AN ECOLOGICAL SURVEY ON THE EFFECT OF THE DUMP GROUND ON BENTHOS IN POVERTY BAY

A thesis
submitted in partial fulfilment
of the requirements for
the degree of
Master of Science in Earth Sciences
by

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The Ocean

There is a pleasure in the pathless woods,
There is a rapture on the lonely shore,
There is a society, where none intrudes,
By the deep Sea, and music in its roar:
I love not Man the less, but nature more,
From these our interviews, in which I steal
From all I may be, or have been before,
To mingle with the Universe, and feel
What I can ne'er express, yet cannot all conceal.

...And I have loved thee, Ocean! and my joy
Of youthful sports was on thy breast to be
Borne, like thy bubbles, onward: from a boy
I wanton'd with thy breakers - they to me
Were a delight; and if the freshening sea
Made them a terror - 'twas a pleasing fear,
For I was as it were a child of thee,
And trusted to thy billows far and near,
And laid my hand upon thy mane - as I do here.

Lord Byron

Abstract:

An investigation of the sediments and ecology of the dump ground was conducted in March 1995. The primary purpose of the investigation was to analyse factors which may be affecting the benthic biota on the dump ground. These include heavy metal content of the sediments, grain size characteristics of the sediments, and population distribution of the benthic biota on and surrounding the dump ground. It was intended that information obtained could be utilised in future investigations on the ecology of the dump ground, noting changes that have occurred over time.

Heavy metal analysis of Cadmium, Chromium, Copper, Mercury, Lead, and Zinc from the dump ground, turning basin, and inner harbour area indicate that concentrations of all heavy metals were all very low and well within resource consent limits.

Sediment and ecological samples from 25 sites on and surrounding the dump ground were taken. Two other sites were also surveyed, one from the turning basin, another from the inner harbour area (dredged material). Examination of the sediments has shown that although the dredged material consists solely of mud sized particles the sediments of the dump ground are mainly sand sized sediments. This suggests that during the dumping process dispersion of mud occurs. Mud is transported off the dump ground ina southeasterly direction.

Ecological evaluation indicates benthic species diversity and abundance of macrofauna is high, with no species in particular dominating the species assemblage. Comparison between this study and a 1993 survey shows increased diversity over the dump ground. Increased population abundance was evident and larger sized bivalves are indicative of an ageing population.

Field experiments examining the kelp beds indicate a decline in the population of *Ecklonia radiata* from 1993 to 1996. It is thought that this decline may be due to suspended sediment load from the Turanganui River, as the kelp beds are situated in the direction of discharge from the River.

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Chapter One:

Introduction

1.1 Study Area

Poverty Bay is a semi-circular oceanic embayment which is situated on the east coast of the North Island of New Zealand (Figure 1.1). The bay has a perimeter of 37 km, and is approximately 9 km wide, with a maximum length of 11 km. Material dredged from the harbour entrance and channel is deposited on the dump ground which is centred at 38°41'92S, 178°00'78E (Healy & Tahata, 1993) and has a radius of 500 m. It is located 2 km offshore from Kaiti Beach in a water depth between 14.0-19.5 m (Kensington, 1990; Figure 1.2).

1.2 The Problem

Maintenance dredging is required for the continued operation of the Port Gisborne Ltd, with the shipping channel entrance needing to be maintained at -8.7 m water depth. Dredging has occurred since early port developments in the 1880's (Whyte, 1984). The formation of a bar in the lee of the present breakwater has meant that maintenance dredging is required as sediment accumulates in the channel and at the entrance inducing a shallowing effect. The accumulating sediment originates from rivers draining into Poverty Bay, particularly the Turanganui River which enters adjacent to the channel entrance. The most rapid rates of sedimentation occur between the harbour end of the channel and 180 m beyond the end of the breakwater (Kensington, 1990).

1.2.1 Resource Consent

The dump ground in Poverty Bay would be classified as a partly dispersive open water disposal site (McAnally & Adamec, 1987). A coastal permit was granted in 1993 permitting the dredging and dumping of the spoil in a new dump ground of circular shape some 250 m to the south of the previous ground. The new ground avoids the Foul Grounds, an area of rocky reefs including Hawea Rock, Tokomaru Rock and Temoana Rock (Figure 1.2).

Under the New Zealand Coastal Policy Statement (1994) a resource consent is required to dump more than 50,000 m^3 annually, classifying the activity as a 'restricted coastal activity'. For this purpose two permits need to be obtained:

(i) Resource Consent for dredging and dumping (Coastal Permit) under the Resource Management Act 1991.

(ii) Dumping Permit issued by Maritime Transport under the Marine Pollution Act 1974.

The Department of Conservation has expressed concern over the impact of dumping on the benthic ecology of the rocky substratum comprising the Foul Grounds, resulting in the need for an impact assessment on the benthic ecology as a condition of the resource consent.

1.2.2 Heavy Metal Consideration

As a condition of the Resource Consent, monitoring of the heavy metal concentration of the sediments at the dump site and in the harbour area need to be assessed. A previous study by Sander (1992) indicated that organic carbon, cadmium, chromium, copper and lead showed slightly elevated levels at the dump ground compared to the control site levels, but these levels were insignificant compared to the United States Environmental Protection Agency and Canadian Ocean Dumping Criteria. Concern was expressed at the high lead concentrations in Kaiti Basin sediments, which exceeded the Canadian Ocean Dumping Criteria, but mixing during the dredging and dumping process diluted this level resulting in levels of lead on the dump ground not being excessively elevated (Sander, 1992).

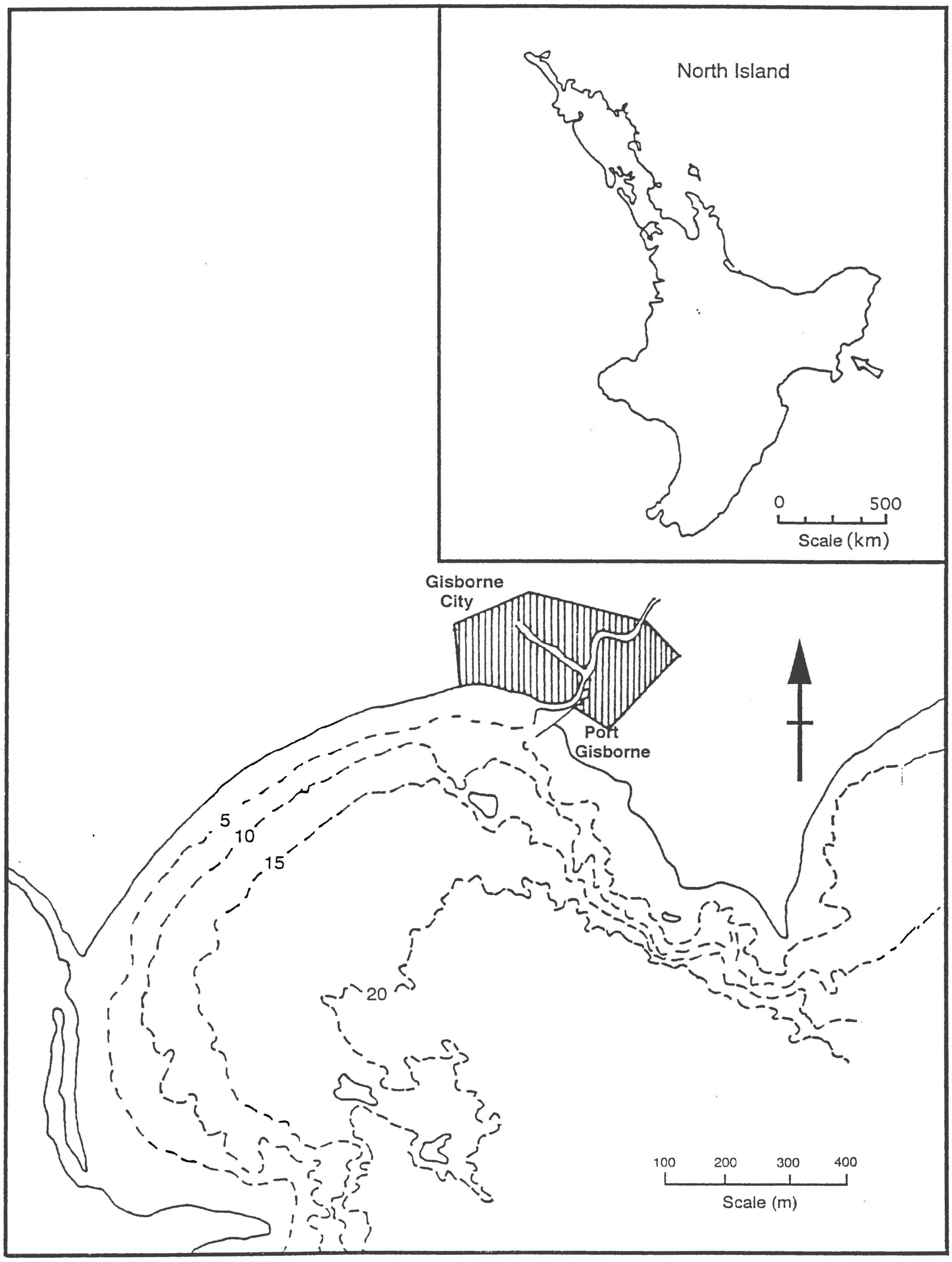

Figure 1.1 Location of Poverty Bay on the East Cape of the North Island.

