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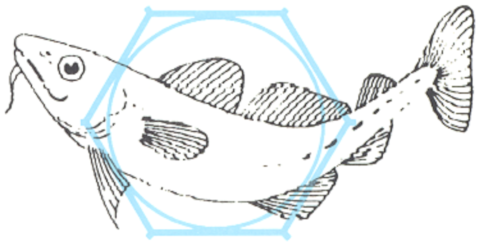

Benthic Studies at Dredged Material Disposal Sites in Liverpool Bay

H.L. Rees, S.M. Rowlatt, D.S. Limpenny,
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Directorate of Fisheries Research
Lowestoft, 1992

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
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CONTENTS

SUMMARY

Studies of the sediments and benthic fauna at dredged material disposal sites in inner Liverpool Bay were conducted between 1974 and 1988.

Dredged material arises mainly from 'maintenance' dredging within the Mersey estuary and its approaches, and consists of sands and muds. The material typically contains elevated levels of organic carbon and certain trace metals, relative to background conditions in the locality.

Contrary to expectation, there was no evidence of a widespread area of faunal impoverishment in the immediate vicinity of the disposal site, even at high disposal rates (several million tonnes per annum) in the early 1970s.

Newly deposited sediment is rapidly recolonised by the larger 'opportunistic' species, notably the polychaetes *Pectinaria* and *Lanice*, and the bivalve *Abra*, which are characteristic of soft sediments of the inner bay area. As a result, the main effect of disposal appears to be one of enhancement in numbers. This may occur both as a result of larval recruitment, or redistribution of adults. It is also probable that, once established, populations on the periphery of the disposal site can survive repeated additions of migrating dredged material.

On cessation of disposal at one of the two sites investigated, a *Pectinaria*-dominated fauna, associated with muddier sediments resulting from the disposal practice, was rapidly replaced by a sparser fauna typical of sandier sediments in the area. Thus, there did not appear to be any lasting impact on the benthos arising from earlier dredgings disposal.

High dominance by *Pectinaria* and *Abra* provided a good indication of the presence of muddy dredged material. However, similar population structures were also encountered in the transient mud deposits off the mouth of the Mersey.

Enhanced benthic counts may be a consequence of the stabilising or nutritional properties of the dispersing dredged material. There was no evidence of a chemical inhibitory effect, associated with elevated levels of contaminants.

Core profiles of muddy sediment at the disposal site showed that these were anoxic at depth, and comparable with a site of natural mud deposition some distance to the south. Animals were confined to the oxic surface layer. There was some evidence for an earlier burial of a *Pectinaria* assemblage as a result of dredgings disposal.

The epifauna from trawl samples mirrored the enrichment gradient associated with finer sediments in the direction of the Mersey mouth. This may have been due to efflux of organic matter from the estuary, though dispersing dredged material may also have had a contributory effect. The fauna at the disposal site was characterised by a reduction in percentage dominance of the first-ranked species; there was no evidence of a reduction in the number of species encountered.

1. INTRODUCTION

About 3 million wet tonnes of sediment, arising from a continual process of dredging of navigational channels in the Mersey estuary and its approaches, are presently disposed of in Liverpool Bay, the bulk going to a site located to the north of the estuary mouth ('new' site Z, Figure 1). Disposal at this site commenced in 1982 because of shoaling at the previous location, which probably occurred as a result of an accumulation of sand deposited there. The 'old' site was again used in the period 1984-85, but has not been used since. The nature of the dredged material ranges from sand to mud, depending on origin, but overall percentages are approximately 70 and 30 respectively.

Quantities of dredgings disposed of at these sites have declined considerably in the past 30 years or so, with nearly a ten-fold reduction between 1955 and 1988, due mainly to altered dredging practices (Figure 2).

The other designated site (site 'Y', Figure 1) is used at discrete intervals for the disposal of dredgings from 'capital' projects (e.g. new harbour construction). In recent years, the quantities deposited at this site have typically amounted to less than 5% of the totals for Liverpool Bay as a whole.

Surveys, in 1984 and 1985, of the physical properties of sediments, trace metal concentrations and the benthic macrofauna, were reported in Rowlatt *et al.* (1986). Some earlier data were also reported in Norton *et al.* (1984), though the main concern of the latter account was with sewage-sludge disposal (see Figure 1 for location of site).

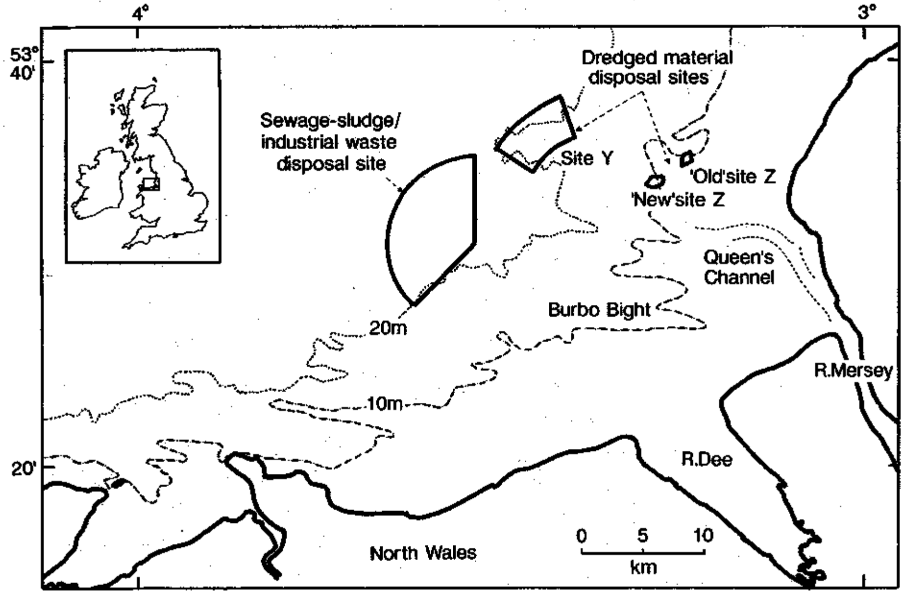

Figure 1. ***Location of sites for disposal of dredged material. The site for the disposal of sewage sludge and industrial waste is also shown***

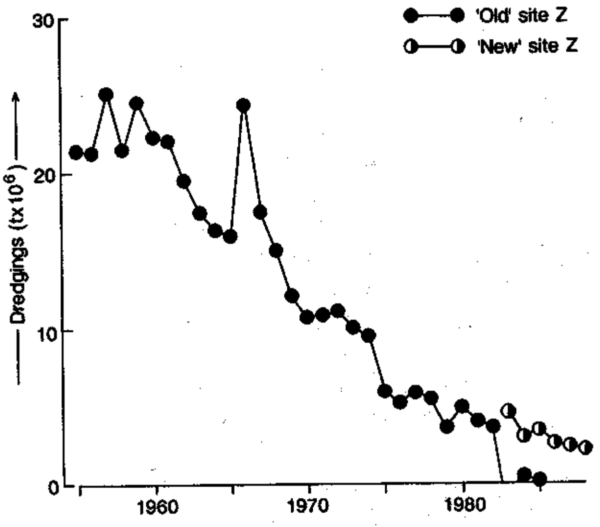

Figure 2. ***Disposal of dredgings at site Z between 1955 and 1988 (source: Agar and McDowell, 1971; Acting Conservator of the River Mersey, 1960-87)***

The purpose of this report is to provide a synthesis of surveys conducted in the period 1974 to 1988 in the vicinity of the 'old' site Z and 'new' site Z, with the emphasis on biological findings. In the light of some of the variation in techniques used for benthic surveys during this time, all of which were *spatial* in emphasis, it is important to highlight the two main objectives of the biological component of this work. These were as follows:

(i) to examine the responses of populations of the larger benthic species to dredged material disposal; and

(ii) to identify their spatial extent.

As will be shown, an intuitive expectation that sediments in the immediate vicinity of the disposal site would be devoid of animal life was not borne out by these surveys.

