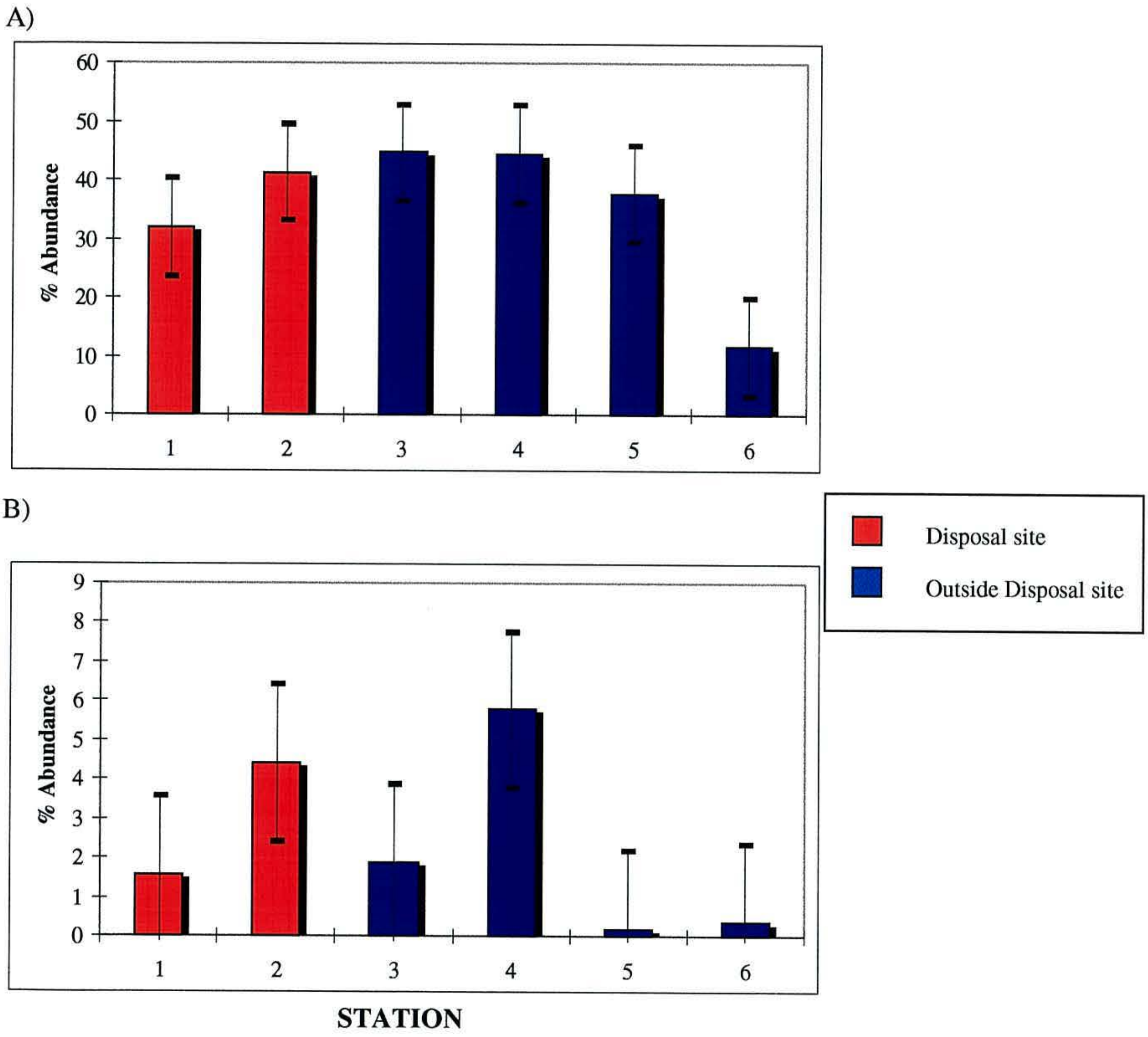


Figure 49 Distribution of the percentage abundance of A) *Sabatieria pulchra* group and B) *Daptonema tenuispiculum* from cores along the Swansea Bay (means and 95% Least Significant Intervals).

A)

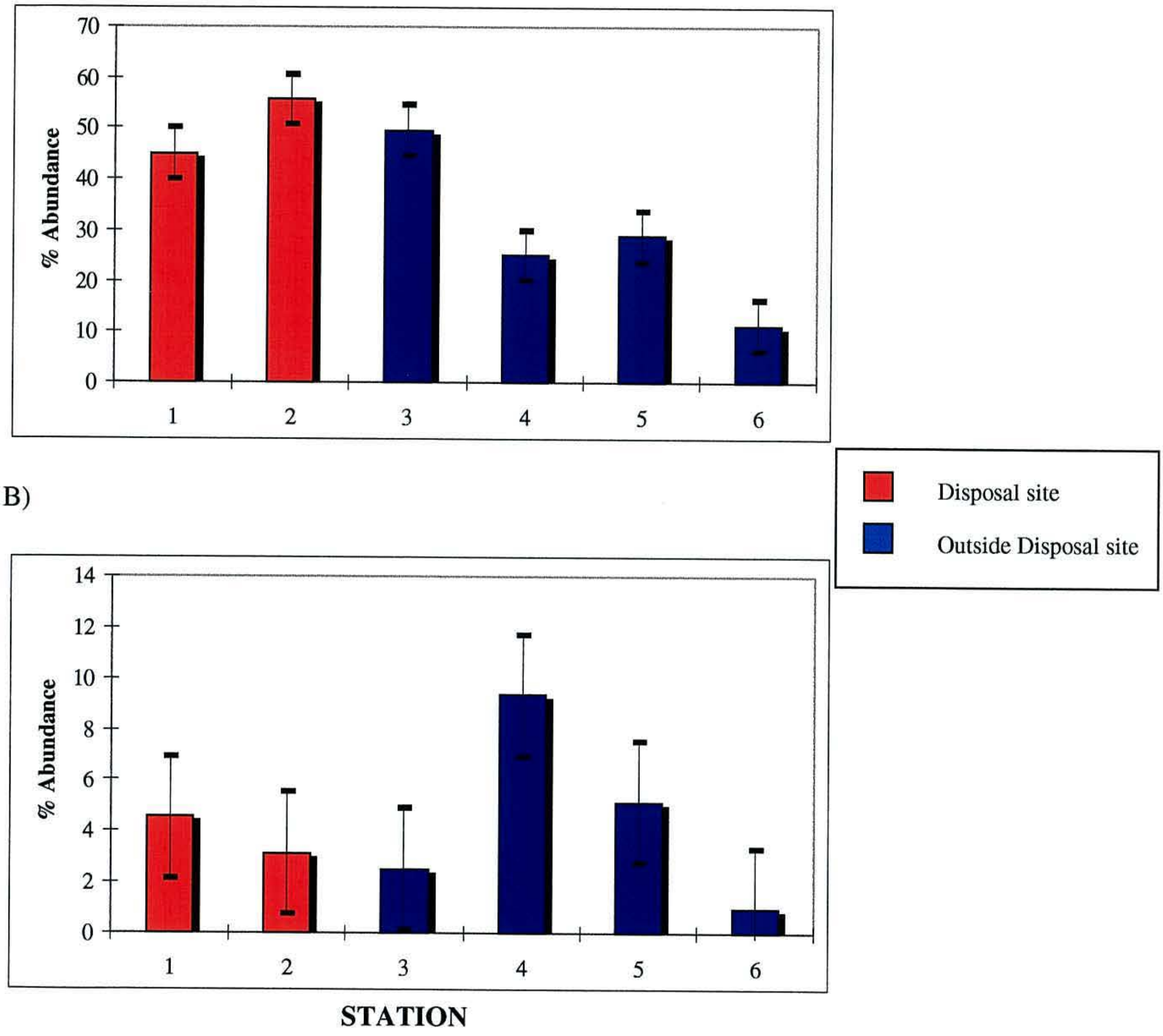


Figure 50 Distribution of the ratio of 1B/2A nematode groups (means and 95% Least significant intervals) along the Swansea Bay from A) grab sub-samples and B) cores.

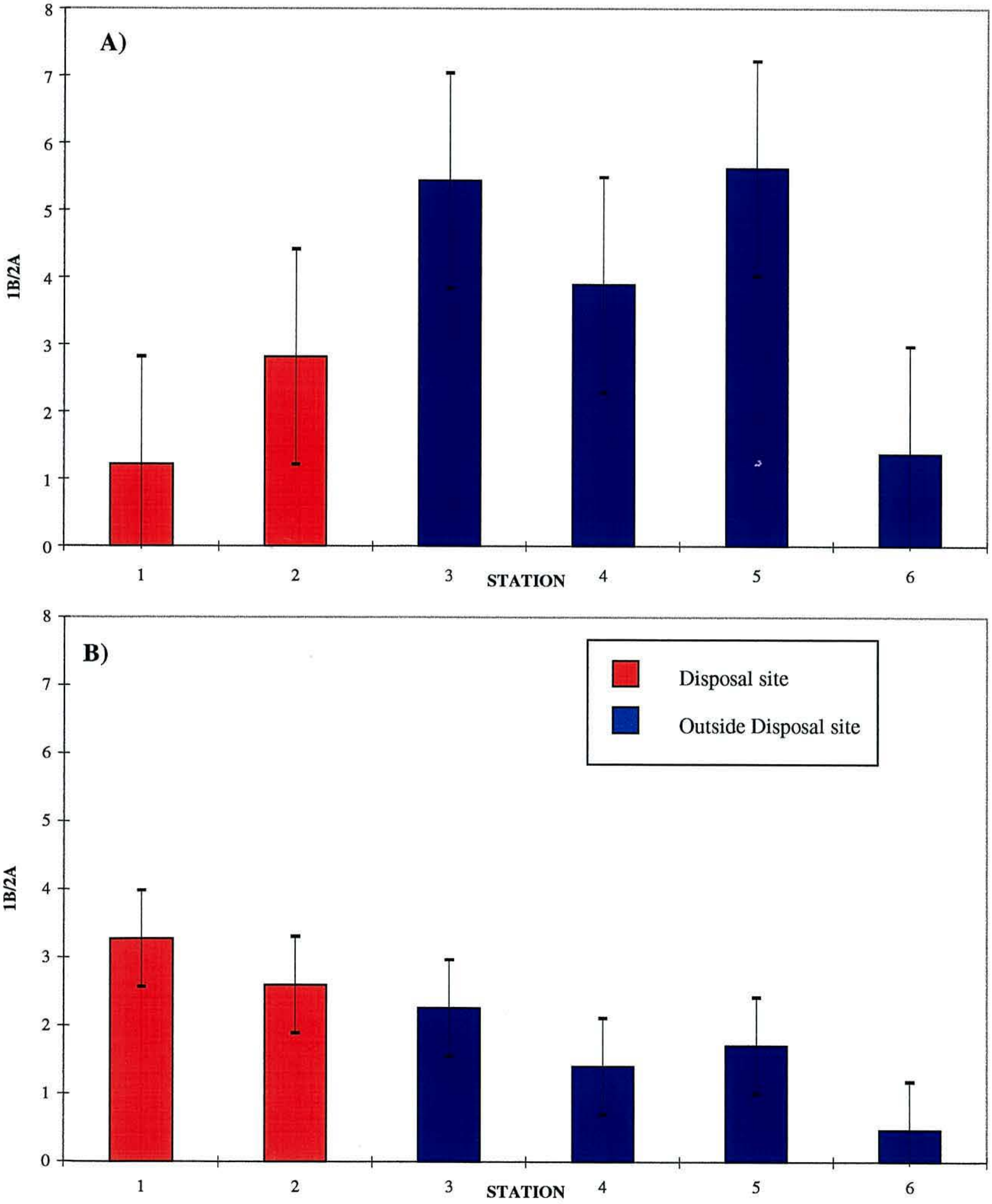


Table 62 The percentage abundance of the 4 nematode feeding types for replicated and pooled grab sub-samples at each station.

Station	Nematode group				
	1A	1B	2A	2B	1B/2A
1a	6	44	47	3	0.95
1b	7	56	35	2	1.58
1c	9	46	41	4	1.14
1a-c	3	79	17	2	4.65
2a	8	70	20	1	3.47
2b	2	76	20	2	3.89
2c	7	47	43	3	1.10
2a-c	4	60	35	1	1.70
3a	6	80	13	1	6.33
3b	2	84	14	0	5.93
3c	3	76	19	2	4.06
3a-c	2	83	13	2	6.52
4a	2	85	13	1	6.79
4b	4	64	30	2	2.16
4c	4	70	26	1	2.73
4a-c	4	64	30	2	2.16
5a	3	70	25	2	2.76
5b	3	85	11	0	7.57
5c	2	84	13	1	6.53
5a-c	7	27	63	3	0.44
6a	6	27	65	2	0.41
6b	10	25	61	5	0.40
6c	3	73	22	1	3.32
6a-c	8	26	63	3	0.42

Similarly the pattern observed with summary statistics derived from nematode grab sub-samples is not consistent with an impact of dredgings disposal, with values tending to be lowest at stations (4 and 5) located away from the disposal operation (Figure 52). Figure 53 shows there is a marked difference ($p<0.05$) in the values of Shannon-Wiener diversity (H') and evenness (J) indices calculated with nematode data from core sediments in the vicinity of the disposal site compared with stations to the north. This situation appears to be largely due to an elevation of comparatively few numerically dominant taxa such as the non-selective deposit feeder *Sabatieria pulchra* grp. within and adjacent to the disposal site (see also Figure 49A).

Table 63 The percentage abundance of the 4 nematode feeding types for replicated and pooled core samples at each station.

Station	Nematode group				
	1A	1B	2A	2B	1B/2A
1a	4	75	16	5	4.67
1b	13	61	18	8	3.48
1c	7	56	33	3	1.69
1a-c	9	62	23	6	2.70
2a	6	66	27	1	2.46
2b	8	58	33	2	1.75
2c	3	76	21	0	3.59
2a-c	5	69	26	1	2.65
3a	6	68	26	0	2.66
3b	3	60	35	2	1.74
3c	4	66	28	2	2.38
3a-c	4	64	30	1	2.13
4a	6	52	40	3	1.30
4b	2	53	44	1	1.19
4c	4	60	35	0	1.73
4a-c	4	56	38	1	1.47
5a	7	58	33	1	1.76
5b	12	60	26	1	2.32
5c	2	49	46	2	1.06
5a-c	6	55	37	2	1.49
6a	14	29	56	2	0.52
6b	17	28	54	1	0.51
6c	9	24	63	4	0.39
6a-c	12	27	58	2	0.47

Table 64 F-ratios and significance levels (from $F_{5,12}$) from 1-way ANOVA tests for differences in various univariate measures of community structure between stations.

Univariate Measure	*Macrofauna (Grabs)*		*Nematodes (Grabs)*		*Nematodes (Cores)*	
	F	p	F	P	F	P
Log (1+S)	0.99	0.4615	4.10	<0.05	3.65	<0.05
Log (1+A)	5.85	<0.01	5.27	<0.01	4.42	<0.05
D	1.91	0.1659	3.44	<0.05	3.84	<0.05
H'	3.21	<0.05	1.41	0.28	13.59	<0.01
J	20.54	<0.01	0.56	0.72	7.86	<0.01

Table 65 Pearson product moment correlations between each pair of log-transformed (1+N) variables from grabs (based on 6 pairs of observations). Diversity indices are derived from pooled macrofauna data. Values highlighted in bold type indicate significant correlation ($p<0.05$).

	Log (1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	0.1254	0.1369	0.0074	0.1441	0.2015
%OrgC	0.2030	0.0778	0.1884	0.2558	0.3551
%N	0.3119	0.0319	0.3415	0.2512	0.4149
%s/c	-0.4233	0.4249	-0.5622	-0.0674	-0.3388
%S	0.5012	-0.4554	0.6530	0.1435	0.4585
%G	0.5763	-0.1548	0.6269	0.3588	0.6883
Cd	0.5933	**0.8876**	0.0476	-0.7587	-0.4441
Cr	0.3330	-0.1176	0.4690	0.4111	0.5908
Cu	0.3024	-0.0866	0.4094	0.3897	0.5509
Hg	0.6264	-0.1902	**0.8150**	0.2870	0.6441
Ni	0.2832	0.0424	0.3026	0.2637	0.4102
Pb	0.3621	-0.0491	0.4492	0.3315	0.5264
Zn	0.3711	0.0210	0.3907	0.2618	0.4607

An examination of the relationships between environmental variables from grabs and a range of biological descriptors show Hg concentrations to be positively associated ($p<0.05$) with macrofaunal species richness (d) (Table 65). A degree of correlation was also noted between a number of the metals, notably Cd, and nematode diversity (H') from grab sub-samples (Table 66). The positive links between metal concentrations and these biological measures may suggest that the fauna in Swansea Bay is not adversely affected by any additional contamination from the disposal operation. Furthermore, the richness (d) of nematode fauna from grab sub-samples is positively associated ($p<0.05$) with the gravel content of grab sediments (Table 66). The interstices and crevices of large sediment particles may provide more niches for colonisation by a greater number of nematode species. In contrast, measures of Shannon - Wiener diversity (H') and evenness (J) calculated from nematode data sampled by cores are inversely related ($p<0.05$) to the gravel content of core sediments (Table 67). This is more difficult to explain, but as the gravel content of core sediments is greatest within and on the periphery of the disposal site, the gravel fraction may have been derived from deposited dredgings and hence represents the "fingerprint" of the disposal operation. Sedimentary carbon levels were also correlated with the densities of nematode taxa (log 1 +A) in core sediments and may indicate a degree of enrichment.

Table 66 Pearson product moment correlations between each pair of log-transformed (1+N) variables from grabs (based on 6 pairs of observations). Diversity indices are derived from pooled nematode data from grab sub-samples. Values highlighted in bold type indicate significant correlation ($p<0.05$).

	Log (1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	0.6284	0.6417	0.5280	-0.5174	0.2411
%OrgC	0.4848	0.5093	0.4126	-0.2444	0.2961
%N	0.4500	0.4241	0.3948	-0.1309	0.3493
%s/c	-0.2700	0.3523	-0.4646	0.3397	-0.0379
%S	0.4129	-0.2665	0.6108	-0.4491	0.0996
%G	0.7658	0.3514	**0.8485**	-0.4314	0.4454
Cd	0.4674	0.7845	0.2308	0.5614	**0.8963**
Cr	0.3871	0.2609	0.4048	-0.1027	0.3033
Cu	0.4246	0.3213	0.4239	-0.1646	0.2950
Hg	0.2859	-0.0059	0.3694	0.2127	0.4477
Ni	0.4638	0.4492	0.4072	-0.1635	0.3373
Pb	0.4317	0.3343	0.4198	-0.0991	0.3533
Zn	0.5349	0.4508	0.4941	-0.1914	0.3900

Table 67 Pearson product moment correlations between each pair of log-transformed (1+N) variables from cores (based on 6 pairs of observations). Diversity indices are derived from pooled nematode data. Values highlighted in bold type indicate significant correlation ($p<0.05$).

	Log (1+S)	*Log(1+A)*	*d*	*J*	*H'*
%C	0.4359	0.8008	-0.0783	-0.2400	-0.1412
%OrgC	0.2188	0.7055	-0.2434	-0.3215	-0.2654
%N	-0.3018	0.4532	-0.6238	-0.6341	-0.6657
%s/c	0.5529	0.5405	0.2321	-0.6691	-0.5252
%S	-0.4304	-0.6046	-0.0505	0.8043	0.6831
%G	-0.0093	0.5301	-0.3966	**-0.8326**	**-0.8027**
Cd	0.4269	0.4262	0.1572	0.0875	0.1586
Cr	0.1565	0.4560	-0.1721	0.1942	0.2081
Cu	0.4128	0.6597	-0.0270	0.0129	0.0881
Hg	0.6703	0.5548	0.3677	-0.0001	0.1423
Ni	0.4072	0.4222	0.1215	0.3256	0.3861
Pb	0.3852	0.5703	0.0063	0.1217	0.1870
Zn	0.3234	0.6721	-0.1108	-0.1684	-0.0991

6.2.2 Multivariate measures of community structure

Clustering

The output from average linkage cluster analysis of 4th root transformed species abundance data were difficult to interpret. With the exception of station 6, sample replicates were generally found to occur in separate clusters (Figure 54). Such an arrangement may suggest that a single variable population of benthic animals is present along the sampled transect.

Ordination

There are no clear patterns in ordinations of either 4th root transformed macrofaunal data or nematode data from grab sub-samples (Figure 55A and B). However, ordinations of 4th root transformed nematode data sampled by the cores revealed that a disposal site station (1) was dissimilar in terms of its composition both between replicates and when compared with stations elsewhere (Figure 55C). A slightly more consistent pattern emerges with MDS ordinations of averaged biotic data, with both macrofaunal and nematode data from cores showing disposal site station 1 to be distinct from the rest of the sampled stations (Figure 56A and C). Apart from the separation of station 1, there is little to suggest that there is a gradient of response away from the disposal site. Furthermore, when the similarity matrices behind these biotic ordinations were compared there was no significant correlation ($p>0.05$) which suggests that no consistent response to dredgings disposal is evident (Table 68).

Station 1 was again found to be separate from all other stations in PCA ordinations of log transformed environmental data from core sediments (Figure 56E). Therefore, there is some correspondence between environmental variables sampled from core sediments and the distribution of biological communities (Figure 56A, C and E). Indeed when the similarity matrices were compared significant association was found ($p<0.05$) between nematode assemblages and environmental variables found in core sediments (Table 69). It is also apparent from Figure 56 that there is no clear relationship ($p>0.05$) between concentrations of PCBs in core sediments and the distribution of faunal assemblages (see also Table 69).

Table 68 Pairwise Spearman rank correlations between similarity matrices derived from averaged 4th root transformed abundance data.

	Macrofauna	Nematode (Grab sub-samples)
Nematodes (Cores)	0.532	-0.075
Nematodes (Grab sub-samples)	0.286	

Table 69 Rank correlations (ρ) between the Euclidean distance matrices derived from environmental variables (log (1+X) transformed) from grabs and cores and similarity matrices derived from 4^{th} root transformed biotic data. *$p<0.05$ by a permutation test.

	Environmental variables (Grab)	Environmental variables (Cores)	PCB (Cores)
Macrofauna	-0.239	0.393	0.243
Nematodes (Cores)	0.346	0.657*	0.079
Nematodes (Grab sub-samples)	0.289	-0.450	0.036

Figure 51 Means and 95% LSD intervals for univariate measures of MACROFAUNA community structure along the SWANSEA BAY transect.

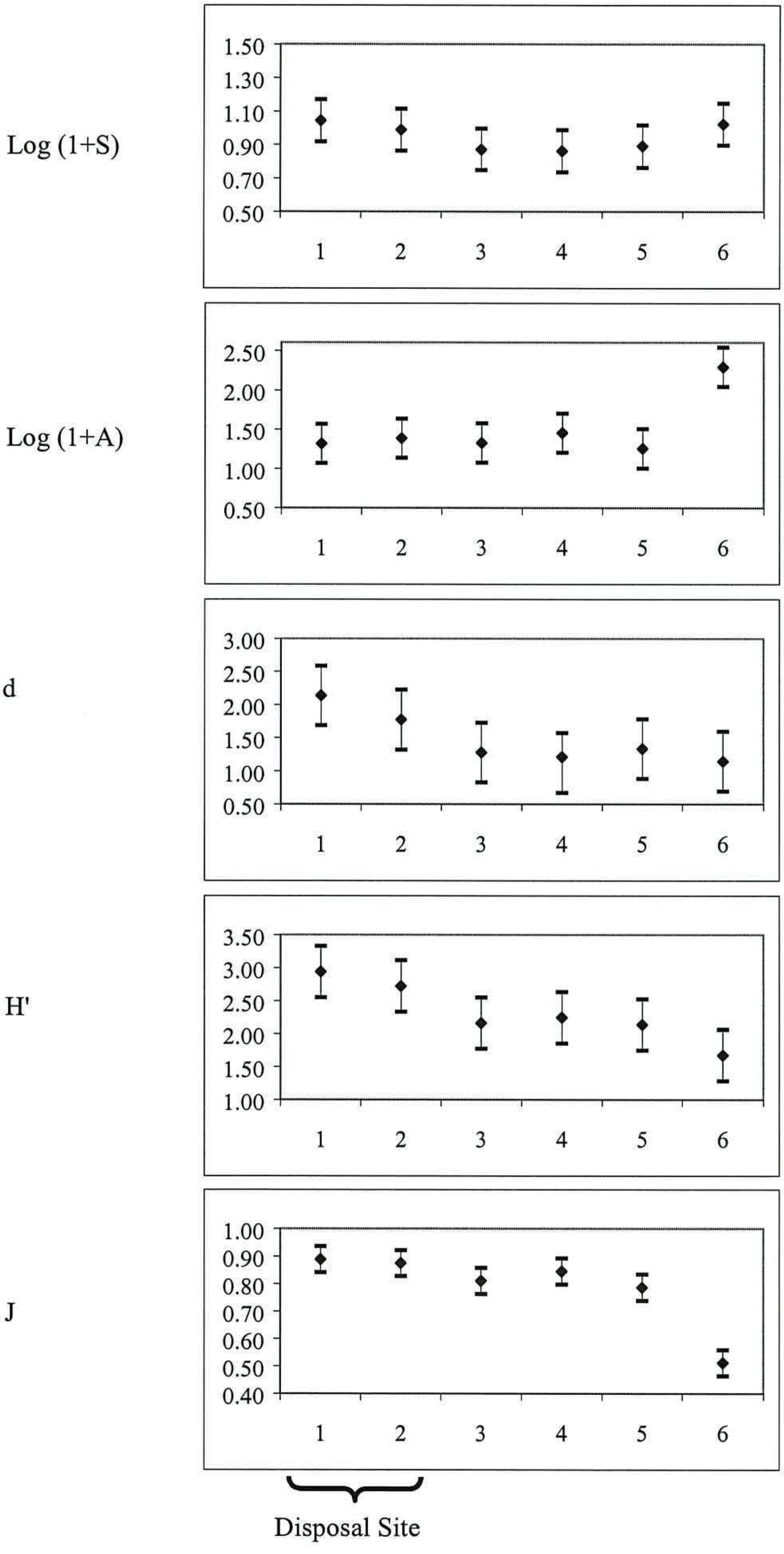


Figure 52 Means and 95% LSD intervals for univariate measures of NEMATODE community structure from grab sub-samples along the SWANSEA BAY transect.

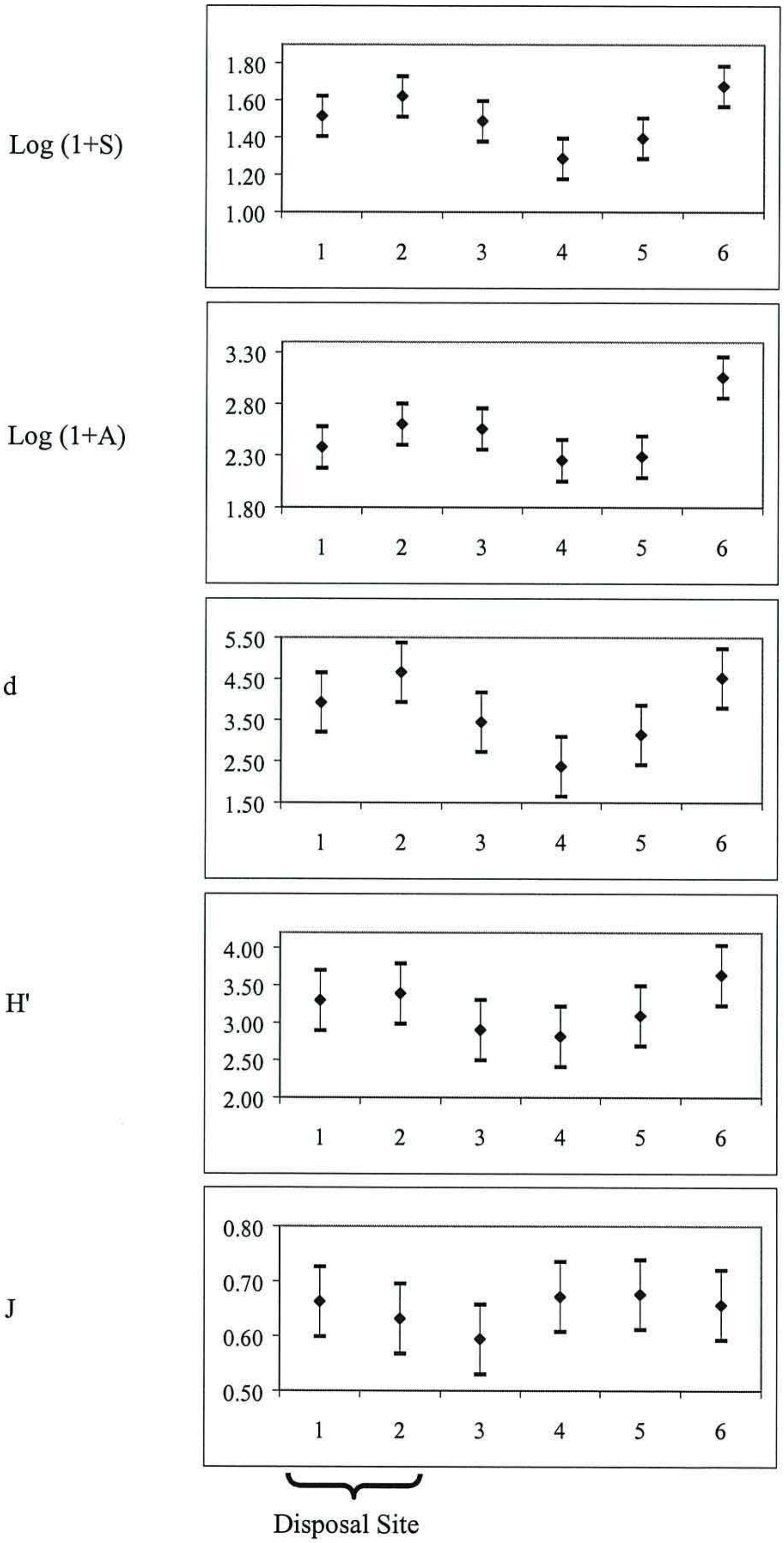


Figure 53 Means and 95 % LSD intervals for univariate measures of NEMATODE community structure from cores along the SWANSEA BAY transect.

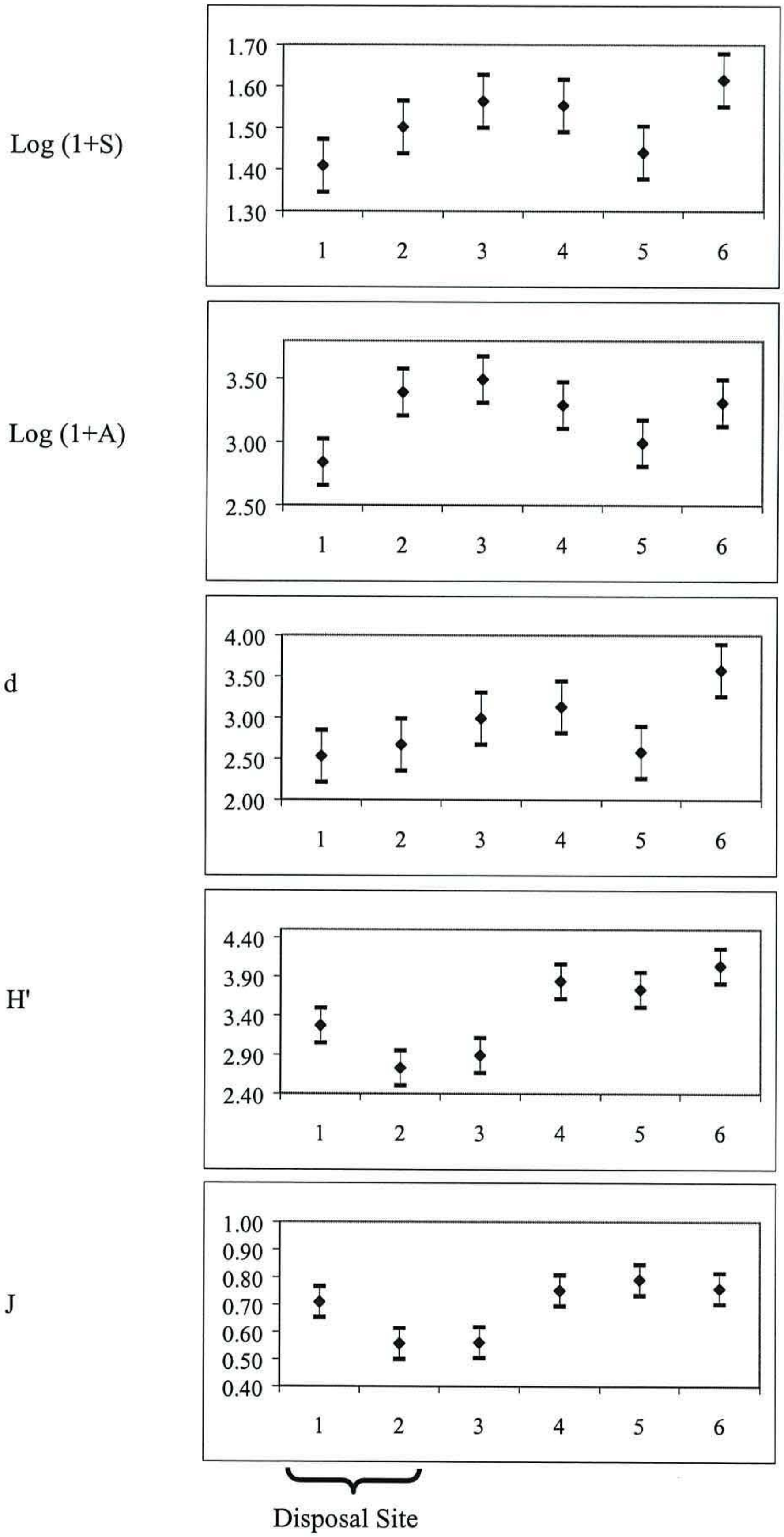
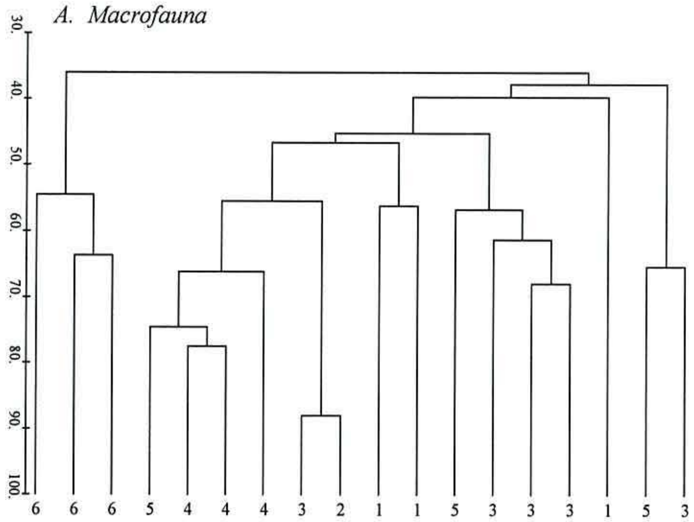
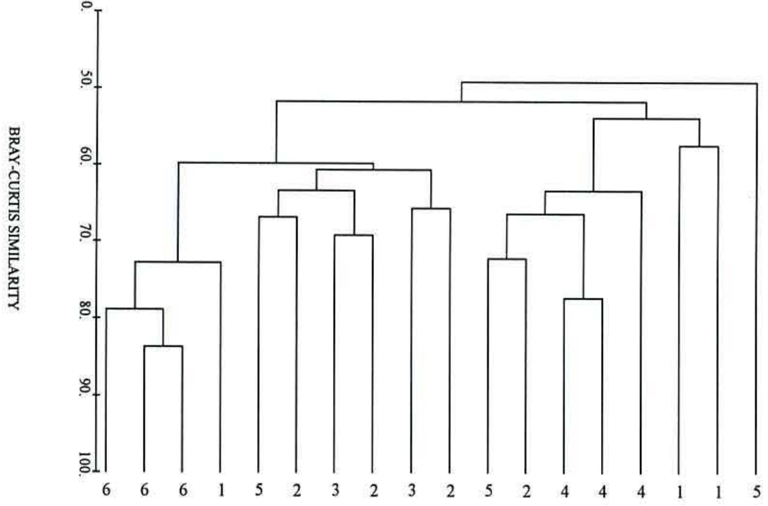


Figure 54 Cluster analysis of 4th root transformed macrofauna and nematode data for stations 1-6 along SWANSEA BAY transect. Stations 1 and 2 are located within the disposal site.