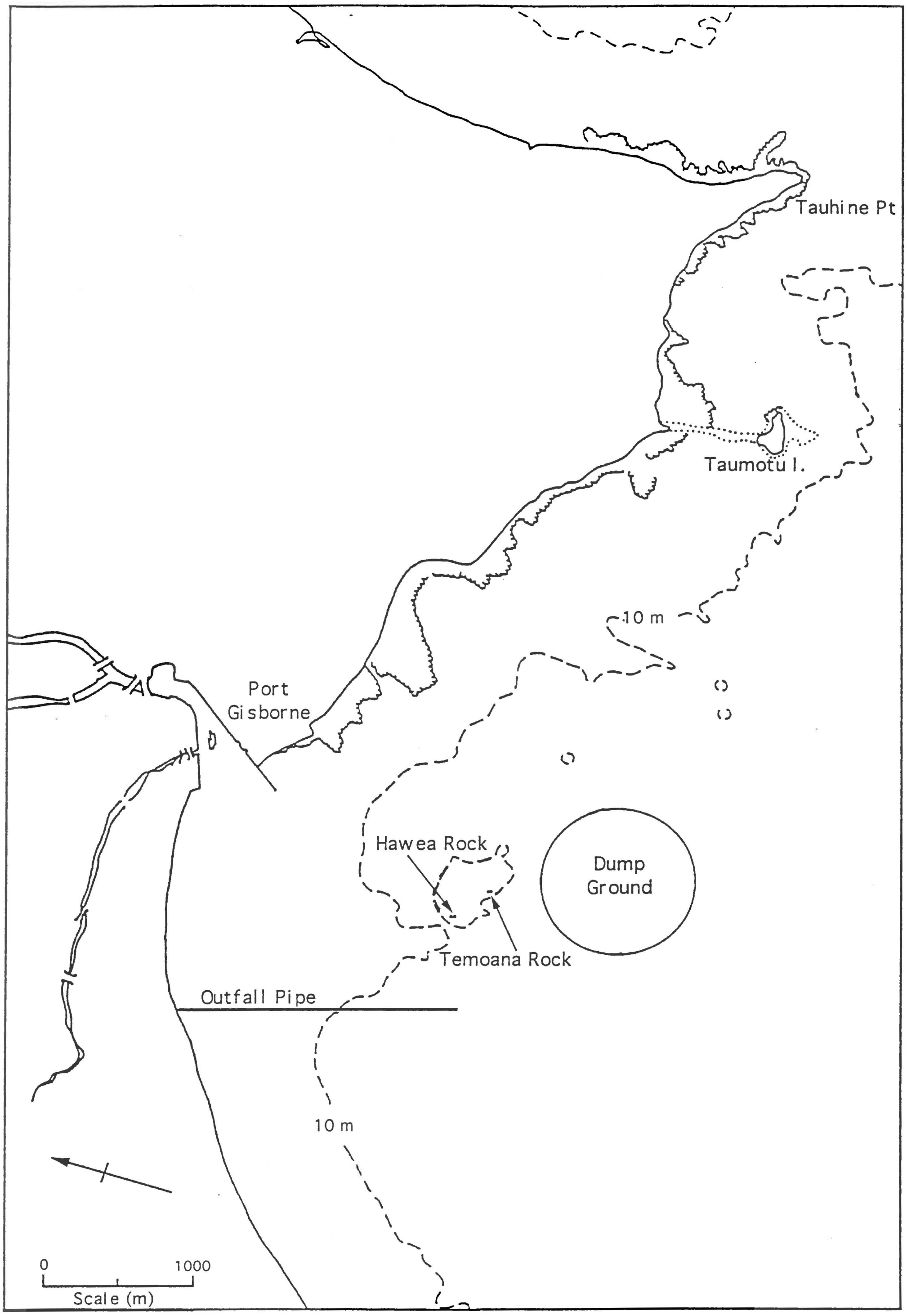

Figure 1.2 Location of the dump ground in Poverty Bay.

1.3 Study Objectives

The present study objectives are to carry out an environmental assessment of the biota of the dump ground, and the adjacent rocky reef and port turning basin to satisfy the conditions of the Resource Consent. This includes:

(i) a description of the fauna and flora of the dump ground and the surrounding rocky reefs, and present the distribution and abundances of the major taxa;

(ii) analysis of the sediment chemistry, heavy metals from the dump ground and the turning basin as specified in the resource consent, and assessment of any impact on the biota;

(iii) identification of likely influences of those organisms on sediment stability, and their sensitivity to changes in sediment regimes as well as a review of the movement of material on the dump ground in relation to biota;

(iv) investigation of the sensitivity of the biota to environmental perturbations; and

(v) assessment of identifiable variation in biota from previous studies.

1.4 Outline of Study

In order to achieve the objectives listed Chapter 2 provides background information which is relevant to the study, including previous studies in the area. Chapter 3 consists of recent analyses of heavy metal concentrations. Chapter 4 details sediment characteristics including both RSA, and pipette analysis to evaluate changes in sediment regimes. Ecological monitoring and analysis is included in Chapter 5 as well as an evaluation of variation in biota over time. Chapter 6 contains ecological field experiments, as well as data concerning the persistence of kelp on the Foul Grounds. Chapter 7 summarises results, and makes suggestions for future studies.

Chapter Two:

Background Information

2.1 Introduction

The sediment cycle of Poverty Bay is dependent on climate, geology and sediment supply. Maintenance dredging is necessary to maintain the port channel at Poverty Bay as sediment eroded from sandstones and mudstones are readily transported by river systems into the harbour, resulting in an accumulation of sediment within the port channel. This in turn leads by necessity to dredging operations. Dredging has periodically occurred since 1929. The impacts of dredging on the fauna in the harbour needs to be considered. These impacts can range from the discoloration of water over the disposal site, to the smothering of benthic fauna.

2.2 Climate

The weather of the Gisborne region is greatly influenced by the orography. The Raukumara Range rising to 1500 m is located to the west of Poverty Bay and provides shelter from westerly winds. The foehn wind effect leads to high temperatures and low rainfall. During easterly air mass conditions the uplift caused by the Raukumara Range orographically induces heavy rainfall (Hessell, 1980). Heavy rainfall can induce mass erosion of sandstones and mudstones, which can dramatically increase the suspended sediment load of local river systems.

The prevailing north-westerly wind is usually warm and dry. Southerly winds tend to be cold and wet but typically of short duration (Smith, 1975). Variations in wind speed throughout the day are also noticeable and are largely due to afternoon sea breezes (Miller, 1981). Rainfall is highest from May to August (Figure 2.1). The mean annual air temperature ranges from 9 to 20 °C at Gisborne aerodrome (Kensington, 1990).

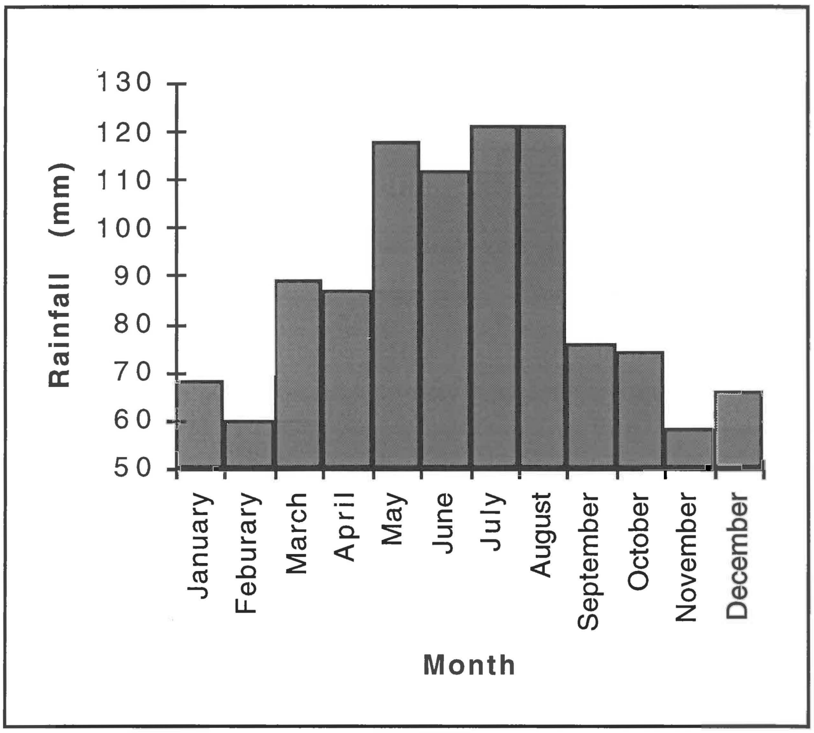

Figure 2.1 Mean monthly rainfall (1941-1970) measured at Gisborne Harbour (from Miller, 1981).

Seasonal variation in water temperature and salinity have also been measured, indicating that during winter, slight stratification of the water column occurs. Bottom waters are more saline and of a higher temperature than surface water. The greatest fluctuations are recorded close to the mouths of the Turanganui River and Waipaoa River. There are three major influences of turbidity in Poverty Bay, the Gisborne City Outfall, Waipaoa River and the Turanganui River which introduce a continuous supply of highly turbid water (Miller, 1981).

Episodic events also impact upon the environment of Poverty Bay. These events include periodic storms which may result in flooding of river systems which produce fluxes of highly turbid water and increased suspended sediment load. As a consequence of increased sediment load, greater rates of infilling in the channel occur after storm events. Estimates of channel infilling during Cyclone Bola from the 6th March to 11th March in 1988 was 2426 m^3 per day.

2.3 Geology

Geologically the Poverty Bay region is young. The region consists of low-lying plains surrounded by hills and steep ranges. The Raukumara Ranges form the main divide and are the headwaters of the Waipaoa Basin. The region is largely made up of greywacke sandstone of Triassic to Jurassic age (Moore, 1988). Other areas of the Poverty Bay Region are mainly made up of Miocene sandstones and mudstones, with small areas of Cretaceous marine sandstones and mudstones. The Miocene sandstones and mudstones have experienced local folding and faulting, with deformation seen in slump folding. The sandstones and mudstones are extraordinarily prone to erosion, particularly when saturated (Claridge, 1960). This leads to a regular supply of sand and mud sized particles to the river systems, resulting in high turbidity and high suspended sediment loads.