2. MATERIALS AND METHODS

Soft sediments (ranging from sand to mud) are found in the area of the disposal sites, and these have been sampled using a 0.1 m^2 Day grab and Tennant box-corer. All surveys were conducted in the months of September or October. Sub-samples of the surface 1-2 cm layer of sediment from each grab were retained for later analyses of trace metal content, but in most surveys the benthic fauna were examined in the field, on sieve meshes ranging from 1 to 5 mm (see Section 4). This work was complemented by visual observations of sediment type, including the presence of dredged material and mud-lumps.

Tennant box-core samples were used to examine the vertical distribution of benthic organisms. This involved sectioning 8 cm diameter sub-cores at 1 or 2 cm intervals, followed by fixing in 5% formaldehyde in sea water prior to identification and enumeration in the laboratory of the benthos retained on a 0.5 mm mesh sieve.

Complementary Eh readings were taken by inserting a 5 mm diameter platinum electrode in a horizontal plane through a series of holes bored at 1 cm intervals along an 8 cm diameter sub-core of sediment. Readings were taken 60 s after insertion of the electrode.

The epifauna were sampled using a standard Lowestoft 2 m beam trawl with fine-mesh (3 mm) cod-end liner (see Riley *et al.*, 1986). Animals were identified and enumerated on deck over a 5 mm mesh screen.

Cluster analyses of the macrofaunal data were carried out after log-transformation ($\log_e x + 1$), and employed squared Euclidean distance as a measure of inter-station affinities and average-linkage as the sorting method (Lance and Williams, 1967).

Methods for the determination of trace metal concentrations in sediments followed those of Harper *et al.* (1989).

3. RESULTS

3.1 Physico-chemical characteristics of the area

The disposal sites are located in shallow water of about 10 m depth, and the entire area is highly dispersive in character. Tidal currents of up to 0.8 m s^{-1} run approximately along an east-west axis nearby (Admiralty: Great Ormes Head to Liverpool, Chart No. L(D3) 1978), but their direction is likely to be modified by a tongue of mobile sand which divides the two disposal sites.

Sediments are particularly vulnerable to disturbance by waves generated from north-westerly winds and, coupled with a net south-easterly residual current in the inner bay area (Ramster and Hill, 1969), a tendency for transport of a proportion of the dredged material towards the mouth of the Mersey can be anticipated.

Observations on the distribution of mud-lumps in 1985 (see Rowlatt *et al.*, 1986) confirmed the active transport of fine material in the general vicinity of the disposal site, at least a proportion of which would be likely to be derived from dredged material.

Another relevant feature is the presence, and variable extent, of a patch of fine material off the mouth of the Mersey (Norton *et al.*, 1984). This feature can lead to difficulty in isolating an imprint of muddy dredgings at the disposal site.

Rowlatt (1988) suggested that a single population of fine material was present in the Mersey estuary. The trace metal burden of sediments from different locations was a function of the *quantity* of fine material present, rather than an indication of the variability in the *concentration* of fine particle-bound contaminants. Recent evidence suggests that this finding may also apply to the whole of inner Liverpool Bay, and this would have implications for assessments of contaminant transfer and any effects on the biota arising from dredgings disposal.

3.2 The effect of dredged material disposal at 'old' site Z

The results of a survey of sediments conducted in the vicinity in 1977 (Norton *et al.*, 1984) showed elevations in organic carbon content and trace metal burdens. These provided a clear imprint of dredged material at, and just to the south of, the disposal site.

Figure 3 shows a time-series of observations on the benthos and sediments between 1974 and 1988. Abundances are expressed on a logarithmic scale and the percentage contributions of the two polychaetes *Pectinaria* and *Lanice* are superimposed. While the use of different mesh sizes precludes detailed quantitative comparisons, some useful conclusions can be drawn.

First, in the early years at a time of high rates of dredged material disposal, a clear mud imprint was identifiable, and this was occupied mainly by high densities of *Pectinaria*. Sandy areas to the west were typically sparsely populated.

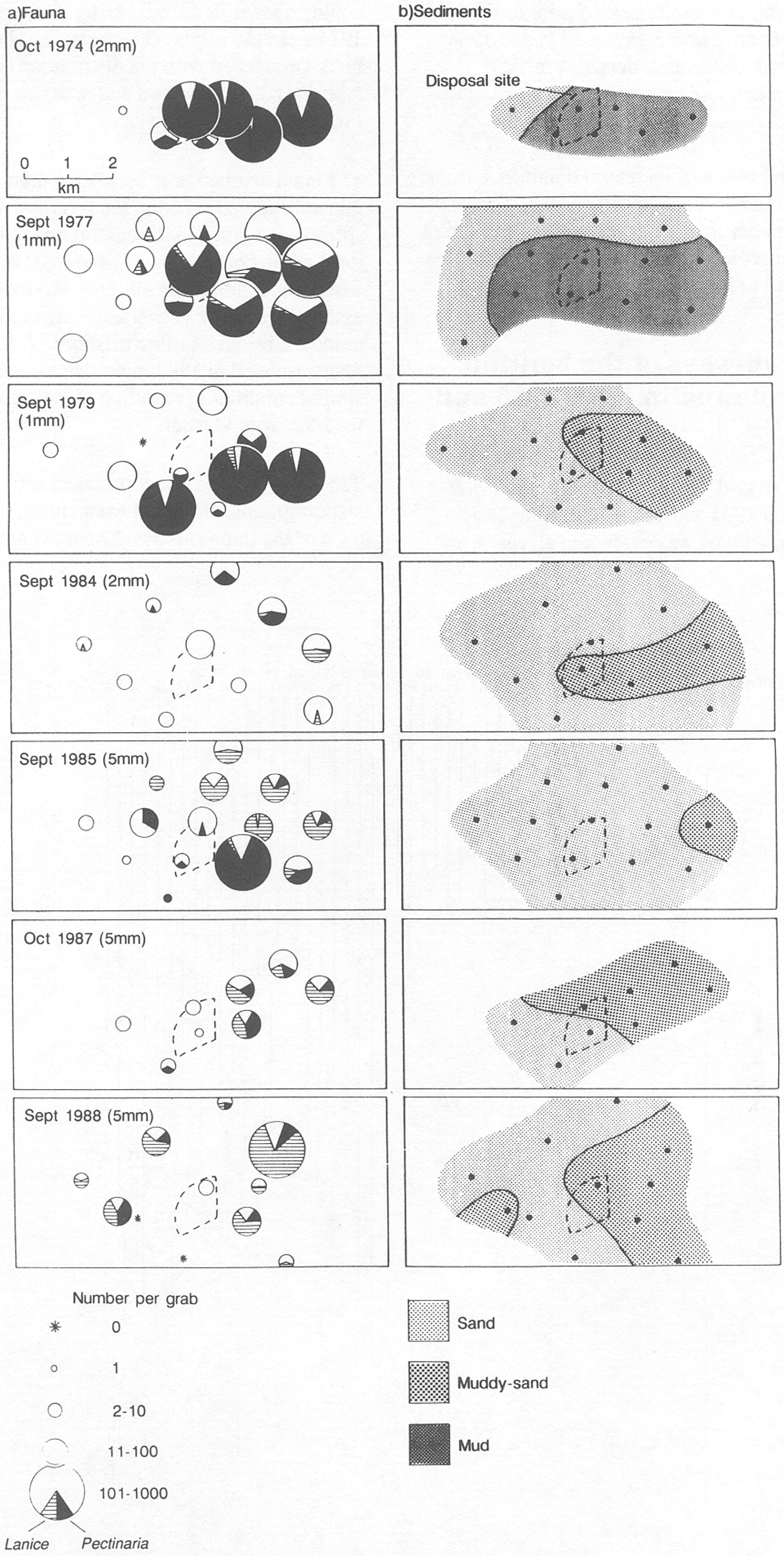

Figure 3. ***Distribution of (a) animal counts in relation to (b) sediments. Disposal in quantity at this site ceased just prior to the 1984 survey***

Second, disposal in quantity ceased prior to the 1984 survey, and a comparison between 1974 and 1984 shows much reduced overall densities in 1984. *Pectinaria* is much less numerous in this and subsequent surveys.