A. Macrofauna


B. Nematodes (Grab sub-samples)

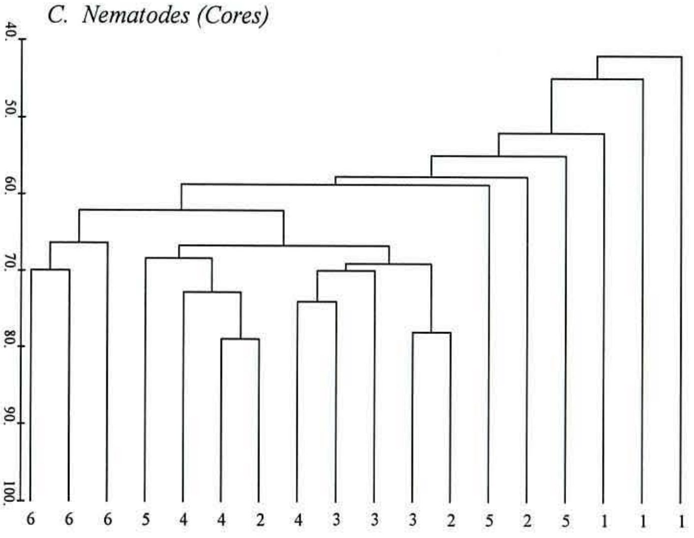
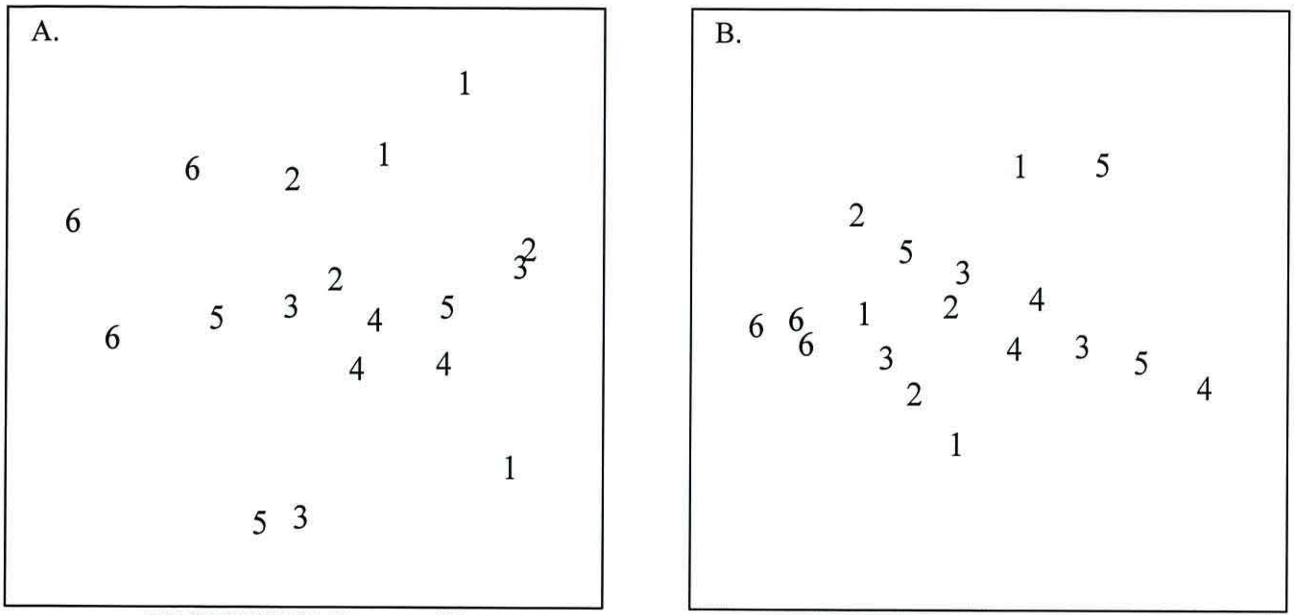
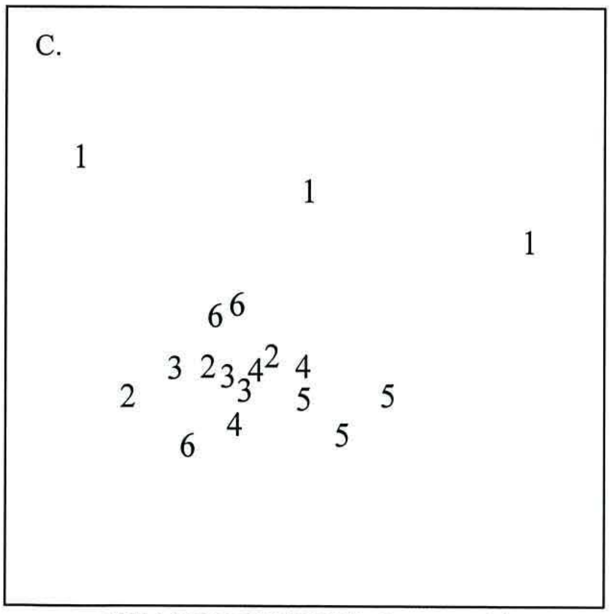

C. Nematodes (Cores)

Figure 55 Multidimensional scaling ordinations of 4th root transformed biotic data for stations 1 to 6.



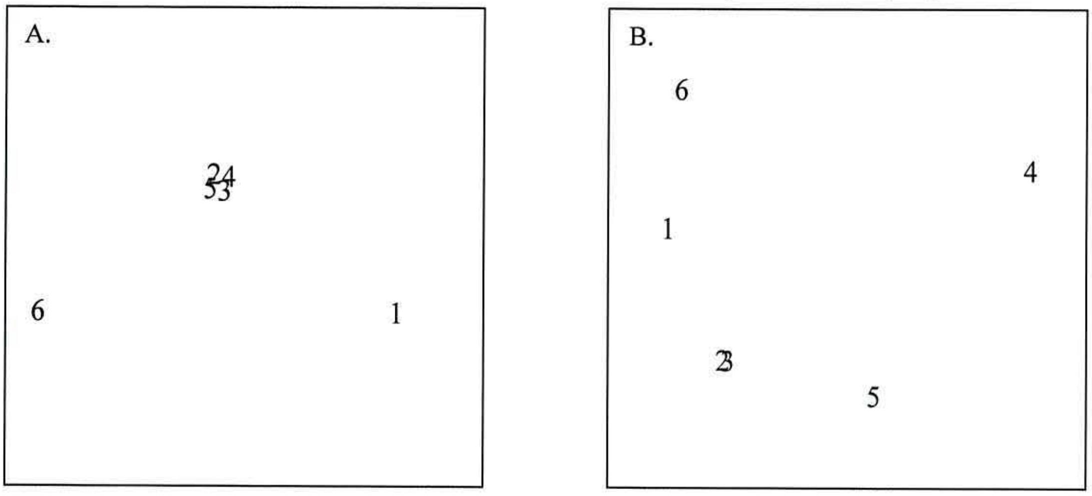
MACROFAUNA, Stress = .17

NEMATODES (Grab sub-samples), Stress = .18



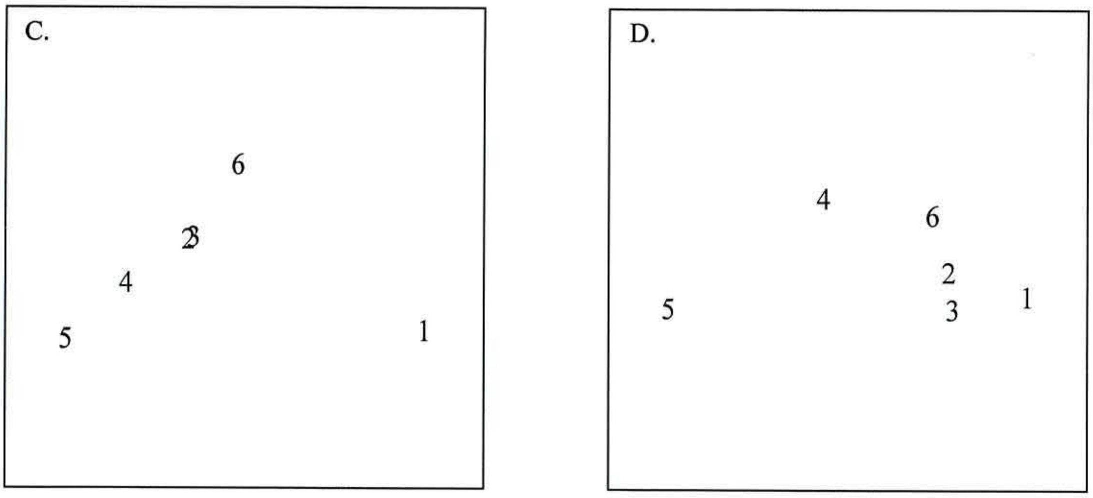
NEMATODES (CORES), Stress = .16

Figure 56 Ordinations by PCA of environmental variables, and by MDS of averaged abundances from stations 1 to 6. Environmental variables log (1 + *N*) transformed, nematodes and macrofauna 4th root transformed.



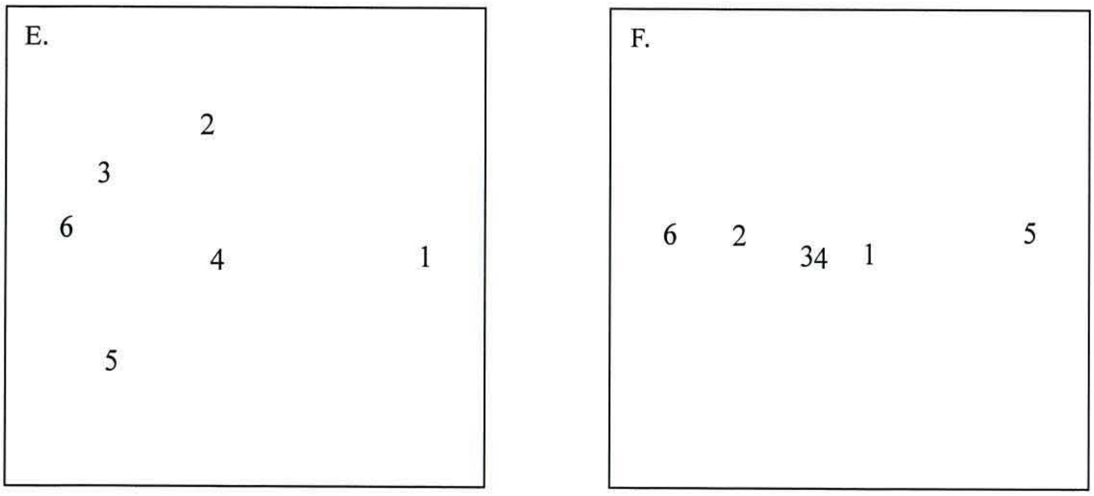
Macrofauna, stress = 0.01

Nematodes (Grab sub-samples), stress = 0.01



Nematodes (Cores), stress = 0.00

Environmental variables (Grabs), stress = 0.01



Environmental variables (Cores), stress = 0.01

PCB'S (Cores), stress = 0.01

Species distributions and densities

Relatively low numbers of macrofaunal species were recorded from grab samples along the transect. Of the 41 macrofaunal species recorded, *Nephtys hombergii* and *Abra alba* had a cosmopolitan distribution. Numbers of individuals were highest at the northern end (station 6) of the transect. The sediments from this area were found to support higher numbers of *Spisula subtruncata* and *Nucula nitidosa* which were absent or reduced elsewhere along the transect (Appendix X). Species found at station 1 within the disposal site, such as the hydroid *Obelia dichotoma*, the polychaetes *Demonax* sp., *Syllis* sp. *Autolytus* sp., the bivalve *Modiolus* sp., the pycnogonid *Nymphon brevirostre* and the bryozoan *Umbonula* sp., were indicative of a gravelly component to the sediment. This was not evident from the results of particle size analysis. A single specimen of *Macoma balthica,* which is more typically associated with estuarine environments, was also recorded from this station.

As with the macrofauna, greater densities of nematodes were recorded from grab sub-samples from the northernmost station (6). A range of species typically found in muddy sediments characterised this station including *Marylynnia complexa*, *Microlaimus turgofrons*, *Molgolaimus demani*, *Terschellingia longicaudata* and *Campylaimus* sp. (see Appendix V). The nematode fauna did not appear to be impoverished, compared with other coastal environments in the UK with a total of 90 taxa being recorded along the transect. Few of these species were restricted to a particular station or group of stations suggesting that the fauna is derived from a single variable population, possibly as a result of the transport and re-establishment of animals through sediment disturbance.

The within station variability as a measure of disturbance was investigated by calculating the r.IMD. (Somerfield *et al.*, 1993). Interestingly, the arrangement of stations imposed by the above index compares well for all faunal groups (Table 70A, B and C). Furthermore, a disposal station (1) was found to have the most variable species composition in terms of both the macrofaunal and nematode assemblages from core sediments (Table 70A and C).

Table 70 Relative Index of Multivariate Dispersion for A) macrofaunal grab samples, B) nematodes from grab sub-samples and C) nematodes from cores for stations 1 to 6. The stations have been placed in the order of increasing r.IMD.

A)

Station	*r.IMD*
4	0.25
6	0.70
2	1.09
3	1.19
5	1.33
1	1.44

B)

Station	*r.IMD*
6	0.25
4	0.63
2	0.77
1	1.09
3	1.54
5	1.72

C)

Station	*r.IMD*
4	0.35
6	0.77
2	0.88
3	0.95
5	1.26
1	1.79

6.2.3 Biotic and environmental relationships

The results of trace metal and particle size analyses of sediments from Swansea Bay are shown in Table 71-74. Zinc, cadmium and lead concentrations in river and Bay sediments near Swansea have previously been reported as being elevated (Bloxam *et al.*, 1972; Vivian, 1980). The high concentrations reported by Bloxam *et al.* (1972) were attributed to the down-river movement of contaminated silts and clays from the smelting industry located along the River Tawe.

In 1995, the highest levels of trace metals from grab sediments were found within the disposal site at station 1 (Table 71). In contrast, core sediments taken from station 1 in 1996 were recorded as having the lowest mean concentrations of trace metals (Table 72). This discrepancy may in part be due to samples being taken a year apart with sediments being extensively reworked both naturally by wave and tidal currents and artificially by dredging activities which prevents the persistence of any localised pattern of input. It is perhaps significant to note that core sediments from station 6, the most inshore of the sampled stations, were found to have the highest concentrations of trace metals. Therefore it may be assumed that the higher levels of trace metals at station 6 may stem from discharges from

Port Talbot or riverine input of trace metals from the historic smelting industry. An indication of recent contamination may be expected from an examination of PCBs in sediments taken along the transect. PCBs were detected in all surface samples tested, and station 6 was again found to have the highest levels of contamination (Table 74). This would suggest that contamination arises from a variety of inshore sources and that any additional input due to the disposal operation remains largely indistinguishable against the background contamination.

All the sediment parameters measured, together with the trace metal results obtained from grab samples were subjected to correlation analysis and the resulting matrix is presented in Appendix XXVII). Significant positive correlations were found between all the trace metals studied except Cd, suggesting a common source or sources of the trace metals. There was also significant positive correlation with some of the trace metals and the organic content of the sediments. A similar pattern is evident with core sediments (Appendix XXVIII and Appendix XXIX). Clifton and Vivian (1975) and Vivian (1980) also found strong positive correlations between trace metals, organic carbon and sedimentary parameters from Swansea Bay sediments. Vivian (1980) observed that trace metals showed a closer correlation with organic carbon than with the mud content of sediments. This is in agreement with the findings of the current study and suggests that the organic content of the sediments is more important in controlling the levels of trace metals in Swansea Bay sediments.

All PCB congeners analysed were found to be significantly related ($r>0.95$, $p<0.05$) (Appendix XXX). This suggests that the input of PCBs is also from a common source or alternatively that the sediments are well mixed (C. Allchin *pers. comm*).

Table 71 Concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 6 from Day Grab samples.

Station	*%C*	*%OrgC*	*% N*	*% s/c*	*% S*	*% G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
1	3.60	2.17	0.24	13.66	85.65	0.70	0.23	90.79	46.48	0.91	35.59	99.95	134.0
2	4.19	2.10	0.17	15.11	84.03	0.87	<0.21	62.45	36.17	0.24	29.52	59.17	105.5
3	4.55	2.50	0.23	16.60	82.97	0.43	<0.16	65.78	39.37	0.28	35.10	72.68	125.2
4	3.24	1.32	0.12	29.79	70.21	0.00	<0.18	45.37	26.31	0.16	23.09	39.50	71.24
5	2.80	0.43	0.02	7.51	92.47	0.02	<0.19	23.62	14.76	0.07	14.32	18.29	45.56
6	4.05	2.06	0.19	25.61	74.07	0.32	0.33	53.79	32.03	0.26	30.54	57.33	105.6

Table 72 Mean concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 6 from core samples.

Station	*%C*	*%OrgC*	*% N*	*% s/c*	*% S*	*% G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
1	3.42	1.38	0.15	54.14	44.38	1.47	0.24	29.33	19.33	0.18	28.00	38.33	137.67
2	4.27	2.59	0.31	58.77	38.39	2.84	0.31	40.00	29.67	0.36	30.67	59.00	195.00
3	4.24	2.41	0.19	60.91	36.47	2.62	0.72	55.33	44.00	0.34	43.67	93.00	203.00
4	3.95	1.81	0.15	50.56	47.52	1.92	0.38	49.67	34.00	0.26	42.00	72.00	167.00
5	4.05	2.32	0.21	31.16	68.53	0.31	0.56	58.33	37.00	0.30	41.33	84.67	196.33
6	4.45	2.59	0.19	53.04	46.47	0.49	0.64	50.67	41.33	0.58	42.33	92.33	215.67

A series of correlation analyses was performed using BIO-ENV to identify the likely causative environmental factors responsible for any differences between stations. The highest correlation using averaged macrofaunal data arose with cadmium and mercury (Table 75). A similar analysis performed with nematode data from grab sub-samples found a combination of sedimentary parameters and cadmium as "best" explaining the faunal pattern (Table 76). In contrast, the outcome of correlation analyses with nematodes and environmental variables from core sediments identified a combination of 5 variables which explained >90% of the variation in the data (Table 77). Furthermore, an examination of the environmental variables in turn showed that the percentage of sedimentary carbon individually accounted for a significant (ρ_w = 0.768) amount of the faunal variation. Therefore, sedimentary carbon or some other related variable can be considered as the primary factor that determined the broad composition of the nematode assemblage in 1996 (Table 77).

Table 73 Concentrations (mg kg^{-1}dry weight) of trace metals and other environmental variables at Stations 1 to 6 from replicated core samples.

Station	*% C*	*% OrgC*	*% N*	*% G*	*% S*	*% s/c*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
1A	3.67	1.64	0.14	1.10	55.93	42.97	<0.24	35	24	0.25	32	47	166
1B	3.27	1.25	0.13	1.38	55.97	42.66	<0.24	24	16	0.18	26	34	117
1C	3.31	1.26	0.17	2.00	22.48	75.52	<0.24	29	18	0.12	26	34	130
2A	4.12	2.37	0.33	0.17	31.59	68.24	<0.24	37	27	0.27	35	53	176
2B	4.31	2.65	0.20	0.00	32.24	67.76	0.36	42	32	0.47	33	62	203
2C	4.37	2.75	0.41	6.03	45.88	48.10	0.32	41	30	0.33	24	62	206
3A	4.24	2.30	0.18	0.32	35.43	64.25	0.59	42	35	0.25	37	75	160
3B	4.54	2.91	0.24	1.34	38.06	60.60	0.83	61	53	0.37	47	106	229
3C	3.95	2.03	0.15	7.83	36.14	56.03	0.73	63	44	0.41	47	98	220
4A	3.79	1.46	0.12	3.65	47.73	48.62	0.45	44	32	0.25	39	69	152
4B	4.09	2.12	0.18	0.05	47.14	52.80	<0.12	60	39	0.31	50	82	201
4C	3.96	1.86	0.16	0.00	47.45	52.55	0.57	45	31	0.21	37	65	148
5A	4.33	2.78	0.29	0.28	56.68	43.03	0.56	68	44	0.32	49	99	231
5B	3.87	2.06	0.14	0.08	73.48	26.44	0.83	48	36	0.53	40	91	180
5C	3.96	2.13	0.21	0.52	68.05	31.42	<0.30	59	31	0.05	35	64	178
6A	4.25	2.34	0.16	0.78	53.99	45.23	0.97	56	47	0.76	47	112	220
6B	4.43	2.54	0.18	0.52	51.45	48.03	0.65	51	44	0.65	43	92	229
6C	4.66	2.88	0.24	0.11	32.63	67.26	0.31	45	33	0.32	37	73	198

Due to the interdependence of the PCB congeners (Appendix XXX), an arbitrary selection of 12 was chosen to compare with the nematode data obtained from core sediments. However, there was limited correlation between nematode data and any single congener or combination of congeners (Table 79): at best, only 35% of the variability in nematode assemblages sampled by core can be accounted for by the concentrations of PCBs in core sediments.

Table 74 Concentrations (μg kg^{-1}dry weight) of PCBs at stations 1 to 6 from core samples.

Station	CB#18	CB#31	CB#28	CB#52	CB#49	CB#47	CB#44	CB#66	CB#101	CB#110	CB#151	CB#149	CB#118	CB#153	CB#105	CB#141	CB#138	CB#158	CB#187	CB#183	CB#128	CB#156	CB#180	CB#170	CB#194
1	0.67	1.08	1.87	0.72	0.97	0.22	0.55	1.29	0.5	1.87	0.18	0.71	0.78	0.96	0.35	0.23	1.09	0.11	0.50	0.24	0.32	0.11	0.79	0.38	0.15
2	2.30	3.07	4.90	1.87	1.68	0.56	1.49	3.01	1.35	4.09	0.47	1.76	1.69	2.12	0.77	0.46	2.37	0.24	1.15	0.52	0.53	0.25	1.77	0.73	0.33
3	0.96	1.67	2.92	0.98	1.07	0.34	0.82	1.98	0.80	2.80	0.29	1.18	1.15	1.50	0.54	0.33	1.69	0.17	0.78	0.36	0.44	0.18	1.21	0.54	0.23
4	0.86	1.49	2.56	0.94	0.98	0.31	0.74	1.80	0.72	2.64	0.27	1.07	1.07	1.35	0.50	0.31	1.56	0.16	0.73	0.34	0.40	0.16	1.10	0.52	0.20
5	0.29	0.34	0.59	0.42	0.59	0.05	0.16	0.38	0.14	0.55	0.03	0.12	0.28	0.26	0.17	0.10	0.36	0.04	0.14	0.09	0.18	0.03	0.27	0.15	0.09
6	2.51	4.07	7.18	2.67	2.44	0.96	2.30	4.96	2.36	6.49	0.88	3.17	2.71	3.77	1.13	0.74	3.89	0.40	1.94	0.82	0.73	0.36	2.90	1.23	0.53

CB = Chlorinated Biphenyl.

Table 75 Spearman rank correlations between macrofauna and environmental similarity matrices (grabs). Org C, N, Cu, Zn, Ni, %s/c excluded as r>0.95

Number of variables	*Best variable combination*	*Correlation (pw)*
1	Cd	0.471
2	**Cd, Hg**	**0.696**
3	Cd, Hg, %G	0.625

Table 76 Spearman rank correlations between nematodes from grab sub-samples and environmental similarity matrices (grabs). Org C, N, Cu, Zn, Ni, %s/c excluded as r>0.95

Number of variables	*Best variable combination*	*Correlation (pw)*
1	%S	0.507
2	%G, Cd	0.693
3	**%S, %G, Cd**	**0.761**
4	%S, %G, Cd, Hg	0.646

Table 77 Spearman rank correlations between nematodes from cores and environmental similarity matrices (cores).

Number of variables	*Best variable combination*	*Correlation (pw)*
1	%C	0.768
2	Cr, Hg	0.779
3	%C, %S, Hg	0.832
4	%C, %S, Cu, Hg,	0.875
5	**%C, %S, Cu, Hg, Cr**	**0.904**
6	%C, %S, Cu, Hg, Cr, Zn	0.886

Table 78 Spearman rank correlations between nematodes from cores and environmental similarity matrices (grabs).

Number of variables	*Best variable combination*	*Correlation (pw)*
1	**Hg**	**0.896**
2	Cr, Hg	0.829
3	Cd, Cr, Hg	0.796

Table 79 Spearman rank correlations between nematodes from cores and PCB similarity matrices (cores).

Number of variables	*Best variable combination*	*Correlation (ρw)*
1	**CB#156**	**0.357**
2	CB#105,138	0.307
3	CB#105,138,128	0.307

6.3 DISCUSSION

The validity of comparing faunal communities that have been sampled a year apart is perhaps questionable at this site, where sediments are known to be extremely mobile over short time-scales. Nevertheless, as the current study sought to describe changes in benthic communities that could be attributed to the disposal of dredgings, with a view to producing a generic model, such an assessment was still considered to have some value.

Results from the present survey support previous findings which indicate that macrofaunal diversity in Swansea Bay is low; this is not atypical for comparable bay areas subject to high tidal and wave energy elsewhere in the Bristol Channel (Hiscock, 1979; Warwick and George, 1980; Warwick and Uncles, 1980; Shackley and Collins, 1984; Conneely, 1988; Mettam *et al.*, 1994). It is probable that both tidal and wave action have served to eliminate the more sensitive macrofaunal species and that the remaining more tolerant organisms are largely resistant to any additional disturbance associated with the disposal operation. In contrast, the nematode community, which is relatively diverse, appears to be more resilient to the sediment mobility in the Bay. Nevertheless, there is some evidence of an effect of organic enrichment, which has resulted in the dominance of taxa such as *Sabatieria pulchra* grp., *Molgolaimus demani*, *Microlaimus turgofrons* and *Daptonema normandicum*. Whether this effect can be attributed to the disposal of dredged material or is a consequence of the many sewage outfalls discharging into the Bay is uncertain. Despite this, it might be predicted that assessments of the nematode community might prove more useful in such high energy environments for isolating the effects of a particular impact than an examination of an already impoverished macrofaunal assemblage.

Evidence of an effect of dredged material disposal in Swansea Bay is limited. No significant effects were evident on the diversity of macrofauna and nematode assemblages in 1995. In 1996, however, reduced nematode diversity at stations within and on the periphery of the disposal site did suggest an effect of the dredgings operation. Also, MDS ordinations of biotic data indicated that station 1, in the southern sector of the disposal site, is altered compared with other sampled stations. Yet this is not supported by environmental data from core sediments, which shows that station 1 is the least contaminated of all the sampled stations, but this does not rule out a physical impact from the disposal operation. An examination of the macrofauna at station 1 shows that the conditions at this station have allowed the co-existence of several macrofaunal species with normally dissimilar requirements. The establishment of such a mixed community would be expected to coincide with heterogeneous sediment capable of providing a wide range of niches. However, there appears to be little evidence of this from particle size analysis. Taken together, the results present a confusing picture, which does not directly bear out an effect of dredgings disposal.

The difficulty in detecting point source effects relates to the close proximity of the inputs with the likelihood that contaminants from any one discharge are not contained within a definable location, but are intermingled with those from other sources and are redistributed over a broad area. This may either be as a result of the mobile nature of sediments within the Bay or, if Shackley and Collins (1984) contention is accepted, by the artificial redistribution of dredged material. This clearly presents difficulties for detecting the effects of a particular disturbance. It is evident from the results of this study that the effects of dredgings disposal could not be adequately resolved using a line transect of stations, given the complexity of the Swansea Bay environment. However, it is also evident that large-scale grid surveys in

Swansea Bay have, for the most part, been ineffective in identifying the effects of specific discharges (Conneely, 1988). An alternative approach would be to carefully select one or more environmentally similar locations as spatial controls (if feasible) for comparisons with sites suspected of being anthropogenically disturbed (see Green, 1979). Warwick and George (1980) compared the functional aspects of a macrofaunal assemblage in Swansea Bay with a stable and unpolluted community from Carmarthen Bay, but they were unable to detect differences in either production levels or in the distribution of individuals among macrofaunal species that could be attributed to either pollution or disturbance. The assessment of benthic faunal communities may have limited value for establishing the effects of point source discharges in an area such as Swansea Bay where sediments are inherently unstable. Nevertheless surveys of the benthos in such an area may furnish the data necessary for assessing the general "health" of the indigenous communities relative to nearby reference areas, which may then have management value.

Although this study has been unable to conclusively demonstrate an effect of dredged material disposal within the Bay, it provides a useful illustration of some of the difficulties that can be encountered in the monitoring of complex coastal environments. For example, it is not uncommon for dredged material disposal sites to be located in areas where other influences (either of natural or anthropogenic origin) obscure the effect(s) of a particular disposal operation, and our existing understanding of benthic community dynamics and the coastal processes which affect them may not always be adequate for discriminating between such impacts.

7. DISCUSSION

7.1 EFFECTS OF DREDGED MATERIAL DISPOSAL ON THE MACROFAUNA

Published studies of the biological effects of the disposal of maintenance dredgings have historically relied on an examination of macrofaunal organisms (Harrison, 1967; Flint, 1979; Van Dolah *et al.*, 1984; Wildish and Thomas 1985; Rees *et al.*, 1992; Harvey *et al.*, 1998). These studies show wide differences in the responses of the fauna to disposal, ranging from minimal effects (Van Dolah *et al.*, 1984) to significant changes in community structure (Harvey *et al.*, 1998). Similarly, the results of the current study show that macrofaunal communities do not respond to dredgings disposal in a consistent and predictable manner. However, some generalisations can be made regarding the nature of macrofaunal response to dredgings disposal. Stations from within the disposal sites differ from others due both to the elimination and reduction of a number of macrofaunal taxa and as a result of a local enhancement of a range of different taxa characteristic of the sediments surrounding each site. Where muddy dredgings are disposed of onto a seabed of sand, for example at the Lune Deep site and at Liverpool Bay in 1991, conditions are produced which favour opportunistic colonisers typical of muddy sands and muds such as *Lagis koreni* and *Mysella bidentata* and species normally found in clean sands become extinct (Rees *et al.*, 1992; Somerfield *et al.*, 1995; Roberts *et al.*, 1998). In contrast, the disposal of sandy dredgings, for example at Liverpool Bay in 1995, led to an increase in species more commonly associated with sandy sediments such as the polychaete *Magelona mirabilis*. Colonisation of the disposal sites by epifaunal taxa also occurs where deposited dredgings contain a coarser component e.g. Swansea Bay and the Lune Deep disposal sites. The identity of such colonisers is therefore dependent, at least in part, on the composition of the newly deposited sediment. This is to be expected since it has long been established that the species composition of macrofaunal communities is contingent on the sediment type (Jones, 1950; Thorson, 1957; Hartnoll, 1983). Thus the macrofaunal response to dredgings disposal can be characterised as a decline in the most sensitive components of the community followed by recolonisation by opportunistic species i.e. species that can respond to open or unexploited habitats by either high reproduction and/or high dispersal ability (Grassle and Grassle, 1974). Few opportunistic colonisers were confined to the impacted areas, supporting the suggestion that their presence at the disposal sites is the result of recruitment or immigration of adults from undisturbed areas. However, recolonisation of disposal sites as a result of the vertical migration of taxa which are resistant to the effects of burial may also be a significant process in the benthic recovery of a disposal site (Maurer *et al.* 1981a and b; 1982). Increases in the densities of opportunistic species exploiting disturbed sediments, shortly after dredgings disposal, have been recorded in both marine (Rhoads *et al.*, 1978; Zambriborsch *et al.*, 1982; Rees *et al.*, 1992; Harvey *et al.*, 1998) and freshwater environments (Flint, 1979). Furthermore this faunal response has been characterised as being largely due to the proliferation of polychaete families (Zambriborsch *et al.*, 1982; Rees *et al.*, 1992; Harvey *et al.*, 1998). Harvey *et al.* (1998) invoked the fast colonising ability of polychaetes compared with crustaceans and molluscs as the explanation for their prevalence as early colonisers at dredged material disposal sites. The survival of such opportunistic colonisers may also be promoted by the enhanced food supply presented by newly deposited dredged material (Rees *et al.*, 1992; Harvey *et al.*, 1998). In contrast to earlier work (Norton *et al.*, 1984), a relationship between fluctuations in the availability of food (inferred from carbon levels) and changes in macrofaunal community structure could not be established, as shifts in carbon levels were often coupled with changes in other environmental influences. Although a consistent response was observed in terms of a local enhancement in the densities of a few opportunistic macrofaunal species, these species were not common among study areas i.e. there were no universal macrofaunal indicators of dredgings disposal.

At both the Tees Bay and Swansea Bay disposal sites, the presence of some macrofaunal species more typical of estuarine conditions, such as the oligochaete worms *Tubificoides* spp. and the bivalve mollusc *Macoma*, also provide strong evidence for the transport of live animals via dredgings disposal. This is especially true for the Tees Bay site, where the community observed from within the disposal site was very similar to an estuarine population recorded from the Tees Estuary (Alexander *et al.*, 1935; Gray, 1976; Kendall, 1979; Hall *et al.*, 1996): the source of the deposited dredgings. Similarly, Wildish and Thomas (1985) observed that the polychaete *Capitella capitata* was conveyed in dredged material and appeared to survive in the absence of any nearby populations to support recruitment (see also Rees *et al.*, 1992).

Both direct burial by discharged material and a change in sediment type are the two factors that may explain the shifts in densities of the various species within the disposal sites. Alterations to the sediment chemistry can also result from the disposal of dredged material (Norton *et al.*, 1984). Sediment particle size exerts a strong influence on the bioavailability and hence the potential toxicity of contaminants. Sands have far fewer contaminant binding sites to which metals can attach than finer sediments. This can lead to high concentrations of dissolved metals in the pore waters. Metals in solution are more readily taken up by organisms so their potential toxicity in this state is likely to be greater (Bryan and Langston, 1992). Studies have revealed that the release of metallic elements is significant during disposal operations (Darby *et al.*, 1986) and that higher concentrations are found in macrobenthic species such as *Lagis koreni* and *Nephtys hombergii* (Rosenberg, 1977). Therefore disposal of dredgings with high burdens of heavy metals and organic pollutants may also contribute to the reduction of macrofaunal taxa. At the Tees Bay disposal site, changes in macrofaunal community structure are related to changes in sediment structure (expressed as % silt and clay) or with some other correlated factor such as concentrations of various heavy metals. In the Lune Deep disposal site the sediment structure is altered as a result of the disposal of relatively uncontaminated dredgings, and modifications to the macrofaunal community structure reflect these changes. Conversely, faunal changes at Liverpool and Swansea Bay disposal sites were attributed to increased concentrations of heavy metals, there being very little variation in sedimentary parameters along the transects at these sites. The disparity in the responses of the macrofaunal communities to contaminants may therefore reflect either differences in the quality and nature of the dredgings or environmental differences at the disposal sites e.g. their dispersive capacity. For example, the disposal sites at Swansea Bay and Liverpool Bay are subjected to greater exposure from wave and tidal current action, compared with the deeper water locations of the Tees Bay and Lune Deep disposal sites.

Elevated benthic biomass peripheral to dredged material disposal sites has been observed by Zambriborsch *et al.* (1982) and Rees *et al.* (1992), while Poiner and Kennedy (1984) reported enhanced abundances in a zone predicted to be influenced by deposition from a sediment plume during dredging operations. Such a response was not evident in the current study, although macrofaunal diversity appeared to be enhanced at a station adjacent to the Liverpool Bay disposal site compared with corresponding areas not affected by dispersing fines.

Univariate measures of community structure tend to be generally insensitive to small changes in community structure. None of the univariate measures calculated with macrofaunal data in the current study were found to change consistently at impacted sites. Furthermore, discrimination between impacted and undisturbed areas was often lost when the data were reduced to a single figure index. This suggests that the enhancement of taxa through recolonisation and introduction with dredgings is balanced by the loss of species through direct burial. Multivariate techniques, however, were shown to be very useful in discriminating between stations. With such methods effects of dredged material disposal were marked although they were often limited to within the disposal site.