The late quaternary uplift of the central axial ranges in the Poverty Bay region is estimated at between 1 and 3 mm per year, while the Gisborne plains remain stable (Pillans, 1986). The Gisborne region is tectonically active, averaging 13 earthquakes of magnitude 4.0 or greater within a 100 km radius of Gisborne per year (Kensington, 1990). This activity likely enhances erosion of the catchment area leading to high suspended sediment loads in the rivers.

2.4 Sediment Supply

Sediment is drained into the harbour by two river systems. The Waipaoa has a drainage area of 1900 km^2 , and the Turanganui - Waimata - Taraheru drains an area of 300 km^2. The Waipaoa River has one of the highest suspended sediment discharges in New Zealand (Griffiths & Glasby, 1985). The average annual runoff is 58 $m^3.s^{-1}$, with the greatest monthly runoff during July of 81^3 $m.s^{-1}$, and the lowest average runoff in January of 8^3 $m.s^{-1}$ (Heath, 1985). The major source of sedimentation in the shipping channel is evidently, as Kensington (1990) noted, directly proportional to the sediment load discharge from the Turanganui River. In periods of rapid infilling in the channel the sediment load of the river was also correspondingly high (Kensington, 1990).

The bed material of the lower Waipaoa river consists mainly of very fine sand, silt and clay sized particles. This indicates that the material is transported as suspended sediment, and constitutes most of the sediment deposited in Poverty Bay from the river system. The additional presence of coarse sand and granule - sized sediment at the river mouth indicates that this material is also transported during periods of high discharge.

2.5 Waves and Tides

Poverty Bay is exposed to swell waves from the south and wind waves from a northeast direction. The significant wave height range in Poverty Bay is from 0.2 - 3.2 $m^3.s^{-1}$. The predominant approach for deep water waves recorded off the east coast of the North Island is from the north through to the east (Kensington, 1990). The tidal range is microtidal and has little effect on the speed of water currents in the bay. Tidal currents have limited influence on the direction of dredge spoil dispersion (Kensington, 1990).

The unidirectional current speeds at the dump site are between 0.08 and 0.26 $m^3.s^{-1}$ (Kensington, 1990). The threshold velocity of very fine sand to very coarse silts is approximately 0.30 $m.s^{-1}$ for unconsolidated sediment. Wave refraction analysis of Poverty Bay indicated that wave focusing at the dump ground occurs when wave approach is between 165 to 185° true. This coincides with the typical storm wave approach along the east coast, south of East Cape. The storm wave generated currents may therefore induce dredge spoil into suspension, allowing unidirectional currents to transport spoil from the dump site (Kensington, 1990).

2.6 Impacts of Dredging

Maintenance dredging of a channel physically alters the sea bed geometry, which results in the continual infilling of the channel. There are several options available for the disposal of dredged material, including beach nourishment, land disposal, or open water disposal. The chemical properties of the spoil are important in influencing the method of disposal, especially if the spoil has high quantities of potentially toxic compounds (Roper and Hickey, 1994).

Open water disposal is the most common method for the deposition of dredge spoil, also being the least expensive method of disposal. There are two kinds of open water disposal, retentive and dispersive. Retentive disposal uses inerodible caps to isolate contaminated spoil from the surrounding environment in sheltered sites. Dispersive sites use ambient currents which may remove and disperse the sediment from off the dump site; these sediments are uncontaminated. For this purpose dumping on like sediments should occur, as adverse effects are more likely to occur if spoil sediments are incompatible with bottom sediments (Kennish, 1991).

Four main factors influence the disposal at open water sites, including placement techniques, site designation, site capacity and dispersion and mixing (Roper and Hickey, 1994).

Dredge spoil may impact on benthic infauna in two main ways: chemical impacts and physical impacts. There are four categories of chemical contamination associated with dredged sediments (Kennish, 1991):
(i)Transition and heavy metal contamination.
(ii) High concentrations of organic matter fostering anoxia.
(iii) the presence of hydrogen sulphide, petroleum hydrocarbons.
(iv) Synthetic organic chemicals.

The physical effects of spoil disposal include the burial of organisms and smothering effects caused by high turbidity and the resulting high sediment settling rates. If dredge spoil is not contaminated then it is the method by which the spoil is disposed of that impacts upon the benthic fauna the most.

Typically sediment may be removed from shipping channels by hydraulic or mechanical removal. Hydraulic dredges operate producing a slurry of sediment and water which is then pumped to the disposal site. Material may be dredged via a mechanical dredge which lifts the sediment from the seabed and transports it to the dump ground via a barge or similar vessel (Kennish, 1991). This method is utilised in Poverty Bay for the disposal of dredge spoil by Port Gisborne Limited.

The short term impacts of dumping may affect the benthic fauna by increasing turbidity, reducing light penetration, release of ammonia, phosphorus, and manganese into the water column and decreasing the availability of food (Ryan, 1989). Long term impacts of dredging may include changes in bottom topography, as well as the composition and texture of the sediments. The impacts on benthic fauna may result in the postponement of recolonisation, reduced species diversity, and possible changes in species composition.

2.7 The Dredging Operation

The Port of Gisborne has required periodic dredging since 1929 (Whyte, 1984), relocating 50,000 to 70,000 m^3 of sediment per year. Dredging has mainly been located in the turning basin and entrance channel. Although dredging occurs throughout the whole year, constraints (e.g. equipment failure and unfavourable weather conditions) mean that dredging typically occurs only about 30% of the time, with the majority of dredging being carried out in the summer months when weather conditions are favourable (Sander, 1993). The average daily rate of infilling has been calculated at 107 m^3 (Kensington 1990).

Dumping of the spoil from 1953 - 1986 at the previous dump ground to the dump site being shallowed by 4 - 6 m (Kensington, 1990). At the present dump site, shallowing does not occur as erosion of the mound results in dispersion of the spoil in a south - east direction (de Lange et al., 1996).

Kensington (1990) noted that at the site of dredge spoil dumping, a noticeable discoloration of the water is visible. The turbidity reduces rapidly within minutes after dumping, and has returned to normal within an hour after dumping has finished. The pH effect of the dredge spoil dumped on the dump ground was measured as being minimal.

2.8 Previous Studies

Previous studies in the Poverty Bay region have investigated a range of characteristics. Roper et al. (1989) studied the impacts of sewage discharge from the outfall pipe has on the biota surrounding the pipe. They identified a polluted zone which extended 200 m from the diffusers, while a transitional zone extended between 800 to 1600 m from the outfall pipe. Kensington (1990) completed a study on sediment and dredge spoil characteristics of Poverty Bay, and proposed a model of dredge spoil dispersion based upon side-scan, sonar monitoring and sediment data. He then suggested that dispersion from the dump ground is a combination of wave action superimposed upon unidirectional currents. Wave action promotes the resuspension of spoil which allows the unidirectional currents to transport the spoil from the site.

Sander (1993) investigated the chemical effects of water and sediment quality on the dump ground as well as Poverty Bay to determine any deleterious effects of dumping of dredge spoil. Wood (1994) carried out a baseline survey on the benthic fauna of the Poverty Bay region. This was expanded upon by Cole and Foster (1994) who completed an ecological survey of the current and previous dump ground. A survey of the Foul Grounds was also completed. This present study expands upon Cole and Foster (1994). Purdue (1996) assessed the impact of the sewerage outfall on the benthic ecology. His results showed that the outfall produces no apparent impact on the diversity of the surrounding benthos. A clear increase of abundance of animals was noted closer to the outfall.

Chapter Three:

Heavy Metals

3.1 Introduction

The resource consent applying to the dredging and dumping of sediment from Gisborne Harbour is issued under Section 372 of the Resource Management Act 1991, and requires heavy metal analysis of the seabed to be undertaken once in the first, second year, and fifth year, and then at five yearly intervals. Samples must be taken at three sites, at least 20m apart, within 100m of the centre of the spoil ground (DG1, DG2 and DG3), and one sample within the ports turning basin (TB). Heavy metal analysis was undertaken by R.J. Hill Laboratories, a Telarc approved laboratory, in accordance with standard methods for the examination of water and wastewater published jointly by the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation. The heavy metals tested for were chromium, cadmium, copper, lead, mercury and zinc.

3.2 Methodology

Samples were collected in March 1995. The co-ordinates for the sites were:

Site	Headings	
DG1	38°42.01S	178°00.80E
DG2	38°42.03S	178°00.71E
DG3	38°41.96S	178°00.74E
TB	38°41.96S	178°00.74E

Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb) and Zinc (Zn) were analysed using acid digestion, flame atomic absorption (AA) spectroscopy. Mercury (Hg) was analysed using persulphate/permanganate digest, cold vapour AA. Atomic absorption spectrometry is used widely for the quantitive determination of metals as minor or trace constituents of samples. If a solution containing a metal is asperated in the form of an aerosol into a hot flame, the solvent is evaporated from the droplets and the metal vaporised mainly as atoms. AA spectroscopy is based on the recognition that the majority of free atoms in the flames used are in ground state and do not have enough energy to excite the atoms except for group 1 elements. A beam of electromagnetic radiation characteristic of a particular element can be passed through the atomic vapour and monitored. If the sample contains that particular element, its atoms will selectively absorb some of the radiation thereby attenuating the beam and causing the detector signal to fall. This absorbance is proportional to the concentraion of that element in the vapour and hence in the original sample (Angino & Billings, 1967; Anthanasopoulos, 1991 and Baker & Suhr 1982).

3.3 Results

All heavy metal concentrations were under the resource consent limits. The results show that the dump ground sediments show consistently lower concentrations than the turning basin except for cadmium, where concentrations for both are < 0.1 (Table 4.1). The differences are not significantly higher. When compared to the Canadian Ocean Dumping Criteria, all of the limits were well under except for lead, which was 0.4 mg/kg higher.

Table 3.1 Heavy metal concentrations (mg/kg dry weight). Resource Consent limits are also given.