Third, the trend is one of increased dominance of the polychaete *Lanice*, which appears to favour areas of muddy sand, rather than the muds within which high counts of *Pectinaria* were found. These preferences will be referred to later in this report.

3.3 Grid surveys of the benthic macrofauna in 1984, 1985 and 1988

Three extensive grid surveys of the area were conducted between 1984 and 1988. The same basic division in faunal type was evident in all cases, and could be identified from cluster analyses, of which the 1984 example is typical (Figure 4). These can be broadly matched with the distribution of substrate types (sand, muddy sand and mud), as shown in Figure 5.

The main distinction is between a muddy sand or mud fauna mostly confined to the south west, and a widespread sand fauna in the central and northern parts. A third group comprises one or more stations at the eastern end, present in all three surveys, with a species assemblage which is characteristic of more stable muddy substrates further offshore. A fourth assemblage, isolated in 1988, provides a useful indication of similar conditions prevailing at the disposal site and in the Mersey mud patch.

Table 1 shows the five top-ranked taxa within station-groups, identified from cluster analyses, for each of the three surveys. The most notable distinction

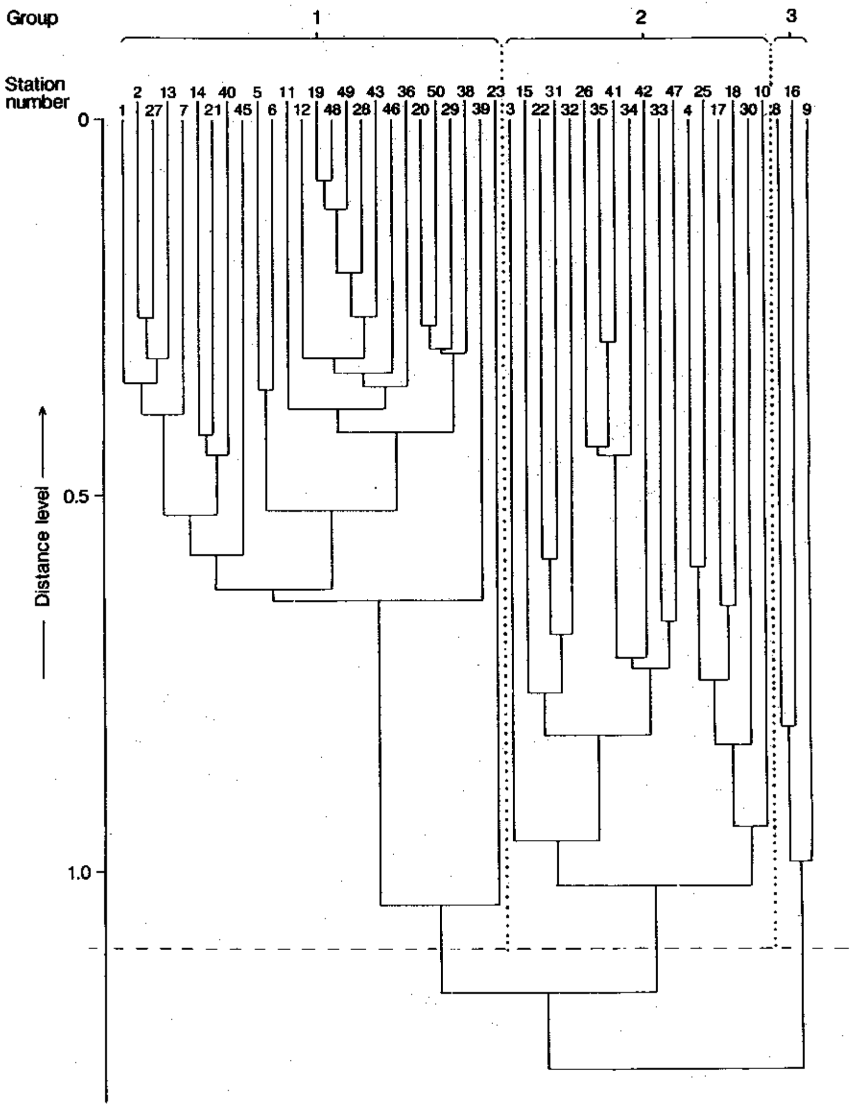

Figure 4. Dendrogram showing the similarity between stations sampled in 1984 (log-transformed data; squared Euclidean distance; average-linkage sorting)

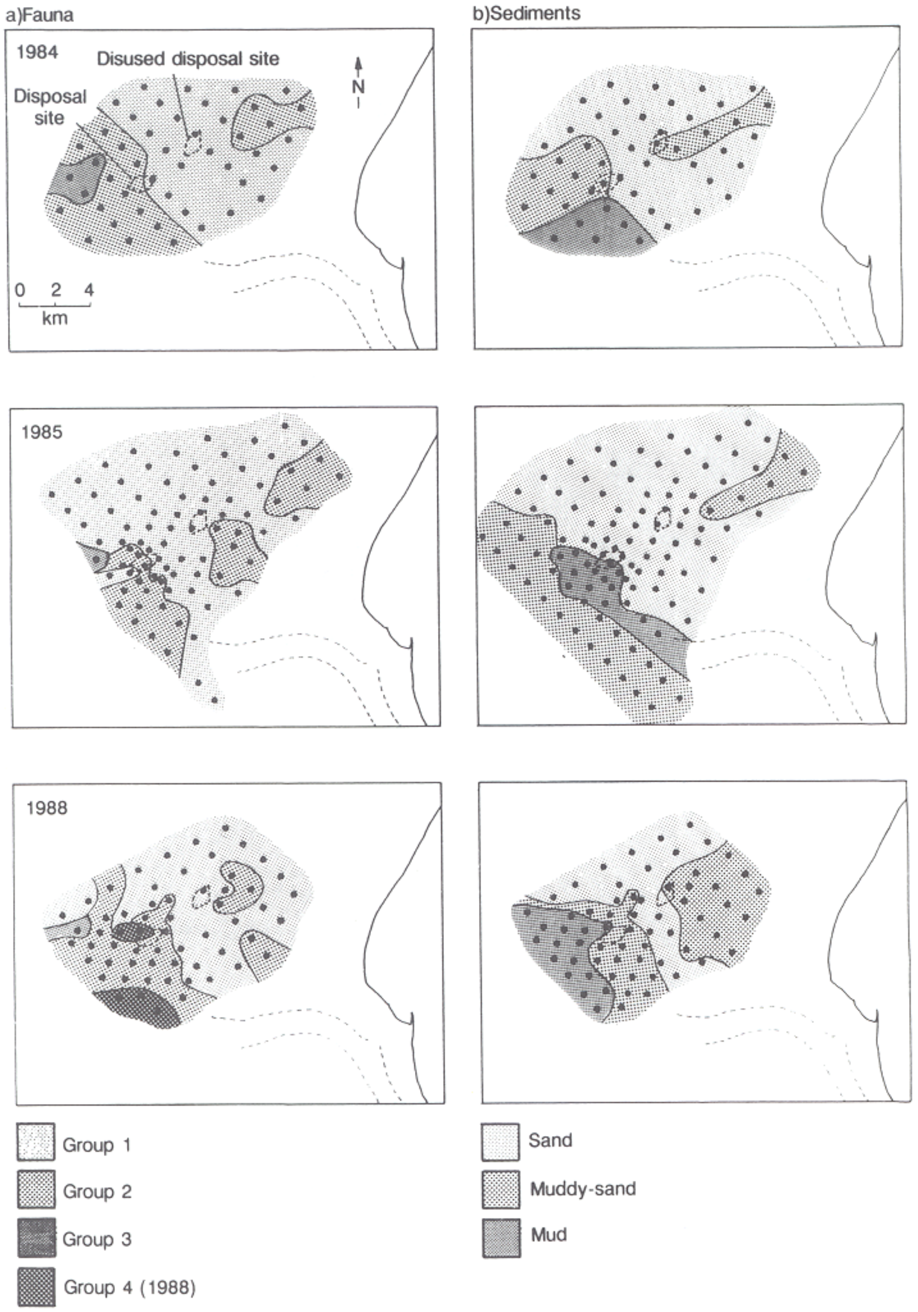

Figure 5. Distribution of (a) faunal assemblages from cluster analyses, and (b) sediments

is between the low counts and patchy occurrence in the sandy areas, and the high counts associated with muddy sand or mud. While *Pectinaria*, *Lanice* and *Abra* are prominent in both associations, the sandy association can be further characterised by the frequent presence, albeit in low numbers, of typical sand-dwellers such as the bivalves *Tellina fabula* and *Ensis* sp.