7.1.1 Conclusions

1. *Gross effects on the composition of the macrofauna are confined to the disposal sites.*
2. *Stations from within the disposal sites differ from others due both to the elimination or reduction of a number of taxa and as a result of local enhancement of a range of different taxa characteristic of the sediments surrounding each site.*
3. *Macrofauna are sensitive to changes in sediment structure. Disposal of muddy dredgings onto a seabed of sand produces conditions favouring the colonisation of species more typical of mud and the elimination of sandy species. With the disposal of sandy dredgings species typical of sands are favoured. Disposal of coarser dredgings allows the development of an epifaunal component.*
4. *There is evidence for the introduction of exotic species along with the deposited dredgings.*
5. *Univariate measures derived from macrofaunal data were not found to be useful in discriminating between stations. Species richness (d), evenness (J), total abundance (A), numbers of species (S) and Shannon Wiener diversity (H) did not change in a predictable and consistent way in all surveys.*
6. *Multivariate analyses were more sensitive for the detection of changes in macrofaunal community structure than univariate measures. This is largely because they utilise information about all of the species present in the community rather than reducing all the information about the community to a single figure.*

7.1.2 Recommendations

The following recommendations are made:

1. *That in areas where it is desirable that the macrofaunal composition is not significantly altered by dredged material disposal, licence conditions must seek to ensure that dredged material is similar in terms of particle size to the sediment in the receiving environment.*
2. *That temporal studies at large dredgings disposal sites are carried out as "one off" studies fail to address the variability in macrofaunal populations associated with alterations in dredging practices or changes in environmental conditions.*

7.2 EFFECTS OF DREDGED MATERIAL DISPOSAL ON NEMATODES

The majority of field studies on the effects of pollution and disturbance on meiobenthic diversity have found that diversity is lower in polluted areas (Olsson *et al.*, 1973; Marcotte and Coull, 1974; Anger and Scheibel, 1976; Van Es *et al.*, 1980; Hennig *et al.*, 1983; Bouwmann *et al.*, 1984; Khera and Rhandhawa, 1985; Vitellio and Aissa, 1985; Arthington *et al.*, 1986; Keller, 1986; Moore and Pearson, 1986; Sandulli and Nicola-Guidici, 1990). These studies complement the findings from this investigation, which revealed that, in general, nematode assemblages from stations located within the disposal sites were less diverse than elsewhere.

The most striking effect of dredgings disposal on nematode assemblages is the proliferation of the non-selective deposit feeders *Sabatieria pulchra* grp. and *Daptonema tenuispiculum* within the disposal sites. Somerfield *et al.* (1995) also found *Daptonema tenuispiculum* and *Sabatieria punctata* (part of the *pulchra* group) numerically abundant at the Liverpool Bay dredged material disposal site. They further suggested that other members of the *Sabatieria pulchra* group might have indicator value as, although they are found in unperturbed situations, they often persist as the dominants of impoverished meiofaunal communities. The present findings support this assertion and clearly demonstrate the usefulness of such characteristic species occurrences in aiding the assessment of pollution effects. This pattern of enhancement of certain nematode species in response to dredgings disposal is perhaps surprising, given the appreciable differences both in sediment type and contaminant burden within each of the disposal sites. Furthermore, the persistence of these taxa over time at Liverpool Bay despite a dramatic change in particle size also implies a high resilience and tolerance to a range of sedimentary conditions. Tietjen (1980) noted the proliferation of *S. pulchra*, a species normally associated with silty sediments in polluted sands. This phenomenon of adaptive "generalist" nematodes such as *Sabatieria* spp. and

Daptonema tenuispiculum rapidly exploiting disturbed sediments is well documented (Heip and Decraemer, 1974; Tietjen 1980; Heip *et al.*, 1984; Lambshead, 1986; Somerfield *et al.*, 1995). If this paradigm holds at other dredgings disposal sites, it will be particularly useful, as such consistent patterns have not so far been reported for macrofaunal species (M.P.M.M.G, 1996). Rygg (1985) classified macrofaunal taxa into positive and negative indicator species. Positive indicators were pollution tolerant and dominated the benthos of low diversity samples. Negative pollution indicators were non-tolerant species whose presence indicated little or no impact but whose collective absence implied high impact. Indicator taxa may also be selected for their importance in the community (Clements *et al.*, 1992), sensitivity to change (Bellan, 1980; Gray and Pearson, 1982; Daan *et al.*, 1994) or cost-effectiveness in assessments (Roberts *et al.*, 1998). *Sabatieria pulchra* grp. and *Daptonema tenuispiculum* appear to fit into the category of positive indicators as they were recorded as the dominants of impoverished nematode communities in areas of pollution influence. However, there are limitations to the concept of universal indicators of pollution and disturbance (Gray, 1981; Platt *et al.*, 1984; see also Chapter 1). This is highlighted at the Lune Deep site, where a station that was apparently undisturbed was also found to have substantial numbers of *S. pulchra* grp.

Unlike the wealth of literature on the ecology of individual macrofaunal species there is more limited knowledge regarding the ecological and environmental interactions that govern the distribution of nematode taxa. Thus it is not possible to discern the specific causes for the dominance of *S. pulchra* grp. and *D. tenuispiculum* at dredgings disposal sites. It is perhaps significant, however, that both taxa are non-selective deposit feeders (Wieser, 1953) which suggests the potential importance of food availability. Deposited dredgings are likely to contain appreciable amounts of organic material derived from decaying and buried fauna. Dredgings from urbanised estuaries may also be organically enriched due to the input of material from sewage discharges. The decomposition of this material at the disposal sites may produce anoxic conditions in localised sediment patches. Changes associated with the strongly reducing conditions that prevail just below the sediment surface may inhibit settlement or survival of the more "sensitive" species (Rhoads *et al.*, 1977; Maurer *et al.*, 1985; Neira and Rackemann, 1996). For species that can withstand the reducing conditions, however, the sediment patches may offer a substantial food source. *Sabatieria pulchra* and *Daptonema* sp. are recognised as typical thiobiotic species capable of surviving in anoxic sediment (Jensen, 1987; Jensen *et al.*, 1992; Hendelberg and Jensen, 1993 and references therein; Dando *et al.*, 1995). Although *Sabatieria pulchra* is a facultative anaerobe in deoxygenated sediments, it is unable to tolerate long periods of anoxia (Hendelberg *et al.*, 1993). However, Steyaert *et al.* (*in press*) observed *Sabatieria punctata* (part of the *pulchra* group) was able to penetrate deep into the sediment and the vertical distribution of this species appeared to be related to food availability rather than oxygen concentrations. It is therefore conceivable that such taxa are able to flourish and exploit the available food resource in sediment patches of partial or complete anoxia. Signs of anoxia were not immediately apparent from disposal site sediments nor were such sediments enriched in carbon. Nevertheless, a low standing stock of particulate organic matter in sediments has been shown previously to be ineffective for predicting the responses of benthic infauna to large amounts of organic deposition (Webb, 1996) i.e. it is the flux of organic carbon that is important. Thus further sampling within the confines of disposal sites would be needed to test this assertion. An alternative explanation for the dominance of *Sabatieria pulchra* grp. and *Daptonema tenuispiculum* may simply be that these taxa are better adapted at upwardly migrating through deposited material. Microcosm experiments currently being carried out at the Burnham Laboratory have been designed to establish whether vertical migration of nematodes is a viable process in the rehabilitation of a dredged material disposal site.

The dominance of nematode "indicator" taxa at geographically disparate locations may suggest that they have been conveyed to the disposal sites along with the dredgings. Many nematode taxa are adapted to sediments of low oxygen content (Warwick and Price, 1979; Tietjen, 1980; Jensen, 1981; 1987) which is likely to be a necessary physiological adaptation required for their survival during transportation to a disposal site. Although there was some evidence for the transport of nematode taxa at the Tees Bay site, *S .pulchra* grp. and *D. tenuispiculum* are not confined to any of the disposal sites but are present in surrounding sediments. Thus it is more probable that recolonisation occurred as a result of immigration from nearby unaffected areas. Nematodes are predominantly dispersed either by passive resuspension by currents and waves or by locally restricted movements in the sediment. However they are also able to swim actively (Hagerman and Rieger, 1981; Chandler and Fleeger, 1983; Decho and Fleeger, 1988; Walters, 1988; Armonies, 1990, 1994). Surviving nematodes can also migrate through deposited sediment providing burial is not too extensive (Romeyn and Leiseboer, 1989; Schratzberger *pers. comm.*) and the deposited material has similar properties to that of their native sediments (Romeyn and Leiseboer, 1989). Thus there is the potential for the rapid re-establishment of nematode populations following disturbance through dredgings disposal.

There is also evidence of a differential impact of dredgings disposal between stations located within the same disposal sites. This may be ascribed to habitat heterogeneity as a consequence of dredgings disposal with communities persisting at different stages in the "recovery" process (Grassle and Saunders, 1973). It is also expected that differences in the nature of nematode assemblages within a disposal site are likely to reveal a high degree of variability both spatially, and with time.

While gross effects are confined to the disposal sites, lesser consequences arising from dispersing material are evident at immediately adjacent sites. This was most pronounced at the Liverpool Bay site, where both univariate and multivariate analyses revealed a gradient of effect away from the disposal site. At this location effects beyond the disposal site were manifested by a reduced complement of species and a decline in the densities of most taxa. Yet at Tees Bay, effects were perceptible as slightly enhanced numbers of taxa and abundance in stations adjacent to the disposal site. Disturbance peripheral to the disposal site probably results from the transport of material as bed load under the influence of wave and tidal current action. At Tees Bay, sediments adjacent to the disposal site are organically rich with a significant silt and clay component whereas peripheral to the Liverpool Bay site, sediments are sandy in nature and have a lower organic content. Thus the response of the nematode fauna to dispersing material may depend on whether the assemblage is adapted to relatively high levels of organic matter on the sediment surface (Webb, 1996). For example, at Tees Bay, fine particulates arising from the dispersing dredged material may enhance the food supply of adjacent sediments (Zambriborsch *et al.*, 1982; Rees *et al.*, 1992). At Liverpool Bay excessive amounts of particulates may have contributed to an inhibitory effect. Such an effect has previously been reported with nematode assemblages in receipt of high levels of organic matter (Gee *et al.*, 1985; McGwynne *et al.*, 1988; Webb, 1996).

It is well known that sediment particle size is a major causal factor in determining the composition of meiobenthic communities (Warwick and Buchanan, 1970; Govaere *et al.*, 1980; Heip *et al.*, 1985; Herman *et al.*, 1985; Coull, 1988; Somerfield *et al.*, 1995). However, few field studies have demonstrated conclusively that heavy metals govern meiobenthic community structure (Somerfield *et al.*, 1994; Millward and Grant, 1995). In one such study, Somerfield *et al.* (1994) observed that nematode diversity tends to be lower in areas with high sediment metal concentrations, and there appears to be a relationship between increased dominance and decreased evenness with increasing metal concentrations. Thus it is to be expected that diversity will decrease with increasing levels of sedimentary metal concentrations in deposited dredgings. There is good evidence for such an expectation as the majority of *in vitro* experiments have tended to show that metals as toxicants have either lethal or sublethal effects on meiobenthic organisms (for review see Coull and Chandler, 1992). In practice, it is frequently difficult to distinguish the effect of contaminants from other modifying factors associated with the disposal of dredgings, such as changes in grain size (Somerfield *et al.*, 1995). This was the case at both the Liverpool and Swansea Bay disposal sites where BIO-ENV analyses jointly implicated heavy metals and sedimentary parameters as determinants of nematode community structure. Conversely BIO-ENV analyses with nematode assemblages from Tees Bay and the Lune Deep showed sedimentary factors as more important in controlling the distribution of nematodes. Evidence from microcosm experiments indicates that, although meiofaunal communities are affected by the same contaminants, the nature of the response is not consistent between communities from different habitats (Austen and McEvoy, 1997). It has also been suggested that this phenomenon may be due, in part, to variation in the recent history of contaminant exposure that a particular community has been subjected to (Austen and McEvoy, 1997) or the frequency at which doses of contaminants are administered (Schratzberger and Warwick, 1998). Owing to the considerable variation in the composition of dredged material, it is difficult to generalise regarding any effects of contaminants on nematode communities. Thus there is a need for additional studies at other dredged material disposal sites in order to resolve the circumstances in which the input of contaminants may be considered the most important factor affecting meiofaunal communities. To complement these field assessments, supporting evidence is required from microcosm experiments in order to understand the ecological implications of sublethal contaminant impact in isolation from confounding natural factors that influence field assessments.

7.2.1 Conclusions

1. *Both gross effects due to the direct impact of dredgings and more subtle effects of disposal extending beyond the disposal sites were discernible with nematode community analyses.*
2. *The same nematode taxa were dominant at all disposal sites despite appreciable environmental differences between locations and variability in the nature of the deposited material.*
3. *Stations from within the disposal sites differ from others due both to the elimination or reduction of a range of taxa and as a result of significant increases in the densities of two non-selective deposit feeders.*
4. *The lack of versatility of the Bowers and Connelly corer in mixed sediments limits the scope for the routine collection of meiofaunal samples at other monitoring locations.*

7.2.2 Recommendations

The following recommendations are made:

1. *That abundances of major taxa such as nematodes should not be used as the primary means of assessment of the effects of dredged material disposal.*
2. *That in areas licensed for dredged material disposal an analysis of nematode community structure should be considered for detecting subtle impacts of disposal arising from dispersing particulates.*
3. *That the ecological requirements of particular nematode species are determined for natural habitats around the UK coast in order to aid in the interpretation of nematode community patterns and for assessing the significance of any changes. This should be achieved by examining nematode populations from sites away from point source discharges in large-scale national monitoring programmes.*
4. *That research is conducted to establish why there is a net enhancement of certain nematode taxa in response to dredgings disposal. This should be assessed in controlled laboratory microcosm experiments where effects of deposition can be separated from contaminant responses. Such studies would place our ability to predict mechanical and chemical effects of dredged material disposal on a firmer basis and would provide useful data to regulators in planning to minimise adverse effects of open water dredgings disposal.*
5. *That further work is carried out to establish the utility of nematode community methods for detecting subtle changes in environmental quality due to other anthropogenic perturbations.*
6. *That a robust sampler is designed which is able to retrieve samples suitable for the analysis of meiofaunal populations from a wide range of sedimentary conditions and which can operate effectively in a range of weather and tidal states.*

7.3 A COMPARISON OF THE RESPONSES OF MACROFAUNAL AND NEMATODE COMMUNITIES TO DREDGED MATERIAL DISPOSAL

The results of the present study show that, whilst the effects of dredged material disposal are marked with macrofaunal populations, they are often limited in extent. In contrast, observations with nematode communities show evidence of the effects of dredgings disposal beyond the margins of the licensed sites. Similarly, Moore and Somerfield (1997) observed that whilst the macrofaunal community was strongly perturbed by sewage sludge disposal at Garroch Head, the area of influence was less than that for nematodes. Such studies demonstrate that nematode and macrofaunal communities respond differently to disposal activities (Somerfield *et al.*, 1995). Differences in the severity of impacts from the settlement of organically enriched fines associated with disposal activities may be related to the differential response that communities exhibit to an enhanced food supply. Indeed, in a comparative experiment designed to examine the response of benthic infauna to the addition of phytodetritus, Webb (1996) found that the macrofauna were relatively unaffected whereas nematode assemblages were significantly depressed. Furthermore, since nematode life histories are more closely integrated with the sediment compared to many macrofaunal species which have a planktonic larval phase, it is perhaps not surprising that nematodes are more sensitive to subtle changes in their sedimentary environment (Moore and Bett, 1989; Coull and Chandler, 1992).

In contrast with earlier studies (Warwick and Buchanan, 1970; Govaere *et al.*, 1980; Heip *et al.*, 1985; Herman *et al.*, 1985), the dominant nematode taxa at the Liverpool Bay disposal site appear less sensitive than macrofaunal species to changes in sediment composition. This finding appears to challenge the theory proposed by Somerfield *et al.* (1995) that nematode assemblages are more responsive than macrofauna to short-term effects of dredgings disposal such as changes in particle size. Indeed it would appear that nematode populations are probably more responsive to fluctuations in the food availability (Steyaert *et al., in press*) rather than changes in particle size, although their dynamics may still be considered to reflect short-term changes in disposal practices.

In common with other studies (Austen *et al.*, 1989; Warwick *et al.*, 1990a and b; Hall *et al.*, 1991), there was evidence from both the Lune Deep and Swansea Bay disposal sites that nematodes are less sensitive to physical disturbance and destabilisation of the sediment. Warwick *et al.* (1990a) suggested that this differential response to physical disturbance was a consequence of the greater capacity of the meiofauna to survive displacement from the sediment, which serves to lessen the impact of sediment instability. In addition, Austen *et al.* (1989) also found the spatial extent of impact on intertidal meiofauna communities was less than that for macrofauna along a gradient of sewage pollution. However, effects on the latter may have been confounded with the wider impact of fishermen digging for shellfish. Warwick (1981a) has suggested an additional explanation for the apparent dissimilarity in responses of benthic communities to disturbance. He argued that meiofaunal communities maintain diversity through partitioning of species into specialised trophic groups whereas the macrofauna may have less discriminating trophic preferences, but maintain diversity by spatial segregation of the species (see also Whitlach, 1980). The effects of perturbation on the meiofauna therefore lead to changes in the proportion of different feeding guilds whereas for macrofauna a change in taxa may reflect an alteration in for example the surfaces for colonising. Thus it appears that meiofauna and macrofauna respond differently to perturbations, and furthermore when examined in parallel they may provide complementary information.

Another important finding from the present study was that the precision of the nematode data was generally higher than that for the macrofauna, largely due to the greater consistency in the quality of samples collected by the corer. This difference was particularly evident with univariate indices where between-sample variability in those derived from macrofaunal data frequently limited the capacity to statistically discriminate between impacted and unimpacted situations.

7.3.1 Conclusions

1. *Where pollution effects were detected in the macrofauna they were found to be relatively extreme over a short distance, whereas changes due to disposal were often detectable in the nematodes over a range of distances from the disposal sites.*
2. *Macrofauna appear to be more sensitive to physical disturbance than nematodes, whereas effects arising from dispersing material were more apparent with nematode analyses.*

7.3.2 Recommendations

The following recommendation is suggested:

1. *That where the aim is to evaluate subtle effects of dredgings disposal consideration should be given to assess meiofaunal community responses. This could be in combination with, or in appropriate cases, instead of macrofaunal studies.*

7.4 IMPLICATIONS FOR MONITORING

Ideally, biological monitoring programmes will involve the application of routine methods which are rapid, effective and straightforward to apply. Historically this has precluded the study of meiofaunal communities, as these require extended effort for the extraction and analysis of samples and relatively advanced identification skills. However, less demanding and therefore more rapid approaches to the study of nematode assemblages are available.

Of these, the simplest would be an examination of the total density of nematodes as an expression of change, but this can be unreliable as a measure of anthropogenic disturbance (Moore and Bett, 1989; Coull and Chandler, 1992). Indeed the present results have demonstrated that dredgings disposal may actually cause the enhancement of some nematode "indicator" species rather than an overall reduction of individuals. Thus, an alternative approach would be a targeted study of "indicator" taxa such as *D. tenuispiculum* and *S. pulchra* grp. as a measure of perturbation and such an approach has been used to develop monitoring indices (Bellan, 1980; Clements *et al.*, 1992; Stark, 1993; Engle *et al.*, 1994; Roberts *et al.*, 1998). However, adopting such a method would require at least some specialist training, since for example, both *Sabatieria pulchra* grp. and *Daptonema* *tenuispiculum* belong to genera containing large numbers of similar species. There are also pitfalls to advocating this method when the ecological reasons for observed responses at dredged material disposal sites are not fully understood.

Requiring less specialist knowledge, an analysis of the relative proportions of nematode "feeding" groups may prove a reasonable method for monitoring the status of a particular nematode community (Heip *et al.*, 1984). They examined trophic diversity ($\theta =$ percentage of each feeding type) and species richness as means to characterise a polluted nematode community off the Belgian coast. Any investigation reliant on such a method would, however, need to consider both sediment grain size and the organic loading of the sediments, as the proportion of feeding groups is known to vary with both these factors. The ratio of nematodes to copepods has been proposed as an index with potential in pollution monitoring studies (see Raffaelli, 1987 for an overview), but as the densities of both taxa are known to vary inconsistently and as such this index has limited value.

For studies at the community level, Warwick (1988) proposed identifying benthic species at higher taxonomic levels. Although this technique has been shown to be effective in a number of cases (Heip *et al.*, 1988; Herman and Heip, 1988; Warwick, 1988a and b; Somerfield and Clarke, 1995) recent work by Vanderklift *et al.* (1996) suggests that complex statistical changes may result from decreasing the level of taxonomic resolution, which may reduce the interpretative value of the data.

It may be concluded that, at present, there is no substitute for conventional, and therefore relatively demanding, examinations of the nematode community for quantifying environmental impacts. However, the present study has demonstrated that the time commitment may be reduced by employing grab sub-samples. The small size of the sub-samples allows rapid processing and hence assessments, without significant loss of information, although there is still a requirement for specialist identification skills. Grabs are robust and can be used in a wider range of sediment types and conditions than corers. Therefore, the use of grab sub-samples for evaluating changes in the meiofauna may offer opportunities for utilising this component of the benthos in areas where core samples cannot be successfully retrieved. However, although the results from Tees Bay are encouraging, Somerfield and Clarke (1997) have shown that subtle differences in meiofaunal sample quality may exist between samples taken from grabs and those obtained by deliberate corers. Further work is therefore needed in order to investigate the advantages and limitations of using samples from grabs for meiofaunal analysis in other areas before this sampling approach can be adopted for routine meiofaunal surveys.

More demanding investigations may still be cost-effective depending on the requirements of the study. In the present study, while gross effects arising from the direct impact of dredgings disposal were readily detectable using nematode community analyses, subtle effects that extended beyond the margins of the disposal sites could also be discerned with such methods. There are often circumstances when environmental managers may be more concerned about the subtle effects of a particular anthropogenic disturbance than the more obvious consequences. For example, when a disposal site is licensed it is invariably accepted that the benthic community in the immediate vicinity will be adversely affected as a direct physical consequence of the disposal operation. However, any influences at distance from the licensed area arising from the disposal of dredged material may be more difficult to demonstrate and it is in these circumstances that meiofaunal community methods may be best applied, especially in areas of environmental or economic sensitivity.

A further example where meiofaunal methods may be particularly effective occurs in situations where the areas are so physically disturbed as a result of wave or tidal current action that the macrofaunal species composition is very impoverished. Due to the high natural diversity of nematode communities their analysis in such areas, e.g. Swansea Bay, may provide the only useful method for assessing the consequences of a particular impact on the benthos. There may also be a need to confirm that the response produced by a particular method such as macrofaunal assessment or bioassay is in broad agreement with an alternative method e.g. meiofaunal study. Without some concordance, the significance of an impact may be called into question. However, this is not to say that trends in the data sets must be identical as meiofaunal and macrofaunal communities may respond in a different way to a similar impact. Such results may therefore ultimately allow the investigator to gain insight into the underlying causes of the particular environmental disturbance. For example, the greater sensitivity of macrofauna to physical disturbance compared with the meiofauna (Thistle, 1980; Austen *et al.*, 1989; Warwick *et al.*, 1990b; Hall *et al.*, 1991) may allow the discrimination between physical and chemical impairment. Thus, any pollution assessment should ideally use both macrofaunal and meiofaunal methods in tandem. By this means, better discrimination between short-term and longer-term effects of waste disposal, as well as between physical and chemical impacts, may be achieved.

Full species identification of meiofaunal taxa is very time consuming and hence expensive. During the course of the present study, it was found that, on average, it takes twice as long to process offshore samples for nematode analysis prior to species identification as it does for macrofaunal analysis. This is largely due to the extended effort needed in separating meiofaunal taxa from the sediment rather than effort directed at identifying specimens. However, when shipboard sieving of macrofaunal samples is included the overall time for extracting both meiofaunal and macrofaunal organisms from the sediment is similar. On board processing of macrofaunal samples is usually carried out whilst the ship is steaming from one sampling station to another or back to port. Although sieving of meiofaunal samples is not required at sea, surveys of the meiofauna will rarely amount to significant reductions in ship-time compared with macrofaunal surveys, as it would be exceptional for a ship to lay to in order to carry out macrofaunal sieving. In practice, the time spent at sea sieving macrofaunal samples is usually accounted for in the overall costs of hiring the ship and associated costs of maintaining staff at sea and it is not an additional cost of macrofaunal survey work. Therefore, until such time as a reliable and effective automated method for sorting meiofaunal sized animals from sediments is available (Thiel *et al.*, 1998), it is likely that extracting meiofaunal taxa from sediments will involve a greater time commitment than would be expected for the laboratory processing of macrofaunal samples.

Another factor that increases the costs of meiofaunal surveys in comparison with those of the macrofauna is the reliability of the samplers employed. In the current study a Bowers and Connelly multiple corer was utilised for collecting meiofaunal samples. This device was found to work satisfactorily in fine sediments, when the weather and tidal conditions were favourable. In sandy sediments, or in weather conditions where the ship was not able to hold position during deployment and retrieval of the corer, there was a relatively high failure rate of the corer in collecting sufficient sample material. Improvements to the collecting efficiency of the corer were obtained if the ship was at anchor. However, for large ships such as the M.A.F.F. research vessels, it is not cost-effective to lower the anchor at each sampling station, as this inevitably takes time. Furthermore, as the Bowers and Connelly Multiple - corer cannot retrieve samples from coarse sediments, this necessarily restricts the use of meiofaunal techniques to areas of fine sediments. Thus, until a more reliable sampler for collecting undisturbed samples from a range of sediment types is found, surveys of the meiofauna are not cost-effective at some of the larger dredgings disposal sites around the UK e.g. Nab and Roughs Tower where coarser sediments predominate. However, in such circumstances grab sub-samples may be utilised for assessing meiofaunal populations (see above).

There are also cost implications associated with the differing levels of expertise and, indeed, motivation required of staff involved in both activities. While it is accepted that aptitude is not solely a function of educational qualifications, the relatively demanding nature of meiofaunal assessments suggests that, in practice, appointment at least at graduate level would be appropriate, with some additional relevant experience and a demonstrable interest in the subject being even more advantageous. A somewhat lower level of initial scientific training may be acceptable for staff involved in analysing macrofaunal samples.

One area where meiofaunal methods are more cost-effective than macrofaunal techniques is in the use of communities in experimental systems. Manipulating meiofaunal communities in controlled laboratory experiments can validate cause and effect relationships, inferred from the results of field surveys. Indeed, as a follow up to the present study, laboratory experiments are currently being undertaken to investigate the mechanical and chemical effects of dredged material disposal and to test assumptions arising from the results of the field surveys. This approach is a lot less demanding than with macrofaunal populations due to the larger space commitment and relatively expensive facilities required to maintain such populations.

Finally, this work has demonstrated that it is entirely feasible for an applied laboratory to develop a sound meiofaunal capability suitable for application to routine monitoring programmes within the space of 3 years. In combination with existing macrofaunal expertise, this much improves flexibility allowing the target for study (macrofauna, meiofauna or both) to be selected on a site-specific basis so as to maximise the information suitable for decisions regarding the continued acceptability of a particular disposal operation or other source of man-made disturbance.

Appendices

Appendix I Nematode species found along TEES BAY transect from grab sub-samples.

MCS CODE	TAXA	STATION																
		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B
HD32	*Mesacanthion diplechma*	9	5	3	12	11	4	7	8	3	1	4	2	12	5	16	2	2
HD45	*Chaetonema riemanni*	.	.	.	.	.	.	2	.	2	2	2	2	.	.	.	.	.
HD89	*Halalaimus isaitshikovi*	1	1	1	4	.	4	.	.	.	.	.	.	2	3	10	1	1
HD91	*Halalaimus longicaudatus*	6	2	2	.	.	1	.	.	.	.	.	.	1	3	.	3	1
HD95	*Oxystomina elongata*	3	1	1	2	6	10	.	.	.	.	.	.	.	4	1	1	.
HD100	*Paroxystomina asymmetrica*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
HD129	*Viscosia abysorum*	.	2	.	1	1	.	.	.	.	.	.	.	.	.	.	.	1
HD131	*Viscosia elegans*	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
HD132	*Viscosia glabra*	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.	.	.
HD137	*Belbolla gallanachmorae*	1	.	1	.	1	.	1	1	.	.	.	.	1	1	3	.	1
HD139	*Calyptronema maxweberi*	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
HD163	*Tripyloides marinus*	4	33	2	9	14	13	4	.	2	1	1	1	5	4	4	.	1
HD174	*Trefusia longicaudata*	.	.	.	1	.	2	.	.	.	.	.	.	.	.	.	1	.
HD186	*Atrochromadora microlaima*	2	.	.	4	.	1	.	.	.	.	.	.	.	.	3	.	.
HD203	*Prochromadorella ditlevseni*	2	5	.	.	.	18	1	1	.	.	6	.	1	3	4	.	1
HD205	*Prochromadorella septempapillata*	.	4	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
HD224	*Chromadorita tentabunda*	1	.	.	.	.	.	.	.	.	.	.	.	2	.	.	1	.
HD	*Trochamus/Nygmatonchus* sp.	2	2	.	1	.	.	.	.	.	.	.	.	.	.	3	.	.
HD228	*Dichromadora cucullata*	.	1	.	2	7	.	2	.	1	.	2	.	1	.	3	.	.
HD249	*Dorylaimopsis punctata*	1	.	.	1	1	6	.	.	.	.	.	.	.	.	.	1	.
HD256	*Sabatieria celtica*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD261	*Sabatieria ornata*	24	17	6	32	13	106	3	1	6	1	1	.	30	56	41	53	11
HD263	*Sabatieria pulchra* grp.	92	11	6	16	9	38	32	12	37	205	903	141	22	36	19	72	80
HD266	*Setosabatieria hilarula*	1	.	.	2	.	2	.	.	1	.	.	.	1	2	.	.	1
HD272	*Comesa cuanensis*	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.
HD273	*Comesa interrupta*	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
HD274	*Comesa vitia*	.	2	1	5	1	2	.	.	1	.	2	.	3	.	6	4	1
HD275	*Comesa votadinii*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
HD276	*Comesa warwicki*	3	.	.	1	.	.	.	.	.	.	.	.	1	.	.	.	1
HD288	*Pomponema multipapillatum*	.	.	.	.	1	.	.	.	.	.	.	2	.	1	2	.	.
HD302	*Paracanthonchus heterodontus*	.	.	.	.	2	.	.	1	.	3	34	4	.	.	.	.	.
HD303	*Paracanthonchus longicaudatus*	2	1	.	.	.	14	1	1	1	.	.	1	.	1	.	.	.
HD304	*Paracanthonchus longus*	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
HD321	*Marylynnia complexa*	.	1	.	1	.	10	.	.	.	.	.	.	11	12	2	.	.
HD323	*Paralongicyatholaimus minutus*	1	4	.	1	1	.	.	.	.	.	.	.	11	3	2	5	.
HD335	*Halichoanolaimus robustus*	.	1	.	.	.	1	.	.	.	.	.	.	2	1	2	1	.
HD338	*Richtersia* sp.	9	14	.	18	36	6	3	.	2	2	3	4	11	7	5	.	1
HD343	*Desmodora pontica*	.	2	.	2	1	.	.	.	.	.	.	.	.	1	.	.	.
HD348	*Desmodora tenuispiculum*	1	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.
HD352	*Spirinia parasitifera*	.	.	.	.	.	4	.	.	1	.	1	.	.	.	.	.	.
HD359	*Metachromadora remanei*	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
HD362	*Metachromadora vivipara*	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.
HD394	*Aponema torosa*	14	15	.	7	17	418	18	2	6	1	3	5	58	112	28	12	5
HD	*Spirobolbolaimus* sp.	1	2	.	.	20	.	1	5	1	.	1	.	1	1	1	1	.
HD397	*Calomicrolaimus* sp.	.	6	2	5	18	1	24	3	9	1	2	3	.	2	3	1	.
HD	*Microlaimus turgofrons*	1	4	1	4	3	13	.	.	.	.	.	3	5	1	.	11	16
HD410	*Molgolaimus* sp.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD431	*Leptolaimus elegans*	2	2	.	2	.	20	.	.	1	.	.	.	.	6	5	12	5
HD433	*Leptolaimus papilliger*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.
HD	*Leptolaimus venustus*	1	1	.	3	.	.	.	.	.	.	.	.	6	3	.	1	.
HD439	*Stephanolaimus jayasreei*	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
HD455	*Aegialoalaimus* sp.	1	4	.	.	2	3	.	.	.	.	.	.	.	.	.	.	2
HD457	*Cyartonema* sp.	.	3	1	.	.	.	1	.	.	.	.	.	5	5	9	.	.
HD463	*Chitwoodia* sp.	.	6	.	.	.	2	1	.	.	.	.	.	1	.	.	.	.
HD481	*Desmoscolex* sp.	2	.	.	4	.	.	.	.	.	.	.	.	.	.	1	.	.
HD496	*Thalassomonhystera* sp.	1	7	.	.	1	4	.	1	.	1	2	2	3	2	3	.	.
HD	*Amphimonhystrella* sp.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	2
HD505	*Cobbia* sp.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	1	.	1
HD507	*Cobbia trefusiaeformis*	15	.	.	2	.	14	.	.	.	.	.	.	2	1	1	.	2
HD508	*Daptonema* sp. 1.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	3	.
HD508	*Daptonema* sp. 2.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
HD510	*Daptonema furcatum*	2	1	1	.	1	1	.	.	.	.	.	.	.	.	.	.	.
HD511	*Daptonema hirsutum*	1	1	.	.	1	.	.	.	.	.	.	1	.	.	1	.	.
HD513	*Daptonema normandicum*	9	17	5	49	15	73	7	6	8	7	11	10	8	25	11	6	32
HD514	*Daptonema oxycerca*	.	2	.	1	2	3	1	.	.	.	.	.	.	2	.	1	.
HD519	*Daptonema tenuispiculum*	.	.	1	.	.	.	.	.	1	5	18	29	.	.	.	.	.
HD521	*Theristus* spp.	.	1	.	.	2	1	.	3	.	.	.	.	1	.	3	.	.
HD540	*Paramonhystera* sp.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.
HD552	*Sphaerolaimus* juv.	.	.	.	1	.	.	.	.	.	.	1	1	1	.	1	1	.
HD554	*Sphaerolaimus balticus*	1	.	.	1	1	3	1	.	1	1	1	2	.	1	.	.	.
HD555	*Sphaerolaimus gracilis*	.	.	.	.	.	1	.	.	.	.	.	1	.	.	5	.	.
HD557	*Sphaerolaimus islandicus*	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

MCS CODE	TAXA	STATION																
		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B
HD558	*Sphaerolaimus macrocirculus*	.	1	.	1	.	2	.	.	.	.	.	.	2	1	1	3	.
HD560	*Parasphaerolaimus paradoxus*	1	.	.	1	.	5	.	.	.	.	.	.	1	3	.	.	.
HD564	*Siphonolaimus ewensis*	1	.	1	1	3	2	.	.	.	.	.	.	.	.	.	.	.
HD568	*Desmolaimus zeelandicus*	1	.	.	.	.	14	.	.	.	1	.	.	.	.	.	.	.
HD570	*Eleutherolaimus stenosoma*	.	1	.	.	.	3	.	.	.	.	.	.	.	.	.	.	2
HD571	*Eumorpholaimus* sp.	.	.	.	.	.	.	2	.	2	6	2	4	.	.	.	.	.
HD573	*Linhomoeus* sp.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.
HD574	*Linhomoeus elongatus*	1	2	.	.	2	5	.	.	.	.	.	.	5	1	2	3	2
HD578	*Paralinhomoeus lepturus*	.	.	.	.	.	18	.	.	.	.	.	.	.	.	.	.	5
HD583	*Metalinhomoeus longiseta*	2	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.
HD588	*Terschellingia longicaudata*	9	1	2	3	1	9	.	.	.	.	.	.	18	8	10	13	4
HD592	*Axonolaimus helgolandicus*	1	.	1	.	2	.	1	3	3	.	.	.	.	2	2	.	.
HD596	*Axonolaimus spinosus*	1	.	.	.	.	2	.	.	.	.	2	.	1	1	.	.	.
HD600	*Ascolaimus elongatus*	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
HD604	*Odontophora longisetosa*	.	.	.	3	13	8	4	2	5	1	5	1	1	1	1	.	.
HD618	*Campylaimus* sp.	1	.	.	.	1	4	.	.	2	.	.	1	2	3	2	1	1
HD623	*Diplopeltula asetosa*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
HD624	*Diplopeltula incisa*	.	.	1	2	.	.	.	.	.	.	.	.	1	3	1	.	.

Appendix II Nematode species found along TEES BAY transect from cores.