	Turning Basin	DG1	DG2	DG3	Consent Limits
Total Cadmium	<0.1	<0.1	<0.1	<0.1	1.0
Total Chromium	25	11	11	15	100
Total Copper	22.6	6.3	5.7	9.5	81
Total Mercury	0.068	0.040	0.033	0.041	0.21
Total Lead	20.4	7.2	6.7	9.6	66
Total Zinc	89.2	41.5	38.8	51.6	160

A comparison with results obtained in July 1992 and February 1993 by Sander (1993) is shown in Table 4.2. Mercury was unable to be compared. The concentrations for the dump ground in 1992 and 1993 are means of the samples taken for those years. Heavy metals from the turning basin were not analysed in 1993.

Table 3.2 Comparison of Heavy Metal Concentration from 1992 - 1995 (mg/kg dry weight).

	Swinging Basin		Dump Ground		
	1992	1995	1992	1993	1995
Cadmium	0.026	<0.1	0.002	0.005	<0.1
Chromium	15	25	3.25	2.6	12.33
Copper	14	22.6	5.25	3.25	7.17
Lead	7	20.4	0.525	1.25	7.83
Zinc	112	89.2	11.5	20.25	43.97

Zinc is the only heavy metal concentration which did not increase from 1992 to 1995, but dropped by 23 points in samples collected from the turning basin. Chromium and copper in samples from the dump ground decreased between 1992 and 1993, and increased between 1993 and 1995. The other metals only showed small rises but it is to be noted that different analysis methods were used between the earlier results of Sander (1993) and those undertaken by R.J.Hill Laboraties.

3.4 Discussion

The results show all heavy metals are well under the limits imposed by the Resource Consent. This indicates that the biota of the dump ground and surrounding area are unlikely to be affected by heavy metal contamination. A comparison with Sander (1993) suggests that heavy metal concentrations may have increased from 1992 to 1995. Concentrations in the turning basin record higher than those taken from the dump ground, which is expected due to land drainage into the relatively passive basin environment from an adjacent industrial area.

Chapter Four:

Sediment Analysis

4.1 Introduction

The characteristics and distribution of sediment inside and outside the dump ground can be an indication of the biota present on the dump ground. The movement of the dredge spoil once it has been deposited, as well as the grain size distribution will be considered. The importance of evaluating the sediment on the dump ground is to analyse whether different sediment assemblages can influence the populations of the benthic biota. An objective for this study was to determine whether the sites on and around the dump ground showed different distributions in grain size characteristics. This will be examined further in Chapter 5.

4.2 Methodology

Sediment Collection

Sediment was collected in March 1995, at the same time as the ecological survey was conducted. Twenty five sites were taken in grid formation on and surrounding the dump ground (Figure 4.1) . Two additional samples were also taken, one from the turning basin and one from the inner harbour area. Sediment was collected using a Smith-McIntyre grab sampler. After the sediment was collected it was treated with 5% formalin to prevent oxidation of organic material.

Method for Laboratory Analysis

A sediment sample from each site was oven dried. This sediment was then dry sieved over a -1 phi sieve and a 4 phi sieve, with the gravel, sand, and mud fraction separated. The weight of the fractions was then taken to determine the percentage of gravel to sand to mud. Size fractions of sediment were determined by Udden - Wentworth grain size classification.

Table 4.1 Udden-Wentworth size classification for sediment grains (after Pettijohn et al., 1972)

Particle Size Distribution	Maximum Size (phi)	Maximum Size (mm)
Boulder		
Cobble	-8.0	256
Pebble	-6.0	64
Granule	-2.0	4
Very coarse sand	-1.0	2
Coarse sand	0.0	1
Medium sand	1.0	0.5
Fine sand	2.0	0.25
Very fine sand	3.0	0.125
Coarse silt	4.0	0.0625
Medium silt	5.0	0.031
Fine silt	6.0	0.0156
Very fine silt	7.0	0.0078
Clay	8.0	0.0039

Method for Analysis of Mud Fraction

An additional sub sample was taken from each site for mud fraction analysis. This was wet sieved over a four phi sieve to separate the mud fraction. Pipette analysis was carried out on this fraction. Pipette analysis applies the principle for settling tube analysis on the ideal settling velocity using Stokes Law (Lewis & McConchie 1994). Extracts are taken at specific time intervals to determine the percentage of silt and clay at phi intervals greater than 4 phi, which is determined by the settling velocity of the grains.

Table 4.2 Removal times for pipette analysis

	Diameter (finer than) total suspension
20 seconds	4 phi
2 minutes	4.5 phi
4 minutes	5 phi
8 minutes	5.5 phi
15 minutes	6 phi
30 minutes	7 phi
2 hours	8 phi
8 hours	9 phi

The temperature of the water is taken to gauge the correct depth for withdrawal of the mud extraction. A temperature measurement is recorded at each time interval to determine withdrawal depth.

For each site the mud sized fraction was disaggregated in distilled water. The liquid mud is transferred to a 1000 ml measuring cylinder. Next 0.5 - 1 gram of sodium hexametaphosphate (calgon) was added to prevent the flocculation of clays. Each of the cylinders were made up to 1000 ml with distilled water. The cylinders were covered and left overnight to confirm that flocculation does not occur. Additional dispersant is added if flocculation occurs.

The procedure is initiated with the cylinders being stirred using a brass stirrer for 1 minute. Short, quick strokes are used at the bottom of the cylinder to stir up all of the settled mud. Stirring should be worked up the column with long vigorous strokes, being careful not to mix air into the suspension. After 1 minute the stirrer is withdrawn. Lower the pipette to 20 cm. At 20 seconds a 20 ml sample was extracted. The sample was emptied into labelled beakers and rinsed in distilled water.

For each time limit after this the pipette was lowered to the correct depth with 20 ml of the solution extracted, and emptied into a pre-weighed and labelled beaker. Once all of the extraction's had been completed the beakers were oven dried to evaporate all the water. The beakers were removed from the oven and left to equilibrate with the atmosphere for at least 1 hr. The beakers were then weighed.

The cumulative weight percentages were calculated by subtracting the beaker weight from the combined sediment and beaker weight, giving the weight of the sediment. The weight of the sediment from the 4 phi sample was then multiplied for each site by 50, with the weight of dispersant in the column subtracted. This gave the total weight of the mud. The weight of the dispersant was calculated by adding the same amount of calgon as was added into the liquid mud samples in a 1000 ml measuring cylinder filled with distilled water. The samples were then removed and oven dried, which allowed the weight of the calgon to be calculated.

Method for Sand Sized Analysis

Grain size distribution of the sand fraction was carried out using rapid sediment analysis (RSA) via a water filled fall tube and balance. Samples were prepared for the RSA by sieving out the fractions smaller than 4.0 phi and larger than -1.5 phi. Sediment was placed in a release cartridge which was then released into the fall tube initiating a timer. As the grains reached the scales at the bottom of the fall tube a timer measured the change in weight over time. Analysis of this data establishes the distribution of grain size. This theory is based on the relationship between settling velocity and grain size as proposed by Gibbs et al (1971). Sorting is the measure of the degree of uniformity in the deposit produced by current action during grain transport and deposition (Leeder 1982).

Method for Analysis of Gravel Size Fraction

The gravel sized fraction was dry sieved through a stack of sieves ranging in whole phi sizes from -8 phi to -1 phi. Each size fraction was then weighted so that a cumulative weight percentage could be calculated.

4.3 Results

The samples from the inner harbour and turning basin were analysed by pipette analysis, as the grain size of these samples was only mud sized.

Table 4.3 Percentages of gravel, sand and mud for each site

Site Number	% Gravel	% Sand	% Mud		Site Number	% Gravel	% Sand	% Mud
Site 1	8	79	13		Site 2	0	77	23
Site 3	0	86	14		Site 4	<1%	95	5
Site 5	0	60	40		Site 6	0	68	32
Site 7	0	64	36		Site 8	0	80	20
Site 9	4	77	19		Site 10	0	64	36
Site 11	0	79	21		Site 12	0	69	31
Site 13	0	94	6		Site 14	0	76	24
Site 15	0	82	18		Site 16	63	37	<1%
Site 17	57	41	2		Site 18	20	72	8
Site 19	0	83	17		Site 20	0	90	10
Site 21	<1%	93	7		Site 22	7	81	12
Site 23	4	75	21		Site 24	3	80	17
Site 25	3	78	19		Site IH	0	0	100
Site TB	0	0	100					

The dump ground is covered by 13 of the 25 sites surveyed in grid formation (these sites are 3, 6, 7, 8, 9, 10, 11, 12, 14, 22, 23, 24, 25). Of these sites on the dump ground only one has over 5 % gravel. In all of the sites on the dump ground the sand fraction consisted of over 64 %. Of the five sites adjacent to the dump site, only one contained a significant gravel percentage of 8; these sites were similar in constitution to the sites on the dump ground, with the lowest percentage of sand calculated at 60 %.

The three outer sites on the eastern side of the dump ground (sites 16, 17, 18) showed greater variability, especially sites 16 and 17. Over half of the sediment at these sites was gravel sized. This gravel sized fraction was mainly made up of coarsely fragmented shell and bedrock. The three outer sites on the western side of the dump ground (19, 20, 21) show higher percentages of sand, and correspondingly lower mud percentages than those sites on the dump ground.

Mean Grain Size

The mean grain size (Figure 4.2) of the sites on the dump ground ranged from 0.38 phi to 3.07 phi, which corresponds to medium sand through to granule sized particles. On the eastern side of the dump ground the sediments ranged in size from 0.30 to 2.20 phi, described as medium sand to granule. On the western side of the dump ground the sediments ranged from 0.58 to 3.0 phi which corresponds to coarse sand to granule. These sites fitted mainly into very coarse sand. A region existed on the western side of the dump ground which consisted dominantly of sand.

Sorting

The degree of sorting depends on four main factors. These include the size range of the material supplied to the environment, the types of deposition processes active, the current characteristics and the time available e.g., the sediment supply rate vs. time available to sort the sediment (Folk, 1968). The sorting values for sites on the dump ground ranged from moderately well sorted to very poorly sorted. The majority of sites were poorly sorted. For the sites outside the dump ground the sorting ranged from moderately sorted to very poorly sorted. The majority of sites were poorly sorted (Figure 4.3). No distinctions between the sorting for sites on the dump ground and outside of the dump ground could be made.