The occurrence in high numbers of the burrowing anemone *Edwardsia* sp. in only the 1984 muddy assemblage 2 can be attributed to the smaller (2 mm) mesh size used. Otherwise, a notable feature is the increase in numerical dominance of *Lanice* in 1988. In the light of this feature, the fourth assemblage identified in 1988 is of special interest, because of the low abundance of *Lanice*. In this respect, it mirrors the 1984 and 1985 muddy assemblages, where *Lanice* was not a dominant member and, as shown in Figure 5, comprises sites in close proximity to the disposal site, as well as those near to the mouth of the Mersey.

Assemblage 3 is characterised by the prominence of the polychaete *Owenia fusiformis* and the brittle-star *Amphiura filiformis*. The tendency for these animals to be confined to the eastern end of the survey area is shown in Figure 6.

Table 1. ***The five top ranked taxa in faunal assemblages identified from cluster analyses ($\bar{\chi}$ per grab). A 2 mm mesh sieve was employed in 1984, and a 5 mm mesh sieve in 1985 and 1988***

Year	Assemblage 1				Assemblage 2			
	Rank	Taxon	$\bar{\chi}$	Freq	Rank	Taxon	$\bar{\chi}$	Freq
				n=26				n=18
1984	1	*Abra alba*	7	12	1	*Pectinaria koreni*	113	18
	2	*Pectinaria koreni*	3	12	2	*Abra alba*	105	18
	3	*Nephtys* spp.	2	24	3	*Edwardsia* sp.	11	10
	4	*Ensis* sp.	1	14	4	*Mactra corallina*	7	15
	5	*Lanice conchilega*	1	10	5	*Cultellus pellucidus*	7	17
				n=59				n=25
1985	1	*Lanice conchilega*	8	37	1	*Pectinaria koreni*	48	25
	2	*Pectinaria koreni*	4	35	2	*Abra alba*	22	25
	3	*Ensis* sp.	1	36	3	*Mactra corallina*	3	16
	4	*Echinocardium cordatum*	1	18	4	*Lanice conchilega*	3	11
	5	*Tellina fabula*	1	4	5	*Nephtys* spp.	1	14
				n=28				n=26
1988	1	*Pectinaria koreni*	3	14	1	*Pectinaria koreni*	65	26
	2	*Lanice conchilega*	2	15	2	*Lanice conchilega*	55	26
	3	*Ensis* sp.	1	13	3	*Abra alba*	5	16
	4	*Abra alba*	1	6	4	*Nucula turgida*	4	21
	5	*Echinocardium cordatum*	1	12	5	*Amphiura filiformis*	3	10
Year	**Assemblage 3**				**Assemblage 4**			
	Rank	Taxon	$\bar{\chi}$	Freq	Rank	Taxon	$\bar{\chi}$	Freq
				n=3				
1984	1	*Pectinaria koreni*	35	2		(Not identified from cluster analysis)		
	2	*Edwardsia* sp.	31	3				
	3	*Amphiura filiformis*	25	3				
	4	*Owenia fusiformis*	25	3				
	5	*Nucula turgida*	4	2				
				n=1				
1985	1	*Pectinaria koreni*	30			(Not identified from cluster analysis)		
	2	*Owenia fusiformis*	10					
	3	*Abra alba*	5					
	3	*Amphiura filiformis*	5					
	5	*Acanthocardia echinata*	2					
	5	*Ophiura* sp.	2					
				n=1				n=5
1988	1	*Amphiura filiformis*	38		1	*Pectinaria koreni*	158	5
	2	*Pectinaria koreni*	14		2	*Abra alba*	40	5
	3	*Owenia fusiformis*	5		3	*Nucula turgida*	6	4
	4	*Echinocardium cordatum*	4		4	*Pharus legumen*	2	3
	5	*Nephtys* spp.	2		5	*Mactra corallina*	1	3
	5	*Notomastus latericeus*	2					
	5	*Acanthocardia echinata*	2					

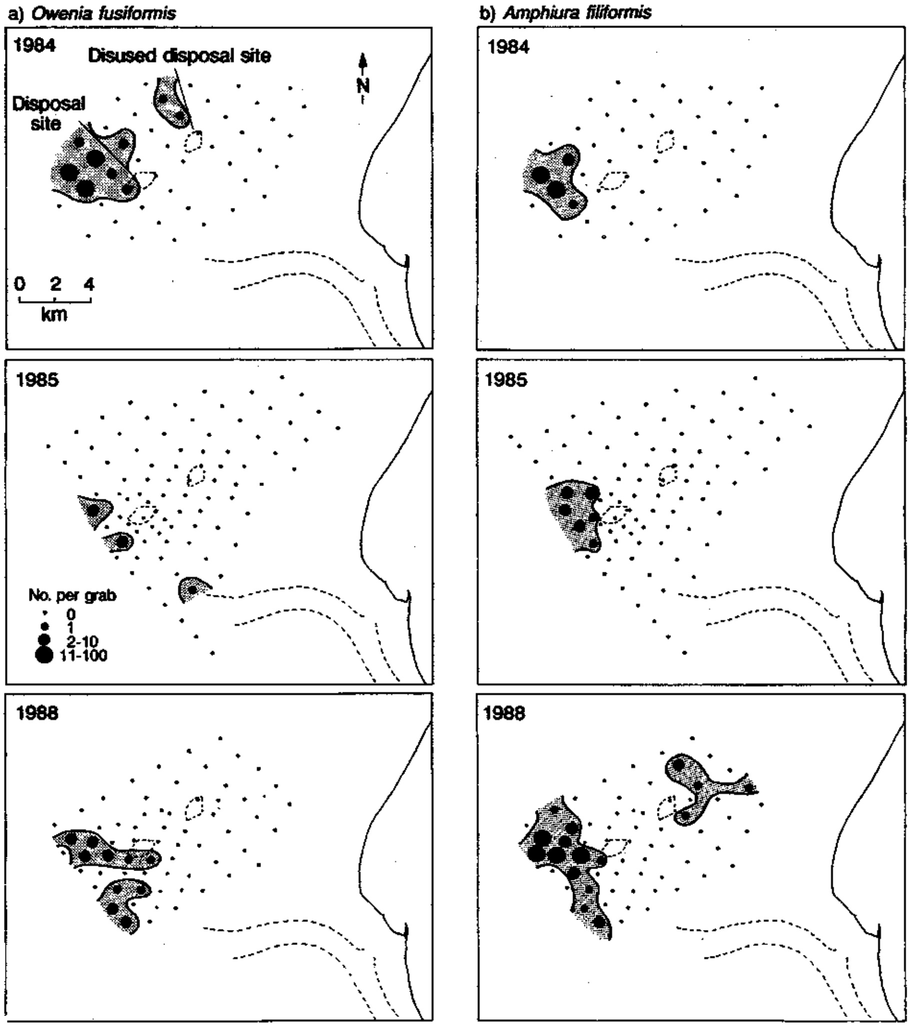

Figure 6. ***Distribution of (a) Owenia fusiformis, and (b) Amphiura filiformis. (Contours define zones of occurrence)***