MCS CODE	TAXA	STATION																	
		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD32	*Mesacanthion diplechma*	48	.	32	104	128	72	24	16	48	8	24	.	72	48	48	8	24	8
HD45	*Chaetonema riemanni*	.	.	.	.	.	.	.	.	16	24	64	32	.	.	.	.	.	.
HD58	IRONIDAE	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.
HD89	*Halalaimus isaitshikovi*	8	.	8	.	16	24	.	.	8	8	.	.	.	.	32	.	.	.
HD91	*Halalaimus longicaudatus*	.	.	.	8	8	.	.	.	.	.	.	.	.	16	.	.	.	.
HD95	*Oxystomina elongata*	8	.	16	56	24	48	.	.	.	.	.	.	8	32	16	.	8	.
HD97	*Nemanema* sp.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.
HD102	*Thalassoalaimus tardus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD113	*Metoncholaimus scanicus*	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.
HD120	*Oncholaimus campylocercoides*	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD131	*Viscosia elegans*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8
HD132	*Viscosia glabra*	8	.	.	16	16	8	8	.	8	.	8	.	8	.	16	.	8	.
HD	*Polygastrophora* sp.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8
HD163	*Tripyloides marinus*	64	.	144	248	96	184	40	8	8	.	.	.	88	128	168	8	.	.
HD171	*Rhabdocoma* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.
HD186	*Atrochromadora microlaima*	.	.	.	16	.	.	.	.	.	.	.	.	.	8	.	.	.	.
HD203	*Prochromadorella ditlevseni*	.	.	8	96	96	48	.	.	.	.	.	.	32	8	8	.	.	.
HD205	*Prochromadorella septempapillata*	.	.	.	.	.	.	.	56	.	.	.	.	.	.	.	.	.	.
HD228	*Dichromadora cucullata*	8	.	.	48	64	48	.	88	16	.	.	8	16	56	8	8	16	.
HD230	*Dichromadora hyalocheile*	.	.	.	.	8	.	.	.	.	.	.	.	.	.	16	.	.	.
HD	*Trochamus/Nygmatonchus* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	16
HD238	*Neochromadora* sp.	8	.	.	.	.	16	8	8	.	16	16	8	16	16	32	.	8	.
HD249	*Dorylaimopsis punctata*	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	8	.	.
HD256	*Sabateria celtica*	.	.	.	.	.	8	.	.	.	.	.	8	.	.	.	.	.	16
HD261	*Sabatieria ornata*	168	192	72	128	328	144	8	16	16	.	8	16	96	80	224	176	496	656
HD262	*Sabateria praedatrix*	.	.	.	.	.	.	.	.	.	.	.	.	40	40	.	.	.	.
HD263	*Sabatieria pulchra* grp.	112	120	152	152	264	160	104	112	24	1656	1136	1304	72	192	96	120	40	256
HD266	*Setosabatieria hilarula*	.	.	.	8	16	.	.	.	.	.	.	.	8	.	16	.	.	.
HD270	*Neotonchus meeki*	16	.	8	8	48	.	.	.	.	.	.	.	.	24	.	.	48	8
HD273	*Comesa interrupta*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	8	.
HD276	*Comesa warwicki*	.	.	24	.	.	8	.	.	.	.	.	.	.	.	8	.	.	.
HD288	*Pomponema multipapillatum*	.	.	.	8	.	40	.	.	8	.	.	.	.	.	8	.	16	.
HD302	*Paracanthonchus heterodontus*	.	.	.	.	.	.	.	.	32	24	64	24	.	.	.	.	.	.
HD304	*Paracanthonchus longus*	.	.	.	.	.	16	8	.	8	8	24	.	.	.	.	.	.	.
HD321	*Marylynnia complexa*	16	.	8	8	48	8	16	.	.	.	.	.	8	16	32	8	.	.
HD323	*Paralongicyatholaimus minutus*	.	.	.	8	64	8	.	.	.	.	.	.	24	8	.	.	.	.
HD332	*Gammanema rapax*	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD335	*Halichoanolaimus robustus*	.	.	.	.	8	8	.	.	.	.	.	.	32	.	.	.	.	.
HD338	*Richtersia* sp.	32	.	8	120	136	224	.	56	16	56	8	16	72	40	88	.	.	.
HD343	*Desmodora pontica*	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.
HD352	*Spirinia parasitifera*	.	.	.	.	.	.	8	.	.	.	.	.	.	.	8	.	.	8
HD374	*Catanema* sp.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.
HD377	*Leptonemella* sp.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.
HD394	*Aponema torosa*	72	.	40	264	488	408	48	64	.	16	16	16	376	568	256	8	24	40
HD	*Spirobolbolaimus* sp.	.	.	.	8	.	32	8	.	.	8	.	.	8	.	.	.	.	.
HD397	*Calomicrolaimus* sp.	8	.	16	.	32	.	8	40	32	.	32	.	.	.	.	.	8	8
HD403	*Microlaimus* sp.2	8	.	.	112	32	96	16	32	16	.	.	.	16	16	8	.	.	.
HD	*Microlaimus turgofrons*	8	.	.	8	16	16	.	.	16	.	.	.	32	.	8	.	56	.
HD	*Leptolaimus* sp.3.	.	.	.	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD431	*Leptolaimus elegans*	.	.	.	40	64	32	.	8	24	.	.	.	32	120	16	.	16	.
HD	*Leptolaimus venustus*	.	.	.	8	.	16	.	.	.	.	.	.	.	.	.	.	16	.
HD455	*Aegialoalaimus* sp.	.	.	.	8	8	8	.	.	.	.	.	.	16	8	.	.	.	.
HD457	*Cyartonema* sp.	.	.	.	.	8	8	.	.	.	.	.	.	16	.	.	.	.	.
HD463	*Chitwoodia* sp.	.	8	.	.	.	.	8	16	32	.	.	.	.	.	.	.	.	.
HD481	*Desmoscolex* sp.	.	.	.	8	.	.	.	8	.	.	.	.	8	.	.	.	.	.
HD496	*Thalassomonhystera* sp.2.	16	8	24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD499	*Thalassomonhystera venusta*	.	.	24	.	.	8	.	.	.	.	.	.	.	.	8	.	.	.
HD	*Amphimonhystrella* sp.	.	.	.	8	.	.	8	.	8	.	.	.	.	.	.	.	.	.
HD505	*Cobbia* sp.	.	.	.	8	48	8	.	40	.	.	.	.	.	16	.	.	.	.
HD507	*Cobbia trefusiaeformis*	8	.	.	32	24	40	.	32	.	.	8	.	24	152	40	.	.	.
HD	*Daptonema* sp. 6.	.	8	.	.	.	.	.	.	.	.	.	.	.	16	.	.	.	.
HD513	*Daptonema normandicum*	216	144	40	48	56	64	24	48	24	16	48	8	184	160	128	80	80	488
HD514	*Daptonema oxycerca*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	8	8
HD516	*Daptonema psammoides*	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.
HD517	*Daptonema setifer*	.	.	.	.	8	.	.	.	.	.	.	.	24	24	8	.	.	.
HD519	*Daptonema tenuispiculum*	.	.	8	.	.	.	8	.	.	32	16	.	.	.	.	.	.	.
HD521	*Theristus* sp.4.	.	.	.	48	24	.	.	.	56	.	8	8	.	.	.	.	.	.
HD523	*Theristus bastiani*	.	.	.	.	.	.	.	16	.	.	.	.	.	.	.	.	.	.
HD526	*Theristus ensifer*	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.
HD528	*Theristus heterospiculum*	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.
HD540	*Paramonhystera* sp.2.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.
HD544	*Paramonhystera riemanni*	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.
HD547	*Gonionchus c.f. inaequalis*	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD553	*Sphaerolaimus* juv	.	.	.	.	16	.	.	.	8	.	.	.	16	24	16	.	32	.

MCS	TAXA	STATION																	
CODE		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD554	*Sphaerolaimus balticus*	8	.	.	16	.	.	.	.	.	8	8	.	.	8	.	.	.	.
HD555	*Sphaerolaimus gracilis*	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.
HD557	*Sphaerolaimus islandicus*	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.
HD558	*Sphaerolaimus macrocirculus*	8	.	.	.	.	.	.	.	.	.	.	.	.	16	.	16	.	.
HD560	*Parasphaerolaimus paradoxus*	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	8	8	.
HD564	*Siphonolaimus ewensis*	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.
HD570	*Eleutherolaimus stenosoma*	.	8	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD571	*Eumorpholaimus* sp.	.	.	.	.	.	.	.	.	.	.	24	16	.	.	.	.	.	.
HD574	*Linhomoeus elongatus*	8	16	8	16	24	16	.	.	8	.	.	.	16	8	16	8	24	16
HD578	*Paralinhomoeus lepturus*	.	.	.	.	8	.	.	.	48	.	.	.	.	.	.	.	.	.
HD580	*Paralinhomoeus uniovarium*	.	.	.	.	16	.	.	.	.	.	.	.	.	.	8	.	.	.
HD582	*Metalinhomoeus filiformis*	.	.	8	.	88	744	8	8	24	8	.	.	8	8	8	.	.	.
HD588	*Terschellingia longicaudata*	8	16	16	.	24	32	.	.	.	.	.	.	24	80	16	24	64	16
HD592	*Axonolaimus helgolandicus*	.	.	16	.	16	8	.	8	8	8	72	.	8	.	.	.	.	.
HD596	*Axonolaimus spinosus*	.	.	.	8	.	48	.	8	72	.	.	.	8	40	24	8	16	8
HD600	*Ascolaimus elongatus*	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.
HD601	*Odontophora* sp.	8	.	.	8	.	32	32	32	16	24	16	24	8	.	8	.	.	.
HD618	*Campylaimus* sp.	.	.	.	.	16	.	.	.	.	.	.	.	16	.	.	.	.	.
HD620	*Diplopeltis* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.
HD623	*Diplopeltula asetosa*	.	.	.	.	8	8	.	.	.	.	.	.	.	.	.	.	.	.
HD624	*Diplopeltula incisa*	8	.	.	16	24	32	.	.	.	.	.	.	.	40	8	.	48	.

Appendix III Nematode species found along LIVERPOOL BAY "Site Z" transect in 1996.

MCS	TAXA	STATION																	
code		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD14	*Enoploides* sp.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD19	*Enoplolaimus* sp.	.	.	.	24	16	32	.	.	.	.	.	.	.	.	.	.	.	.
HD32	*Mesacanthion diplechma*	96	128	208	48	40	40	8	32	8	.	16	.	48	8	72	24	40	24
HD87	*Halalaimus capitulatus*	8	16	8	.	16	16	.	.	.	.	.	.	.	.	.	.	40	.
HD91	*Halalaimus longicaudatus*	.	32	.	.	8	8	.	8	.	.	.	.	.	.	.	8	24	.
HD94	*Oxystomina asetosa*	16	40	16	.	.	.	.	.	.	.	.	.	8	.	.	24	.	.
HD101	*Thalassoalaimus tardus*	16	16	56	.	.	.	.	.	.	8	16	.	.	8	.	.	16	8
HD113	*Metoncholaimus scanicus*	1400	7248	14456	1504	184	10424	48	56	168	8	32	48	72	64	48	3640	1320	1160
HD129	*Viscosia abyssorum*	.	.	16	.	8	48	.	.	.	.	.	8	8	16	16	.	.	.
HD131	*Viscosia elegans*	40	64	168	8	64	72	.	24	.	.	8	.	24	16	32	.	40	56
HD136	*Belbolla* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD151	*Bathylaimus* sp.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD163	*Tripyloides marinus*	8	.	8	8	.	.	.	.	.	.	.	.	.	.	8	.	.	.
HD165	*Rhadodemania major*	24	48	112	16	16	.	.	.	.	.	.	8	.	8	.	8	8	16
HD171	*Rhabdocoma americana*	40	8	8	.	.	.	.	.	.	.	.	.	.	.	.	24	16	8
HD174	*Trefusia longicaudata*	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	8	8	.
HD190	*Chromadora nudicapitata*	.	8	8	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.
HD191	*Chromadorella* sp.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.
HD195	*Chromadorina* sp.	40	16	24	8	16	16	.	.	.	.	.	.	.	.	.	.	8	.
HD201	*Prochromadorella attenuata*	32	184	304	8	.	8	8	.	8	.	.	.	.	.	.	32	.	8
HD203	*Prochromadorella ditlevseni*	360	624	680	16	16	56	48	8	24	8	40	8	32	40	72	80	48	64
HD222	*Chromadorita* c.f. *nana*	.	128	88	.	.	.	.	.	16	.	.	.	8	8	8	.	.	.
HD224	*Chromadorita tentabunda*	32	8	24	8	.	56	.	.	.	.	.	.	.	.	.	.	24	8
HD228	*Dichromadora cucullata*	368	720	560	.	.	48	16	16	.	.	.	8	.	.	.	24	.	8
HD231	*Marylynnia complexa*	24	16	8	16	.	.	8	8	.	.	8	8	48	64	64	56	64	8
HD238	*Neochromadora* spp.	8	8	32	32	96	96	8	.	8	.	.	.	24	24	8	32	72	40
HD	*Neochromadora munita*	72	88	112	8	16	24	.	.	16	.	16	8	16	8	.	32	16	16
HD241	*Neochromadora* c.f. *poecilosomoides*	8	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD253	*Laimella longicaudata*	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD256	*Sabatieria celtica*	1864	1072	2328	184	632	800	192	416	168	96	72	520	616	640	664	360	544	112
HD259	*Sabatieria longispinosa*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8
HD261	*Sabatieria ornata*	8	.	.	.	.	.	.	.	16	.	.	48	.	.	.	.	.	.
HD262	*Sabatieria praedatrix*	.	8	8	.	.	.	.	.	.	.	.	.	.	.	.	8	16	.
HD263	*Sabatieria pulchra* grp.	744	808	1576	56	96	96	1096	1184	400	1712	1576	2192	168	608	304	240	752	80
HD271	*Comesa* sp.	8	40	96	.	.	.	.	.	.	8	.	.	.	.	.	16	.	24
HD278	*Nannolaimus fusus*	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	16	8
HD287	*Pomponema debile*	232	112	96	56	16	72	.	16	.	.	.	8	.	16	8	32	24	8
HD303	*Paracanthonchus longicaudatus*	72	8	336	16	8	24	8	208	.	48	.	.	8	24	16	16	24	8
HD304	*Paracanthonchus longus*	48	120	64	16	.	16	.	.	16	.	.	.	.	.	.	8	16	8
HD307	*Paracanthonchus* c.f. *platti*	72	408	184	64	56	64	40	.	24	.	16	176	40	56	48	24	104	32
HD323	*Paralongicyatholaimus minutus*	24	8	80	24	8	32	8	16	8	.	.	.	16	.	.	16	24	16
HD329	*Choniolaimus papillatus*	176	136	208	24	40	56	16	16	8	.	.	.	80	48	64	.	24	16
HD338	*Richtersia* sp.	584	552	952	112	208	320	72	40	168	40	16	64	272	160	128	168	280	296
HD342	*Desmodora* c.f. *communis*	160	200	112	56	88	120	.	24	8	8	.	.	8	8	8	32	64	40
HD343	*Desmodora pontica*	.	.	8	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.
HD348	*Desmodora* c.f. *tenuispiculum*	.	.	.	.	.	8	.	.	.	.	.	.	.	8	.	.	.	.
HD351	*Spirinia* c.f. *laevis*	.	.	.	.	8	24	.	.	.	.	.	.	.	.	.	.	.	8
HD352	*Spirinia parasitifera*	336	656	368	72	88	176	40	72	8	16	.	.	.	48	40	368	600	80
HD354	*Chromaspirina* sp.	472	192	512	8	40	80	32	64	32	8	8	.	24	40	16	104	544	80
HD370	*Polysigma fuscum*	48	72	16	48	184	256	8	.	.	.	.	.	.	16	.	24	296	256
HD371	*Pseudonchus deconincki*	24	24	40	.	24	24	.	16	8	8	.	.	.	.	16	16	8	24
HD378	*Leptonemella aphanothecae*	.	8	.	.	.	16	.	.	.	.	.	.	.	.	.	8	.	.
HD394	*Aponema torosa*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD396	*Bolbolaimus teutonicus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD399	*Calomicrolaimus honestus*	40	48	40	16	16	16	.	.	.	.	8	.	.	.	.	120	568	176
HD404	*Microlaimus acinaces*	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD405	*Microlaimus conothelis*	80	160	120	40	248	200	.	.	8	.	.	.	8	8	8	32	104	104
HD407	*Microlaimus* c.f. *ostracion*	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.
HD	*Microlaimus turgofrons*	120	32	96	.	16	24	56	56	.	32	8	16	56	88	80	16	40	8
HD	*Microlaimus* sp.4.	40	56	48	.	.	.	.	24	8	.	.	.	.	.	8	8	24	8
HD410	*Molgolaimus* sp.	.	8	.	8	16	40	.	.	8	.	.	.	.	8	.	24	24	56
HD416	*Monoposthia mirabilis*	8	.	.	.	.	16	.	.	.	.	.	.	.	.	.	.	.	.
HD421	*Antomicron* sp.	8	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD424	*Cricolaimus elongatus*	.	.	8	8	.	.	.	.	.	.	8	16	.	.	.	.	.	.
HD426	*Dagda bipapillata*	.	16	.	.	.	.	.	.	.	.	.	.	.	.	.	32	120	72
HD431	*Leptolaimus* c.f. *elegans*	40	32	56	.	32	40	.	8	.	.	.	.	8	8	8	32	72	32

MCS	TAXA	STATION																	
code		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD	*Leptolaimus luridus*	112	88	72	16	.	56	.	8	.	.	.	.	.	.	.	64	176	.
HD	*Leptolaimus venustus*	8	.	8	.	.	.	.	.	.	.	.	8	.	.	8	.	8	8
HD	*Leptolaimus* sp.4	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.	8
HD439	*Stephanolaimus jayasreei*	.	8	48	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.
HD440	*Stephanolaimus spartinae*	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	8
HD456	*Aegialolaimus elegans*	8	8	8	.	.	.	.	.	.	.	.	.	.	.	.	8	.	8
HD458	*Cyartonema elegans*	.	.	16	.	.	.	.	.	8	.	.	.	8	8	.	16	8	24
HD492	*Diplolaimella* sp.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.
HD499	*Thalassomonhystera venusta*	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	8	8
HD	*Monhystera microthalma*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8
HD507	*Cobbia trefusiaeformis*	64	8	16	.	.	.	.	.	.	.	.	.	.	.	.	16	.	.
HD509	*Daptonema* c.f. *biggi*	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD510	*Daptonema* c.f. *furcatum*	.	.	.	8	.	8	.	.	.	.	.	24	.	.	.	.	.	.
HD511	*Daptonema* c.f. *hirsutum*	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD513	*Daptonema* c.f. *normandicum*	8	24	8	8	.	32	16	32	16	.	32	64	8	16	8	8	16	16
HD519	*Daptonema tenuispiculum*	48	16	8	.	8	8	336	312	184	312	560	560	16	64	16	8	32	.
HD	*Daptonema* sp.4	.	.	.	.	.	.	8	.	8	.	8	8	.	.	.	.	.	.
HD	*Daptonema* sp.5	32	.	32	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD521	*Theristus* sp.2	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.
HD525	*Theristus* c.f. *denticulatus*	.	16	8	.	16	.	.	.	.	.	.	.	8	.	.	16	8	8
HD537	*Metadesmolaimus aduncus*	8	8	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.
HD540	*Paramonhystera* sp.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD554	*Sphaerolaimus balticus*	8	48	40	.	8	.	.	.	.	.	.	.	16	8	16	24	40	24
HD571	*Eumorpholaimus* sp.	24	40	72	8	8	.	8	.	.	.	.	.	.	.	8	.	.	.
HD573	*Linhomoeus* sp.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	16	.
HD576	*Paralinhomoeus* sp.	16	8	.	.	.	.	.	16	.	.	.	.	.	.	.	8	16	.
HD582	*Metalinhomoeus filiformis*	136	72	16	16	.	40	.	.	.	.	.	.	.	.	.	24	320	160
HD583	*Metalihomoeus longiseta*	24	8	8	.	.	.	.	.	.	.	.	.	8	.	8	48	24	.
HD	*Metalinhomoeus* sp.3.	32	8	8	.	.	.	.	.	.	.	.	.	.	.	.	8		
HD586	*Terschellingia communis*	.	.	16	.	.	8	.	.	.	16	.	.	.	8	.	.	.	.
HD588	*Terschellingia longicaudata*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD596	*Axonolaimus spinosus*	144	240	208	104	16	80	8	16	.	16	8	32	.	16	24	.	16	16
HD600	*Ascolaimus elongatus*	24	40	32	40	8	24	8	8	.	48	40	8	24	48	32	8	8	32
HD601	*Odontophora* sp.1	144	64	368	24	24	24	120	240	136	72	56	40	56	88	80	56	40	16
HD601	*Odontophora* sp.2	32	40	24	8	8	16	.	8	8	.	.	8	16	40	24	.	8	.
HD601	*Odontophora* sp.3.	.	8	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.
HD618	*Campylaimus* sp.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	8	.	.	.
HD623	*Diplopeltula asetosa*	8	8	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD	*Rhynchonema* sp.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Appendix IV Nematode species found along LUNE DEEP transect from cores.

MCS CODE	TAXA	STATION																				
		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C
HD32	*Mesacanthion diplechma*	16	16	8	40	8	32	40	40	32	40	24	32	56	88	128	128	72	152	112	152	128
HD45	*Chaetonema riemanni*	.	.	.	8	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.
HD102	*Thalassoalaimus tardus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD113	*Metonchoanolaimus scanicus*	.	.	.	.	.	8	8	16	24	.	.	.	8	8	8	.	.	.	.	.	.
HD114	*Oncholaimellus* sp.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.
HD123	*Oncholaimus skawensis*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.
HD131	*Viscosia elegans*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40	.	.
HD172	*Rhabdocoma riemanni*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD174	*Trefusia longicaudata*	.	.	.	.	.	.	.	.	.	16	.	.	.	.	.	.	.	.	.	.	.
HD	*Trefusia zostericola*	16	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD202	*Prochromadorella attenuata*	.	.	.	.	.	.	16	8	8	8	8	8	.	.	16	.	.	.	.	.	.
HD203	*Prochromadorella ditlevseni*	8	.	.	.	.	.	.	.	.	8	.	16	.	.	.	.	.	.	.	.	.
HD223	*Chromadorita nana*	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.
HD228	*Dichromadora cucullata*	.	.	.	8	.	.	.	8	.	.	.	.	24	24	24	16	16	8	.	.	.
HD253	*Laimella longicaudata*	.	.	.	.	.	.	8	.	.	.	8	.	.	.	.	8	.	.	8	16	8
HD256	*Sabatieria celtica*	16	16	24	.	8	24	16	8	.	8	.	.	16	32	8	32	40	16	640	.	.
HD259	*Sabatieria longispinosa*	16	.	.	.	.	.	8	.	.	24	24	24	8	.	.	.	.	.	.	528	648
HD263	*Sabatieria pulchra* grp.	400	344	480	320	144	240	120	480	224	180	184	200	200	248	224	56	24	32	768	344	320
HD266	*Setosabatieria hilarula*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	80	.	64
HD	*Hopperia* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.
HD272	*Comesa cuanensis*	.	.	.	.	.	8	8	16	8	24	16	8	24	.	8	.	.	.	.	8	8
HD278	*Nannolaimus c.f. fusus*	.	.	.	.	.	.	.	.	.	.	8	.	8	.	.	.	.	.	.	.	.
HD302	*Paracanthonchus heterodontus*	.	8	.	8	.	.	.	32	.	32	16	40	8	8	24	24	16	8	24	40	32
HD323	*Paralongicyatholaimus minutus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.
HD338	*Richtersia* sp.	16	16	32	24	56	40	40	104	32	96	80	56	96	48	40	48	56	64	128	136	160
HD343	*Desmodora pontica*	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.
HD349	*Spirinia* sp. 2	32	8	.	.	8	.	8	.	8	.	16	.	16	.	.	8	.	.	16	72	24
HD352	*Spirinia parasitifera*	.	.	.	.	.	.	8	.	8	.	.	8	16	.	.	16	.	8	16	8	.
HD378	*Leptonemella aphanothecae*	.	.	.	.	.	.	8	8	16	8	8	8	.	.	.	.	.	8	.	.	.
HD394	*Aponema torosa*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	8
HD396	*Bolbolaimus teutonicus*	.	.	.	.	.	.	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD	*Spirobolbolaimus* sp.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD398	*Calomicrolaimus acanthus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	8	.	.
HD401	*Calomicrolaimus parahonestus*	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD404	*Microlaimus acinaces*	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	8	.
HD405	*Microlaimus conothelis*	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.
HD406	*Microlaimus marinus*	.	.	.	.	.	.	.	.	.	.	.	8	8	.	.	.	8	8	.	8	16
HD	*Microlaimus turgofrons*	.	24	.	.	.	16	.	.	.	8	24	16	8	8	.	8	8	24	56	72	80
HD409	*Microlaimus c.f. zosterae*	.	8	.	.	.	.	.	8	16	.	.	.	.	.	.	.	.	.	.	.	.
HD411	*Molgolaimus cuanesis*	.	8	.	.	.	.	.	8	.	.	.	.	8	.	.	.	.	8	.	.	.
HD421	*Antomicron* n.sp.	.	.	.	.	.	.	.	.	8	.	.	.	8	.	8	.	.	8	.	.	.
HD430	*Leptolaimus* sp.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	16	8
HD431	*Leptolaimus elegans*	.	.	.	8	8	8	8	8	.	.	.	.	24	8	.	.	.	.	16	.	.
HD	*Leptolaimus luridus*	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.
HD	*Leptolaimus venustus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.
HD439	*Stephanolaimus jayasreei*	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	8	8	.	.	.	.
HD444	*Camacolaimus tardus*	.	.	.	.	.	.	16	.	8	.	.	8	32	40	24	24	24	8	.	16	8
HD459	*Cyartonema germanicum*	.	.	.	.	.	.	8	8	8	16	16	16	24	.	.	16	16	16	8	.	.

MCS CODE	TAXA	STATION																				
		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C
HD461	*Southernia zosterae*	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.
HD465	*Chitwoodia warwicki*	.	.	.	.	.	.	16	16	32	16	.	8	48	24	32	80	24	40	24	24	16
HD466	*Ceramonematidae*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.
HD499	*Thalassmonhystera venusta*	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	8	8
HD507	*Cobbia trefusiaeformis*	.	8	.	.	.	.	.	8	.	8	16	24	.	.	.	.	.	.	.	8	.
HD511	*Daptonema hirsutum*	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.
HD512	*Daptonema invagiferoum*	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD513	*Daptonema normandicum*	16	32	40	16	16	32	40	408	96	136	96	56	80	56	128	48	.	24	40	16	24
HD519	*Daptonema tenuispiculum*	488	480	420	200	376	320	104	168	280	152	136	96	16	56	32	8	.	8	8	24	8
HD529	*Theristus interstitialis*	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD536	*Metadesmolaimus* sp.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.
HD541	*Paramonhystera c.f. albigensis*	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	8	8
HD544	*Paramonhystera riemanni*	184	152	208	344	152	400	96	80	88	56	40	56	64	40	104	24	16	40	64	24	56
HD553	*Spharolaimus* juv.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	24	32	40
HD554	*Sphaerolaimus balticus*	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	48	16	8
HD558	*Sphaerolaims macrocirculus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD569	*Eleutherolaimus stenosoma*	8	8	24	8	.	8	.	.	8	.	16	8	24	.	8	8	8	8	32	.	.
HD578	*Paralinhomoeus lepturus*	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	16	8
HD582	*Metalinhomoeus filiformis*	8	8	8	.	.	.	.	8	.	.	.	16	24	.	.	.	.	8	.	56	32
HD583	*Metalinhomoeus longiseta*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	8	16
HD584	*Metalinhomoeus c.f. typicus*	8	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD600	*Ascolaimus elongatus*	24	36	32	40	16	48	48	32	80	48	.	56	192	288	256	328	184	232	160	56	40
HD601	*Odontophora* sp.	24	32	16	48	8	.	16	88	16	96	8	16	112	56	48	40	40	64	32	.	.
HD603	*Odontophora exharena*	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	24	8	16
HD613	*Araeolaimus elegans*	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.
HD619	*Campylaimus lefevrei*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.

Appendix V Nematode species found along SWANSEA BAY transect from grab sub-samples.

MCS	TAXA	STATION																	
code		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD23	*Enoplaimus propinquus*	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
HD32	*Mesacanthion diplechma*	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
HD55	*Anticoma acuminata*	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	1	.	.
HD58	IRONIDAE	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
HD88	*Halalaimus gracilis*	2	.	.	.	.	1	.	.	.	.	.	.	.	.	.	8	5	3
HD91	*Halalaimus longicaudatus*	1	.	.	.	2	.	1	.	1	.	.	.	.	1	.	2	2	2
HD94	*Oxystomina asetosa*	.	.	.	.	.	.	.	1	.	.	.	1	1	1	.	4	6	10
HD102	*Thalassoalaimus tardus*	7	.	7	2	4	4	3	9	4	1	2	.	.	.	1	5	2	13
HD112	*Metoncholaimus albidus*	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD129	*Viscosia abysorrum*	.	.	.	.	1	2	1	1	.	.	.	.	.	.	.	.	.	2
HD134	*Viscosia viscosia*	1	.	.	4	1	4	1	2	.	.	1	1	.	2	.	16	1	39
HD	*Polygastrophora* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
HD	*Pandolaimus* sp.	2	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	1	1
HD172	*Rhabdocoma riemanni*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
HD201	*Prochromadorella* sp.	.	.	.	.	3	.	.	1	.	.	.	.	2	.	.	6	.	.
HD174	*Trefusia longicaudata*	4	1	.	.	1	.	.	1	1	.	1	.	.	.	.	1	1	2
HD203	*Prochromadorella ditlevseni*	1	1	1	1	5	2	.	.	1	.	.	1	2	2	.	1	4	21
HD222	*Chromadorita nana*	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.
HD228	*Dichromadora cucullata*	2	.	2	1	.	2	.	2	.	.	.	.	1	.	.	2	12	18
HD230	*Dichromadora hyalocheile*	1	.	.	.	1	2	2	.	.	.	1	.	.	.	.	.	.	.
HD241	*Neochromadora poecilosomoides*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1
HD3246	*Spilophorella paradoxa*	.	.	2	.	1	.	.	2	1	1	1	2	5	.	.	.	.	1
HD253	*Laimella longicaudata*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.
HD261	*Sabatieria ornata*	2	.	.	.	.	3	.	.	.	.	.	5	.	5	1	4	1	17
HD262	*Sabateria praedatrix*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
HD263	*Sabatieria pulchra* grp.	113	58	65	226	54	323	243	171	89	51	85	110	37	118	85	139	113	144
HD266	*Setosabatieria hilarula*	3	2	.	1	.	1	1	.	.	.	.	.	.	.	.	5	10	15
HD272	*Comesa cuanensis*	6	3	16	25	15	16	44	51	11	9	14	22	2	8	20	15	26	38
HD300	*Paracanthonchus* sp.	.	.	3	1	1	1	1	.	.	.	.	.	.	2	.	1	.	1
HD321	*Marylynnia complexa*	43	3	8	8	2	5	3	7	2	.	6	7	.	2	.	145	140	146
HD335	*Halichoanolaimus robustus*	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.
HD339	*Richtersia inaequalis*	.	.	.	2	1	4	.	2	2	.	.	.	1	2	.	3	.	1
HD352	*Spirinia parasitifera*	1	1	2	.	.	.	.	.	.	.	.	.	.	2	.	3	.	2
HD355	*Chromaspirinia inglisi*	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.
HD363	*Onyx* sp.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD377	*Leptonemella* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
HD394	*Aponema torosa*	4	1	1	.	.	5	3	19	.	.	1	1	2	3	.	20	53	72
HD	*Spirobolaimus* sp.	2	.	.	.	3	3	.	2	.	.	.	.	.	1	.	.	.	.
HD399	*Calomicrolaimus honestus*	7	2	.	3	4	6	.	9	.	.	1	1	3	3	.	6	2	2
HD	*Microlaimus turgofrons*	122	36	63	40	13	65	38	146	17	13	15	17	5	66	14	346	297	352
HD412	*Molgolaimus demani*	5	6	2	21	7	19	20	6	2	.	1	1	8	9	2	79	150	203
HD420	LEPTOLAIMIDAE	1	.	.	1	.	.	.	4	1	.	.	.	1	1	4	6	.	.
HD431	*Leptolaimus elegans*	1	.	3	3	7	5	1	4	.	.	1	.	1	2	.	8	3	5
HD432	*Leptolaimus limicolus*	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD	*Leptolaimus luridus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	2
HD437	*Stephanolaimus* sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
HD441	*Camacolaimus* sp.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD456	*Aegialoalaimus elegans*	.	.	1	1	.	.	1	.	.	1	.	.	1	.	.	2	2	5
HD457	*Cyartonema* sp.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.
HD465	*Chitwoodia* sp.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
HD482	*Desmoscolex falcatus*	1	.	.	2	1	.	1	.	.	.	.	.	.	.	.	.	.	1
HD493	*Diplolaimella stagnosa*	.	1	.	1	.	.	2	.	5	.	.	2	.	.	.	3	.	.
HD497	*Thalassomonhystera parva*	.	.	.	.	1	1	.	2	.	.	.	.	.	1	.	.	.	.

MCS	TAXA	STATION																	
code		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD508	*Daptonema* sp. 8.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	2	2	1
HD508	*Daptonema* sp. 9.	9	.	3	4	2	1	.	7	1	.	2	.	.	3	1	5	3	7
HD510	*Daptonema furcatum*	.	.	2	3	4	.	.	.	.	.	.	.	.	.	.	.	.	.
HD	*Daptonema fallax*	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD513	*Daptonema normandicum*	17	9	3	77	13	36	18	22	28	9	15	39	12	80	37	16	12	8
HD514	*Daptonema oxycerca*	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	2	1	1
HD516	*Daptonema psammoides*	6	.	.	1	1	.	.	.	.	.	.	.	.	.	.	2	1	2
HD518	*Daptonema setosum*	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
HD519	*Daptonema tenuispiculum*	2	5	2	7	20	15	1	10	7	5	18	10	.	.	1	1	4	8
HD	*Rhynchonema* sp.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
HD521	*Theristus* sp. 5.	2	.	1	8	5	8	5	.	3	3	31	23	.	7	3	66	77	59
HD523	*Theristus bastiani*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
HD525	*Theristus denticulatus*	.	1	.	.	2	1	1	.	.	.	.	.	.	1	.	.	.	.
HD527	*Theristus flevensis*	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.
HD530	*Theristus longus*	.	.	.	1	.	3	.	.	.	.	.	.	7	2	.	.	.	.
HD441	*Paramonhystera riemanni*	2	4	.	2	12	49	4	44	5	2	4	10	6	20	8	1	1	4
HD553	*Sphaerolaimus* juv.	4	.	.	1	.	.	.	.	.	.	2	2	.	2	.	4	6	10
HD554	*Sphaerolaimus balticus*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
HD555	*Sphaerolaimus gracilis*	2	2	4	.	.	.	.	1	.	.	.	.	1	.	.	.	.	5
HD558	*Sphaerolaimus macrocirculus*	4	1	3	.	.	1	.	1	.	.	2	.	.	.	.	6	10	8
HD570	*Eleutherolaimus stenosoma*	3	.	.	.	1	2	2	1	.	3	2	1	1	2	.	1	1	5
HD571	*Eumorpholaimus* sp.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
HD575	*Linhomoeus hirsutus*	1	.	1	1	1	.	1	3	.	.	.	.	.	.	.	4	5	1
HD576	*Paralinhomoeus* sp.	.	.	.	.	2	2	.	.	2	.	.	.	1	.	.	.	.	1
HD580	*Paralinhomoeus uniovarium*	17	1	5	8	11	23	8	32	6	1	5	4	1	8	3	17	29	24
HD582	*Metalihomoeus c.f. filiformis*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
HD583	*Metalinhomoeus longiseta*	1	.	.	.	2	1	.	1	.	.	.	.	.	.	.	.	.	6
HD585	*Terschellingia longicaudata*	3	1	4	.	1	.	2	1	.	.	.	.	.	1	.	13	25	55
HD586	*Terschellingia communis*	.	.	.	1	.	1	1	.	.	.	.	.	.	.	.	.	.	.
HD593	*Axonolaimus hexapilus*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
HD596	*Axonolaimus spinosus*	1	.	1	.	.	1	.	2	.	.	.	.	.	2	.	1	1	2
HD	*Nicascolaimus* sp.	.	.	.	3	.	4	2	.	.	.	.	.	.	2	.	.	.	1
HD600	*Ascolaimus elongatus*	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.
HD604	*Odontophora longisetosa*	7	3	5	3	1	15	7	7	1	.	1	3	2	6	4	27	23	35
HD607	*Odontophora villoti*	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	.	.	.
HD618	*Campylaimus* sp. *1*	4	4	1	1	.	.	.	1	.	.	.	1	.	1	.	13	18	23
HD618	*Campylaimus* sp. 2	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	11
HD624	*Diplopeltula incisa*	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD626	*Disconema/Coninckia* sp.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.

Appendix VI Nematode species found along SWANSEA BAY transect from cores.