Skewness

The level of skewness (Figure 4.4) provides information on the symmetry of the sediment size frequency curve (Friedman and Sanders, 1978). Positive values indicate an excess of fine particles, while a negative value indicates an excess of coarse particles. Skewness for sites on the dump ground range from strongly fine skewed to strongly coarse skewed. The majority of sites were from coarse skewed to strongly coarse skewed. The skewness for the sites outside the dump ground ranged from strongly fine skewed to strongly coarse skewed. For sites on the eastern side of the dump ground the majority were strongly fine skewed. Sites on the western side of the dump ground were mainly strongly coarse skewed.

Grain Size Distribution

Grain size distribution can be mapped by gravel - sand - mud, and sand - silt - clay diagrams as proposed by Folk et al. (1970). By this method textural descriptions can be mapped (Figure 4.5). Textural facies for sites inside the dump ground are described as silty sand, for the sites with no gravel content. Those sites situated inside the dump ground with gravel content fit in the textural description of slightly gravelly muddy sand.

Sites on the western side of the dump ground (sites 1,15, 16, 17, 18) fit in the size range of sand to silty sand. Site 21 contained a gravel content, having the description of slightly gravelly sand.

Four of the five sites on the eastern side of the dump ground (sites 5, 13, 19, 20, 21) had gravel sized particles. These sites fitted in the textural descriptions of sandy gravel and gravelly muddy sand. Site 1 is described as silty sand.

The turning basin and inner harbour area both have the textural description of silt.

Mud Content

The mud content can be broken into silt and clay. The clay content of the mud sized fraction (Figure 4.6) ranged for sites on the dump ground from 2 % to 19 %, with a mean of 7.6 %. On the eastern side of the dump ground, the range was from 2 % to 14%, with a mean of 10.4 %. The western side of the dump ground showed a range from 1 % to 12 %, with a mean of 7 %. The low amount of clay in the sediments may be a result of dumping where the clay fraction becomes suspended in the water column, dispersing over significant distances, lowering the clay content of the dump ground by up to 5 % (Truitt, 1988).

The silt content of all sites was high, with the majority of the mud sized fraction for each site within the silt size class. Sites 26 and 27 consisted of 100 % mud sized particles. The sites situated on the dump ground show higher mud contents than those sites which are situated outside the dump ground. The clay content on the eastern side of the dump ground was higher than the clay content on the western side.

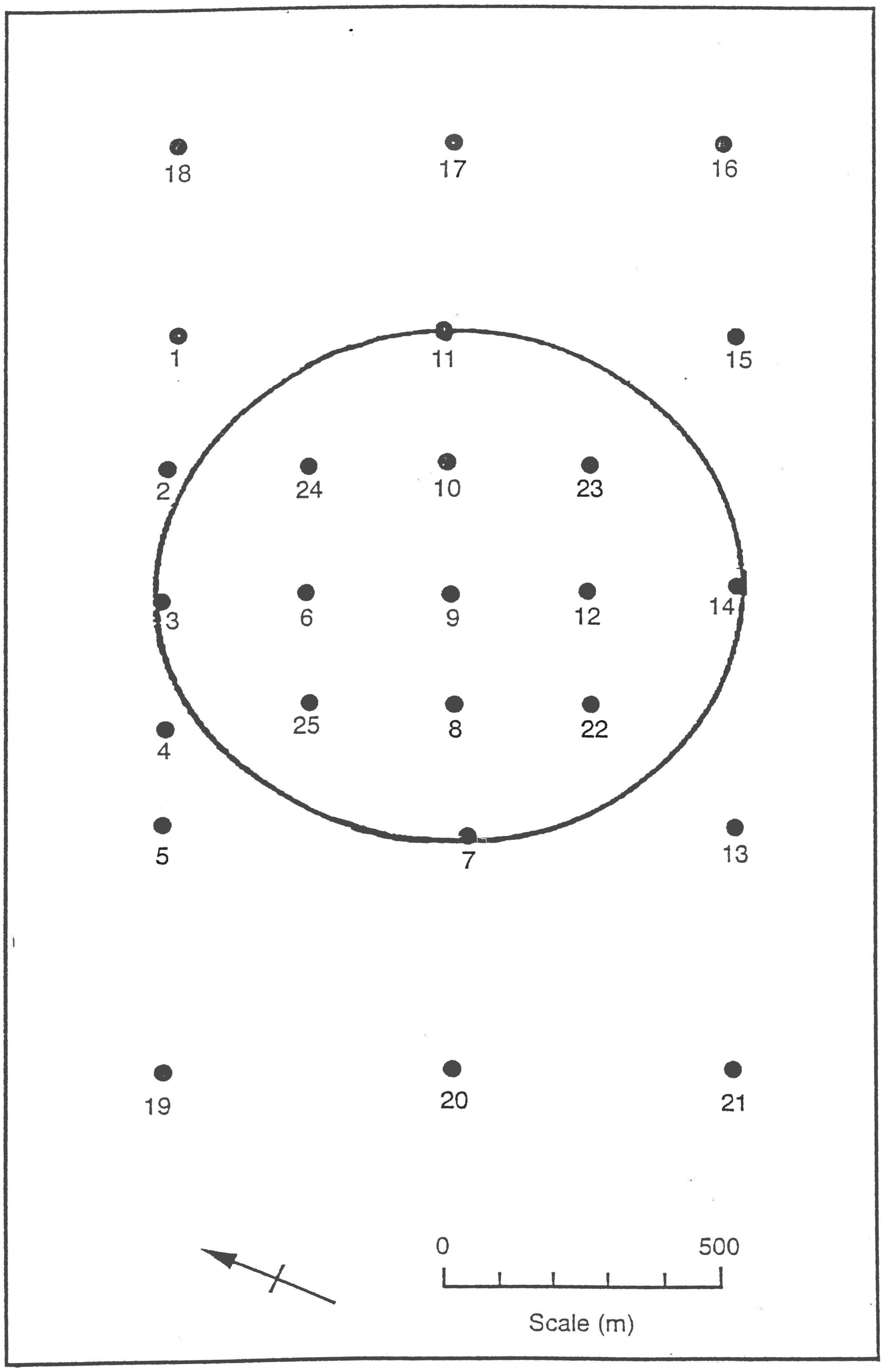

Figure 4.1 Location of survey sites on and surrounding the dump ground.

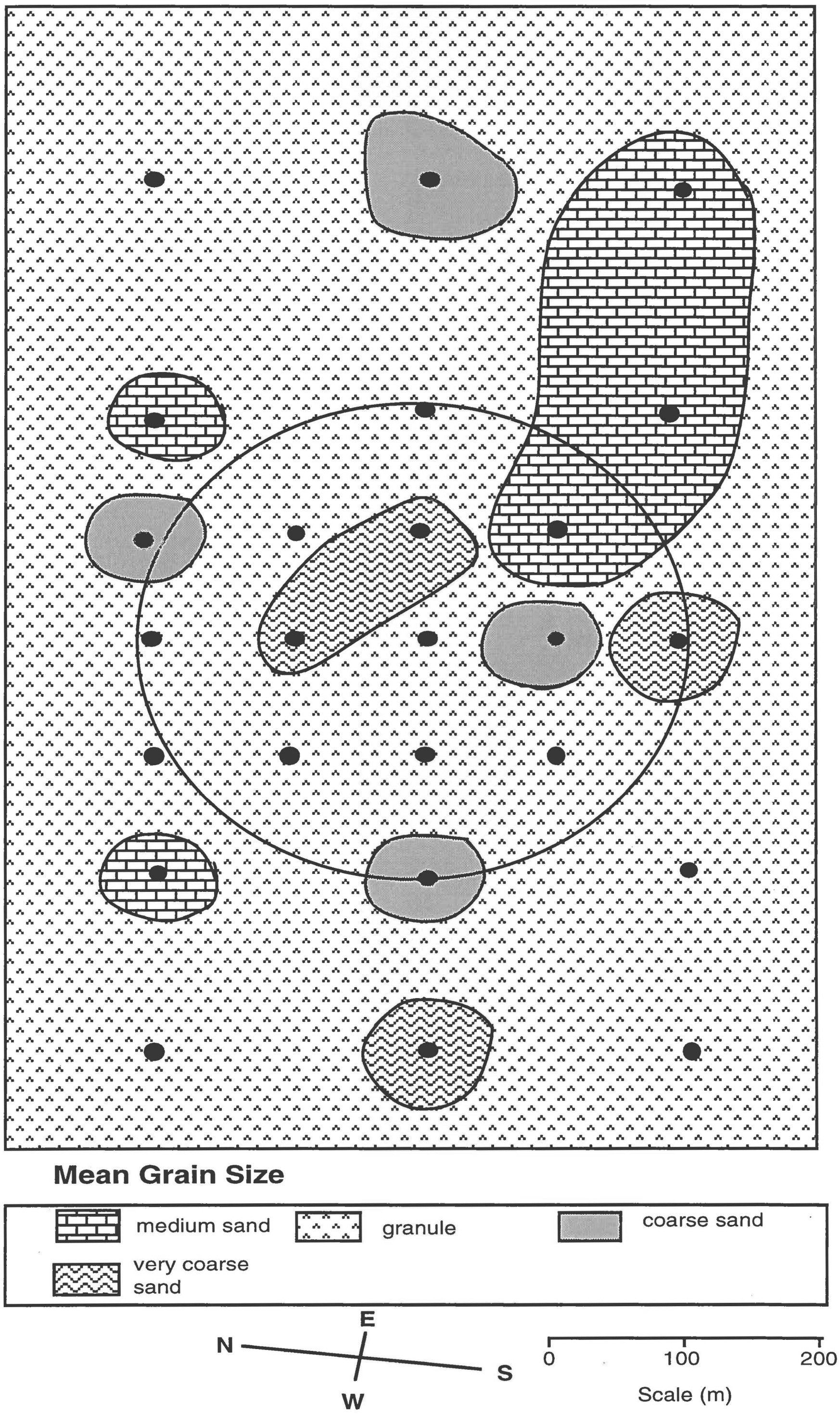

Figure 4.2 Mean grain size of surficial sediments on and around the dump ground using textural descriptions based on the Udden-Wentworth grain size scale.