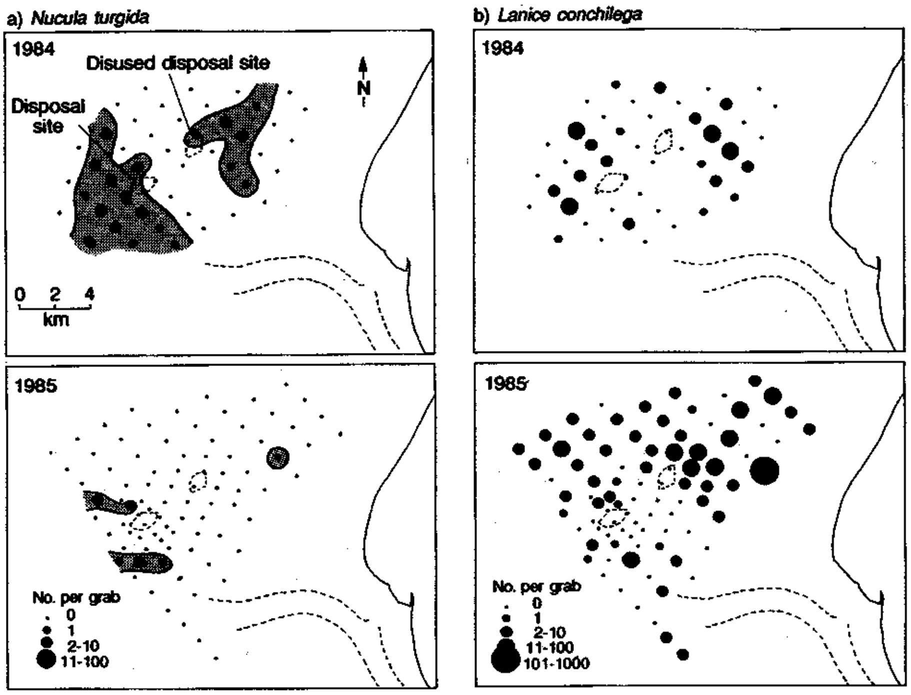

Figure 7. ***Distribution of (a) Nucula turgida, and (b) Lanice conchilega. (For the former species, contours define zones of occurrence)***

Figure 7. Continued

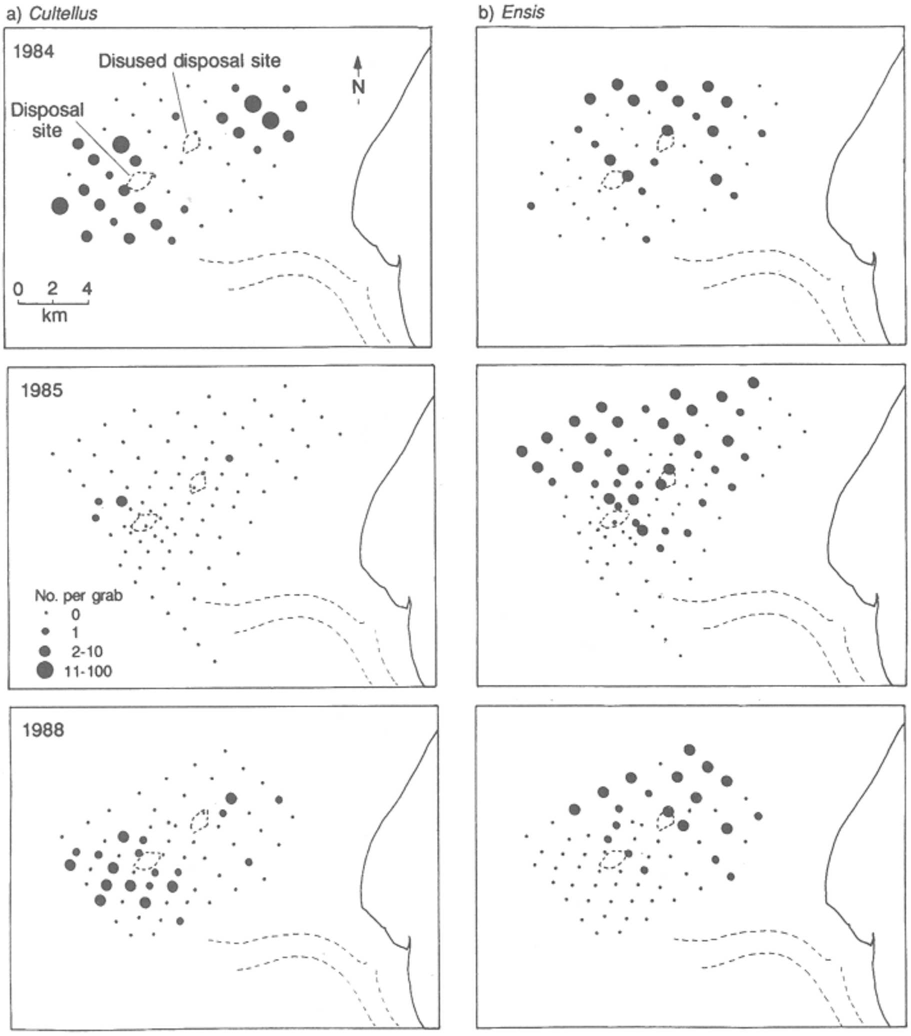

Figure 8. Distribution of (a) Cultellus pellucidus, and (b) Ensis sp.

The distribution of *Nucula turgida* (Figure 7a) provides a useful means of distinguishing muddy from sandy conditions. This is also true for the distribution of the razor shells *Cultellus pellucidus* and *Ensis* sp. (Figure 8), the latter showing a clear preference for sandier substrates as noted by Tebble (1976).

The tendency for high abundances to be associated with muddier substrates, including the area of active dredgings disposal, is shown in Figure 9(a), which again expresses counts on a logarithmic scale, and includes the proportional contribution of *Pectinaria* and *Abra*. High dominance by one or both of these species occurred to the south of the disposal site. This pattern was also evident in 1985 (Figure 9(b)). Here, there is no suggestion of an overlap with the Mersey mud-patch. Overall, the abundances were lower than those in 1984 and this may be ascribed, at least in part, to the use of a larger (5 mm) mesh size in 1985.

In the 1988 survey (Figure 9(c)), which also employed a 5 mm mesh sieve, high abundances were again found