	TAXA	STATION																	
		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD14	*Enoploides* sp.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD32	*Mesacanthion diplechma*	16	8	16	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.
HD43	*Anoplostoma viviparum*	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	8
HD88	*Halalaimus gracilis*	8	.	8	.	.	.	.	8	.	.	.	.	.	.	.	.	8	8
HD91	*Halalaimus longicaudatus*	8	8	.	8	16	.	.	.	8	8	.	.	.	.	.	8	8	.
HD94	*Oxystomina asetosa*	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	16	8	8
HD102	*Thalassoalaimus tardus*	.	16	8	48	32	16	40	32	16	8	8	16	.	16	.	16	48	56
HD129	*Viscosia abyssorrum*	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	8	.	8
HD131	*Viscosia elegans*	.	16	.	16	.	.	.	32	16	8	.	.	.	8	8	24	8	48
HD136	*Belbolla* sp.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	8
HD174	*Trefusia longicaudata*	.	8	.	.	.	.	8	.	.	8	.	.	.	.	.	8	.	.
HD203	*Prochromadorella ditlevseni*	.	.	16	8	32	40	32	24	48	16	8	16	.	8	.	56	56	40
HD223	*Chromadorita nana*	.	.	8	8	.	.	.	.	8	.	.	8	.	.	8	.	.	8
HD228	*Dichromadora cucullata*	.	.	16	8	40	16	.	8	48	8	16	104	128	24	32	128	40	48
HD229	*Dichromadora geophila*	.	.	.	.	8	.	.	.	.	8	.	.	.	.	.	.	32	8
HD246	*Spilophorella paradoxa*	.	.	16	8	.	.	8	.	8	16	8	8	8	8	16	.	8	.
HD253	*Laimella longicaudata*	.	.	.	16	.	.	.	8	.	.	.	.	.	.	.	.	.	8
HD256	*Sabatieria celtica*	.	8	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.
HD257	*Sabatieria elongata*	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD261	*Sabatieria ornata*	8	.	8	8	.	16	8	.	.	8	8	.	.	8	.	.	16	24
HD263	*Sabatieria pulchra* grp.	200	416	360	2744	520	1800	1856	1568	1224	432	368	736	408	176	296	488	72	256
HD266	*Setosabatieria hilarula*	.	8	8	.	.	.	.	.	.	.	.	8	.	.	.	.	.	8
HD270	*Neotonchus meeki*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.
HD272	*Comesa cuanensis*	40	56	72	184	112	136	296	264	296	128	136	16	24	.	16	200	80	16
HD288	*Pomponema multipapillatum*	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.
HD301	*Paracanthonchus caecus*	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.
HD303	*Paracanthonchus longicaudatus*	.	.	.	16	24	.	16	8	8	16	.	16	8	.	8	.	.	.
HD313	*Praecanthonchus punctatus*	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD321	*Marylynnia complexa*	.	.	8	16	8	16	.	40	16	32	24	72	.	.	16	.	24	24
HD335	*Halichoanolaimus robustus*	.	.	.	.	.	.	.	.	8	.	.	.	8	.	.	.	.	.
HD339	*Richtersia inaequalis*	.	.	.	8	8	.	16	.	8	8	.	.	8	.	.	.	8	.
HD343	*Desmodora pontica*	8	.	16	.	.	.	8	.	40	8	16	16	.	.	8	8	.	.
HD352	*Spirinia parasitifera*	.	.	.	.	.	.	.	8	.	.	.	24	.	.	8	16	24	16
HD357	*Chromaspirinia parapontica*	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.
HD359	*Metachromadora remanei*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8
HD368	*Sigmophoranema rufum*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.
HD394	*Aponema torosa*	.	56	8	16	.	8	16	.	16	24	56	56	8	24	16	112	88	88
HD	*Spirobolbolaimus* sp.	8	.	8	.	.	8	.	.	.	.	8	8	8	8	.	8	.	.
HD399	*Calomicrolaimus honestus*	.	32	24	24	32	32	48	24	32	.	8	48	.	.	16	56	24	40
HD	*Microlaimus turgofrons*	8	8	48	744	56	232	296	824	32	288	184	456	80	56	272	536	16	1056
HD412	*Molgolaimus demani*	.	8	8	88	.	120	24	16	136	72	104	232	128	.	152	336	248	176
HD418	*Nudora bipapillata*	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HD420	*Leptolaimidae*	.	.	.	.	.	.	.	.	8	.	.	.	24	16	8	16	.	8
HD431	*Leptolaimus elegans*	.	16	.	16	.	24	8	8	24	24	16	40	40	32	.	40	24	24
HD	*Leptolaimus luridus*	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.
HD	*Leptolaimus mixtus*	.	.	.	.	.	16	.	.	.	.	.	8	8	.	.	16	.	.
HD436	*Halaphanolaimus pellucidus*	.	.	8	.	.	.	8	.	8	.	.	.	.	.	.	.	.	.
HD438	*Stephanolaimus elegans*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	8
HD456	*Aegialoalaimus elegans*	.	.	8	24	.	.	8	.	.	8	.	.	8	8	8	24	8	16
HD465	*Chitwoodia warwicki*	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.
HD482	*Desmoscolex falcatus*	.	.	.	.	.	.	.	.	.	.	.	8	.	.	8	8	.	8
HD492	*Diplolaimella stagnosa*	.	.	.	24	8	.	8	8	8	16	.	8	.	.	.	24	8	.
HD 510	*Daptonema furcatum*	8	.	24	24	8	56	32	48	.	16	.	72	48	.	40	24	8	48
HD513	*Daptonema normandicum*	16	.	8	24	.	128	40	192	152	48	88	240	48	16	72	32	32	16
HD516	*Daptonema psammoides*	.	16	.	16	.	16	8	.	8	8	8	24	24	.	.	.	.	16
HD519	*Daptonema tenuispiculum*	16	96	.	88	32	136	32	80	112	104	128	408	40	32	88	16	24	8
HD	*Daptonema* sp. 5.	8	.	.	8	.	.	8	.	.	.	.	.	.	.	.	.	.	.
HD	*Daptonema* sp. 6.	.	.	.	.	.	16	40	.	40	8	16	24	16	.	24	.	8	32
HD525	*Theristus denticulatus*	8	.	.	.	.	.	.	.	.	.	.	8	.	.	.	16	.	.
HD526	*Theristus ensifer*	.	.	.	8	.	8	16	8	.	.	8	16	.	8	.	40	.	48
HD	*Theristus* sp. 3.	16	.	.	16	.	56	24	8	24	32	72	72	24	40	48	112	96	136
HD544	*Paramonhystera riemanni*	16	.	8	72	8	16	40	296	112	32	16	40	40	32	16	.	8	.
HD554	*Sphaerolaimus balticus*	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.
HD555	*Sphaerolaimus gracilis*	.	24	.	8	8	.	.	16	8	.	.	.	.	.	.	8	8	.
HD558	*Sphaerolaimus macrocirculus*	.	24	8	8	.	.	.	24	.	.	.	.	.	.	.	.	.	24
HD	*Sphaerolaimus* juv.	.	.	.	.	8	.	8	8	8	24	16	8	.	.	16	.	.	.
HD569	*Eleutherolaimus* sp.	.	.	.	24	24	8	.	8	8	16	40	40	.	16	32	16	.	8
HD572	*Eumorpholaimus sabulicolus*	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	24	.	.
HD575	*Linhomoeus hirsutus*	.	.	.	24	24	8	8	8	.	.	24	16	.	8	8	.	.	8
HD580	*Paralinhomoeus uniovarium*	40	8	8	48	16	32	32	32	.	104	.	280	40	8	32	16	40	16

	TAXA	STATION																	
		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
HD583	*Metalinhomoeus longiseta*	.	8	8	.	.	.	.	.	8	.	.	.	8	.	8	.	24	.
HD586	*Terschellingia communis*	.	8	.	24	.	.	8	32	.	.	.	.	.	.	.	8	.	.
HD588	*Terschellingia longicaudata*	.	40	24	128	8	8	88	8	16	8	.	8	.	.	.	128	40	48
HD595	*Axonolaimus paraspinosus*	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.
HD600	*Ascolaimus elongatus*	.	16	.	.	.	8	.	.	.	8	.	.	.	.	.	.	.	.
HD608	*Odontophora wieseri*	8	.	.	56	16	24	48	48	16	16	32	48	8	16	48	48	48	72
HD	*Odontophora* sp. 2.	.	.	.	40	.	.	8	16	.	.	.	8	.	.	.	8	.	.
HD 619	*Campylaimus lefevrei*	.	.	.	.	8	.	8	.	.	8	.	8	8	.	.	8	8	.
HD	*Campylaimus* sp. 2.	.	16	.	16	8	16	8	8	16	8	.	16	.	.	.	24	24	16

Appendix VII Macrofaunal taxa found along TEES Bay transect.

	Station Replicate	1A	1B	1C	2A	2B	2C	4A	4B	4C	3A	3B	3C	5A	5B	5C	6A	6B
D1056	Virgularia mirabilis	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	-	-
D1329	Edwardsiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
G0000	NEMERTEA	2	-	2	1	-	4	1	-	-	3	1	1	1	2	1	2	1
N0011	Golfingia vulgaris (?)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N0028	Phascolion strombi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
P0027	Aphrodita aculeata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
P0093	Gattyana cirrosa	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0097	Harmothoe	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	1	1
P0120	Harmothoe lunulata (agg.)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
P0169	Pholoe minuta	3	-	-	-	1	4	-	-	-	-	-	-	3	-	1	13	5
P0205	Eteone longa	-	1	-	-	1	1	-	-	-	-	1	-	-	2	-	-	2
P0481	Glycera tridactyla	-	-	-	-	1	-	1	-	1	1	1	1	1	-	-	-	1
P0487	Glycinde nordmanni	-	-	-	1	-	-	-	-	-	-	-	-	2	1	1	-	-
P0493	Goniada maculata	3	-	-	2	-	1	1	-	1	-	-	-	5	2	5	1	1
P0527	Sphaerodorum gracilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
P0867	Nephtys (juv.)	3	1	1	-	1	2	-	4	-	1	1	1	5	8	2	-	5
P0868	Nephtys caeca	-	1	-	2	1	-	5	2	2	1	-	2	-	2	-	-	-
P0871	Nephtys hombergii	1	3	-	1	3	-	3	15	10	1	2	2	2	1	3	-	3
P1008	Lumbrineris gracilis	2	3	2	2	1	-	3	2	-	1	4	3	1	5	2	-	1
P1066	Ophryotrocha	-	-	-	-	-	-	-	-	17	-	-	-	-	-	-	-	-
P1097	Schistomeringos caeca	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
P1152	Scoloplos armiger	1	1	1	1	2	6	-	1	-	-	1	-	2	1	4	2	2
P1179	Levinsenia gracilis	-	-	-	-	-	-	-	-	-	-	-	-	4	-	1	-	2
P1250	Laonice bahusiensis	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
P1278	Polydora ciliata (agg.)	-	-	-	-	-	1	1	174	8	-	-	-	-	-	-	-	-
P1302	Prionospio fallax	8	2	-	18	2	15	-	-	-	-	-	-	14	9	5	3	-
P1334	Spio armata (?)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1336	Spio filicornis	-	-	-	-	-	-	-	-	1	1	1	2	-	-	-	-	-
P1343	Spiophanes bombyx	-	-	-	2	-	-	1	1	3	2	-	1	2	3	2	-	1
P1363	Magelona filiformis	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
P1364	Magelona minuta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
P1392@	Aphelochaeta	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-
P1398	Caulleriella zetlandica	-	1	-	-	3	2	-	1	1	1	1	3	1	-	-	-	2
P1403	Chaetozone setosa (agg.)	17	6	2	11	12	10	-	3	3	1	14	25	11	8	10	7	8
P1479	Diplocirrus glaucus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
P1530	Capitella	-	-	-	-	-	-	-	32	1	-	-	-	-	-	-	-	-
P1553	Heteromastus filiformis	-	-	-	1	-	2	-	1	-	-	-	-	2	-	-	1	1
P1719	Ophelina acuminata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
P1743	Scalibregma inflatum	1	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	1
P1836	Owenia fusiformis	1	1	-	-	-	-	1	-	-	-	-	-	5	1	2	-	-
P1843	Amphictene auricoma	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-
P1854	Lagis koreni	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
P1904	Ampharete	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1927	Anobothrus gracilis	2	-	-	-	-	-	-	-	-	-	-	-	7	4	4	1	1
P1990	Terebellides stroemi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
P2117	Polycirrus	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
P2487	Tubificoides benedii	-	-	-	-	-	-	2	8	1	-	2	1	-	-	-	-	-
P2489	Tubificoides pseudogaster	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-
P2491	Tubificoides swirencoides	-	-	-	4	-	3	-	1	2	-	-	-	1	-	-	-	-
Q0004	Nymphon brevirostre	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
R0120	Elminius modestus	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0091	Leptomysis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Station Replicate	1A	1B	1C	2A	2B	2C	4A	4B	4C	3A	3B	3C	5A	5B	5C	6A	6B
S0145	Schistomysis	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0228	Perioculodes longimanus	-	1	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-
S0468	Acidostoma sarsi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
S0494	Hippomedon denticulatus	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-
S0539	Orchomene nana	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0607	Argissa hamatipes	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-
S0710	Ampelisca brevicornis	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
S0714	Ampelisca macrocephala	-	-	-	-	1	1	-	-	-	-	-	1	5	1	2	-	-
S0718	Ampelisca spinipes	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
S0720	Ampelisca tenuicornis	-	-	-	1	-	-	-	-	-	-	-	-	1	1	-	-	-
S0741	Bathyporeia elegans	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
S0899	Gammaropsis nitida	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0924	Photis pollex	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0981	Lembos denticarpus	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1023	Corophium crassicorne	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2003	Bodotria scorpioides	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
S2022	Eudorella truncatula	-	-	-	1	-	-	-	-	-	-	-	1	1	3	1	2	3
S2032	Leucon nasica	3	-	4	-	-	1	-	-	-	-	-	-	-	-	2	-	-
S2098	Diastylis laevis	-	-	5	1	1	1	-	-	-	1	-	-	-	-	-	-	-
S2100	Diastylis rathkei	4	-	56	2	1	-	4	-	1	1	1	2	2	2	2	7	32
S2444	Paguridae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W0010	Chaetoderma nitidulum	3	-	-	-	-	-	-	-	-	-	-	-	3	-	1	3	2
W0582	Eulimella laevis	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
W0758	Carinariidae	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
W0770@	Polinices	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
W0969	Cylichna cylindracea	2	-	-	1	-	-	-	-	-	-	-	-	-	-	2	9	1
W0977	Philine	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
W0986	Philine scabra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W0994	Diaphana minuta	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	1
W1025	Rhizorus acuminatus	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
W1618	Nucula nitidosa	75	6	-	92	41	22	-	-	4	1	14	-	27	28	27	13	7
W1625	Nuculoma tenuis	15	-	2	4	2	3	-	-	-	-	-	-	4	2	8	9	6
W1650	Mytilus edulis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
W1650	Mytilus edulis (juv.)	-	-	-	1	-	-	2	1	6	-	-	-	-	-	-	-	-
W1842	Lucinoma borealis	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
W1852	Thyasira flexuosa	22	-	-	8	-	2	-	-	-	-	-	-	13	21	20	23	17
W1905	Mysella bidentata	11	-	-	-	-	7	-	2	-	-	-	-	7	1	7	43	5
W1911	Tellimya ferruginosa	-	3	-	-	2	-	-	-	-	-	-	-	-	-	-	1	2
W1969	Acanthocardia echinata	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
W1998	Mactra stultorum	-	-	-	1	1	-	-	-	1	-	-	-	-	-	-	1	-
W1998	Mactra stultorum (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
W2032	Phaxas pellucidus	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	1	-
W2057	Fabulina fabula	-	-	-	-	3	-	-	3	5	1	4	3	1	-	-	-	-
W2102	Abra alba	12	-	6	6	2	-	9	7	1	1	-	1	3	3	3	59	48
W2104	Abra nitida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
W2125	Arctica islandica	7	-	-	3	1	1	-	-	-	-	-	-	15	28	18	2	3
W2162	Dosinia (juv.)	3	-	-	6	4	2	-	-	1	-	-	1	4	3	9	3	-
W2164	Dosinia lupinus	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
W2189	Chamelea gallina	8	3	-	12	3	10	-	4	1	3	4	-	13	10	20	7	1
W2227	Mya truncata	1	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-
W2227	Mya truncata (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
W2239	Corbula gibba	-	-	-	-	1	-	-	-	-	-	-	-	5	-	4	-	2
W2251	Hiatella arctica	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W2348	Thracia (juv.)	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
ZA0003	Phoronis	-	-	-	-	-	-	-	1	-	-	-	-	7	-	-	1	1

	Station Replicate	1A	1B	1C	2A	2B	2C	4A	4B	4C	3A	3B	3C	5A	5B	5C	6A	6B
ZB0288	Amphiura filiformis	8	-	-	1	-	6	-	-	-	-	-	-	10	5	7	39	4
ZB0311	Ophiura (juv.)	-	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-
ZB0313	Ophiura albida	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
ZB0407	Echinocardium cordatum	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4
ZB0469	Paracucumaria hyndmani	-	-	-	1	-	1	-	-	-	-	-	-	2	2	5	4	2
ZB0526	Leptosynapta inhaerens	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	8

Appendix VIII Macrofaunal taxa found along LIVERPOOL BAY "Site Z" transect in 1996.

	Station	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
	Replicate	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D0141	Tubularia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P
D0144	Tubularia indivisa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D0703	Clytia hemisphaerica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D1131	ACTINIARIA	-	-	-	5	-	3	-	-	-	-	-	-	1	8	4	7	2	4
D1341	Edwardsia claparedii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F0001	TURBELLARIA	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G0000	NEMERTEA	12	26	19	25	15	14	4	11	13	1	6	8	5	7	19	12	18	5
P0093	Gattyana cirrosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1
P0107	Harmothoe impar	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0120	Harmothoe lunulata (agg.)	-	3	2	-	1	-	-	-	-	-	-	-	2	-	-	4	1	3
P0169	Pholoe minuta	3	11	18	1	2	-	-	4	-	-	-	-	7	-	4	16	7	5
P0181	Sigalion mathildae	-	3	1	2	1	1	1	-	1	-	-	1	-	1	-	2	-	-
P0187	Sthenelais boa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0205	Eteone longa (agg.)	6	3	9	3	3	2	-	-	-	-	-	-	-	1	-	-	-	-
P0224	Eteone picta	-	-	-	1	1	2	1	-	-	-	-	1	-	-	-	2	1	2
P0253	Phyllodoce groenlandica	-	1	1	1	1	1	1	-	-	1	-	-	1	-	-	1	-	-
P0257	Phyllodoce mucosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
P0283	Eumida bahusiensis	-	3	-	2	-	1	1	-	-	-	-	-	2	1	12	4	3	1
P0481	Glycera tridactyla	-	1	-	3	1	2	4	6	4	3	5	3	1	4	5	1	-	1
P0487	Glycinde nordmanni	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-
P0541	Gyptis helgolandica	3	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
P0834	Nereis longissima	-	1	-	-	1	-	-	-	-	-	-	-	-	-	1	2	-	-
P0867	Nephtys (juv.)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0871	Nephtys hombergii	-	4	7	8	53	16	4	1	1	-	-	5	5	3	1	2	3	3
P1152	Scoloplos armiger	-	1	-	1	-	-	-	1	-	-	-	-	-	-	-	1	1	-
P1221	Poecilochaetus serpens	-	2	1	11	4	2	1	1	1	-	2	1	2	-	2	3	1	2
P1312	Pseudopolydora pulchra	-	1	1	-	5	1	3	-	3	-	-	-	14	4	7	1	2	3
P1317	Pygospio elegans	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-
P1335	Spio decorata	-	-	-	25	10	13	1	1	3	2	1	1	5	7	4	2	1	-
P1343	Spiophanes bombyx	-	1	-	2	3	-	-	-	1	-	-	-	-	-	-	-	-	-
P1362	Magelona alleni	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1363	Magelona filiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1365	Magelona mirabilis	-	1	3	13	44	22	11	16	33	7	3	16	1	3	1	-	1	-
P1397	Tharyx killariensis	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
P1403	Chaetozone setosa (agg.)	-	-	-	2	-	1	-	-	-	-	-	-	-	3	1	-	-	-
P1424	Aphelochaeta marioni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
P1530	Capitella	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
P1558	Mediomastus fragilis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
P1743	Scalibregma inflatum	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-
P1836	Owenia fusiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1854	Lagis koreni	106	219	236	17	17	12	5	7	10	4	19	14	1	-	3	132	73	87
P1910	Ampharete lindstroemi	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
P2031	Lanice conchilega	-	10	5	1	13	2	6	2	1	-	-	-	10	7	9	30	28	18
P2303	Pomatoceros lamarcki	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P2459	Tubificidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P2486	Tubificoides amplivasatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P2489	Tubificoides pseudogaster	-	-	-	2	-	-	-	-	2	-	-	-	2	-	6	-	1	-
R0110	Balanus crenatus	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	1	-	3
R0120	Elminius modestus	-	-	-	-	-	15	-	-	-	-	1	-	-	-	-	-	-	-
S0149	Schistomysis spiritus	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
S0228	Perioculodes longimanus	1	-	-	-	-	-	-	-	-	1	-	2	-	-	2	-	1	-
S0240	Synchelidium maculatum	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-
S0280	Amphilochus neapolitanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
S0370	Stenothoe marina	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	1	1	-
S0539	Orchomene nana	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-
S0607	Argissa hamatipes	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
S0683	Atylus swammerdami	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-
S0710	Ampelisca brevicornis	2	2	1	1	-	1	1	-	-	-	-	-	-	-	1	-	-	-

	Station	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
	Replicate	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
S0720	Ampelisca tenuicornis	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0740	Bathyporeia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0741	Bathyporeia elegans	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
S0743	Bathyporeia guilliamsoniana	-	1	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-
S0790	Megaluropus agilis	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	2	-	-
S0808	Abludomelita obtusata	-	-	-	-	1	1	2	-	-	-	-	-	1	1	6	1	7	2
S0923	Photis longicaudata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
S0972	Aoridae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
S1084	Pariambus typicus	-	-	-	1	1	-	-	-	-	-	-	-	-	-	3	1	-	-
S1096	Phtisica marina	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1	-
S2015	Iphinoe trispinosa	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	1	-
S2096	Diastylis bradyi	5	6	2	-	1	9	4	1	-	3	10	7	1	1	2	3	3	4
S2098	Diastylis laevis	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
S2341	Philocheras bispinosus	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
S2347	Philocheras trispinosus	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2388	Callianassidae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2465	Pagurus bernhardus	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
S2502	Pisidia longicornis	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
S2566	Achaeus cranchii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
S2666	Liocarcinus (juv.)	-	-	-	-	2	-	1	-	-	-	-	-	2	1	4	1	3	1
S2669	Liocarcinus depurator	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2670	Liocarcinus holsatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
W0773	Polinices catena	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
W0777	Polinices polianus	2	3	2	2	-	4	-	-	-	-	-	-	-	1	2	3	3	2
W0977	Philine	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W0979	Philine aperta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W1618	Nucula nitidosa	7	9	3	1	4	3	1	-	-	-	-	1	17	8	12	13	5	12
W1905	Mysella bidentata	6	59	50	1	-	1	4	8	14	4	4	5	5	4	10	117	16	44
W1911	Tellimya ferruginosa	-	1	-	-	-	-	-	8	12	-	-	-	5	-	-	12	1	8
W1991	Cerastoderma edule (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W1998	Mactra stultorum	3	-	-	5	4	7	3	1	-	-	1	-	-	-	-	-	4	-
W2006	Spisula subtruncata	2	1	3	5	5	6	-	-	-	-	-	-	-	-	-	-	-	-
W2006	Spisula subtruncata (juv.)	66	123	10	87	112	109	10	1	1	4	4	4	13	1	17	39	30	37
W2009	Lutraria (juv.)	1	3	1	2	-	7	-	1	-	-	-	-	1	-	2	5	1	4
W2023	Ensis arcuatus	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W2025	Ensis ensis	-	-	-	1	-	3	-	-	-	-	-	-	-	-	-	-	-	1
W2032	Phaxas pellucidus	3	13	14	3	-	8	-	-	-	-	-	-	-	-	2	4	9	6
W2057	Fabulina fabula	7	3	9	39	27	27	9	20	7	4	5	7	20	23	33	4	14	12
W2081	Donax vittatus	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
W2102	Abra alba	2	2	6	1	1	2	1	-	2	4	7	2	-	-	-	7	2	4
W2119	Pharus legumen	3	4	6	4	7	2	1	2	1	-	2	-	10	5	5	8	3	7
W2166	Dosinia exoleta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
W2189	Chamelea gallina	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	2	1	1
W2227	Mya truncata (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W2239	Corbula gibba	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
W2348	Thracia (juv.)	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
W2353	Thracia villosiuscula	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Y0658	Eucratea loricata	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-
Y0669	Conopeum reticulatum	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	P	P	P
Y0678	Electra pilosa	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	P
ZA0003	Phoronis	3	-	-	4	2	-	-	-	2	-	-	-	11	6	18	2	2	2
ZB0282	Amphiuridae (juv.)	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	1	-
ZB0285	Amphiura brachiata	-	1	3	-	-	-	-	-	-	-	-	-	-	-	4	4	3	7
ZB0311	Ophiura (juv.)	7	9	1	1	-	5	-	-	-	1	6	2	1	-	4	1	1	2
ZB0313	Ophiura albida	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
ZB0315	Ophiura ophiura	-	2	-	1	1	-	-	-	-	-	-	-	-	-	2	1	-	2
ZB0406	Echinocardium (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ZB0407	Echinocardium cordatum	-	1	1	1	-	-	1	5	3	-	-	-	1	-	-	6	1	3

Appendix IX Macrofaunal taxa found along LUNE DEEP transect.

	Station	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7
	Replicate	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D0106	ATHECATA	-	-	P	-	P	P	-	-	P	-	-	-	-	-	-	-	-	P	-	-	-
D0457	Lovenella clausa	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D0583	Kirchenpaueria	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-
D0664	Sertularella	-	-	-	-	P	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-
D0677	Sertularia cupressina	-	-	-	-	-	-	-	-	-	-	P	P	-	-	-	-	-	-	-	-	-
D0694	Campanulariidae	P	-	-	-	-	-	-	-	P	-	-	P	-	-	-	-	-	-	P	-	-
G0000	NEMERTEA	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-
P0027	Aphrodita aculeata (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
P0169	Pholoe minuta	2	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
P0186	Sthenelais (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
P0205	Eteone longa	2	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	1	1
P0253	Phyllodoce groenlandica	-	-	-	-	-	-	-	-	-	-	-	2	-	3	-	-	-	-	2	7	2
P0254	Phyllodoce lineata	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-
P0257	Phyllodoce mucosa	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
P0258	Phyllodoce rosea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
P0283	Eumida bahusiensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
P0481	Glycera tridactyla	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
P0487	Glycinde nordmanni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
P0541	Gyptis helgolandica	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0761	Autolytus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0834	Nereis longissima	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0867	Nephtys (juv.)	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	1	1
P0868	Nephtys caeca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	2
P0870	Nephtys cirrosa	-	-	-	-	-	-	2	2	1	-	-	-	-	-	-	-	-	-	-	-	-
P0871	Nephtys hombergii	8	1	2	5	9	7	1	4	1	8	4	4	1	5	-	4	3	3	20	36	29
P0878	Nephtys assimilis	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1152	Scoloplos armiger	-	1	-	-	-	-	-	-	-	1	1	-	1	-	1	4	2	-	7	-	-
P1312	Pseudopolydora pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	2	1
P1335	Spio decorata	-	-	1	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-
P1343	Spiophanes bombyx	-	-	-	1	-	1	-	-	-	-	-	-	-	-	3	-	-	-	1	1	1
P1363	Magelona filiformis	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1365	Magelona mirabilis	-	-	-	2	4	11	18	24	15	8	1	5	-	1	-	1	2	17	3	-	-
P1530	Capitella	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
P1558	Mediomastus fragilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	1	-
P1719	Ophelina acuminata	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	1	-	-
P1854	Lagis koreni	58	11	12	3	2	-	1	-	1	-	-	-	-	-	-	1	-	-	9	23	62
P2031	Lanice conchilega	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q0004	Nymphon brevirostre	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q0062	Anoplodactylus petiolatus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R0110	Balanus crenatus	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0146	Schistomysis kervillei	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-
S0228	Perioculodes longimanus	1	3	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-
S0233	Pontocrates altamarinus	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0240	Synchelidium maculatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
S0539	Orchomene nana	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
S0681	Atylus falcatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
S0790	Megaluropus agilis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2096	Diastylis bradyi	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
S2330	Crangon allmani	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2331	Crangon crangon	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-
S2620	Corystes cassivelaunus	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2666	Liocarcinus (juv.)	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-
W1618	Nucula nitidosa	5	3	7	19	9	24	4	7	3	21	28	3	220	356	330	64	55	103	14	37	18
W1650	Mytilus edulis (juv.)	2	2	-	2	1	1	1	2	1	-	-	5	1	1	2	-	3	1	-	-	1
W1905	Mysella bidentata	237	128	82	10	13	19	-	-	-	-	3	2	3	2	-	4	1	5	29	103	84
W2006	Spisula subtruncata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	6
W2032	Phaxas pellucidus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
W2057	Fabulina fabula	1	1	4	26	26	28	29	16	17	35	43	26	13	11	7	35	14	28	1	-	-
W2102	Abra alba	2	-	9	3	6	5	1	-	-	-	1	-	-	-	2	1	1	-	192	299	350
Y0024	Crisia	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Y0200	Walkeria uva	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Y0658	Eucratea loricata	-	-	P	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-
Y0669	Conopeum reticulatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-
Y0678	Electra pilosa	P	P	P	-	-	-	P	P	P	-	P	P	-	P	-	-	-	P	-	-	-
Y0875	Bugula plumosa	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ZB0315	Ophiura ophiura	-	-	-	-	-	-	-	-	-	-	-	-	4	2	3	-	-	1	-	-	-
ZD0129	Perophora listeri	-	P	-	-	-	-	-	-	-	-	P	P	-	P	-	-	-	-	-	-	-
	Sagitta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-

Appendix X Macrofaunal taxa found along SWANSEA BAY transect.

	Station	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
	Replicate	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D0730	Obelia dichotoma	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0270	Eulalia bilineata	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0481	Glycera tridactyla	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-
P0654	Syllis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0761	Autolytus	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P0871	Nephtys hombergii	8	4	4	4	-	6	7	7	6	9	4	3	5	7	2	14	3	12
P0878	Nephtys assimilis	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	1
P1008	Lumbrineris gracilis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P1152	Scoloplos armiger	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-
P1312	Pseudopolydora pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
P1334	Spio armata	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
P1343	Spiophanes bombyx	3	-	-	-	3	9	-	2	-	6	2	2	15	21	5	1	-	-
P1562	Notomastus	-	-	-	-	2	2	2	-	-	-	-	-	1	-	-	-	1	-
P1743	Scalibregma inflatum	-	-	1	-	3	-	-	-	-	1	-	-	1	-	-	-	-	-
P1836	Owenia fusiformis	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
P2031	Lanice conchilega	-	1	2	-	3	1	6	-	-	-	-	-	1	-	-	-	-	17
P2179	Demonax	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q0004	Nymphon brevirostre	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
S0681	Atylus falcatus	-	-	-	-	1	1	1	-	-	-	-	1	-	-	1	-	-	-
S0701	Tritaeta gibbosa	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S0710	Ampelisca brevicornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
S0718	Ampelisca spinipes	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	1	1	-
S0741	Bathyporeia elegans	-	-	3	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
S2003	Bodotria scorpioides	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2022	Eudorella truncatula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
S2096	Diastylis bradyi	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
S2100	Diastylis rathkei	1	4	1	5	3	2	-	-	5	8	8	2	-	-	1	-	2	-
S2144	DECAPODA (juv.)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2331	Crangon crangon	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S2620	Corystes cassivelaunus	1	-	-	1	1	-	1	1	1	-	-	-	1	-	-	-	-	2
S2690	Carcinus maenas	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
W1618	Nucula nitidosa	-	2	-	-	2	2	2	11	-	3	-	8	4	12	-	65	69	116
W1650	Mytilus edulis (juv.)	1	-	-	-	-	-	1	1	-	-	1	1	-	1	-	-	-	-
W1905	Mysella bidentata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
W1998	Mactra stultorum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
W2006	Spisula subtruncata	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	180	24	88
W2067	Macoma balthica	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W2102	Abra alba	8	3	1	2	9	6	5	-	1	3	14	6	1	-	4	14	3	10
W2189	Chamelea gallina	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Y0305	Umbonula	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ZB0285	Amphiura brachiata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3

Appendix XI Sediment particle size data from TEES BAY grab samples.

Sample	**Weights (g) within um ranges from 63 mm to 63 um**																					**Tot**	**Tot**		**% G**	**% S**	**% M**
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**				
1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.04	0.04	0.10	0.22	0.55	1.48	4.17	5.40	9.61	4.22	11.95	25.90	11.95	37.85 **tot wt**	0.18	68.24	31.57
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.11	0.11	0.26	0.58	1.45	3.91	11.02	14.27	25.39	11.15	31.57	68.43	31.57				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.29	0.40	0.66	1.24	2.69	6.61	17.62	31.89	57.28	68.43	100.00				**% G**	**% S**	**% M**
1B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.09	0.17	0.33	0.92	2.14	10.09	20.08	7.95	4.64	1.69	4.97	48.15	4.97	53.12 **tot wt**	0.09	90.55	9.36
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.17	0.32	0.62	1.73	4.03	18.99	37.80	14.97	8.73	3.18	9.36	90.64	9.36				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.26	0.58	1.20	2.94	6.97	25.96	63.76	78.73	87.46	90.64	100.00				**% G**	**% S**	**% M**
1C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.14	0.17	0.33	0.74	1.25	2.40	1.85	14.05	7.00	14.05	21.05 **tot wt**	0.00	33.25	66.75
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.33	0.67	0.81	1.57	3.52	5.94	11.40	8.79	66.75	33.25	66.75				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.57	1.24	2.04	3.61	7.13	13.06	24.47	33.25	100.00				**% G**	**% S**	**% M**
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.06	0.22	0.71	1.25	1.30	1.72	3.82	8.10	4.71	6.55	21.97	6.55	28.52 **tot wt**	0.00	77.03	22.97
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.21	0.77	2.49	4.38	4.56	6.03	13.39	28.40	16.51	22.97	77.03	22.97				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.49	1.26	3.75	8.13	12.69	18.72	32.12	60.52	77.03	100.00				**% G**	**% S**	**% M**
2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.08	0.16	0.40	0.78	3.19	9.20	8.65	5.51	1.85	2.53	29.89	2.53	32.42 **tot wt**	0.00	92.20	7.80
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.25	0.49	1.23	2.41	9.84	28.38	26.68	17.00	5.71	7.80	92.20	7.80				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.46	0.96	2.19	4.60	14.44	42.81	69.49	86.49	92.20	100.00				**% G**	**% S**	**% M**
2C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.41	0.22	0.26	0.19	0.36	0.43	0.61	1.16	3.29	4.50	4.81	2.67	10.15	19.31	10.15	29.46 **tot wt**	3.50	62.05	34.45
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	1.39	0.75	0.88	0.64	1.22	1.46	2.07	3.94	11.17	15.27	16.33	9.06	34.45	65.55	34.45				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	2.75	3.50	4.38	5.02	6.25	7.71	9.78	13.71	24.88	40.16	56.48	65.55	100.00				**% G**	**% S**	**% M**
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.10	0.26	0.53	0.71	1.06	3.10	7.08	7.97	2.90	2.47	23.79	2.47	26.26 **tot wt**	0.08	90.52	9.41
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.23	0.38	0.99	2.02	2.70	4.04	11.81	26.96	30.35	11.04	9.41	90.59	9.41				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.30	0.69	1.68	3.69	6.40	10.43	22.24	49.20	79.55	90.59	100.00				**% G**	**% S**	**% M**
4B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.06	0.09	0.16	0.35	0.72	0.86	1.62	3.11	4.66	5.02	2.25	4.80	19.00	4.80	23.80 **tot wt**	0.67	79.16	20.17
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.25	0.38	0.67	1.47	3.03	3.61	6.81	13.07	19.58	21.09	9.45	20.17	79.83	20.17				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.42	0.67	1.05	1.72	3.19	6.22	9.83	16.64	29.71	49.29	70.38	79.83	100.00				**% G**	**% S**	**% M**
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.36	0.56	0.52	0.95	1.41	1.52	2.27	5.91	7.06	5.01	2.50	5.20	28.30	5.20	33.50 **tot wt**	1.76	82.72	15.52
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	1.07	1.67	1.55	2.84	4.21	4.54	6.78	17.64	21.07	14.96	7.46	15.52	84.48	15.52				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	1.76	3.43	4.99	7.82	12.03	16.57	23.34	40.99	62.06	77.01	84.48	100.00						
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.08	0.19	0.36	0.50	1.86	6.96	13.87	10.51	2.45	1.71	36.84	1.71	38.55 **tot wt**	0.00	95.56	4.44
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.21	0.49	0.93	1.30	4.82	18.05	35.98	27.26	6.36	4.44	95.56	4.44				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.36	0.86	1.79	3.09	7.91	25.97	61.95	89.21	95.56	100.00				**% G**	**% S**	**% M**
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.03	0.12	0.17	0.17	0.39	0.85	1.20	1.60	4.29	8.48	8.14	2.69	4.20	28.33	4.20	32.53 **tot wt**	1.08	86.01	12.91
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.09	0.37	0.52	0.52	1.20	2.61	3.69	4.92	13.19	26.07	25.02	8.27	12.91	87.09	12.91				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.71	1.08	1.60	2.12	3.32	5.93	9.62	14.54	27.73	53.80	78.82	87.09	100.00				**% G**	**% S**	**% M**
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.24	0.38	0.52	0.76	1.12	1.11	2.40	5.16	6.39	4.31	0.96	2.60	23.48	2.60	26.08 **tot wt**	1.42	88.61	9.97
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.92	1.46	1.99	2.91	4.29	4.26	9.20	19.79	24.50	16.53	3.68	9.97	90.03	9.97				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.42	2.88	4.87	7.78	12.08	16.33	25.54	45.32	69.82	86.35	90.03	100.00						

Sample	Weights (g) within um ranges from 63 mm to 63 um																						Tot	Tot				
ID	63	45	31.5	22.4	16	11.2	8	5.6	4	2.8	2	1.4	1	710	500	355	250	180	125	90	63	<63	> 63	< 63		% G	% S	% M
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.06	0.05	0.10	0.20	0.28	0.41	1.59	11.42	5.44	8.20	19.59	8.20	27.79 tot wt	0.14	70.35	29.51
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.22	0.18	0.36	0.72	1.01	1.48	5.72	41.09	19.58	29.51	70.49	29.51				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.14	0.14	0.36	0.54	0.90	1.62	2.63	4.10	9.82	50.92	70.49	100.00				% G	% S	% M
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.14	0.33	0.45	1.40	6.74	3.16	9.69	12.30	9.69	21.99 tot wt	0.00	55.93	44.07
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.27	0.64	1.50	2.05	6.37	30.65	14.37	44.07	55.93	44.07				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.36	1.00	2.50	4.55	10.91	41.56	55.93	100.00				% G	% S	% M
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.02	0.04	0.08	0.17	0.25	0.38	1.49	9.15	4.75	7.25	16.40	7.25	23.65 tot wt	0.21	69.13	30.66
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.08	0.08	0.17	0.34	0.72	1.06	1.61	6.30	38.69	20.08	30.66	69.34	30.66				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.30	0.38	0.55	0.89	1.61	2.66	4.27	10.57	49.26	69.34	100.00				% G	% S	% M
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.06	0.24	0.42	0.51	1.43	2.71	16.15	5.43	16.15	21.58 tot wt	0.00	25.16	74.84
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.19	0.28	1.11	1.95	2.36	6.63	12.56	74.84	25.16	74.84				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.28	0.56	1.67	3.61	5.98	12.60	25.16	100.00				% G	% S	% M
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.02	0.06	0.13	0.28	0.47	1.61	3.92	17.95	6.54	17.95	24.49 tot wt	0.00	26.70	73.30
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.04	0.08	0.08	0.24	0.53	1.14	1.92	6.57	16.01	73.30	26.70	73.30				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.12	0.20	0.29	0.53	1.06	2.20	4.12	10.70	26.70	100.00						

Appendix XII Sediment particle size data from TEES BAY core samples.