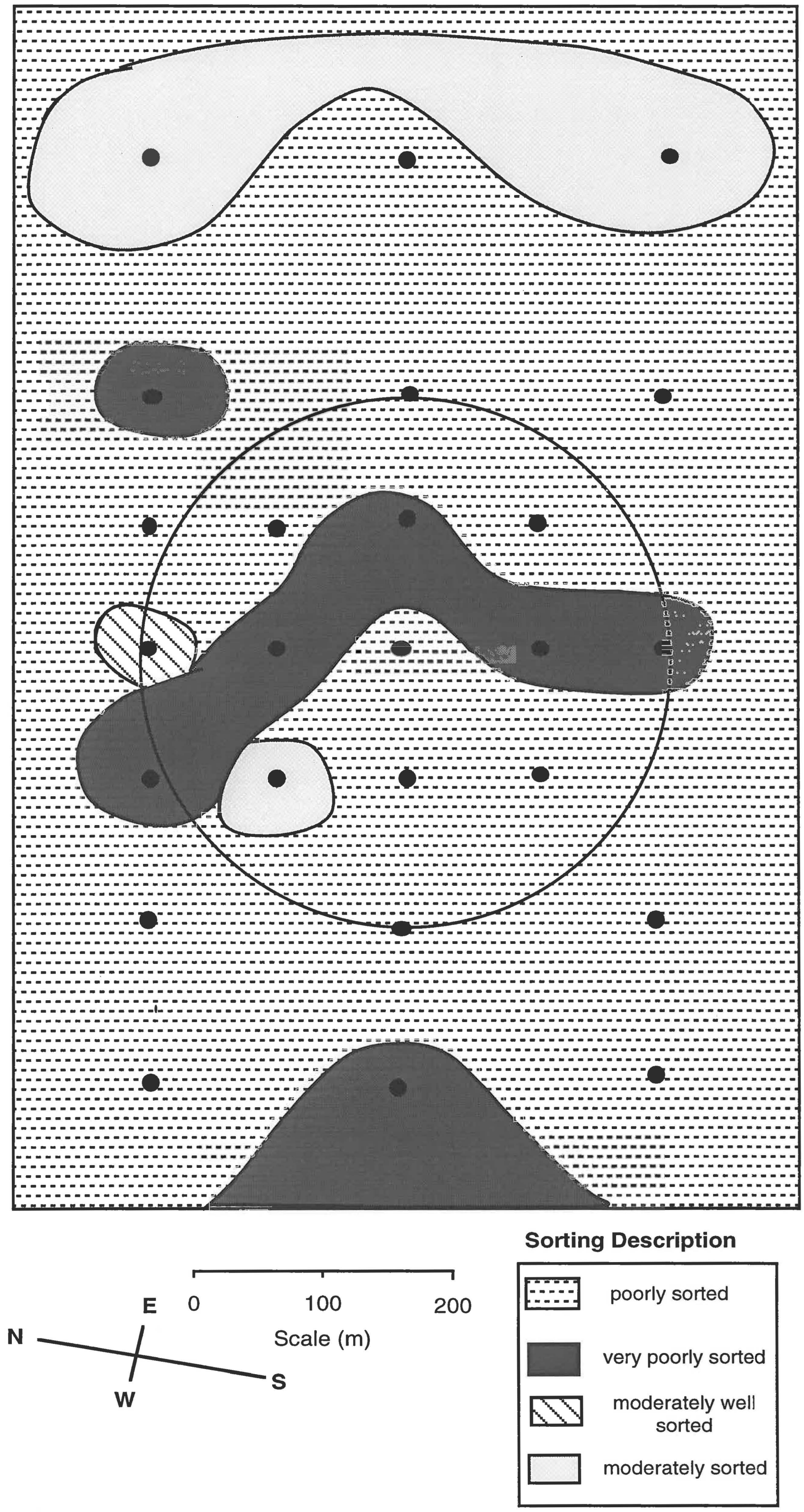

Figure 4.3 Sorting values of the surficial sediments on and around the dump ground.

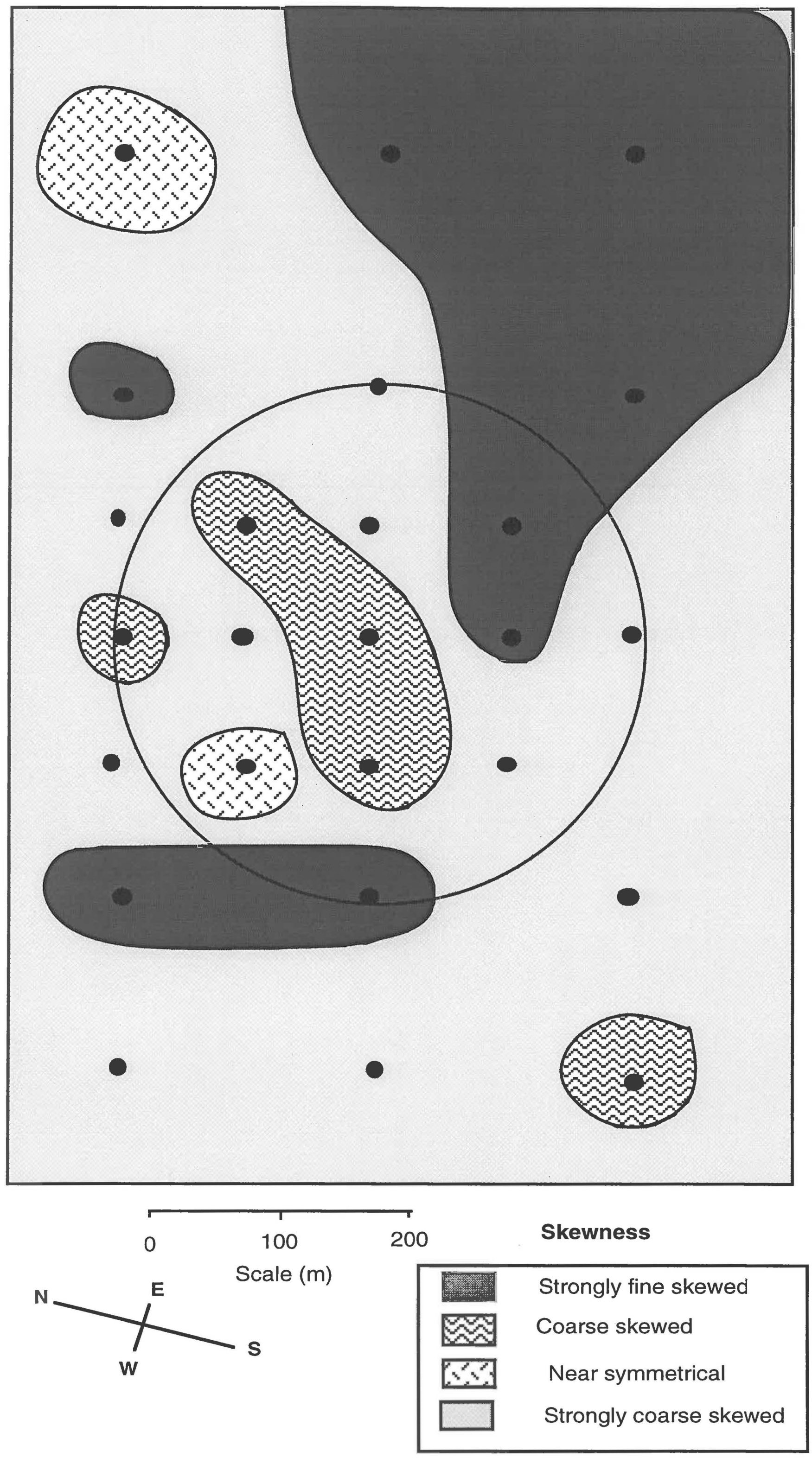

Figure 4.4 Skewness values of the surficial sediments on and around the dump ground.