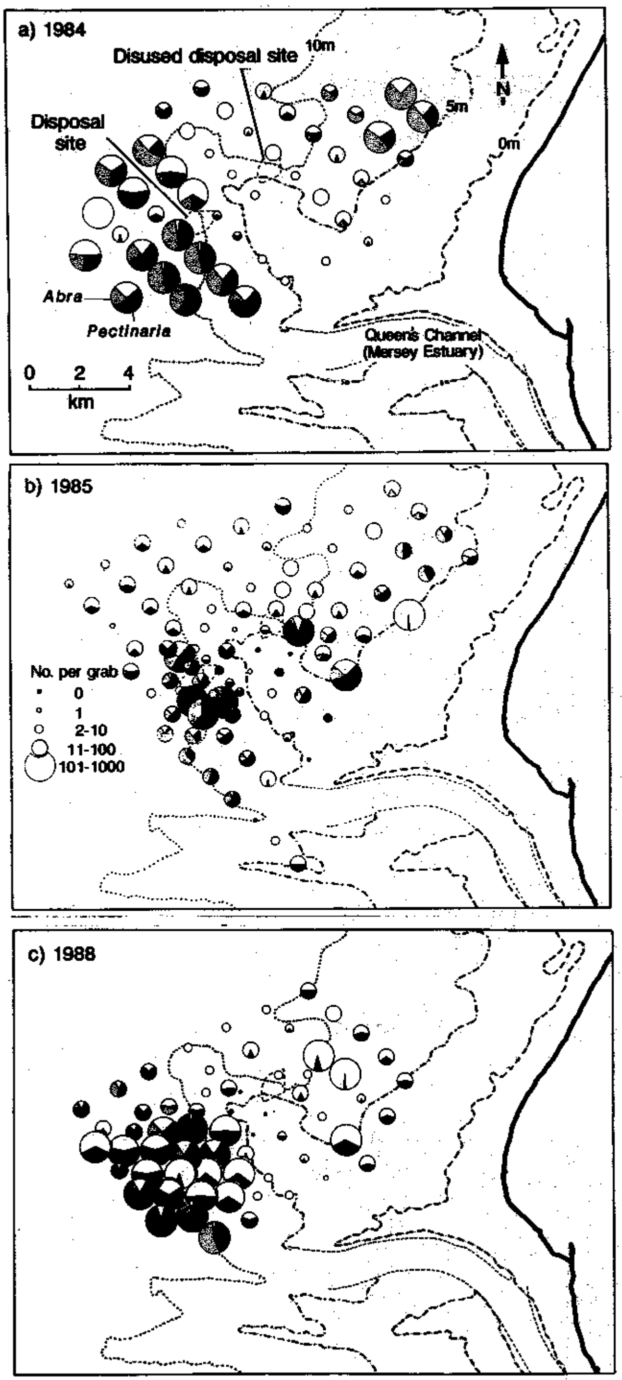

Figure 9. Distribution of Pectinaria and Abra (a) in 1984, (b) in 1985 and (c) in 1988

throughout the area of muddy sand. A high proportional contribution of these two species was evident in the immediate vicinity of the disposal site, and in the vicinity of the Mersey mud-patch.

The fact that the dominance by *Pectinaria* and *Abra* was not so great at a number of sites, when compared with previous years, is also clear. This was due to the incursion of *Lanice* which, as can be seen from Figure 7(b), had notably increased in abundance and provided a means of distinguishing between areas of muddy sand and the muddier sites characterised by high densities of the two species.

3.4 Vertical distribution of macrofauna in 1985 and 1987, from core samples

The vertical distribution of macrofauna at the disposal site was determined by sectioning 8 cm core subsamples from a Tennant box-corer at 1 or 2 cm intervals, and then examining the biota retained on a 0.5 mm mesh sieve.

The results for 1985 (Figure 10) show that colonisation was confined to surface layers but, at a depth of about 12 cm, moribund specimens of certain crustacean species were found. These are characteristic inhabitants at the surface of sandy sediments at outer-estuary locations, and therefore appear to be associated with deposited dredged material. The presence of live animals in surface layers, which are typical of 'background' conditions in the vicinity, demonstrates relatively rapid recolonisation within the disposal site.

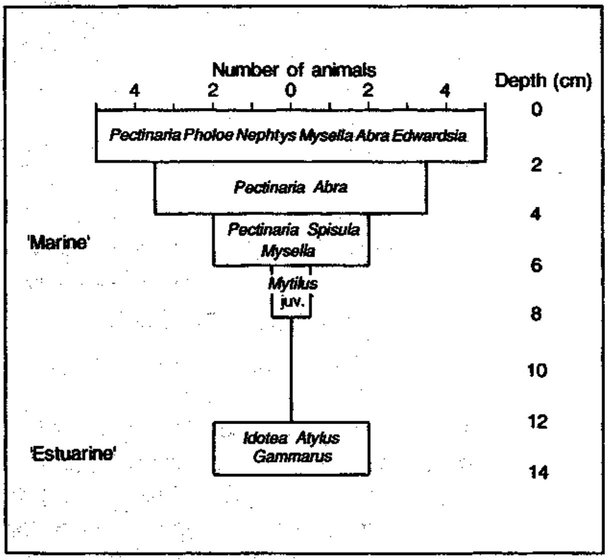

Figure 10. Vertical distribution of animals at site Z

In 1987, vertical distribution was examined in relation to Eh, as an expression of oxidising or reducing conditions in sediments. The comparison in Figure 11 is between a station at the centre of the disposal site and a station in the Burbo Bight, to the south. In both cases, Eh values show a rapid decline to reducing conditions beneath the surface layer. Counts of benthic organisms at site Z also show a correspondingly rapid decline with depth. Counts of *Pectinaria* tubes provide evidence for prior burial of a live assemblage by dredged material; there is a second peak in abundance below about 12 cm depth.

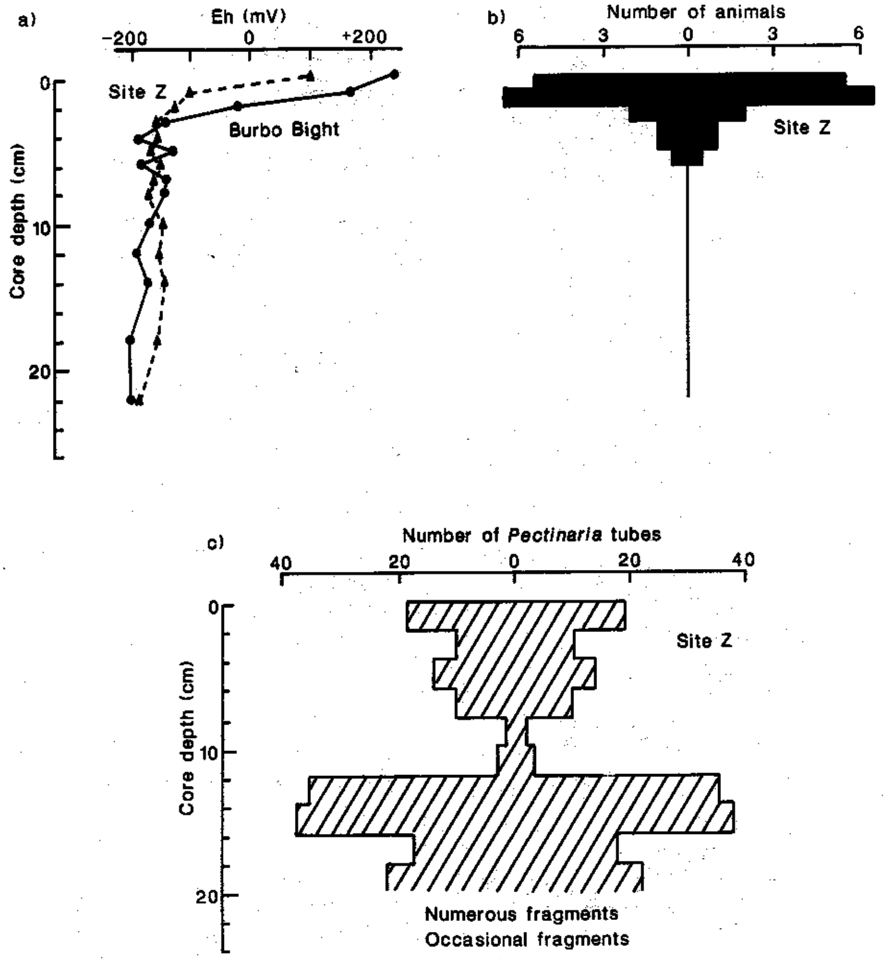

Figure 11.* *Vertical distribution of (a) Eh values, (b) live animals, and (c) Pectinaria tubes

3.5 Sampling by two-metre beam trawl in 1985 and 1987

Evidence of an 'enrichment' gradient in a north-south direction through the disposal site is supported by beam trawl samples taken in 1985 and 1987 (Figure 12). The trend southwards is one of a marked increase in numbers and dominance, notably by the brittle star *Ophiura* spp., the predatory mollusc *Philine aperta* and the starfish *Asterias rubens* (Tables 2 and 3). This trend can be expressed graphically by means of 'k-dominance' curves (Figure 13), where the proportional contributions of taxa to the total sample count are plotted cumulatively against their rank (see Lambshead *et al.*, 1983). Curves at the disposal site take an intermediate shape, suggesting that the epifauna from these samples were not noticeably influenced by dredgings disposal.