Sample	Weights (g) within um ranges from 63 mm to 63 um																						Tot	Tot				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.42	1.49	1.68	1.47	1.54	1.09	1.65	2.10	3.04	10.23	20.09	49.36	45.19	49.36	94.55 **tot wt**	0.86	46.94	52.21
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.44	1.58	1.78	1.55	1.63	1.15	1.75	2.22	3.22	10.82	21.25	52.21	47.79	52.21				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.86	2.43	4.21	5.76	7.39	8.55	10.29	12.51	15.73	26.55	47.79	100.00						
1B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.21	0.40	1.30	1.51	1.32	1.69	1.88	4.00	7.10	10.55	18.38	15.05	62.87	63.50	62.87	126.37 **tot wt**	0.57	49.68	49.75
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.17	0.32	1.03	1.19	1.04	1.34	1.49	3.17	5.62	8.35	14.54	11.91	49.75	50.25	49.75				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.25	0.57	1.60	2.79	3.84	5.18	6.66	9.83	15.45	23.80	38.34	50.25	100.00						
1C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.35	0.51	0.53	0.68	1.22	1.53	3.38	8.36	13.39	20.64	14.48	45.86	65.36	45.86	111.22 **tot wt**	0.58	58.19	41.23
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.31	0.46	0.48	0.61	1.10	1.38	3.04	7.52	12.04	18.56	13.02	41.23	58.77	41.23				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.58	1.03	1.51	2.12	3.22	4.59	7.63	15.15	27.19	45.75	58.77	100.00						
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.06	0.11	0.10	0.28	0.71	1.11	1.96	4.49	16.82	23.74	12.06	8.04	61.53	8.04	69.57	0.22	88.23	11.56
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.09	0.16	0.14	0.40	1.02	1.60	2.82	6.45	24.18	34.12	17.34	11.56	88.44	11.56				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.22	0.37	0.52	0.92	1.94	3.54	6.35	12.81	36.98	71.11	88.44	100.00						
2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.09	0.18	0.17	0.25	0.68	1.10	1.87	3.10	8.36	12.27	9.13	13.16	37.26	13.16	50.42 **tot wt**	0.30	73.60	26.10
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.18	0.36	0.34	0.50	1.35	2.18	3.71	6.15	16.58	24.34	18.11	26.10	73.90	26.10				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.30	0.65	0.99	1.49	2.84	5.02	8.73	14.88	31.46	55.79	73.90	100.00						
2C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.14	0.10	0.23	0.38	0.84	1.24	1.95	3.30	9.00	10.53	6.59	9.95	34.34	9.95	44.29 **tot wt**	0.41	77.13	22.47
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.32	0.23	0.52	0.86	1.90	2.80	4.40	7.45	20.32	23.78	14.88	22.47	77.53	22.47				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.41	0.63	1.15	2.01	3.91	6.71	11.11	18.56	38.88	62.66	77.53	100.00						
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.05	0.12	0.29	0.48	1.04	1.33	2.55	6.73	20.55	15.22	4.66	10.20	53.11	10.20	63.31 **tot wt**	0.22	83.67	16.11
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.08	0.19	0.46	0.76	1.64	2.10	4.03	10.63	32.46	24.04	7.36	16.11	83.89	16.11				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.22	0.41	0.87	1.63	3.27	5.37	9.40	20.03	52.49	76.53	83.89	100.00						
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.73	0.32	0.39	0.49	0.51	0.72	1.28	1.59	3.79	9.60	18.94	10.17	3.10	1.44	52.30	1.44	53.74 **tot wt**	3.93	93.39	2.68
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25	1.36	0.60	0.73	0.91	0.95	1.34	2.38	2.96	7.05	17.86	35.24	18.92	5.77	2.68	97.32	2.68				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25	2.61	3.20	3.93	4.84	5.79	7.13	9.51	12.47	19.52	37.38	72.63	91.55	97.32	100.00						
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.11	0.15	0.30	0.48	1.23	2.41	7.81	22.54	41.37	16.72	4.23	1.43	97.47	1.43	98.90 **tot wt**	0.23	98.32	1.45
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.11	0.15	0.30	0.49	1.24	2.44	7.90	22.79	41.83	16.91	4.28	1.45	98.55	1.45				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.23	0.38	0.69	1.17	2.42	4.85	12.75	35.54	77.37	94.28	98.55	100.00						
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.23	0.30	0.37	0.52	1.22	2.02	4.25	8.18	28.94	25.22	8.02	7.06	79.50	7.06	86.56 **tot wt**	0.53	91.31	8.16
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.27	0.35	0.43	0.60	1.41	2.33	4.91	9.45	33.43	29.14	9.27	8.16	91.84	8.16				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.53	0.88	1.31	1.91	3.32	5.65	10.56	20.01	53.44	82.58	91.84	100.00						
4B	0.00	0.00	0.00	0.00	0.00	3.06	0.00	0.32	0.19	0.00	0.04	0.17	0.20	0.28	0.74	1.27	2.93	6.77	24.90	21.90	7.02	3.66	69.79	3.66	73.45 **tot wt**	4.91	90.10	4.98
% wt	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.44	0.26	0.00	0.05	0.23	0.27	0.38	1.01	1.73	3.99	9.22	33.90	29.82	9.56	4.98	95.02	4.98				
Cum %	0.00	0.00	0.00	0.00	0.00	4.17	4.17	4.60	4.86	4.86	4.91	5.15	5.42	5.80	6.81	8.54	12.53	21.74	55.64	85.46	95.02	100.00						
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.15	0.36	0.50	0.45	0.57	1.65	1.27	2.23	3.96	12.27	9.33	2.92	0.84	35.72	0.84	36.56 **tot wt**	1.56	96.14	2.30
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.41	0.98	1.37	1.23	1.56	4.51	3.47	6.10	10.83	33.56	25.52	7.99	2.30	97.70	2.30				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.57	1.56	2.93	4.16	5.72	10.23	13.70	19.80	30.63	64.20	89.72	97.70	100.00						

Sample	Weights (g) within um ranges from 63 mm to 63 um																					Tot	Tot				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.02	0.04	0.08	0.23	0.58	1.12	1.00	3.68	21.94	18.39	10.93	47.13	10.93	58.06 **tot wt**	0.09	81.09	18.83
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.03	0.07	0.14	0.40	1.00	1.93	1.72	6.34	37.79	31.67	18.83	81.17	18.83				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.12	0.19	0.33	0.72	1.72	3.65	5.37	11.71	49.50	81.17	100.00				**% G**	**% S**	**% M**
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.04	0.08	0.13	0.29	0.40	4.03	29.10	23.38	15.66	57.53	15.66	73.19 **tot wt**	0.03	78.58	21.40
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.04	0.05	0.11	0.18	0.40	0.55	5.51	39.76	31.94	21.40	78.60	21.40				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.11	0.16	0.27	0.45	0.85	1.39	6.90	46.66	78.60	100.00				**% G**	**% S**	**% M**
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.07	0.07	0.07	0.09	0.21	0.33	0.69	0.96	4.75	29.20	21.56	4.32	58.04	4.32	62.36 **tot wt**	0.18	92.90	6.93
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.11	0.11	0.11	0.14	0.34	0.53	1.11	1.54	7.62	46.82	34.57	6.93	93.07	6.93				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.18	0.29	0.40	0.55	0.88	1.41	2.52	4.06	11.67	58.50	93.07	100.00						
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.14	0.23	0.39	0.66	2.00	2.84	4.34	8.05	19.98	40.75	23.78	54.24	103.24	54.24	157.48 **tot wt**	0.14	65.42	34.44
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.09	0.15	0.25	0.42	1.27	1.80	2.76	5.11	12.69	25.88	15.10	34.44	65.56	34.44				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.14	0.29	0.53	0.95	2.22	4.03	6.78	11.89	24.58	50.46	65.56	100.00				**% G**	**% S**	**% M**
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.50	0.80	0.94	1.13	0.90	1.55	2.13	2.69	7.52	16.64	47.86	34.94	47.86	82.80 **tot wt**	0.17	42.03	57.80
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.60	0.97	1.14	1.36	1.09	1.87	2.57	3.25	9.08	20.10	57.80	42.20	57.80				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.77	1.74	2.87	4.24	5.33	7.20	9.77	13.02	22.10	42.20	100.00				**% G**	**% S**	**% M**
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	1.01	2.12	2.40	2.18	2.33	1.68	1.97	1.85	2.13	3.74	6.34	66.01	27.98	66.01	93.99 **tot wt**	1.32	28.45	70.23
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	1.07	2.26	2.55	2.32	2.48	1.79	2.10	1.97	2.27	3.98	6.75	70.23	29.77	70.23				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	1.32	3.57	6.13	8.45	10.93	12.71	14.81	16.78	19.04	23.02	29.77	100.00						

Appendix XIII Sediment particle size data from LIVERPOOL BAY grab samples.

Sample	Weights (g) within um ranges from 63 mm to 63 um																						Tot	Tot				
ID	63	45	31.5	22.4	16	11.2	8	5.6	4	2.8	2	1.4	1	710	500	355	250	180	125	90	63	<63	> 63	< 63		% G	% S	% M
1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.04	0.05	0.06	0.05	1.30	3.34	20.09	35.68	21.73	3.27	2.08	12.56	87.80	12.56	100.36 **tot wt**	0.15	87.34	12.51
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.04	0.05	0.06	0.05	1.30	3.33	20.02	35.55	21.65	3.26	2.07	12.51	87.49	12.51				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.15	0.20	0.26	0.31	1.60	4.93	24.95	60.50	82.15	85.41	87.49	100.00				% G	% S	% M
1B	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.10	0.05	0.05	0.05	0.06	0.13	0.11	0.12	4.15	22.58	39.12	23.56	2.84	1.38	6.36	94.52	6.36	100.88 **tot wt**	0.47	93.23	6.30
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.10	0.05	0.05	0.05	0.06	0.13	0.11	0.12	4.11	22.38	38.78	23.35	2.82	1.37	6.30	93.70	6.30				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.32	0.37	0.42	0.47	0.53	0.65	0.76	0.88	5.00	27.38	66.16	89.51	92.33	93.70	100.00				% G	% S	% M
1C	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.03	0.03	0.18	0.32	0.15	0.14	0.18	4.25	21.88	38.70	23.80	2.84	1.39	7.15	94.04	7.15	101.19 **tot wt**	0.39	92.55	7.07
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.03	0.03	0.18	0.32	0.15	0.14	0.18	4.20	21.62	38.24	23.52	2.81	1.37	7.07	92.93	7.07				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.18	0.21	0.39	0.70	0.85	0.99	1.17	5.37	26.99	65.23	88.75	91.56	92.93	100.00				% G	% S	% M
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.30	0.10	0.09	0.13	0.13	0.15	6.16	27.59	37.13	16.98	2.15	1.55	8.41	92.51	8.41	100.92 **tot wt**	0.45	91.22	8.33
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.30	0.10	0.09	0.13	0.13	0.15	6.10	27.34	36.79	16.83	2.13	1.54	8.33	91.67	8.33				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.35	0.45	0.54	0.66	0.79	0.94	7.05	34.38	71.18	88.00	90.13	91.67	100.00				% G	% S	% M
2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	0.18	0.14	0.22	0.25	0.23	0.22	1.72	6.75	28.37	37.09	17.17	1.93	1.37	5.84	97.28	5.84	103.12 **tot wt**	2.11	92.22	5.66
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	0.17	0.14	0.21	0.24	0.22	0.21	1.67	6.55	27.51	35.97	16.65	1.87	1.33	5.66	94.34	5.66				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	1.76	1.90	2.11	2.36	2.58	2.79	4.46	11.01	38.52	74.49	91.14	93.01	94.34	100.00				% G	% S	% M
2C	0.00	0.00	0.00	0.00	0.00	0.00	1.56	0.54	0.13	0.23	0.19	0.25	0.24	0.21	1.70	7.94	30.00	37.05	17.12	1.71	0.97	3.73	99.84	3.73	103.57 **tot wt**	2.56	93.84	3.60
% wt	0.00	0.00	0.00	0.00	0.00	0.00	1.51	0.52	0.13	0.22	0.18	0.24	0.23	0.20	1.64	7.67	28.97	35.77	16.53	1.65	0.94	3.60	96.40	3.60				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	1.51	2.03	2.15	2.38	2.56	2.80	3.03	3.23	4.88	12.54	41.51	77.28	93.81	95.46	96.40	100.00				% G	% S	% M
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.01	0.04	0.06	0.09	1.82	19.92	35.58	20.53	4.81	2.65	14.68	85.62	14.68	100.30 **tot wt**	0.11	85.25	14.64
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.01	0.04	0.06	0.09	1.81	19.86	35.47	20.47	4.80	2.64	14.64	85.36	14.64				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.11	0.11	0.11	0.12	0.16	0.22	0.31	2.12	21.98	57.46	77.93	82.72	85.36	100.00				% G	% S	% M
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.04	0.04	0.10	2.11	19.82	36.80	21.75	4.65	2.30	12.59	87.67	12.59	100.26 **tot wt**	0.04	87.40	12.56
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.04	0.04	0.10	2.10	19.77	36.70	21.69	4.64	2.29	12.56	87.44	12.56				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.06	0.10	0.14	0.24	2.34	22.11	58.82	80.51	85.15	87.44	100.00				% G	% S	% M
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.05	0.12	2.03	22.38	39.51	22.30	3.97	1.78	8.05	92.25	8.05	100.30 **tot wt**	0.00	91.97	8.03
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.05	0.12	2.02	22.31	39.39	22.23	3.96	1.77	8.03	91.97	8.03				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.11	0.16	0.28	2.30	24.62	64.01	86.24	90.20	91.97	100.00						
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.10	1.67	23.76	41.66	25.35	3.94	1.07	2.57	97.65	2.57	100.22 **tot wt**	0.00	97.44	2.56
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.10	1.67	23.71	41.57	25.29	3.93	1.07	2.56	97.44	2.56				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.10	0.20	1.87	25.57	67.14	92.44	96.37	97.44	100.00				% G	% S	% M
4B	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.06	0.02	0.04	0.02	0.05	0.05	1.47	18.07	37.21	27.77	6.65	2.19	6.63	93.78	6.63	100.41 **tot wt**	0.26	93.14	6.60

Weights (g) within um ranges from 63 mm to 63 um

Sample ID	63	45	31.5	22.4	16	11.2	8	5.6	4	2.8	2	1.4	1	710	500	355	250	180	125	90	63	<63	Tot > 63	Tot < 63		% G	% S	% M
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.06	0.02	0.04	0.02	0.05	0.05	1.46	18.00	37.06	27.66	6.62	2.18	6.60	93.40	6.60				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.18	0.18	0.24	0.26	0.30	0.32	0.37	0.42	1.88	19.88	56.94	84.59	91.22	93.40	100.00				% G	% S	% M
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	1.61	24.12	41.61	25.93	4.28	1.19	1.27	98.78	1.27	100.05 **tot wt**	0.00	98.73	1.27
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	1.61	24.11	41.59	25.92	4.28	1.19	1.27	98.73	1.27				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	1.65	25.76	67.35	93.26	97.54	98.73	100.00						
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.02	0.03	0.05	0.03	0.07	3.14	24.06	37.28	19.71	5.09	3.88	6.84	93.45	6.84	100.29 **tot wt**	0.11	93.07	6.82
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.02	0.03	0.05	0.03	0.07	3.13	23.99	37.17	19.65	5.08	3.87	6.82	93.18	6.82				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.11	0.14	0.19	0.22	0.29	3.42	27.41	64.58	84.24	89.31	93.18	100.00				% G	% S	% M
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.02	0.02	0.01	0.08	2.99	24.27	37.72	20.24	5.00	3.75	6.05	94.15	6.05	100.20 **tot wt**	0.05	93.91	6.04
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.02	0.02	0.01	0.08	2.98	24.22	37.64	20.20	4.99	3.74	6.04	93.96	6.04				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.07	0.09	0.10	0.18	3.16	27.39	65.03	85.23	90.22	93.96	100.00				% G	% S	% M
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.18	3.01	24.63	37.74	20.53	5.10	3.52	5.47	94.80	5.47	100.27 **tot wt**	0.01	94.53	5.46
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.18	3.00	24.56	37.64	20.47	5.09	3.51	5.46	94.54	5.46				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.09	0.27	3.27	27.83	65.47	85.95	91.03	94.54	100.00				% G	% S	% M
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.10	0.12	0.26	0.33	0.40	2.32	6.10	22.03	34.93	22.90	4.83	2.83	4.56	97.21	4.56	101.77 **tot wt**	0.28	95.24	4.48
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.10	0.12	0.26	0.32	0.39	2.28	5.99	21.65	34.32	22.50	4.75	2.78	4.48	95.52	4.48				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.16	0.28	0.53	0.85	1.25	3.53	9.52	31.17	65.49	87.99	92.74	95.52	100.00				% G	% S	% M
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.01	0.08	0.10	0.16	0.25	0.24	2.03	6.41	21.53	30.93	20.19	6.33	4.52	8.51	93.08	8.51	101.59 **tot wt**	0.48	91.14	8.38
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.01	0.08	0.10	0.16	0.25	0.24	2.00	6.31	21.19	30.45	19.87	6.23	4.45	8.38	91.62	8.38				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.31	0.38	0.48	0.64	0.89	1.12	3.12	9.43	30.62	61.07	80.94	87.17	91.62	100.00				% G	% S	% M
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.02	0.05	0.23	0.21	0.27	0.34	2.01	5.67	21.51	32.89	21.24	5.88	4.07	7.22	94.75	7.22	101.97 **tot wt**	0.65	92.27	7.08
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.02	0.05	0.23	0.21	0.26	0.33	1.97	5.56	21.09	32.25	20.83	5.77	3.99	7.08	92.92	7.08				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.37	0.42	0.65	0.85	1.12	1.45	3.42	8.98	30.08	62.33	83.16	88.93	92.92	100.00						

Appendix XIV Sediment particle size data from LIVERPOOL BAY core samples.

Sample	Weights (g) within um ranges from 63 mm to 63 um																						Tot	Tot				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.10	0.14	0.21	0.37	0.66	3.60	15.66	31.41	3.93	0.77	4.20	56.91	4.20	61.11 **tot wt**	0.10	93.03	6.87
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.07	0.16	0.23	0.34	0.61	1.08	5.89	25.63	51.40	6.43	1.26	6.87	93.13	6.87				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.10	0.26	0.49	0.83	1.44	2.52	8.41	34.04	85.44	91.87	93.13	100.00				**% G**	**% S**	**% M**
1B	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.53	0.17	0.13	0.12	0.16	0.18	0.29	0.47	1.02	6.88	26.43	50.67	4.99	0.83	8.58	93.01	8.58	101.59 **tot wt**	1.07	90.48	8.45
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.52	0.17	0.13	0.12	0.16	0.18	0.29	0.46	1.00	6.77	26.02	49.88	4.91	0.82	8.45	91.55	8.45				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.66	0.83	0.95	1.07	1.23	1.41	1.69	2.16	3.16	9.93	35.95	85.83	90.74	91.55	100.00				**% G**	**% S**	**% M**
1C	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.19	0.10	0.10	0.12	0.19	0.27	0.37	0.72	1.63	8.34	30.10	58.31	6.64	1.63	3.57	108.91	3.57	112.48 **tot wt**	0.63	96.19	3.17
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.17	0.09	0.09	0.11	0.17	0.24	0.33	0.64	1.45	7.41	26.76	51.84	5.90	1.45	3.17	96.83	3.17				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.35	0.44	0.52	0.63	0.80	1.04	1.37	2.01	3.46	10.87	37.63	89.47	95.38	96.83	100.00				**% G**	**% S**	**% M**
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12	0.13	0.12	0.17	0.32	0.95	7.71	26.97	29.27	2.92	0.71	2.46	69.44	2.46	71.90 **tot wt**	0.24	96.34	3.42
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.17	0.18	0.17	0.24	0.45	1.32	10.72	37.51	40.71	4.06	0.99	3.42	96.58	3.42				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.24	0.42	0.58	0.82	1.27	2.59	13.31	50.82	91.53	95.59	96.58	100.00				**% G**	**% S**	**% M**
2B	0.00	0.00	0.00	0.00	0.00	0.00	1.81	1.35	0.37	0.76	0.58	0.56	0.61	0.72	1.28	3.28	18.62	56.38	58.57	5.29	1.10	5.13	151.28	5.13	156.41 **tot wt**	3.11	93.61	3.28
% wt	0.00	0.00	0.00	0.00	0.00	0.00	1.16	0.86	0.24	0.49	0.37	0.36	0.39	0.46	0.82	2.10	11.90	36.05	37.45	3.38	0.70	3.28	96.72	3.28				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	1.16	2.02	2.26	2.74	3.11	3.47	3.86	4.32	5.14	7.24	19.14	55.19	92.63	96.02	96.72	100.00				**% G**	**% S**	**% M**
2C	0.00	0.00	0.00	0.00	0.00	0.00	1.84	0.06	0.20	0.05	1.19	0.35	0.40	0.46	0.91	2.27	13.71	42.37	42.53	3.08	0.55	3.39	109.97	3.39	113.36 **tot wt**	2.95	94.06	2.99
% wt	0.00	0.00	0.00	0.00	0.00	0.00	1.62	0.05	0.18	0.04	1.05	0.31	0.35	0.41	0.80	2.00	12.09	37.38	37.52	2.72	0.49	2.99	97.01	2.99				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	1.62	1.68	1.85	1.90	2.95	3.26	3.61	4.01	4.82	6.82	18.91	56.29	93.81	96.52	97.01	100.00				**% G**	**% S**	**% M**
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.14	0.28	0.46	0.49	3.57	37.92	35.50	5.76	1.49	8.60	85.68	8.60	94.28 **tot wt**	0.01	90.87	9.12
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.15	0.30	0.49	0.52	3.79	40.22	37.65	6.11	1.58	9.12	90.88	9.12				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.22	0.52	1.01	1.53	5.31	45.53	83.19	89.30	90.88	100.00				**% G**	**% S**	**% M**
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.03	0.12	0.17	0.22	0.29	0.38	3.23	42.42	48.62	9.62	2.52	8.29	107.75	8.29	116.04 **tot wt**	0.14	92.72	7.14
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.03	0.10	0.15	0.19	0.25	0.33	2.78	36.56	41.90	8.29	2.17	7.14	92.86	7.14				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.14	0.24	0.39	0.58	0.83	1.15	3.94	40.49	82.39	90.68	92.86	100.00				**% G**	**% S**	**% M**
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.02	0.05	0.09	0.13	0.95	15.20	21.28	4.89	1.25	4.29	43.92	4.29	48.21 **tot wt**	0.06	91.04	8.90
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.06	0.04	0.10	0.19	0.27	1.97	31.53	44.14	10.14	2.59	8.90	91.10	8.90				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.12	0.17	0.27	0.46	0.73	2.70	34.23	78.37	88.51	91.10	100.00				**% G**	**% S**	**% M**
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.08	0.11	0.18	2.04	24.48	37.88	6.69	1.36	0.57	2.45	73.48	2.45	75.93 **tot wt**	0.04	96.73	3.23
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	0.11	0.14	0.24	2.69	32.24	49.89	8.81	1.79	0.75	3.23	96.77	3.23				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.12	0.22	0.37	0.61	3.29	35.53	85.42	94.23	96.02	96.77	100.00						

Sample	Weights (g) within um ranges from 63 mm to 63 um																					Tot	Tot				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
4B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.02	0.03	0.05	0.14	2.10	20.92	27.87	5.83	1.39	1.10	58.42	1.10	59.52 **tot wt**	0.03	98.12	1.85
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.03	0.05	0.08	0.24	3.53	35.15	46.82	9.80	2.34	1.85	98.15	1.85				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.12	0.15	0.20	0.29	0.52	4.05	39.20	86.02	95.82	98.15	100.00						
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.03	0.04	0.08	0.28	4.81	34.73	44.22	11.51	2.41	2.53	98.16	2.53	100.69 **tot wt**	0.03	97.46	2.51
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.03	0.04	0.08	0.28	4.78	34.49	43.92	11.43	2.39	2.51	97.49	2.51				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.08	0.12	0.20	0.48	5.25	39.75	83.66	95.09	97.49	100.00				**% G**	**% S**	**% M**
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.10	0.18	0.50	6.09	43.95	47.88	4.74	1.07	3.94	104.64	3.94	108.58 **tot wt**	0.00	96.37	3.63
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.09	0.17	0.46	5.61	40.48	44.10	4.37	0.99	3.63	96.37	3.63				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12	0.21	0.38	0.84	6.45	46.92	91.02	95.39	96.37	100.00				**% G**	**% S**	**% M**
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.01	0.05	0.09	0.12	0.18	0.45	5.18	40.07	49.92	5.21	1.10	5.28	102.48	5.28	107.76 **tot wt**	0.10	95.00	4.90
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.01	0.05	0.08	0.11	0.17	0.42	4.81	37.18	46.33	4.83	1.02	4.90	95.10	4.90				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.09	0.09	0.10	0.15	0.23	0.34	0.51	0.93	5.73	42.92	89.24	94.08	95.10	100.00				**% G**	**% S**	**% M**
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.07	0.12	0.12	0.19	0.50	6.19	46.80	54.11	5.66	1.42	4.50	115.30	4.50	119.80 **tot wt**	0.10	96.14	3.76
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.06	0.10	0.10	0.16	0.42	5.17	39.07	45.17	4.72	1.19	3.76	96.24	3.76				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.16	0.26	0.36	0.52	0.93	6.10	45.17	90.33	95.06	96.24	100.00				**% G**	**% S**	**% M**
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.20	0.06	0.18	0.47	0.43	0.54	0.81	1.52	8.83	25.57	43.55	3.46	0.87	3.13	87.02	3.13	90.15 **tot wt**	1.08	95.45	3.47
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.22	0.07	0.20	0.52	0.48	0.60	0.90	1.69	9.79	28.36	48.31	3.84	0.97	3.47	96.53	3.47				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.81	0.88	1.08	1.60	2.07	2.67	3.57	5.26	15.05	43.42	91.72	95.56	96.53	100.00				**% G**	**% S**	**% M**
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.08	0.00	0.16	0.15	0.29	0.30	0.47	0.82	5.14	17.64	30.81	2.71	0.63	3.95	59.27	3.95	63.22 **tot wt**	0.49	93.26	6.25
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.13	0.00	0.25	0.24	0.46	0.47	0.74	1.30	8.13	27.90	48.73	4.29	1.00	6.25	93.75	6.25				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.24	0.24	0.49	0.73	1.19	1.66	2.40	3.70	11.83	39.73	88.47	92.76	93.75	100.00				**% G**	**% S**	**% M**
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.13	0.00	0.16	0.24	0.34	0.38	0.57	1.00	5.70	16.06	23.26	1.68	0.42	2.32	50.03	2.32	52.35 **tot wt**	0.73	94.84	4.43
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.25	0.00	0.31	0.46	0.65	0.73	1.09	1.91	10.89	30.68	44.43	3.21	0.80	4.43	95.57	4.43				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.42	0.42	0.73	1.18	1.83	2.56	3.65	5.56	16.45	47.13	91.56	94.77	95.57	100.00				**% G**	**% S**	**% M**

Appendix XV Sediment particle size data from LUNE DEEP grab samples.

Sample	**Weights (g) within um ranges from 63 mm to 63 um**																						**Tot**	**Tot**				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.25	0.15	0.13	0.30	3.52	7.34	7.89	11.06	24.85	23.56	13.66	7.00	93.00	7.00	100.00 **tot wt**	0.56	92.44	7.00
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.25	0.15	0.13	0.30	3.52	7.34	7.89	11.06	24.85	23.56	13.66	7.00	93.00	7.00				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.56	0.71	0.84	1.13	4.65	11.98	19.87	30.93	55.78	79.34	93.00	100.00				**% G**	**% S**	**% M**
1B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.18	0.17	0.18	0.17	0.15	0.87	1.88	1.72	2.58	7.00	17.63	21.89	20.40	24.74	75.26	24.74	100.00 **tot wt**	0.97	74.29	24.74
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.18	0.17	0.18	0.17	0.15	0.87	1.88	1.72	2.58	7.00	17.63	21.89	20.40	24.74	75.26	24.74				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.63	0.80	0.97	1.14	1.29	2.16	4.04	5.76	8.34	15.34	32.97	54.86	75.26	100.00				**% G**	**% S**	**% M**
1C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.25	0.03	0.20	0.31	0.12	1.16	2.75	3.75	6.63	12.11	20.70	19.18	14.56	18.15	81.85	18.15	100.00 **tot wt**	0.59	81.26	18.15
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.25	0.03	0.20	0.31	0.12	1.16	2.75	3.75	6.63	12.11	20.70	19.18	14.56	18.15	81.85	18.15				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.36	0.39	0.59	0.90	1.02	2.18	4.93	8.67	15.31	27.42	48.12	67.30	81.85	100.00				**% G**	**% S**	**% M**
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.06	0.01	0.03	0.01	0.04	0.00	1.67	11.85	32.27	29.42	16.32	8.27	91.73	8.27	100.00 **tot wt**	0.12	91.61	8.27
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.06	0.01	0.03	0.01	0.04	0.00	1.67	11.85	32.27	29.42	16.32	8.27	91.73	8.27				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.12	0.13	0.16	0.17	0.21	0.21	1.88	13.72	45.99	75.41	91.73	100.00				**% G**	**% S**	**% M**
2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.56	8.36	29.50	33.20	20.49	7.86	92.14	7.86	100.00 **tot wt**	0.01	92.13	7.86
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.56	8.36	29.50	33.20	20.49	7.86	92.14	7.86				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.04	0.04	0.60	8.96	38.45	71.65	92.14	100.00				**% G**	**% S**	**% M**
2C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.55	0.80	1.51	8.85	26.04	28.49	19.65	14.05	85.95	14.05	100.00 **tot wt**	0.00	85.95	14.05
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.55	0.80	1.51	8.85	26.04	28.49	19.65	14.05	85.95	14.05				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.62	1.42	2.93	11.78	37.81	66.30	85.95	100.00				**% G**	**% S**	**% M**
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	3.11	20.39	37.52	23.84	10.15	4.97	95.03	4.97	100.00 **tot wt**	0.00	95.03	4.97
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	3.11	20.39	37.52	23.84	10.15	4.97	95.03	4.97				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	3.13	23.52	61.04	84.88	95.03	100.00				**% G**	**% S**	**% M**
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.56	22.2	38.5	22.4	8.72	4.578	95.4	4.578	100 **tot wt**	0.00	95.42	4.58
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	3.56	22.18	38.54	22.41	8.72	4.58	95.42	4.58				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	3.57	25.75	64.29	86.71	95.42	100.00				**% G**	**% S**	**% M**
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	3.43	21.91	38.86	23.38	9.03	3.37	96.63	3.37	100.00 **tot wt**	0.00	96.63	3.37
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	3.43	21.91	38.86	23.38	9.03	3.37	96.63	3.37				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.03	3.46	25.37	64.23	87.61	96.63	100.00				**% G**	**% S**	**% M**
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.02	0.01	0.00	0.00	2.37	21.67	40.45	21.74	8.43	5.23	94.77	5.23	100.00 **tot wt**	0.08	94.69	5.23
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.02	0.01	0.00	0.00	2.37	21.67	40.45	21.74	8.43	5.23	94.77	5.23				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.08	0.10	0.11	0.11	0.11	2.48	24.15	64.60	86.34	94.77	100.00						

Sample	Weights (g) within um ranges from 63 mm to 63 um																					Tot	Tot				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
4B	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	1.79	19.88	39.06	23.30	10.33	5.61	94.39	5.61	100.00 **tot wt**	0.03	94.36	5.61
% wt	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	1.79	19.88	39.06	23.30	10.33	5.61	94.39	5.61				
Cum %	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	1.82	21.70	60.76	84.06	94.39	100.00				**% G**	**% S**	**% M**
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	2.60	20.31	37.45	21.51	10.39	7.73	92.27	7.73	100.00 **tot wt**	0.00	92.27	7.73
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	2.60	20.31	37.45	21.51	10.39	7.73	92.27	7.73				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	2.62	22.93	60.37	81.88	92.27	100.00				**% G**	**% S**	**% M**
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	2.02	20.82	36.74	19.30	10.49	10.59	89.41	10.59	100.00 **tot wt**	0.01	89.40	10.59
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	2.02	20.82	36.74	19.30	10.49	10.59	89.41	10.59				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.04	2.06	22.88	59.62	78.93	89.41	100.00				**% G**	**% S**	**% M**
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.02	0.02	0.03	0.02	0.01	0.01	0.00	2.10	18.93	32.79	16.65	10.17	19.14	80.86	19.14	100.00 **tot wt**	0.16	80.70	19.14
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.02	0.02	0.03	0.02	0.01	0.01	0.00	2.10	18.93	32.79	16.65	10.17	19.14	80.86	19.14				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.14	0.16	0.19	0.21	0.22	0.23	0.23	2.32	21.25	54.05	70.70	80.86	100.00				**% G**	**% S**	**% M**
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.07	0.03	0.04	0.01	0.02	0.02	0.01	2.67	15.41	26.30	17.87	10.86	26.53	73.47	26.53	100.00 **tot wt**	0.25	73.22	26.53
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.07	0.03	0.04	0.01	0.02	0.02	0.01	2.67	15.41	26.30	17.87	10.86	26.53	73.47	26.53				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.22	0.25	0.29	0.30	0.32	0.34	0.35	3.02	18.43	44.73	62.60	73.47	100.00				**% G**	**% S**	**% M**
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.04	0.03	0.02	0.05	0.00	4.16	22.54	38.21	20.22	8.80	5.86	94.14	5.86	100.00 **tot wt**	0.07	94.07	5.86
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.04	0.03	0.02	0.05	0.00	4.16	22.54	38.21	20.22	8.80	5.86	94.14	5.86				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.11	0.14	0.16	0.21	0.21	4.37	26.91	65.12	85.34	94.14	100.00				**% G**	**% S**	**% M**
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.01	0.00	0.02	0.01	0.03	0.00	4.09	23.45	38.20	18.95	8.48	6.58	93.42	6.58	100.00 **tot wt**	0.18	93.24	6.58
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.01	0.00	0.02	0.01	0.03	0.00	4.09	23.45	38.20	18.95	8.48	6.58	93.42	6.58				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.18	0.18	0.20	0.21	0.24	0.24	4.33	27.78	65.99	84.94	93.42	100.00				**% G**	**% S**	**% M**
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.01	0.01	0.03	0.00	3.15	20.55	36.12	18.22	8.74	13.12	86.88	13.12	100.00 **tot wt**	0.04	86.84	13.12
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.01	0.01	0.03	0.00	3.15	20.55	36.12	18.22	8.74	13.12	86.88	13.12				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.06	0.07	0.08	0.11	0.11	3.26	23.80	59.92	78.14	86.88	100.00				**% G**	**% S**	**% M**
7A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.03	0.02	0.01	0.02	0.01	0.20	0.35	0.40	2.01	9.60	17.44	19.47	50.36	49.64	50.36	100.00 **tot wt**	0.13	49.51	50.36
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.03	0.02	0.01	0.02	0.01	0.20	0.35	0.40	2.01	9.60	17.44	19.47	50.36	49.64	50.36				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.08	0.11	0.13	0.14	0.16	0.17	0.37	0.72	1.12	3.12	12.73	30.17	49.64	100.00				**% G**	**% S**	**% M**
7B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.02	1.76	11.27	21.24	23.79	41.78	58.22	41.78	100.00 **tot wt**	0.11	58.11	41.78
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.02	1.76	11.27	21.24	23.79	41.78	58.22	41.78				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.10	0.11	0.12	0.13	0.14	0.14	0.14	0.16	1.92	13.19	34.43	58.22	100.00				**% G**	**% S**	**% M**
7C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.01	0.06	0.04	0.02	0.02	0.00	0.08	2.50	12.66	21.62	23.29	39.63	60.37	39.63	100.00 **tot wt**	0.07	60.30	39.63
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.01	0.06	0.04	0.02	0.02	0.00	0.08	2.50	12.66	21.62	23.29	39.63	60.37	39.63				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.06	0.07	0.13	0.17	0.19	0.21	0.21	0.29	2.79	15.46	37.08	60.37	100.00						

Appendix XVI Sediment particle size data from LUNE DEEP core samples.