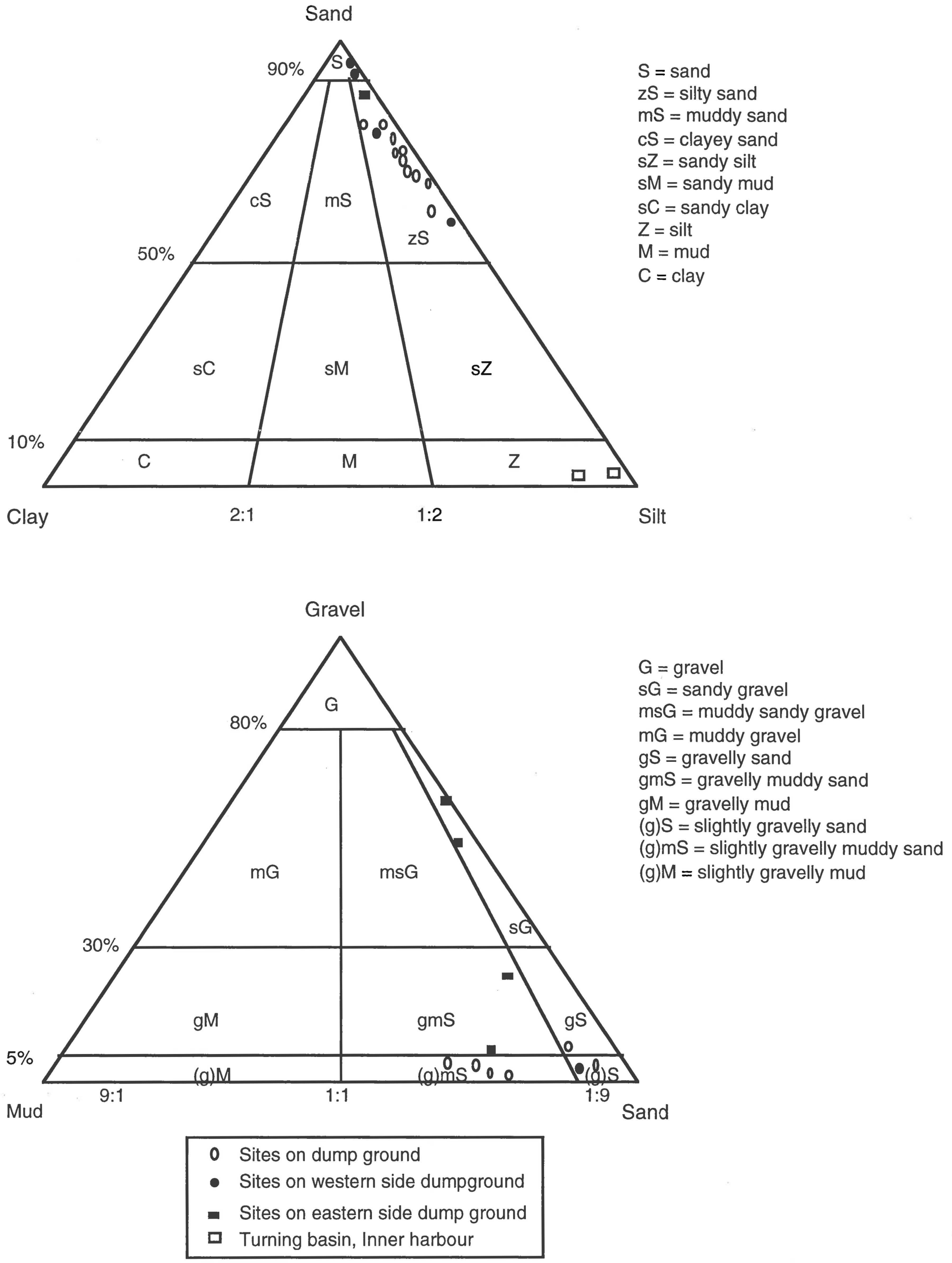

Figure 4.5 Textural facies descriptions of sites on and around the dump ground.

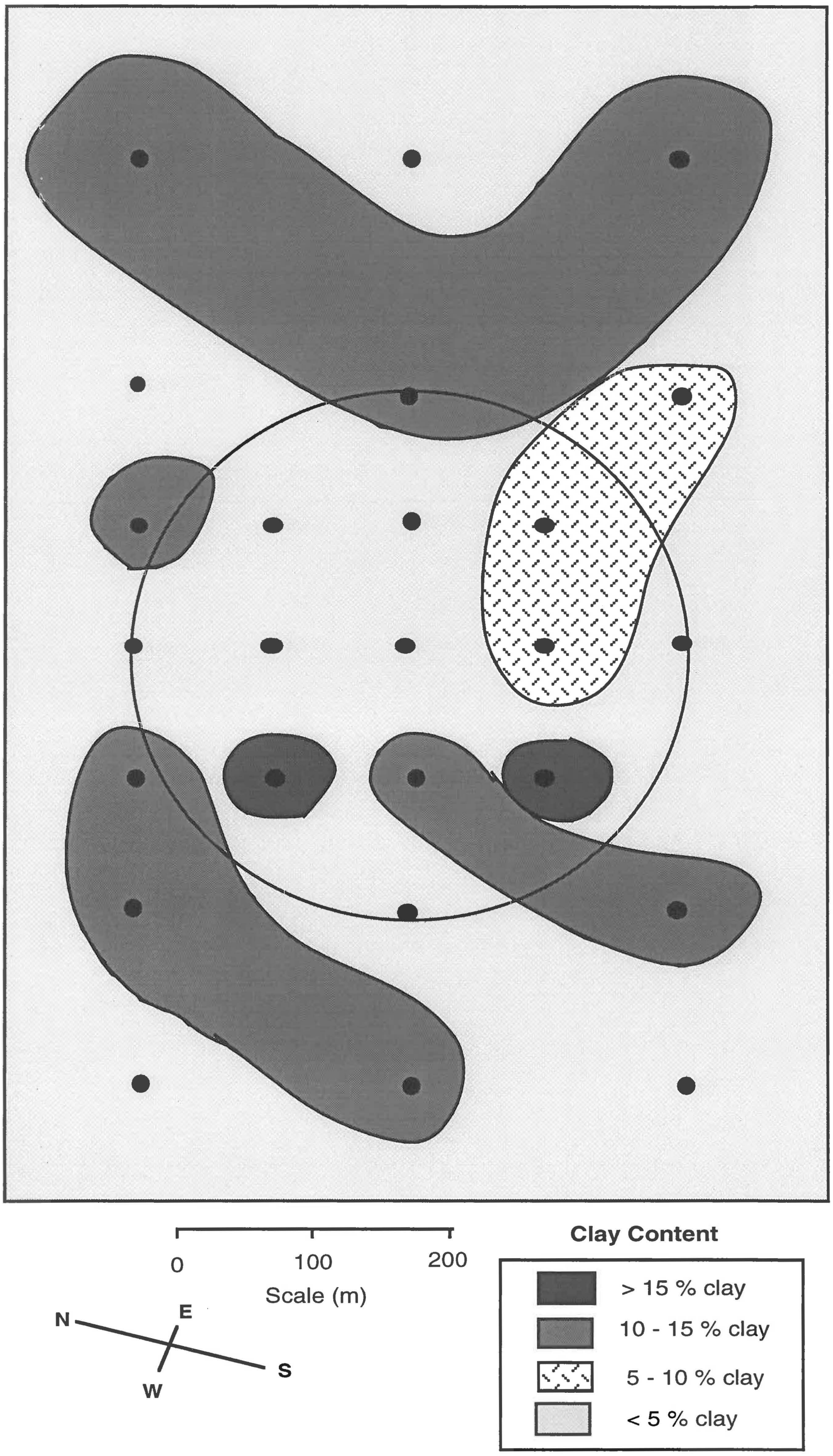

Figure 4.6 Clay (<8.0 phi) percentage of the surficial sediments on and around the dump ground.

Results from pipette analysis, RSA and sieving of gravels, combined to give distribution over all phi sizes for each site (Appendix One), indicate that all sites over the survey have a clay percentages of less than 2 % except for the turning basin which had a clay percentage of less than 10 %. The majority of sediments range from sand to silt size, except for 16, 17 and 18 (to a lesser extent) which have high percentages of gravel. Most other sites either have bell shaped sediment distribution e.g. site 8, or a double peak e.g. site 14 with a peak within the sand fraction and another in the silt fraction.

4.4 Discussion

Sediments within the dump ground are poorly sorted and can be described as silty sand. The mud content of sediments on the dump ground are higher than those in the area surrounding the dump ground. Sediments from sites surrounding the dump ground on the western side can be separated from sediments on the eastern side of the dump ground. Sediments on the western side of the dump ground are poorly sorted and can be described as gravelly muddy sand. Sediments on the eastern side of the dump ground can be described as sandy gravel, and are also poorly sorted. Sediments with a gravel sized component are more common for sites on the eastern side of the dump ground, indicating a localised area of coarse sediment.

The dominant factor of dredge spoil movement is wave generated currents, as well as the grain size of the dredged material that is deposited on the dump ground (Kensington, 1990). The material that is dredged from the turning basin and inner harbour area consists of 100 % mud. This material is dredged and released over the centre of the dump ground, where dispersion occurs. Contouring of the dump ground has shown the spoil mound to be double humped (de Lange et al., 1996). Erosion of the dump ground occurs with movement to a south eastward direction from the southern mound, with erosion concentrated on the crests of the mounds (de Lange et al., 1996).

In a physical sense the sediment on the sea bed is generally a reflection of the near-bed flow regime in the area. Therefore relatively coarse beds occur in regions that regularly experience high boundary shear velocity (a measure of the magnitude of turbulent mixing in the flow). Under these circumstances fine grained material is prevented from settling onto the bed. The processes operating over the dump ground may be an example of this.

A comparison with Kensington (1990), of sediments for the present dump ground site indicate that the mean grain size has changed from a mixture of fine sand to very fine sand, to mainly granule sized sediment. Sorting of the sediments has changed slightly from moderately sorted to poorly sorted (Kensington 1990), to mainly poorly sorted - with a zone of very poorly sorted sediment in the 1995 survey. The skewness of sediments from the 1995 survey are mainly strongly coarse skewed. A zone of strongly fine skewed sediment also occurs in an easterly direction. The survey conducted in 1988/1989 by Kensington showed skewness ranging from fine to strongly fine skewed. Analysis of the textural facies between the two surveys shows that sediments were described as sandy mud for 1989, and silty sand for 1995.

The differences between the two surveys may be an effect of Cyclone Bola in March 1988, which caused extensive erosion within the Waipaoa and Turanganui River catchments and resulted in large amounts of eroded material to be transported into Poverty Bay by the river systems (Kensington 1990). This deposition of fine material may still have been present over the dump ground when the survey was conducted between December 1988 and January 1989 by Kensington. The increased suspended sediment load from the Turanganui River due to Cyclone Bola also resulted in a period of intensive dredging from the shipping channel. Increased deposition of the dredge spoil on the dump ground may have also influenced the predominantly fine sediments which were present on the dump ground in 1988/1989 in comparison to 1995.