However, it appears that in both years the percentage dominance of the top-ranked species was reduced, as can be seen from the manner in which curves C and C' cross over those for northern sites B and B' between taxon rank 1 and 2 (Figure 13). The total number of taxa present at the disposal site was not significantly reduced, as can be deduced from the lateral extent of curves C and C', relative to the other curves.

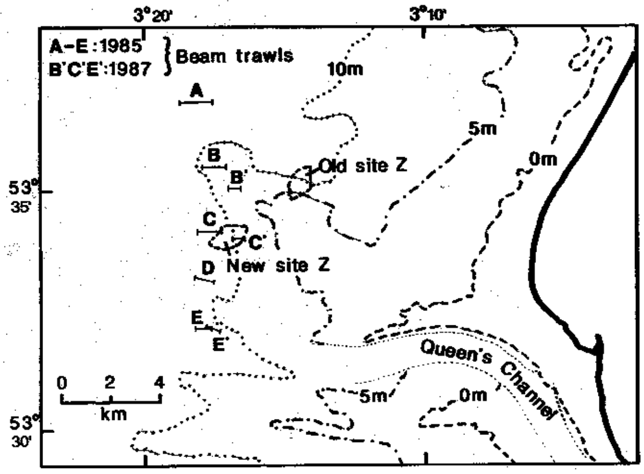

Figure 12.* *Location of beam trawl sites in 1985 and 1987

Of the three dominant taxa to the south of the disposal site, the brittle star *Ophiura* feeds unselectively on small benthic organisms and on detritus, while *Philine* burrows in sand for a similar range of benthic species. Both are preyed upon by flatfish such as dab and sole which are common in the area.

Table 2. Summary statistics for beam trawls sampled in 1985 and 1987

(a) 1985 (10-minute beam trawls)

	A	B	C	D	E
Total taxa	18	22	18	16	16
Total abundance	328	403	6 790	19 540	34 570
H'	1.94	1.68	1.50	0.97	0.31
Dominance (%)	44	60	44	73	94

(b) 1987 (5-minute beam trawls)

	B'	C'	E'
Total taxa	15	19	14
Total abundance	92	673	4 168
H'	2.05	1.73	0.89
Dominance (%)	39	37	77

Table 3. The three top-ranked taxa from beam trawls sampled in 1985 and 1987

(a) 1985 (10-minute beam trawls)

A	No.	B	No.	C	No.	D	No.	E	No.
Pomatoschistus sp.	144	*Ophiura* spp.	240	*Ophiura* spp.	2 976	*Ophiura* spp.	14 208	*Ophiura* spp.	32 384
Ophiura spp.	41	*Pomatoschistus* sp.	45	*Philine aperta*	2 144	*Philine aperta*	3 072	*Philine aperta*	1 024
Asterias rubens	36	*Callionymus lyra*	17	*Asterias rubens*	800	*Asterias rubens*	1 032	*Asterias rubens*	827

(b) 1987 (5-minute beam trawls)

B'	No.	C'	No.	E'	No.
Asterias rubens	36	*Philine aperta*	250	*Ophiura* spp.	3 200
Liocarcinus spp.	16	*Crangon* spp.	170	*Philine aperta*	480
Solea solea	8	*Liocarcinus* spp.	124	*Asterias rubens*	168

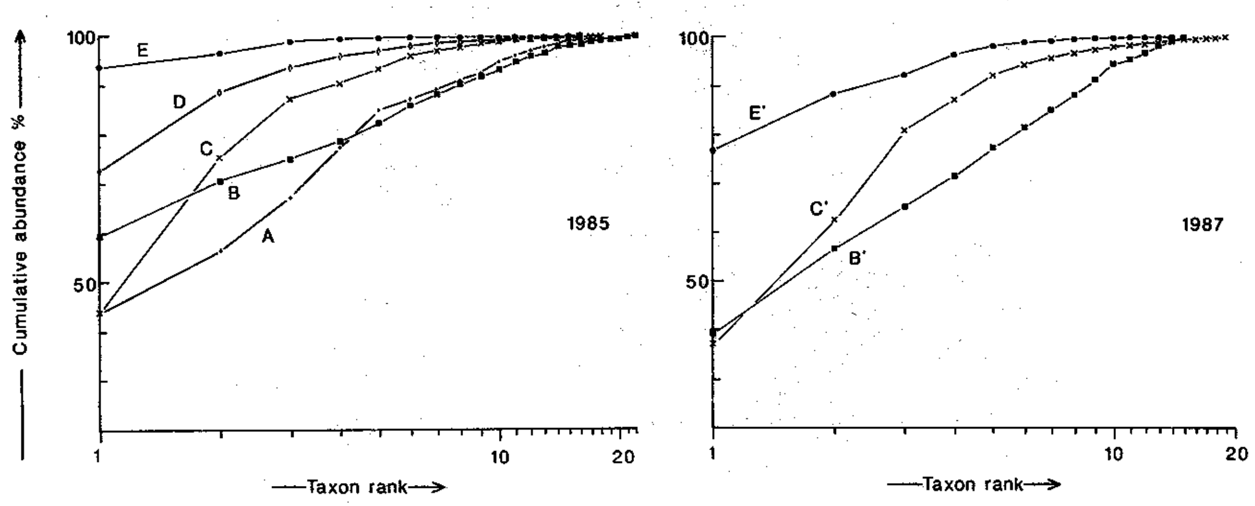

Figure 13. 'k-dominance' curves for the epifauna from beam trawls sampled in 1985 and 1987

4. DISCUSSION

4.1 Effects of mesh size on interpretation of benthos data

The use of larger mesh sizes for the macrofauna could be justified because of the known importance to community structure in this vicinity of relatively few larger and fast-growing species, notably the polychaete *Pectinaria koreni*, and the bivalve *Abra alba*, both deposit feeders, and the suspension-feeding polychaete *Lanice conchilega* (Rees *et al.*, 1976; Eagle, 1975; Rees and Walker, 1983).

Figure 14(a-c) illustrates vertical profiles of these species in sediments. The long and ramifying tubes of *Lanice* tend to stabilise sediments, while the deposit-feeders *Pectinaria* and *Abra* are prodigious bioturbators (see Eagle, 1975) and as such do not contribute to sediment stability. It is also evident, from Figure 14(a), that *Lanice* can survive repeated additions of settling material at the sea bed, through upward burrowing and tube-building activity (Schafer, 1972; Ziegelmeier, 1978).

Since it was anticipated that the immediate local effect of dredgings disposal would be physical blanketing of bottom sediments, the local absence of these otherwise widespread and easily recognisable species would provide a clear indication of change. The use of large mesh sizes also had the advantage of permitting rapid processing of samples on site. It was justified on this basis alone, and precluded both quantitative assessment of the immediate recolonisation phase and any effects on small-sized species. (These aspects will be reported separately: H. L. Rees *et al.*, in preparation).

Table 4. ***Retention of macrofauna on 1 mm and 5 mm mesh sieves. (N is the total count for all species)***

Station	N (1 mm mesh)	% retention on 5 mm mesh	
		N	*Pectinaria*
65	234	61	73
66	240	71	82
67	300	60	76
68	265	44	84
	$\bar{\chi}$	59	79

Clearly, the use of *different* mesh sizes between years means that further caution is required in drawing comparisons. An example of retentive efficiency is available for a series of 4 stations sampled in September, 1977 in this area (Table 4): about 60% (range = 44-71) of animals on a 1 mm mesh were also retained on a 5 mm mesh. For *Pectinaria*, some 80% (range = 73-84) were retained on the larger mesh. Thus, a relatively high proportion of animals was sampled in this area using a large mesh size.