Sample	**Weights (g) within um ranges from 63 mm to 63 um**																						**Tot**	**Tot**				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
1A	0.00	0.00	0.00	0.00	0.00	0.00	1.71	4.49	0.92	0.11	0.54	0.38	0.40	0.55	0.87	0.84	1.68	2.83	14.48	14.82	20.91	32.26	65.53	32.26	97.79 **tot wt**	7.95	59.07	32.99
% wt	0.00	0.00	0.00	0.00	0.00	0.00	1.75	4.59	0.94	0.11	0.55	0.39	0.41	0.56	0.89	0.86	1.72	2.89	14.81	15.15	21.38	32.99	67.01	32.99				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	1.75	6.34	7.28	7.39	7.95	8.33	8.74	9.31	10.20	11.05	12.77	15.67	30.47	45.63	67.01	100.00				**% G**	**% S**	**% M**
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.03	0.06	0.04	0.05	0.07	0.17	0.49	22.13	32.48	31.78	12.81	87.32	12.81	100.13 **tot wt**	0.02	87.19	12.79
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.03	0.06	0.04	0.05	0.07	0.17	0.49	22.10	32.44	31.74	12.79	87.21	12.79				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.05	0.11	0.15	0.20	0.27	0.44	0.93	23.03	55.47	87.21	100.00				**% G**	**% S**	**% M**
2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.02	0.05	0.06	0.04	0.10	0.47	17.24	24.44	27.23	9.22	69.73	9.22	78.95 **tot wt**	0.00	88.32	11.68
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.03	0.06	0.08	0.05	0.13	0.60	21.84	30.96	34.49	11.68	88.32	11.68				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.13	0.19	0.27	0.32	0.44	1.04	22.88	53.83	88.32	100.00				**% G**	**% S**	**% M**
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.04	0.03	0.10	1.02	52.93	29.11	14.70	6.64	98.01	6.64	104.65 **tot wt**	0.01	93.65	6.34
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.04	0.03	0.10	0.97	50.58	27.82	14.05	6.34	93.66	6.34				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.08	0.11	0.14	0.24	1.21	51.79	79.61	93.66	100.00				**% G**	**% S**	**% M**
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.01	0.01	0.04	0.03	0.03	0.04	0.04	0.15	1.36	60.15	37.93	23.88	17.24	123.78	17.24	141.02 **tot wt**	0.09	87.68	12.23
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01	0.01	0.03	0.02	0.02	0.03	0.03	0.11	0.96	42.65	26.90	16.93	12.23	87.77	12.23				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.08	0.09	0.09	0.12	0.14	0.16	0.19	0.22	0.33	1.29	43.94	70.84	87.77	100.00				**% G**	**% S**	**% M**
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.07	0.07	0.13	0.11	0.30	1.64	57.49	51.30	41.67	29.45	152.85	29.45	182.30 **tot wt**	0.01	83.83	16.15
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.04	0.07	0.06	0.16	0.90	31.54	28.14	22.86	16.15	83.85	16.15				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.08	0.12	0.19	0.25	0.41	1.31	32.85	60.99	83.85	100.00				**% G**	**% S**	**% M**
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.03	0.03	0.08	1.61	45.48	26.72	16.58	8.24	90.60	8.24	98.84 **tot wt**	0.00	91.66	8.34
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.03	0.03	0.08	1.63	46.01	27.03	16.77	8.34	91.66	8.34				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.10	0.13	0.21	1.84	47.86	74.89	91.66	100.00				**% G**	**% S**	**% M**
4B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.06	0.06	0.08	0.07	0.21	2.23	59.62	42.63	27.54	15.68	132.54	15.68	148.22 **tot wt**	0.01	89.41	10.58
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.04	0.05	0.05	0.14	1.50	40.22	28.76	18.58	10.58	89.42	10.58				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.11	0.16	0.21	0.35	1.86	42.08	70.84	89.42	100.00				**% G**	**% S**	**% M**
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.01	0.03	0.07	1.50	47.92	29.76	18.51	5.68	97.85	5.68	103.53 **tot wt**	0.00	94.51	5.49
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.01	0.03	0.07	1.45	46.29	28.75	17.88	5.49	94.51	5.49				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06	0.09	0.15	1.60	47.89	76.63	94.51	100.00				**% G**	**% S**	**% M**
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.33	0.07	0.09	0.08	0.10	0.09	0.16	0.16	0.32	1.68	49.48	25.30	15.92	15.32	93.89	15.32	109.21 **tot wt**	0.55	85.42	14.03
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.30	0.06	0.08	0.07	0.09	0.08	0.15	0.15	0.29	1.54	45.31	23.17	14.58	14.03	85.97	14.03				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.40	0.47	0.55	0.62	0.71	0.80	0.94	1.09	1.38	2.92	48.23	71.39	85.97	100.00				**% G**	**% S**	**% M**
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.02	0.02	0.05	0.11	0.16	0.19	0.33	0.24	0.34	1.39	46.19	25.95	17.85	24.50	92.95	24.50	117.45 **tot wt**	0.17	78.97	20.86
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.02	0.04	0.09	0.14	0.16	0.28	0.20	0.29	1.18	39.33	22.09	15.20	20.86	79.14	20.86				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.11	0.13	0.17	0.26	0.40	0.56	0.84	1.05	1.34	2.52	41.85	63.94	79.14	100.00				**% G**	**% S**	**% M**
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.14	0.04	0.06	0.12	0.18	0.34	0.30	0.43	1.81	48.21	22.36	14.63	16.55	89.28	16.55	105.83 **tot wt**	0.79	83.57	15.64
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.13	0.04	0.06	0.11	0.17	0.32	0.28	0.41	1.71	45.55	21.13	13.82	15.64	84.36	15.64				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.76	0.79	0.85	0.96	1.13	1.46	1.74	2.14	3.86	49.41	70.54	84.36	100.00						

Sample	Weights (g) within um ranges from 63 mm to 63 um																					Tot	Tot					
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**			**% G**	**% S**	**% M**
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.06	0.04	0.07	0.17	0.20	0.52	2.70	44.53	24.60	12.61	8.35	85.56	8.35	93.91	**tot wt**	0.06	91.04	8.89
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.06	0.04	0.07	0.18	0.21	0.55	2.88	47.42	26.20	13.43	8.89	91.11	8.89					
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.13	0.17	0.24	0.43	0.64	1.19	4.07	51.49	77.68	91.11	100.00					**% G**	**% S**	**% M**
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.06	0.07	0.10	0.13	0.12	0.31	1.81	29.43	17.07	8.71	6.62	57.83	6.62	64.45	**tot wt**	0.03	89.70	10.27
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.09	0.11	0.16	0.20	0.19	0.48	2.81	45.66	26.49	13.51	10.27	89.73	10.27					
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.12	0.23	0.39	0.59	0.78	1.26	4.07	49.73	76.21	89.73	100.00					**% G**	**% S**	**% M**
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.04	0.02	0.07	0.10	0.23	0.24	0.53	2.68	39.21	21.87	10.63	6.17	75.65	6.17	81.82	**tot wt**	0.09	92.37	7.54
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.05	0.02	0.09	0.12	0.28	0.29	0.65	3.28	47.92	26.73	12.99	7.54	92.46	7.54					
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.09	0.11	0.20	0.32	0.60	0.89	1.54	4.82	52.74	79.47	92.46	100.00					**% G**	**% S**	**% M**
7A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.11	0.08	0.08	0.08	0.14	0.14	0.23	0.40	6.69	10.64	17.02	32.04	35.68	32.04	67.72	**tot wt**	0.27	52.42	47.31
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.16	0.12	0.12	0.12	0.21	0.21	0.34	0.59	9.88	15.71	25.13	47.31	52.69	47.31					
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.10	0.27	0.38	0.50	0.62	0.83	1.03	1.37	1.96	11.84	27.55	52.69	100.00					**% G**	**% S**	**% M**
7B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12	0.38	0.52	0.59	0.85	1.00	0.73	1.12	20.52	23.30	26.01	39.38	75.19	39.38	114.57	**tot wt**	0.15	65.48	34.37
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.33	0.45	0.51	0.74	0.87	0.64	0.98	17.91	20.34	22.70	34.37	65.63	34.37					
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.48	0.93	1.45	2.19	3.06	3.70	4.68	22.59	42.93	65.63	100.00					**% G**	**% S**	**% M**
7C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.16	0.02	0.12	0.30	0.32	0.37	0.57	0.41	0.52	0.97	17.52	26.72	32.27	48.43	80.46	48.43	128.89	**tot wt**	0.38	62.05	37.57
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.12	0.02	0.09	0.23	0.25	0.29	0.44	0.32	0.40	0.75	13.59	20.73	25.04	37.57	62.43	37.57					
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.27	0.29	0.38	0.61	0.86	1.15	1.59	1.91	2.31	3.06	16.66	37.39	62.43	100.00							

Appendix XVII Sediment particle size data from SWANSEA BAY grab samples.

Sample	Weights (g) within um ranges from 63 mm to 63 um																						Tot	Tot					
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**			**% G**	**% S**	**% M**
1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.04	0.06	0.27	4.06	9.66	9.50	3.56	1.39	1.87	4.06	7.78	34.53	7.78	42.31	**tot wt**	0.14	81.47	18.39
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.02	0.05	0.09	0.14	0.63	9.61	22.83	22.45	8.41	3.29	4.42	9.61	18.39	81.61	18.39					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.09	0.14	0.23	0.38	1.01	10.62	33.44	55.89	64.30	67.59	72.01	81.61	100.00					**% G**	**% S**	**% M**
1B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.07	1.24	2.90	3.80	3.63	4.07	4.30	7.17	10.52	27.24	10.52	37.76	**tot wt**	0.00	72.14	27.86
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.19	3.28	7.69	10.07	9.62	10.79	11.39	18.98	27.86	72.14	27.86					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.13	0.32	3.60	11.29	21.36	30.98	41.77	53.16	72.14	100.00					**% G**	**% S**	**% M**
1C	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.10	0.04	0.31	0.38	0.58	0.76	1.04	10.50	26.22	26.06	8.33	3.50	1.90	3.14	4.62	83.14	4.62	87.76	**tot wt**	1.26	93.48	5.26
% wt	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.12	0.04	0.36	0.43	0.66	0.86	1.19	11.97	29.88	29.70	9.49	3.99	2.17	3.58	5.26	94.74	5.26					
Cum %	0.00	0.00	0.00	0.00	0.00	0.31	0.31	0.43	0.47	0.83	1.26	1.92	2.78	3.97	15.94	45.82	75.51	85.00	88.99	91.16	94.74	100.00					**% G**	**% S**	**% M**
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.03	0.06	0.11	0.10	0.15	1.35	2.66	3.81	4.45	6.19	6.86	9.50	11.25	35.42	11.25	46.67	**tot wt**	0.53	75.37	24.10
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.06	0.13	0.23	0.21	0.32	2.89	5.70	8.17	9.53	13.25	14.70	20.36	24.10	75.90	24.10					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.40	0.53	0.77	0.98	1.30	4.19	9.89	18.06	27.59	40.84	55.54	75.90	100.00					**% G**	**% S**	**% M**
2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.25	0.09	0.29	0.34	0.36	0.65	3.78	5.97	6.79	6.67	8.48	7.48	8.77	9.65	50.19	9.65	59.84	**tot wt**	1.50	82.37	16.13
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.42	0.15	0.49	0.57	0.60	1.09	6.31	9.98	11.35	11.14	14.18	12.50	14.65	16.13	83.87	16.13					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.86	1.01	1.50	2.07	2.67	3.76	10.07	20.05	31.40	42.54	56.72	69.22	83.87	100.00					**% G**	**% S**	**% M**
2C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.11	0.18	0.31	1.06	10.08	17.97	14.32	5.76	5.23	4.92	5.44	6.02	65.67	6.02	71.69	**tot wt**	0.56	91.05	8.39
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.14	0.15	0.25	0.44	1.47	14.06	25.07	19.98	8.04	7.30	6.86	7.59	8.39	91.61	8.39					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.27	0.41	0.56	0.81	1.24	2.72	16.77	41.84	61.82	69.86	77.16	84.02	91.61	100.00					**% G**	**% S**	**% M**
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.21	0.20	0.15	0.23	0.24	1.61	8.27	15.02	11.64	6.91	3.93	5.41	7.56	53.91	7.56	61.46	**tot wt**	0.83	86.87	12.29
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.34	0.32	0.24	0.37	0.38	2.61	13.45	24.44	18.95	11.24	6.40	8.80	12.29	87.71	12.29					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.51	0.83	1.07	1.44	1.83	4.44	17.89	42.33	61.28	72.51	78.91	87.71	100.00					**% G**	**% S**	**% M**
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.07	0.09	0.07	0.10	1.09	5.02	11.86	12.05	7.62	4.14	6.40	9.26	48.55	9.26	57.80	**tot wt**	0.19	83.80	16.01
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.12	0.15	0.12	0.17	1.89	8.69	20.52	20.85	13.18	7.16	11.08	16.01	83.99	16.01					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.19	0.34	0.46	0.64	2.53	11.21	31.73	52.58	65.76	72.91	83.99	100.00					**% G**	**% S**	**% M**
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01	0.00	0.01	0.01	0.57	2.23	5.91	8.14	7.20	3.99	6.13	10.40	34.28	10.40	44.68	**tot wt**	0.20	76.53	23.27
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.02	0.00	0.02	0.02	1.27	4.98	13.23	18.22	16.12	8.94	13.72	23.27	76.73	23.27					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.18	0.18	0.20	0.20	0.22	0.25	1.52	6.50	19.74	37.95	54.07	63.01	76.73	100.00					**% G**	**% S**	**% M**
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.10	0.68	0.66	1.73	3.50	4.82	4.46	7.03	10.83	22.99	10.83	33.82	**tot wt**	0.00	67.97	32.03
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.29	2.01	1.95	5.10	10.35	14.24	13.18	20.79	32.03	67.97	32.03					
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.35	2.36	4.31	9.41	19.76	34.00	47.18	67.97	100.00							

Sample	Weights (g) within um ranges from 63 mm to 63 um																						Tot	Tot				
ID	**63**	**45**	**31.5**	**22.4**	**16**	**11.2**	**8**	**5.6**	**4**	**2.8**	**2**	**1.4**	**1**	**710**	**500**	**355**	**250**	**180**	**125**	**90**	**63**	**<63**	**> 63**	**< 63**		**% G**	**% S**	**% M**
4B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.35	0.72	1.94	3.07	3.27	3.16	6.02	10.01	18.59	10.01	28.60 **tot wt**	0.00	65.00	35.00
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.10	1.22	2.51	6.77	10.75	11.44	11.06	21.04	35.00	65.00	35.00				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.10	0.21	1.43	3.94	10.71	21.46	32.90	43.96	65.00	100.00				**% G**	**% S**	**% M**
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.46	1.14	3.57	6.00	6.05	3.20	3.72	7.06	24.19	7.06	31.25 **tot wt**	0.00	77.40	22.60
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.13	1.47	3.64	11.41	19.21	19.37	10.23	11.89	22.60	77.40	22.60				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.19	1.66	5.31	16.71	35.92	55.29	65.52	77.40	100.00				**% G**	**% S**	**% M**
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.06	0.10	1.48	3.66	17.96	30.44	22.29	5.16	3.08	3.30	84.29	3.30	87.59 **tot wt**	0.05	96.19	3.76
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.07	0.11	1.69	4.18	20.50	34.75	25.45	5.89	3.51	3.76	96.24	3.76				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.08	0.15	0.26	1.96	6.14	26.64	61.39	86.83	92.72	96.24	100.00				**% G**	**% S**	**% M**
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.04	0.71	5.99	17.99	22.16	15.28	4.48	3.54	5.11	70.24	5.11	75.35 **tot wt**	0.00	93.22	6.78
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.05	0.94	7.95	23.87	29.41	20.28	5.95	4.70	6.78	93.22	6.78				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.12	1.06	9.01	32.88	62.29	82.57	88.52	93.22	100.00				**% G**	**% S**	**% M**
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.09	0.90	2.15	7.58	13.09	12.42	5.46	5.22	7.94	46.94	7.94	54.89 **tot wt**	0.00	85.52	14.48
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.04	0.16	1.64	3.91	13.80	23.84	22.62	9.95	9.51	14.48	85.52	14.48				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.09	0.25	1.89	5.80	19.60	43.44	66.07	76.01	85.52	100.00				**% G**	**% S**	**% M**
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.03	0.01	0.01	0.01	0.01	0.05	0.60	0.70	2.19	4.75	5.92	4.56	6.57	9.89	25.53	9.89	35.42 **tot wt**	0.48	71.61	27.91
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.08	0.03	0.03	0.03	0.03	0.14	1.69	1.97	6.19	13.42	16.71	12.89	18.54	27.91	72.09	27.91				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.34	0.42	0.45	0.48	0.51	0.53	0.68	2.36	4.33	10.52	23.94	40.66	53.55	72.09	100.00				**% G**	**% S**	**% M**
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.45	0.67	2.34	5.24	7.06	5.71	7.57	10.98	29.12	10.98	40.10 **tot wt**	0.00	72.61	27.39
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.17	1.12	1.67	5.83	13.06	17.60	14.23	18.87	27.39	72.61	27.39				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.22	1.35	3.02	8.85	21.91	39.51	53.74	72.61	100.00				**% G**	**% S**	**% M**
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.03	0.05	0.02	0.08	0.08	0.55	0.88	3.23	6.93	7.45	3.31	3.43	6.94	26.14	6.94	33.08 **tot wt**	0.54	78.47	20.99
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.09	0.15	0.06	0.24	0.24	1.65	2.65	9.77	20.96	22.52	10.01	10.37	20.99	79.01	20.99				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.39	0.54	0.60	0.84	1.08	2.74	5.38	15.15	36.11	58.63	68.64	79.01	100.00						

Appendix XVIII Sediment particle size data from SWANSEA BAY core samples.

Sample	Weights (g) within um ranges from 63 mm to 63 um																						Tot	Tot				
ID	63	45	31.5	22.4	16	11.2	8	5.6	4	2.8	2	1.4	1	710	500	355	250	180	125	90	63	<63	> 63	< 63		% G	% S	% M
1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.27	0.28	1.19	2.03	2.05	2.41	5.45	7.48	18.42	31.34	29.37	9.10	5.04	86.59	114.91	86.59	201.50 **tot wt**	1.10	55.93	42.97
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.13	0.14	0.59	1.01	1.02	1.20	2.70	3.71	9.14	15.55	14.58	4.52	2.50	42.97	57.03	42.97				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.37	0.51	1.10	2.11	3.13	4.32	7.03	10.74	19.88	35.43	50.01	54.53	57.03	100.00				**% G**	**% S**	**% M**
1B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12	0.56	0.70	1.54	1.77	2.42	4.56	4.93	7.83	7.62	18.03	8.74	3.45	46.41	62.39	46.41	108.80 **tot wt**	1.38	55.97	42.66
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.51	0.64	1.42	1.63	2.22	4.19	4.53	7.20	7.00	16.57	8.03	3.17	42.66	57.34	42.66				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.22	0.74	1.38	2.79	4.42	6.65	10.84	15.37	22.56	29.57	46.14	54.17	57.34	100.00				**% G**	**% S**	**% M**
1C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.19	2.08	3.20	3.42	3.08	3.21	2.48	2.76	2.86	5.79	5.39	4.62	123.65	40.08	123.65	163.73 **tot wt**	2.00	22.48	75.52
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	1.27	1.95	2.09	1.88	1.96	1.51	1.69	1.75	3.54	3.29	2.82	75.52	24.48	75.52				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	2.00	3.95	6.04	7.92	9.88	11.40	13.08	14.83	18.37	21.66	24.48	100.00				**% G**	**% S**	**% M**
2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.07	0.36	0.57	0.71	1.12	1.05	1.31	1.85	9.85	9.25	4.91	66.93	31.15	66.93	98.08 **tot wt**	0.17	31.59	68.24
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.07	0.37	0.58	0.72	1.14	1.07	1.34	1.89	10.04	9.43	5.01	68.24	31.76	68.24				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.17	0.54	1.12	1.85	2.99	4.06	5.39	7.28	17.32	26.75	31.76	100.00				**% G**	**% S**	**% M**
2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.45	1.14	2.33	1.94	2.16	2.45	7.16	9.03	4.60	65.92	31.37	65.92	97.29 **tot wt**	0.00	32.24	67.76
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.46	1.17	2.39	1.99	2.22	2.52	7.36	9.28	4.73	67.76	32.24	67.76				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.58	1.75	4.14	6.14	8.36	10.87	18.23	27.52	32.24	100.00				**% G**	**% S**	**% M**
2C	0.00	0.00	0.00	0.00	0.00	0.00	1.97	4.45	0.80	1.53	1.43	2.96	2.61	2.31	3.05	3.30	9.81	12.20	16.49	16.20	8.56	81.24	87.67	81.24	168.91 **tot wt**	6.03	45.88	48.10
% wt	0.00	0.00	0.00	0.00	0.00	0.00	1.17	2.63	0.47	0.91	0.85	1.75	1.55	1.37	1.81	1.95	5.81	7.22	9.76	9.59	5.07	48.10	51.90	48.10				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	1.17	3.80	4.27	5.18	6.03	7.78	9.32	10.69	12.50	14.45	20.26	27.48	37.24	46.84	51.90	100.00				**% G**	**% S**	**% M**
3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.38	1.01	1.75	2.34	3.48	2.90	3.22	3.83	11.28	9.55	5.90	82.07	45.67	82.07	127.74 **tot wt**	0.32	35.43	64.25
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.30	0.79	1.37	1.83	2.72	2.27	2.52	3.00	8.83	7.48	4.62	64.25	35.75	64.25				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.32	1.11	2.48	4.31	7.04	9.31	11.83	14.83	23.66	31.13	35.75	100.00				**% G**	**% S**	**% M**
3B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	1.12	2.03	3.01	3.63	4.73	3.53	3.48	2.99	6.16	5.82	3.13	61.32	39.87	61.32	101.19 **tot wt**	1.34	38.06	60.60
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	1.11	2.01	2.97	3.59	4.67	3.49	3.44	2.95	6.09	5.75	3.09	60.60	39.40	60.60				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	1.34	3.35	6.32	9.91	14.59	18.07	21.51	24.47	30.56	36.31	39.40	100.00				**% G**	**% S**	**% M**
3C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.21	1.32	1.72	2.10	2.74	2.51	2.22	2.59	1.88	2.01	1.82	5.51	5.63	2.38	45.41	35.64	45.41	81.05 **tot wt**	7.83	36.14	56.03
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49	1.63	2.12	2.59	3.38	3.10	2.74	3.20	2.32	2.48	2.25	6.80	6.95	2.94	56.03	43.97	56.03				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49	3.12	5.24	7.83	11.22	14.31	17.05	20.25	22.57	25.05	27.29	34.09	41.04	43.97	100.00						
4A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	1.63	3.98	5.01	4.70	4.15	4.91	3.88	5.43	14.08	30.07	5.91	3.62	83.29	88.02	83.29	171.31 **tot wt**	3.65	47.73	48.62
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.95	2.32	2.92	2.74	2.42	2.87	2.26	3.17	8.22	17.55	3.45	2.11	48.62	51.38	48.62				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	1.33	3.65	6.58	9.32	11.74	14.61	16.88	20.05	28.26	45.82	49.27	51.38	100.00						

Sample	Weights (g) within um ranges from 63 mm to 63 um																					Tot	Tot				
ID	63	45	31.5	22.4	16	11.2	8	5.6	4	2.8	2	1.4	1	710	500	355	250	180	125	90	63	<63	> 63	< 63		% G	% S	% M
4B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04	0.16	0.32	0.57	0.53	1.63	7.79	19.96	3.29	1.18	39.73	35.51	39.73	75.24 **tot wt**	0.05	47.14	52.80
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.21	0.43	0.76	0.70	2.17	10.35	26.53	4.37	1.57	52.80	47.20	52.80				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.11	0.32	0.74	1.50	2.21	4.37	14.73	41.25	45.63	47.20	100.00				**% G**	**% S**	**% M**
4C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.45	0.77	1.27	1.15	2.79	9.02	16.31	4.75	2.11	42.90	38.74	42.90	81.64 **tot wt**	0.00	47.45	52.55
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.55	0.94	1.56	1.41	3.42	11.05	19.98	5.82	2.58	52.55	47.45	52.55				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.70	1.64	3.20	4.61	8.02	19.07	39.05	44.87	47.45	100.00				**% G**	**% S**	**% M**
5A	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.06	0.07	0.21	0.40	0.55	0.75	0.63	1.21	6.11	17.06	2.39	0.55	22.67	30.01	22.67	52.68 **tot wt**	0.28	56.68	43.03
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.11	0.13	0.40	0.76	1.04	1.42	1.20	2.30	11.60	32.38	4.54	1.04	43.03	56.97	43.03				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.15	0.28	0.68	1.44	2.49	3.91	5.11	7.40	19.00	51.39	55.92	56.97	100.00				**% G**	**% S**	**% M**
5B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.12	0.22	0.34	0.62	1.21	10.15	27.80	50.74	10.30	2.45	37.41	104.06	37.41	141.47 **tot wt**	0.08	73.48	26.44
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.01	0.08	0.16	0.24	0.44	0.86	7.17	19.65	35.87	7.28	1.73	26.44	73.56	26.44				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.08	0.16	0.32	0.56	1.00	1.85	9.03	28.68	64.54	71.82	73.56	100.00				**% G**	**% S**	**% M**
5C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.76	1.53	1.54	1.49	1.54	1.24	5.66	24.64	58.21	11.42	3.23	51.02	111.35	51.02	162.37 **tot wt**	0.52	68.05	31.42
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.47	0.94	0.95	0.92	0.95	0.76	3.49	15.18	35.85	7.03	1.99	31.42	68.58	31.42				
cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.52	1.47	2.41	3.33	4.28	5.04	8.53	23.71	59.56	66.59	68.58	100.00				**% G**	**% S**	**% M**
6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.33	0.83	1.59	1.68	1.74	2.48	2.20	3.76	15.14	37.75	10.79	3.83	67.82	82.13	67.82	149.95 **tot wt**	0.78	53.99	45.23
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.22	0.55	1.06	1.12	1.16	1.65	1.47	2.51	10.10	25.18	7.20	2.55	45.23	54.77	45.23				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.23	0.78	1.84	2.96	4.12	5.78	7.24	9.75	19.85	45.02	52.22	54.77	100.00				**% G**	**% S**	**% M**
6B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.50	1.48	2.07	2.23	3.65	3.43	4.94	11.59	17.31	5.24	2.51	50.83	55.00	50.83	105.83 **tot wt**	0.52	51.45	48.03
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.47	1.40	1.96	2.11	3.45	3.24	4.67	10.95	16.36	4.95	2.37	48.03	51.97	48.03				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.52	1.92	3.87	5.98	9.43	12.67	17.34	28.29	44.65	49.60	51.97	100.00				**% G**	**% S**	**% M**
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.76	1.23	1.45	2.06	1.76	2.30	3.72	11.94	9.28	4.54	80.46	39.17	80.46	119.63 **tot wt**	0.11	32.63	67.26
% wt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.64	1.03	1.21	1.72	1.47	1.92	3.11	9.98	7.76	3.80	67.26	32.74	67.26				
Cum %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.74	1.77	2.98	4.71	6.18	8.10	11.21	21.19	28.95	32.74	100.00						

Appendix XIX Pearson product moment correlations between each pair of environmental variables from TEES BAY grabs (n=6). P values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	%C	*%OrgC*	*%N*	*%s/c*	*%S*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨											
%OrgC	**0.9625** **(0.0021)**	▨										
%N	0.6866 (0.1319)	0.6866 (0.1319)	▨									
%s/c	0.7498 (0.0861)	0.7016 (0.1203)	0.8052 (0.0532)	▨								
%S	-0.6227 (0.1867)	-0.6135 (0.1952)	-0.5484 (0.2599)	**-0.8868** **(0.0185)**	▨							
Cd	-0.1188 (0.8226)	-0.0164 (0.9755)	-0.2560 (0.6244)	-0.2362 (0.6532)	0.2421 (0.6439)	▨						
Cr	0.0751 (0.8876)	0.2767 (0.5955)	-0.4001 (0.4319)	-0.2328 (0.6572)	0.0267 (0.9600)	0.7164 (0.1092)	▨					
Cu	-0.1382 (0.7940)	-0.0856 (0.8719)	-0.2704 (0.6043)	-0.2700 (0.6048)	0.1409 (0.7900)	**0.9183** **(0.0097)**	0.7009 (0.1208)	▨				
Hg	0.1360 (0.7973)	0.1784 (0.7352)	-0.1603 (0.7616)	-0.3296 (0.5235)	0.1669 (0.7519)	0.6960 (0.1246)	0.7726 (0.0717)	**0.8344** **(0.0389)**	▨			
Ni	0.4721 (0.3445)	0.6203 (0.1889)	0.0046 (0.9931)	0.2079 (0.6926)	-0.4205 (0.4065)	0.5103 (0.3010)	**0.8741** **(0.0228)**	0.5640 (0.2437)	0.7015 (0.1203)	▨		
Pb	0.2594 (0.6197)	0.4682 (0.3490)	-0.2879 (0.5800)	-0.0707 (0.8941)	-0.1690 (0.7488)	0.4409 (0.3815)	**0.9359** **(0.0060)**	0.4417 (0.3805)	0.6381 (0.1727)	**0.9180** **(0.0098)**	▨	
Zn	-0.4475 (0.3736)	-0.3932 (0.4406)	-0.5030 (0.3091)	-0.4991 (0.3135)	0.3614 (0.4815)	**0.8753** **(0.0224)**	0.5936 (0.2141)	**0.9462** **(0.0043)**	0.7101 (0.1139)	0.3328 (0.5192)	0.2921 (0.5743)	▨

Appendix XX Pearson product moment correlations between each pair of environmental variables from TEES BAY cores (n=18). P values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted in bold type.

	%C	*%OrgC*	*%N*	*%s/c*	*%S*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨											
%OrgC	**0.9594** **(<0.0001)**	▨										
%N	**0.8778** **(<0.0001)**	**0.8567** **(<0.0001)**	▨									
%s/c	0.4234 (0.0799)	0.4274 (0.0769)	0.3816 (0.1181)	▨								
%S	**-0.5198** **(0.0270)**	**-0.4727** **(0.0476)**	**-0.5120** **(0.0299)**	**-0.8282** **(<0.0001)**	▨							
Cd	0.4061 (0.0944)	0.3891 (0.1105)	0.3765 (0.1236)	0.1641 (0.5152)	-0.1659 (0.5106)	▨						
Cr	0.2688 (0.2808)	0.2482 (0.3208)	0.3595 (0.1428)	-0.3145 (0.2038)	0.2563 (0.3046)	0.3890 (0.1106)	▨					
Cu	0.2947 (0.2352)	0.3456 (0.1601)	0.1548 (0.5395)	-0.3561 (0.1470)	0.2433 (0.3307)	0.2635 (0.2907)	**0.7184** **(0.0008)**	▨				
Hg	**0.5543** **(0.0170)**	**0.5099** **(0.0307)**	0.3516 (0.1525)	0.0953 (0.7067)	-0.1668 (0.5082)	**0.6202** **(0.0060)**	**0.8613** **(<0.0001)**	**0.5755** **(0.0125)**	▨			
Ni	**0.4955** **(0.0365)**	**0.4892** **(0.0394)**	**0.4898** **(0.0391)**	0.2611 (0.2953)	-0.4100 (0.0911)	0.0698 (0.7831)	0.4326 (0.0729)	0.3157 (0.2019)	**0.5186** **(0.0275)**	▨		
Pb	0.4234 (0.0800)	0.3957 (0.1040)	0.4014 (0.0987)	-0.2591 (0.2992)	0.1847 (0.4631)	0.3830 (0.1167)	**0.8555** **(<0.0001)**	**0.5905** **(0.0099)**	**0.8092** **(<0.0001)**	0.4656 (0.0515)	▨	
Zn	0.4061 (0.0945)	0.3990 (0.1010)	0.3392 (0.1686)	-0.1140 (0.6523)	0.0542 (0.8308)	**0.6305** **(0.0050)**	**0.8551** **(< 0.0001)**	**0.7428** **(0.0004)**	**0.8862** **(<0.0001)**	0.4367 (0.0700)	**0.8366** **(<0.0001)**	▨

Appendix XXI Pearson product moment correlations between each pair of mean environmental variables in sediments from TEES BAY cores (n=6). P values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted in bold type.

	%C	*%OrgC*	*%N*	*%s/c*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨												
%OrgC	**0.9747** **(0.0010)**	▨											
%N	**0.9166** **(0.0102)**	**0.8632** **(0.0268)**	▨										
%s/c	0.7777 (0.0687)	**0.8824** **(0.0199)**	0.5411 (0.2675)	▨									
%S	**-0.9278** **(0.0076)**	**-0.9662** **(0.0017)**	-0.7668 (0.0752)	**-0.9378** **(0.0057)**	▨								
%G	-0.1315 (0.8039)	-0.0186 (0.9721)	0.4629 (0.3553)	-0.4188 (0.4085)	0.1157 (0.8273)	▨							
Cd	0.3157 (0.5422)	0.2949 (0.5704)	0.3051 (0.5565)	0.3381 (0.5122)	-0.4755 (0.3404)	0.2682 (0.6074)	▨						
Cr	-0.3122 (0.5469)	-0.4213 (0.4055)	-0.1335 (0.8009)	-0.4860 (0.3284)	0.3004 (0.5630)	0.5948 (0.2130)	0.6576 (0.1558)	▨					
Cu	-0.2550 (0.6259)	-0.3277 (0.5261)	0.0856 (0.8720)	-0.5758 (0.2318)	0.4154 (0.4127)	**0.8432** **(0.0350)**	0.1018 (0.8479)	0.5497 (0.2585)	▨				
Hg	0.4648 (0.3530)	0.4251 (0.4008)	0.4493 (0.3714)	0.4079 (0.4221)	-0.5809 (0.2267)	0.3151 (0.5430)	**0.9841** **(0.0004)**	0.5918 (0.2159)	0.0710 (0.8937)	▨			
Ni	**0.9492** **(0.0038)**	**0.9690** **(0.0014)**	**0.8984** **(0.0150)**	0.7824 (0.0659)	**-0.8743** **(0.0227)**	-0.0618 (0.9074)	0.1045 (0.8438)	-0.5176 (0.2930)	-0.2286 (0.6631)	0.2459 (0.6386)	▨		
Pb	-0.2826 (0.5874)	-0.4238 (0.4024)	-0.1107 (0.8347)	-0.5741 (0.2335)	0.3808 (0.4564)	0.3934 (0.4404)	0.1917 (0.7159)	0.6508 (0.1616)	0.1365 (0.7966)	0.1795 (0.7336)	-0.4360 (0.3875)	▨	
Zn	-0.0249 (0.9627)	-0.0921 (0.8622)	0.2248 (0.6685)	-0.2307 (0.6601)	0.0219 (0.9672)	0.7499 (0.0860)	0.7397 (0.0928)	**0.8678** **(0.0251)**	0.7168 (0.1089)	0.6997 (0.1217)	-0.1503 (0.7763)	0.3775 (0.4607)	▨

Appendix XXII Pearson product moment correlations between each pair of log (1+N) transformed environmental variables from LIVERPOOL BAY grabs (n=6). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted in bold type.

	%C	*%OrgC*	*%N*	*%sc*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨												
%OrgC	**0.9849**	▨											
	(0.0003)												
%N	**0.9539**	**0.9796**	▨										
	(0.0031)	**(0.0006)**											
%sc	0.1872	0.0731	0.0959	▨									
	(0.7225)	(0.8906)	(0.8566)										
%S	-0.2057	-0.1193	-0.1402	**-0.9744**	▨								
	(0.6958)	(0.8218)	(0.7911)	**(0.0010)**									
%G	-0.2708	-0.1626	-0.0737	-0.1197	-0.0050	▨							
	(0.6037)	(0.7582)	(0.8897)	(0.8213)	(0.9925)								
Cd	0.0954	0.1842	0.1462	-0.6817	0.6225	-0.3454	▨						
	(0.8574)	(0.7268)	(0.7823)	(0.1358)	(0.1869)	(0.5026)							
Cr	**0.9689**	**0.9701**	**0.9427**	0.1440	-0.1856	-0.3358	0.2836	▨					
	(0.0014)	**(0.0013)**	**(0.0048)**	(0.7855)	(0.7247)	(0.5153)	(0.5861)						
Cu	**0.9629**	**0.9589**	**0.8978**	0.0745	-0.1139	-0.3859	0.3171	**0.9837**	▨				
	(0.0020)	**(0.0025)**	**(0.0151)**	(0.8884)	(0.8298)	(0.4499)	(0.5402)	**(0.0004)**					
Hg	**0.9053**	**0.9192**	**0.8417**	-0.0599	0.0014	-0.3828	0.4523	**0.9498**	**0.9838**	▨			
	(0.0130)	**(0.0095)**	**(0.0356)**	(0.9102)	(0.9979)	(0.4538)	(0.3678)	**(0.0037)**	**(0.0004)**				
Ni	**0.9646**	**0.9664**	**0.8994**	0.1104	-0.1713	-0.2114	0.1699	**0.9473**	**0.9719**	**0.9504**	▨		
	(0.0019)	**(0.0017)**	**(0.0147)**	(0.8350)	(0.7456)	(0.6877)	(0.7476)	**(0.0041)**	**(0.0012)**	**(0.0036)**			
Pb	**0.9547**	**0.9896**	**0.9714**	-0.0117	-0.0552	-0.1424	0.3031	**0.9699**	**0.9571**	**0.9380**	**0.9532**	▨	
	(0.0030)	**(0.0002)**	**(0.0012)**	(0.9825)	(0.9173)	(0.7878)	(0.5593)	**(0.0013)**	**(0.0027)**	**(0.0057)**	**(0.0032)**		
Zn	0.6722	0.6977	0.5538	-0.2447	0.1558	-0.2627	0.4565	0.6956	0.8013	**0.8753**	**0.8259**	0.7256	▨
	(0.1436)	(0.1233)	(0.2542)	(0.6402)	(0.7682)	(0.6150)	(0.3628)	(0.1249)	(0.0553)	**(0.0224)**	**(0.0428)**	(0.1026)	

Appendix XXIII Pearson product moment correlations between each pair of log (1+N) environmental variables from LIVERPOOL BAY cores (n=6). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted in bold type.

	%C	*%OrgC*	*%N*	*%G*	*%S*	%sc	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨												
%OrgC	-0.0222	▨											
	(0.9667)												
%N	-0.1746	0.3796	▨										
	(0.7407)	(0.4579)											
%G	**-0.8259**	-0.4652	-0.0334	▨									
	(0.0428)	(0.3525)	(0.9499)										
%S	0.5998	-0.5824	-0.5661	-0.2821	▨								
	(0.2082)	(0.2252)	(0.2416)	(0.5880)									
%sc	-0.2773	0.7926	0.6750	-0.1756	**-0.8747**	▨							
	(0.5948)	(0.0600)	(0.1412)	(0.7393)	**(0.0226)**								
Cd	-0.2114	**0.9164**	0.1157	-0.2132	-0.5789	0.6286	▨						
	(0.6876)	**(0.0102)**	(0.8272)	(0.6851)	(0.2287)	(0.1813)							
Cr	0.4939	0.4458	-0.0632	-0.4301	-0.1596	0.1889	0.4762	▨					
	(0.3193)	(0.3756)	(0.9054)	(0.3946)	(0.7626)	(0.7200)	(0.3397)						
Cu	0.2588	0.6886	0.1096	-0.3940	-0.4920	0.5394	0.6903	**0.9177**	▨				
	(0.6205)	(0.1304)	(0.8362)	(0.4395)	(0.3215)	(0.2693)	(0.1290)	**(0.0099)**					
Hg	0.6719	-0.4461	0.1877	-0.2605	0.5048	-0.4157	-0.6219	0.2224	-0.0786	▨			
	(0.1438)	(0.3753)	(0.7217)	(0.6181)	(0.3071)	(0.4123)	(0.1874)	(0.6719)	(0.8823)				
Ni	-0.3380	0.6599	**0.8221**	0.0711	**-0.8367**	0.8107	0.5654	0.3030	0.5218	-0.1211	▨		
	(0.5123)	(0.1539)	**(0.0447)**	(0.8936)	**(0.0378)**	(0.0503)	(0.2423)	(0.5593)	(0.2883)	(0.8192)			
Pb	-0.0089	0.3444	0.3305	0.0915	-0.5760	0.3986	0.3960	0.7754	0.7910	0.1683	0.6860	▨	
	(0.9867)	(0.5039)	(0.5223)	(0.8632)	(0.2315)	(0.4337)	(0.4370)	(0.0700)	(0.0610)	(0.7499)	(0.1324)		
Zn	0.2922	0.5345	0.0674	-0.3057	-0.4215	0.4056	0.5637	**0.9594**	**0.9771**	0.0632	0.4758	**0.8670**	▨
	(0.5742)	(0.2746)	(0.8990)	(0.5557)	(0.4052)	(0.4250)	(0.2441)	**(0.0024)**	**(0.0008)**	(0.9053)	(0.3402)	**(0.0254)**	

Appendix XXIV Pearson product moment correlations between each pair of environmental variables from LUNE DEEP grabs (n=7). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	%C	*%OrgC*	*%N*	*%sc*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨												
%OrgC	**0.8797**	▨											
	(0.0090)												
%N	**0.8134**	**0.9854**	▨										
	(0.0261)	**(<0.0001)**											
%sc	0.1198	-0.1091	-0.1239	▨									
	(0.7980)	(-0.8159)	(0.7913)										
%S	-0.2643	-0.0756	-0.0363	**-0.9304**	▨								
	(0.5668)	(0.8720)	(0.9385)	**(0.0024)**									
%G	-0.3901	-0.5178	-0.5589	0.3521	-0.1394	▨							
	(0.3870)	(0.2339)	(0.1921)	(0.4387)	(0.7657)								
Cd	0.1050	-0.0313	-0.0251	0.1816	-0.2135	-0.4325	▨						
	(0.8226)	(0.9469)	(0.9574)	(0.6967)	(0.6458)	(0.3324)							
Cr	0.4907	0.4445	0.4446	0.5407	-0.5135	0.0481	0.4630	▨					
	(0.2636)	(0.3177)	(0.3176)	(0.2102)	(0.2385)	(0.9185)	(0.2954)						
Cu	0.6779	0.5327	0.4869	0.5722	-0.5298	0.2537	0.0809	**0.8617**	▨				
	(0.0942)	(0.2183)	(0.2678)	(0.1795)	(0.2213)	(0.5831)	(0.8632)	**(0.0127)**					
Hg	0.7406	0.6220	0.5889	0.5469	-0.5110	0.1763	-0.0517	**0.7756**	**0.9727**	▨			
	(0.0569)	(0.1358)	(0.1641)	(0.2040)	(0.2411)	(0.7053)	(0.9124)	**(0.0404)**	**(0.0002)**				
Ni	**0.7604**	0.5667	0.4966	0.4314	-0.4210	0.1412	0.2241	**0.8387**	**0.9600**	**0.9070**	▨		
	(0.0472)	(0.1847)	(0.2569)	(0.3338)	(0.3469)	(0.7626)	(0.6290)	**(0.0184)**	**(0.0006)**	**(0.0048)**			
Pb	0.5864	0.4080	0.3309	0.4878	-0.4413	0.4231	0.0297	**0.7859**	**0.9578**	**0.8892**	**0.9500**	▨	
	(0.1664)	(0.3635)	(0.4685)	(0.2668)	(0.3215)	(0.3443)	(0.9495)	**(0.0362)**	**(0.0007)**	**(0.0074)**	**(0.0010)**		
Zn	0.7917	0.6290	0.5918	0.5209	-0.5245	-0.0560	0.3467	**0.8941**	**0.9386**	**0.9136**	**0.9542**	**0.8470**	▨
	(0.0339)	(0.1302)	(0.1616)	(0.2306)	(0.2268)	(0.9051)	(0.4462)	**(0.0066)**	**(0.0017)**	**(0.0040)**	**(0.0008)**	**(0.0162)**	

Appendix XXV Pearson product moment correlations between each pair of environmental variables from LUNE DEEP cores (n=18). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	%C	*%OrgC*	*%N*	*%sc*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*	*As*
%C	▨													
%OrgC	**0.8393**	▨												
	(<0.0001)													
%N	**0.8518**	**0.8910**	▨											
	(<0.0001)	**(<0.0001)**												
%sc	0.4422	0.4434	0.2177	▨										
	0.0661	(0.0654)	(0.3854)											
%S	-0.4173	-0.3820	-0.1739	**-0.9448**	▨									
	(0.0849)	(0.1177)	(0.4902)	**(<0.0001)**										
%G	0.2595	0.2966	0.1188	0.4014	**-0.5112**	▨								
	(0.2983)	(0.2321)	(0.6387)	0.0987	**(0.0301)**									
Cd	**0.6157**	**0.6279**	**0.7500**	**0.5211**	-0.4581	0.0578	▨							
	(0.0065)	**(0.0053)**	**(0.0003)**	**(0.0266)**	(0.0559)	(0.8197)								
Cr	**0.8446**	**0.7536**	**0.8092**	0.3890	-0.3016	0.2075	**0.7024**	▨						
	(<0.0001)	**(0.0003)**	**(<0.0001)**	(0.1106)	(0.2238)	(0.4086)	**(0.0012)**							
Cu	**0.9165**	**0 .7387**	**0.8217**	0.2885	-0.2478	0.2181	**0.6016**	**0.9287**	▨					
	(<0.0001)	**(0 .0005)**	**(<0.0001)**	(0.2457)	(0.3215)	(0.3847)	**(0.0083)**	**(<0.0001)**						
Hg	**0.8867**	**0.7914**	**0.7670**	**0.5447**	**-0.5073**	**0.4924**	**0.6440**	**0.8543**	**0.8739**	▨				
	(<0.0001)	**(0.0001)**	**(0.0002)**	**(0.0194)**	**(0.0316)**	**(0.0379)**	**(0.0039)**	**(<0.0001)**	**(<0.0001)**					
Ni	**0.8864**	**0.8189**	**0.8437**	0.4191	-0.3658	0.3120	**0.6115**	**0.9240**	**0.9282**	**0.8994**	▨			
	(<0.0001)	**(<0.0001)**	**(<0.0001)**	(0.0835)	(0.1354)	(0.2075)	**(0.0070)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**				
Pb	**0.8886**	**0.6968**	**0.7270**	0.4078	-0.3562	0.2862	**0.5672**	**0.9464**	**0.9698**	**0.9049**	**0.9271**	▨		
	(<0.0001)	**(0.0013)**	**(0.0006)**	(0.0930)	(0.1468)	(0.2495)	**(0.0141)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**			
Zn	**0.6530**	**0.6625**	**0.6300**	**0.5340**	**-0.4234**	0.3736	**0.5517**	**0.8278**	**0.7037**	**0.8300**	**0.8665**	**0.7881**	▨	
	(0.0033)	**(0.0027)**	**(0.0051)**	**(0.0225)**	**(0.0800)**	(0.1268)	**(0.0176)**	**(<0.0001)**	**(0.0011)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**		
As	**0.9084**	**0.7560**	**0.7533**	0.2935	-0.2888	0.2426	0.4494	**0.8348**	**0.9498**	**0.8113**	**0.8863**	**0.9128**	**0.6036**	▨
	(<0.0001)	**(0.0003)**	**(0.0003)**	(0.2372)	(0.2451)	(0.3320)	(0.0614)	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(0.0080)**	

Appendix XXVI Pearson product moment correlations between each pair of environmental variables from LUNE DEEP cores (n=7). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	%C	*%OrgC*	*%N*	*%sc*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*	*As*
%C	▨													
%OrgC	**0.9037** **(0.0052)**	▨												
%N	**0.8818** **(0.0087)**	**0.8940** **(0.0066)**	▨											
%sc	0.5916 (0.1618)	0.6216 (0.1362)	0.3404 (0.4550)	▨										
%S	-0.6003 (0.1541)	-0.6355 (0.1251)	-0.3288 (0.4716)	**-0.9751** **(0.0002)**	▨									
%G	0.4376 (0.3261)	0.5993 (0.1550)	0.2077 (0.6550)	0.6264 (0.1323)	-0.7296 (0.0627)	▨								
Cd	-0.3899 (0.3872)	-0.2241 (0.6290)	-0.2985 (0.5156)	0.2355 (0.6111)	-0.1635 (0.7261)	-0.2211 (0.6337)	▨							
Cr	0.7162 (0.0703)	0.9255 (0.0028)	**0.8069** **(0.0283)**	0.63865 (0.1227)	-0.6312 (0.1284)	0.5187 (0.2330)	0.1190 (0.7995)	▨						
Cu	**0.9124** **(0.0042)**	**0.8388** **(0.0183)**	**0.8095** **(0.0274)**	0.3929 (0.3833)	-0.4818 (0.2736)	0.4979 (0.2555)	-0.4636 (0.2947)	0.6358 (0.1248)	▨					
Hg	**0.8200** **(0.0239)**	**0.8940** **(0.0660)**	0.6454 (0.1175)	**0.7666** **(0.0444)**	**-0.8003** **(0.0306)**	**0.8367** **(0.0189)**	-0.3189 (0.4858)	0.7675 (0.0440)	0.7331 (0.0608)	▨				
Ni	**0.8702** **(0.0109)**	**0.8949** **(0.0065)**	0.7566 (0.0490)	0.6655 (0.1028)	-0.7232 (0.0663)	0.7085 (0.0748)	-0.4190 (0.3494)	0.7506 (0.0519)	**0.8118** **(0.0266)**	**0.9417** **(0.0015)**	▨			
Pb	**0.9566** **(0.0007)**	**0.9425** **(0.0015)**	**0.8167** **(0.0250)**	0.6464 (0.1167)	-0.6999 (0.0800)	0.6624 (0.1050)	-0.3756 (0.4063)	**0.7759** **(0.0403)**	**0.9358** **(0.0019)**	**0.9171** **(0.0036)**	**0.9379** **(0.0018)**	▨		
Zn	0.5540 (0.1969)	0.6854 (0.0892)	0.3602 (0.4274)	**0.8183** **(0.0245)**	**-0.8332** **(0.0199)**	**0.8599** **(0.0131)**	-0.1581 (0.7349)	0.6334 (0.1267)	0.4086 (0.3628)	**0.9130** **(0.0041)**	**0.8137** **(0.0260)**	0.6866 (0.0884)	▨	
As	0.4247 (0.3422)	0.5660 (0.1853)	0.3329 (0.4656)	0.5058 (0.2468)	-0.5227 (0.2287)	0.4821 (0.2732)	0.3528 (0.4376)	0.6298 (0.1296)	0.4875 (0.2672)	0.4635 (0.2949)	0.2816 (0.5410)	0.5188 (0.2329)	0.2985 (0.5155)	▨

Appendix XXVII Pearson product moment correlations between each pair of environmental variables from SWANSEA BAY grabs (n=7). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	%C	*%OrgC*	*%N*	*%sc*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨												
%OrgC	**0.9113** **(0.0115)**	▨											
%N	**0.8213** **(0.0450)**	**0.9711** **(0.0012)**	▨										
%sc	0.3772 (0.4610)	0.5069 (0.3048)	0.4286 (0.3965)	▨									
%S	-0.1894 (0.7193)	-0.3169 (0.5406)	-0.2416 (0.6446)	**-0.9780** **(0.0007)**	▨								
%G	0.6946 (0.1257)	0.7424 (0.0910)	0.7222 (0.1050)	-0.0751 (0.8876)	0.2609 (0.6176)	▨							
Cd	0.1627 (0.7581)	0.2278 (0.6642)	0.2314 (0.6591)	0.3078 (0.5529)	-0.2960 (0.5690)	0.1821 (0.7299)	▨						
Cr	0.7136 (0.1113)	**0.9263** **(0.0080)**	**0.9636** **(0.0020)**	0.3719 (0.4679)	-0.1909 (0.7172)	0.7887 (0.0622)	0.1674 (0.7512)	▨					
Cu	0.7815 (0.0664)	**0.9590** **(0.0025)**	**0.9796** **(0.0006)**	0.3954 (0.4378)	-0.2074 (0.6934)	**0.7942** **(0.0591)**	0.1661 (0.7532)	**0.9946** **<0.0001**	▨				
Hg	0.2499 (0.6330)	0.5621 (0.2457)	0.7197 (0.1068)	-0.0030 (0.9955)	0.1250 (0.8135)	0.6250 (0.1846)	0.2088 (0.6913)	**0.8099** **(0.0508)**	0.7550 (0.0827)	▨			
Ni	0.8506 (0.0318)	**0.9870** **(0.0003)**	**0.9963** **(<0.0001)**	0.4581 (0.3609)	-0.2691 (0.6061)	0.7438 (0.0901)	0.2357 (0.6529)	**0.9635** **(0.0020)**	**0.9834** **(0.0004)**	0.6803 (0.1369)	▨		
Pb	0.7518 (0.0847)	**0.9447** **(0.0045)**	**0.9860** **(0.0003)**	0.3759 (0.4626)	-0.1912 (0.7166)	0.7736 (0.0711)	0.2135 (0.6845)	**0.9934** **(0.0001)**	**0.9946** **(<0.0001)**	0.7999 (0.0561)	**0.9821** **(0.0005)**	▨	
Zn	**0.8438** **(0.0347)**	**0.9747** **(0.0010)**	**0.9927** **(0.0001)**	0.3656 (0.4761)	-0.1708 (0.7462)	0.7984 (0.0568)	0.2460 (0.6385)	**0.9673** **(0.0016)**	**0.9843** **(0.0004)**	0.7194 (0.1070)	**0.9941** **(0.0001)**	**0.9861** **(0.0003)**	▨

Appendix XXVIII Pearson product moment correlations between each pair of environmental variables from SWANSEA BAY cores (n=18). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	%C	*%OrgC*	*%N*	*%sc*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C	▨												
%OrgC	**0.9612** **(<0.0001)**	▨											
%N	**0.5387** **(0.0211)**	**0.6502** **(0.0035)**	▨										
%sc	-0.2463 (0.3244)	-0.2628 (0.2921)	0.0510 (0.8409)	▨									
%S	-0.0532 (0.8340)	-0.0308 (0.9036)	-0.2003 (0.4256)	**-0.9474** **(<0.0001)**	▨								
%G	0.1831 (0.4670)	0.1206 (0.6336)	0.2153 (0.3908)	0.0485 (0.8484)	-0.1331 (0.5986)	▨							
Cd	0.3501 (0.1543)	0.3171 (0.1998)	-0.1917 (0.4459)	-0.2305 (0.3574)	0.2328 (0.3525)	0.0687 (0.7865)	▨						
Cr	**0.6453** **(0.0038)**	**0.6192** **(0.0061)**	0.1370 (0.5877)	-0.2225 (0.3748)	0.2836 (0.2542)	-0.0747 (0.7683)	**0.5077** **(0.0315)**	▨					
Cu	**0.7743** **(0.0002)**	**0.7164** **(0.0008)**	0.1266 (0.6167)	-0.0854 (0.7361)	0.1842 (0.4645)	-0.0776 (0.7596)	**0.6899** **(0.0015)**	**0.9153** **(<0.0001)**	▨				
Hg	**0.4981** **(0.0354)**	**0.4719** **(0.0480)**	-0.0438 (0.8631)	-0.084 (0.7404)	0.1506 (0.5507)	-0.0729 (0.7737)	**0.6507** **(0.0035)**	0.3779 (0.1221)	**0.6318** **(0.0049)**	▨			
Ni	**0.4847** **(0.0415)**	0.4084 (0.0924)	-0.1876 (0.4559)	-0.1080 (0.6696)	0.2195 (0.3815)	-0.2453 (0.3265)	**0.5497** **(0.0181)**	**0.8436** **(<0.0001)**	**0.8545** **(<0.0001)**	**0.487** **(0.0404)**	▨		
Pb	**0.7248** **(0.0007)**	**0.6689** **(0.0024)**	0.0661 (0.7945)	-0.1968 (0.4339)	0.2798 (0.2608)	-0.0837 (0.7413)	**0.7407** **(0.0004)**	**0.9013** **(<0.0001)**	**0.9823** **(<0.0001)**	**0.6660** **(0.0026)**	**0.8595** **(<0.0001)**	▨	
Zn	**0.8280** **(<0.0001)**	**0.849** **(<0.0001)**	0.4111 (0.0901)	-0.0276 (0.9134)	0.1021 (0.6869)	-0.0205 (0.9355)	0.4433 (0.0654)	**0.8145** **(<0.0001)**	**0.8696** **(<0.0001)**	**0.6543** **(0.0032)**	**0.6434** **(0.0040)**	**0.8277** **(<0.0001)**	▨

Appendix XXIX Pearson product moment correlations between each pair of environmental variables from SWANSEA BAY cores (n=7). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	%C	*%OrgC*	*%N*	*%sc*	*%S*	*%G*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
%C													
%OrgC	**0.9603**												
	(0.0023)												
%N	0.5269	0.6834											
	(0.2828)	(0.1345)											
%sc	0.0876	-0.0187	0.0739										
	(0.8689)	(0.9720)	(0.8893)										
%S	-0.1381	-0.0725	-0.1965	**-0.9765**									
	(0.7942)	(0.8915)	(0.7090)	**(0.0008)**									
%G	-0.0533	-0.0823	0.2506	0.7599	**-0.8361**								
	(0.9202)	(0.8769)	(0.6320)	(0.0795)	**(0.0381)**								
Cd	0.6853	0.6463	-0.0614	-0.1450	0.0911	-0.3195							
	(0.1329)	(0.1655)	(0.9080)	(0.7840)	(0.8637)	(0.5370)							
Cr	0.7054	0.6595	0.0517	-0.4090	0.3411	-0.3077	**0.8419**						
	(0.1174)	(0.1541)	(0.9226)	(0.4207)	(0.5082)	(0.5531)	**(0.0355)**						
Cu	**0.8537**	0.7784	0.1212	-0.1181	0.0617	-0.1754	**0.9103**	**0.9418**					
	(0.0305)	(0.0682)	(0.8191)	(0.8237)	(0.9075)	(0.7396)	**(0.0117)**	**(0.0050)**					
Hg	**0.8695**	**0.8025**	0.3259	0.1328	-0.0971	-0.3106	0.6200	0.4711	**0.9156**				
	(0.0244)	**(0.0547)**	(0.5284)	(0.8020)	(0.8549)	(0.5491)	(0.1892)	(0.3457)	**(0.0104)**				
Ni	0.6041	0.4774	-0.2495	-0.2679	0.2570	-0.3088	**0.8577**	**0.9364**	**0.9927**	0.4671			
	(0.2041)	(0.3383)	(0.6335)	(0.6077)	(0.6230)	(0.5516)	**(0.0289)**	**(0.0059)**	**(0.0001)**	(0.3503)			
Pb	**0.8237**	0.7533	0.0758	-0.2214	0.1742	-0.2882	**0.9194**	**0.9610**	**0.8840**	0.6691	**0.9354**		
	(0.0439)	(0.0838)	(0.8865)	(0.6733)	(0.7413)	(0.5797)	**(0.0095)**	**(0.0022)**	**(0.0194)**	(0.1461)	**(0.0061)**		
Zn	**0.9678**	**0.9743**	0.5039	-0.0818	0.0085	-0.2002	0.7886	0.7754	0.4128	**0.8403**	0.6447	**0.8719**	
	(0.0015)	**(0.0010)**	(0.3082)	(0.8776)	(0.9873)	(0.7037)	(0.0623)	(0.0700)	(0.4159)	**(0.0362)**	(0.1670)	**(0.0236)**	

Appendix XXX Pearson product moment correlations between each pair of PCB congeners from SWANSEA BAY cores (n=7). P-values are also shown in parentheses, values below 0.05 indicate significant non-zero correlations at the 95% level and are highlighted.

	CB#18	*CB#31*	*CB#28*	*CB#52*	*CB#49*	*CB#47*	*CB#44*	*CB#66*	*CB#101*	*CB#110*	*CB#151*	*CB#149*	*CB#118*	*CB#153*	*CB#105*	*CB#141*	*CB#138*	*CB#158*	*CB#187*	*CB#183*	*CB#128*	*CB#156*	*CB#180*	*CB#170*	*CB#194*
CB#18	▨																								
CB#31	0.9825 (0.0005)	▨																							
CB#28	0.9676 (0.0016)	0.9977 (<0.0001)	▨																						
CB#52	0.9840 (0.0004)	0.9806 (0.0006)	0.9708 (0.0013)	▨																					
CB#49	0.9666 (0.0017)	0.9700 (0.0013)	0.9640 (0.0019)	0.9918 (0.0001)	▨																				
CB#47	0.9558 (0.0029)	0.9761 (0.0009)	0.9752 (0.0009)	0.9900 (0.0001)	0.9919 (0.0001)	▨																			
CB#44	0.9776 (0.0007)	0.9922 (0.0001)	0.9891 (0.0002)	0.9942 (<0.0001)	0.9908 (0.0001)	0.9950 (<0.0001)	▨																		
CB#66	0.9547 (0.0030)	0.9922 (0.0001)	0.9972 (<0.0001)	0.9709 (0.0013)	0.9684 (0.0015)	0.9838 (0.0004)	0.9946 (0.0001)	▨																	
CB#101	0.9630 (0.0020)	0.9845 (0.0004)	0.9838 (0.0004)	0.9909 (0.0001)	0.9897 (0.0002)	0.9990 (<0.0001)	0.9978 (<0.0001)	0.9899 (0.0002)	▨																
CB#110	0.9420 (0.0049)	0.9878 (0.0002)	0.9958 (<0.0001)	0.9533 (0.0032)	0.9500 (0.0037)	0.9688 (0.0014)	0.9791 (0.0007)	0.9974 (<0.0001)	0.9773 (0.0008)	▨															
CB#151	0.9419 (0.0050)	0.9659 (0.0017)	0.9663 (0.0017)	0.9843 (0.0004)	0.9882 (0.0002)	0.9989 (<0.0001)	0.9894 (0.0002)	0.9782 (0.0007)	0.9963 (<0.0001)	0.9623 (0.0021)	▨														
CB#149	0.9474 (0.0041)	0.9871 (0.0003)	0.9929 (0.0001)	0.9718 (0.0012)	0.9710 (0.0013)	0.9885 (0.0002)	0.9907 (0.0001)	0.9989 (<0.0001)	0.9929 (0.0001)	0.9944 (<0.0001)	0.9851 (0.0003)	▨													
CB#118	0.9567 (0.0028)	0.9901 (0.0001)	0.9937 (0.0001)	0.9791 (0.0006)	0.9771 (0.0008)	0.9917 (0.0001)	0.9946 (<0.0001)	0.9986 (<0.0001)	0.9958 (<0.0001)	0.9925 (0.0001)	0.9877 (0.0002)	0.9994 (<0.0001)	▨												
CB#153	0.9437 (0.0047)	0.9855 (0.0003)	0.9923 (0.0001)	0.9687 (0.0015)	0.9693 (0.0014)	0.9872 (0.0002)	0.9890 (0.0002)	0.9987 (<0.0001)	0.9916 (0.0001)	0.9948 (0.0001)	0.9839 (0.0004)	0.9999 (<0.0001)	0.9989 (<0.0001)	▨											
CB#105	0.9635 (0.0020)	0.988 (0.0002)	0.988 (0.0002)	0.9877 (0.0002)	0.9805 (0.0006)	0.9952 (<0.0001)	0.9964 (<0.0001)	0.9927 (0.0001)	0.9982 (<0.0001)	0.9823 (0.0005)	0.9917 (0.0001)	0.9949 (<0.0001)	0.9971 (<0.0001)	0.9934 (0.0001)	▨										
CB#141	0.9464 (0.0042)	0.9746 (0.0010)	0.9764 (0.0008)	0.9839 (0.0004)	0.9854 (0.0003)	0.9989 (<0.0001)	0.9925 (0.0001)	0.9867 (0.0003)	0.9984 (<0.0001)	0.9737 (0.0010)	0.9988 (0.0001)	0.9921 (0.0001)	0.9938 (0.0001)	0.9911 (0.0001)	0.9961 (<0.0001)	▨									
CB#138	0.9464 (0.0042)	0.9884 (0.0002)	0.9950 (<0.0001)	0.9664 (0.0017)	0.9634 (0.0020)	0.9827 (0.0004)	0.9875 (0.0002)	0.9995 (<0.0001)	0.9887 (0.0002)	0.9973 (<0.0001)	0.09783 (0.0007)	0.9993 (<0.0001)	0.9982 (<0.0001)	0.9993 (<0.0001)	0.9924 (0.0001)	0.9870 (0.0003)	▨								
CB#158	0.9396 (0.0054)	0.9674 (0.0016)	0.9691 (0.0014)	0.982 (0.0005)	0.9835 (0.0004)	0.9982 (<0.0001)	0.9889 (0.0002)	0.9811 (0.0005)	0.9965 (<0.0001)	0.9665 (0.0017)	0.9994 (<0.0001)	0.988 0.0002	0.9899 (0.0002)	0.9869 (0.0003)	0.9937 (0.0001)	0.9994 (<0.0001)	0.9820 (0.0005)	▨							
CB#187	0.9517 (0.0034)	0.9858 (0.0003)	0.9896 (0.0002)	0.9796 (0.0006)	0.9782 (0.0007)	0.9942 (0.0001)	0.994 (0.0001)	0.9965 (<0.0001)	0.997 (<0.0001)	0.989 (0.0002)	0.9917 (0.0001)	(0.9989) (<0.0001)	0.9994 (<0.0001)	0.9983 (<0.0001)	0.9978 (<0.0001)	0.9966 (<0.0001)	0.9968 (<0.0001)	0.9937 (0.0001)	▨						
CB#183	0.9538 (0.0032)	0.9815 (0.0005)	0.983 (0.0004)	0.9858 (0.0003)	0.9842 (0.0004)	0.9982 (<0.0001)	0.9951 (<0.0001)	0.9911 (0.0001)	0.9992 (<0.0001)	0.9797 (0.0006)	0.9967 (<0.0001)	(0.9950) (<0.0001)	0.9967 (<0.0001)	0.9939 (0.0001)	0.9984 (<0.0001)	0.9993 (<0.0001)	0.9911 (0.0001)	0.9978 (<0.0001)	0.9985 (<0.0001)	▨					
CB#128	0.9471 (0.0041)	0.9858 (0.0003)	0.9913 (0.0001)	0.9723 (0.0011)	0.9698 (0.0014)	0.9889 (0.0002)	0.9902 (0.0001)	0.9972 (<0.0001)	0.9933 (0.0001)	0.9913 (0.0001)	0.9857 (0.0003)	(0.9990) (<0.0001)	0.9985 (<0.0001)	0.9988 (<0.0001)	0.9962 (<0.0001)	0.9981 (0.0001)	(0.9981) (<0.0001)	0.9892 (0.0002)	0.9984 (<0.0001)	0.9953 (<0.0001)	▨				
CB#156	0.9602 (0.0023)	0.9898 (0.0002)	0.9918 (0.0001)	0.9828 (0.0004)	0.9776 (0.0007)	0.9931 (0.0001)	0.9954 (<0.0001)	0.9962 (<0.0001)	0.9970 (<0.0001)	0.9879 (0.0002)	0.9891 (0.0002)	(0.9976) (<0.0001)	0.9988 (<0.0001)	0.9967 (<0.0001)	0.9992 (<0.0001)	0.9948 (<0.0001)	(0.9960) (<0.0001)	0.9916 (0.0001)	0.9968 (<0.0001)	0.9976 (<0.0001)	0.9987 (<0.0001)	▨			
CB#180	0.9557	0.9898	0.9936	0.9785	0.9764	0.9916	0.9943	0.9985	0.9957	0.9923	0.9877	(0.9995)	0.9999	0.999	0.9973	0.9939	(0.9983)	0.9900	0.9995	0.9968	0.9990	0.9991	▨		

	CB#18	CB#31	CB#28	CB#52	CB#49	CB#47	CB#44	CB#66	CB#101	CB#110	CB#151	CB#149	CB#118	CB#153	CB#105	CB#141	CB#138	CB#158	CB#187	CB#183	CB#128	CB#156	CB#180	CB#170	CB#194
	(0.0029)	**(0.0002)**	**(0.0001)**	**(0.0007)**	**(0.0008)**	**(0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(0.0001)**	**(0.0002)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(0.0001)**	**(<0.0001)**	**0.0001**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**			
CB#170	**0.9379**	**0.9748**	**0.9797**	**0.9759**	**0.9783**	**0.9956**	**0.9896**	**0.9908**	**0.9960**	**0.9812**	**0.9957**	**(0.9958)**	**0.9960**	**0.9953**	**0.9949**	**0.9986**	**(0.9920)**	**(0.9973)**	**0.9983**	**0.9985**	**0.9953**	**0.9951**	**0.9960**		
	(0.0057)	**(0.0009)**	**(0.0006)**	**(0.0009)**	**(0.0007)**	**(<0.0001)**	**(0.0002)**	**(0.0001)**	**(<0.0001)**	**(0.0005)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**0.0001**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**		
CB#194	**0.9446**	**0.9581**	**0.9547**	**0.9865**	**0.9871**	**0.9955**	**0.985**	**0.9654**	**0.9919**	**0.9446**	**0.9964**	**(0.9732)**	**0.9775**	**0.9713**	**0.9873**	**0.9935**	**(0.9650)**	**(0.9954)**	**0.9823**	**0.9907**	**0.9768**	**0.9828**	**0.978**	**0.9864**	
	(0.0045)	**(0.0026)**	**(0.0030)**	**(0.0003)**	**(0.0002)**	**(<0.0001)**	**(0.0003)**	**(0.0018)**	**(0.0001)**	**(0.0045)**	**(<0.0001)**	**0.0011**	**(0.0008)**	**(0.0012)**	**(0.0002)**	**(0.0001)**	**0.0018**	**(<0.0001)**	**(0.0005)**	**(0.0001)**	**(0.0008)**	**(0.0004)**	**(0.0007)**	**(0.0003)**	

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