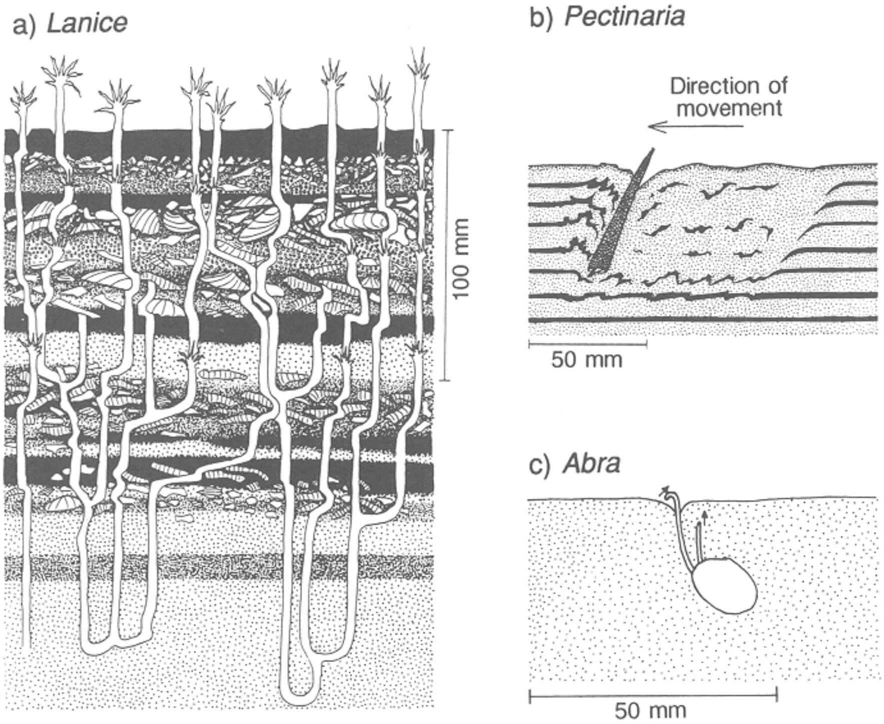

Figure 14. ***Profiles of three common species found in soft-sediments: (a) and (b) from Schafer (1972), reproduced by permission of Oliver and Boyd, London; and (c) after Hughes (1973)***

4.2 Effects of dredged material disposal

A response to dredgings disposal can be deduced from all surveys: higher numbers and percentage dominance, especially of *Pectinaria* and *Abra*, were found in the immediate vicinity of areas of deposited dredged material. Thus, they appear to be useful indicators of the effects of dispersing dredged material on larger organisms in this area.

The life-cycle and productivity of these two species have been studied by a number of workers in recent years, partly as a result of interest in their role as food for commercial fish. A feature of these studies is the occurrence of marked annual fluctuations in abundance due to variation in recruitment success or mortality of adults. This variation has been ascribed to the effects of external factors such as storm disturbance (Nicolaidou, 1983 for Colwyn Bay, UK) and oxygen deficiency (Nichols, 1977 for Kiel Bay, FRG), as well as to the feeding activities of the animals themselves, which can result in destabilisation of sediments at the same time as inhibiting colonisation by newly-settled juveniles (Eagle, 1975).

Reported periods of recruitment vary between localities. Dauvin and Gentil (1989) found three recruitments for *Abra alba* (in February-March, April-June and August-October) which occurred in response to eutrophic conditions in the Bay of Morlaix, France. They considered this to be an adaptive response over the normally occurring twice-yearly recruitment. Warwick and George (1980) inferred that settlement of *Abra alba* in Swansea Bay, UK could occur over a period of several months (July-November). Similarly, Glemarec and Menesguen (1980) identified overlapping cohorts from size-frequency histograms of *Abra alba* from the Bay of Concarneau, France, which indicated pulses of recruitment occurring throughout the year.

Nichols (1977) noted an early and late summer recruitment of *Pectinaria koreni* in Kiel Bay, Germany, but with additional sporadic recruitment occurring through most of the year. Comparable events were recorded by Elkaim and Irlinger (1987) in Seine Bay, France, with one or two main recruitment periods, depending on year and location. Nicolaidou (1983) observed only one recruitment (in June) in Colwyn Bay, UK.

Both species typically exhibit fast growth to sexual maturity within one year, and most individuals do not survive beyond one year (Eagle, 1975; Nichols, 1977; Nicolaidou, 1983; Dauvin, 1986; Elkaim and Irlinger, 1987). These attributes, accompanied by flexibility in other life-cycle traits, are commonly associated with species that thrive in unstable environments.

Pectinaria and *Abra* are characteristic inhabitants of inshore muddy substrates in north-western European waters, including the eastern Irish Sea area (Rees *et al.*, 1976), and the present study confirms that they are capable of rapidly exploiting any new or disturbed substratum suitable for colonisation. This may occur either through larval recruitment or by redistribution of adults (Eagle, 1975; Rees *et al.*, 1977). As in the case of *Lanice*, they may also have the ability to excavate themselves if lightly buried.

There was no evidence for a lasting effect at the now disused disposal site; dispersal mechanisms and the suitability of surface sediments for colonisation have clearly acted to preclude any obvious longer-term impact. Neither was there any evidence for a widespread azoic area, even during periods of very high rates of disposal, from which we may infer that there is no chemical inhibitory effect associated with contaminants in dredged material.

Two possible explanations exist for enhanced benthic counts near to the disposal site: first, that recently deposited material confers temporary stability, enhancing survival rate; and, second, that the material provides an enhanced food supply. Evidence for the latter is provided by Norton *et al.* (1984) who found elevated levels of organic carbon at the inner disposal ground.

Local enrichment, associated with dispersing dredged material, may be superimposed upon a general enrichment gradient as sediments become finer towards the mouth of the estuary. This is suggested by enhanced counts of predatory epibenthic species in trawls, as well as of the benthic infauna, and may be due to efflux of organic matter from the River Mersey itself.

Rhoads *et al.* (1978) observed enhanced benthic production as a consequence of dredged material disposal in Long Island Sound, USA. Dredging took place over a discrete period, and the disposal procedure involved a final capping of contaminated material with a surface layer of clean, sandy sediment. The authors proposed that, where circumstances permitted, dredgings disposal could be managed in such a way as to maximise productivity, with beneficial consequences for the local fishery through increased availability of food.

The disposal of 'maintenance' dredgings at the Liverpool Bay site is a continual process, and we cannot presently dismiss the possibility of enhanced bio-accumulation and then transfer of contaminants through the food chain as an end result of the peripheral recolonisation process. However, there is no reason to suppose that levels of bio-accumulated contaminants would exceed those in other areas of mud deposition in inner Liverpool Bay, since it is likely that the concentration of fine particle-bound contaminants would be the same in both cases (see Sub-section 3.1).

A more detailed survey of the benthos at site Z was conducted in 1987, involving replicate sampling at stations along a transect through the disposal site, and the use of a finer (1 mm mesh) sieve for extraction of the macrofauna; the results of this work will be reported separately (H. L. Rees *et al.*, in preparation). Further site-specific studies are required on the routes, and rates, of contaminant transfer through the food chain, in order to allow a proper appraisal of the possible benefits of alternative strategies for sea disposal of dredged material in Liverpool Bay and other areas.

5. CONCLUSIONS

The immediate physical impact of dredged material is quickly obscured by opportunistic colonisation of surface sediments either by larval recruitment or redistribution of adults. Thus, there is no widespread zone of azoic sediments.

The macrofauna of muddy substrates at the disposal site is confined to the oxic surface layer; the presence of fine deposits at depth indicates recent deposition of muddy dredgings. These sub-surface sediments are anoxic and comparable with naturally-deposited mud in the Burbo Bight to the south.

Preferential colonisation, or alternatively survival to a greater mean size, for the larger macrofaunal species in sediments near to the disposal site, may be due to the stabilising or nutritional properties of the dispersing material. There is no evidence for a chemical inhibitory effect associated with contaminants in dredged material.

A strong 'enrichment' gradient in the epibenthos, in a north-south direction through the disposal site, may be connected with efflux from the Mersey, though dispersing dredged material may have a contributory role. No gross effects were identified at the disposal site, despite ample evidence of the physical presence of dredgings.

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