Chapter 5:

Ecological Survey

5.1 Introduction

Ecological surveys have become an important means of identifying impacts induced on the environment by the actions of people. Identifying spatial and temporal patterns are important in evaluating the effects of dredging and dumping of dredge - spoil, as they provide the basis for models by which we generate hypotheses, both about the patterns and the processes that may govern them (Andrew and Mapstone, 1987). The analysis of spatial patterns in soft-bottom communities is difficult, as many species are not apparent from the surface, necessitating the need to disrupt the habitat (Thrush, 1991). Temporal patterns are also difficult to measure, as changes in the assemblage could be due to natural variability rather than human influences. For this reason, long-term temporal and spatial patterns are desired for the habitat being investigated.

5.2 Pilot Experiments

5.2.1 Introduction

Initially pilot experiments were conducted to investigate whether sampling methods were responsible for the highly variable results both Wood (1994) and Cole and Foster (1994) recorded. Two pilot experiments were carried out to investigate whether sampling and sieving methods affected results. Experiment one analyses whether different sampling methods cause statistical differences in the diversity of biota sampled. Experiment two attempts to differentiate whether different sieving methods influence the number of biota collected.

5.2.2 Experiment One

Aim

The aim of this study was to analyse the previously identified differences in benthic species diversity when hand sampling with SCUBA compared to the Smith-McIntyre grab sampler.

Method

All samples were collected over the centre of the dump ground within approximately 10 m radius at 38°41.92S, 178°00.78E in November 1994. Five samples were collected using a Smith-McIntyre grab sampler collecting a volume of 0.01 m^3 per grab, and deployed from the tug vessel Turihaua. Three samples were collected by SCUBA using a metal hand held sampler collecting to a depth of 9 cm, on the same day at the same site, collecting a total volume of 0.01 m^3. Further SCUBA samples were unable to be collected due to constraints of bottom time.

Collected samples were sieved over 1 mm mesh to extract benthic organisms. A 1 mm mesh size was employed as only the macrobenthic biota were required to be identified (Ferraro et al., 1989). Other considerations in determining mesh size included factors like sorting time, which is significantly longer over a 0.5 mm mesh than for 1 mm mesh (James et al., 1995). All sieving throughout this study was carried out over 1 mm mesh sieves. The organisms were then stored in 5 % formalin until they were sorted. After sorting, the remaining whole organisms were stored in 95 % ethanol.

Results

The grab samples show higher means for all types of organisms as well as greater diversity except for mysids (Table 5.1). Grab sampling resulted in more than double the number of polychaetes per grab compared to hand sampling. Polychaete numbers were higher for grab samples compared to SCUBA hand collected samples, especially for grab 2 and 3 which had over 100 polychaetes each. None of the SCUBA samples collected contained any cumaceans. Three of the five grab samples contained no mysids. The grab samples showed the highest number of organisms collected.

Table 5.1 Raw data on the number of benthic organisms collected.

	Grab 1	Grab 2	Grab 3	Grab 4	Grab 5	Dive 1	Dive 2	Dive 3
Bivalves	3	3	28	14	11	5	8	10
Polychaetes	49	684	107	71	74	45	2	49
Amphipods	1	9	15	9	7	6	2	11
Cumaceans	2	3	1	4	3	0	0	0
Mysids	1	0	0	0	3	2	1	1

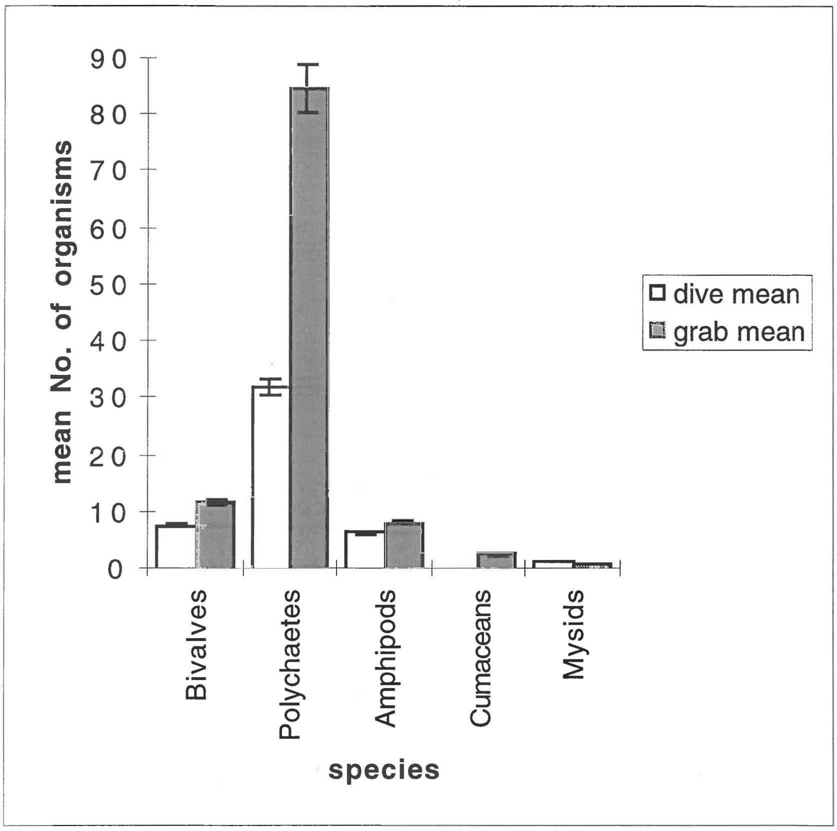

Figure 5.1 Showing the mean number of organisms for SCUBA sampling and Smith-McIntyre grab sampling over all replicates.

Discussion

These results show that grab sampling collected more organisms than a diver deployed hand sampler, especially for polychaetes. This would likely be due to small scale spatial variability, other factors may involve the mobility of the organisms. Mysids could have been able to move away from the hand held sampler, due to the lengthy operating time. The Smith-McIntyre also samples to a greater depth in the sediments. The other taxa showed only small percentage differences. This indicates that the Smith-McIntyre samples were comparable in variability to those collected by the SCUBA hand held sampler. For this reason the Smith-McIntyre grab sampler was used for all further sampling. Zero underwater visibility also rendered SCUBA sampling unsatisfactory.

5.2.3 Experiment Two

Aim

The aim of this experiment was to determine the efficiency of sieving using a high pressure salt water hose (available on the M.V. Turihaua) to extract benthic organisms from the sediment samples. This method was compared with gentle sieving in shallow water, which limits damage incurred by organisms. A comparison was made as it was previously unknown whether smaller organisms might be forced through 1 mm mesh, or whether larger specimens could be damaged.

Method

Samples were collected in November 1994 using the Smith-McIntyre grab sampler. Ten samples were collected; two replicates at five random sites. At each site, one replicate was sieved onshore by washing sediment through a sieve gently. The other replicate was sieved on the boat using the high pressure salt water hose. All samples were sieved over a 1 mm mesh size. The sieved samples were fixed in a 5 % formalin solution. Once sorted they were stored in 95 % ethanol.

Results

The total number of organisms collected from the 5 boat replicates was 235, while shore sieving collected was 223. Sieving on the boat showed higher percentages for polychaetes, cumaceans and mysids (Figure 5.2). Sieving onshore resulted in higher percentages for bivalves and amphipods. The difference in the percentages for the two methods was negligible. There was no consistent trend recorded in these results and the differences may have been due to variability between the sites.

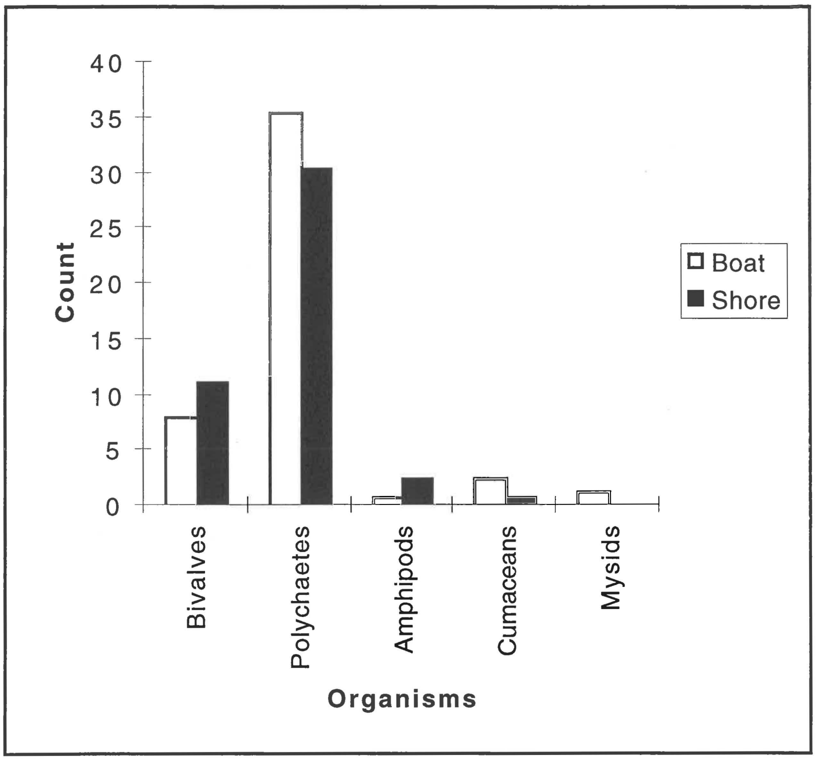

Figure 5.2 Comparison between organisms sieved onshore and those sieved using the high pressure hose.

Discussion

The results show little discernible difference in species composition between the two methods, and because of the ready availability and effectiveness of the salt water pressure hose, this method was used for all future sampling for this study.

5.3 Ecological Survey

5.3.1 Sampling Design

A sampling survey over the dump ground and surrounding area was carried out in March 1995. The survey consisted of a systematic sampling design distributing the samples evenly over the population (Snedecor and Cochran, 1972). Twenty five sites were sampled in grid formation (Figure 5.3). Five replicate samples were taken at each site. Eberhardt and Thomas (1991) and Hurlbert (1984) comment that when experimenting with replication, strong inferences can be drawn, this being the preferred method of sampling when feasible. Two other sites were sampled, one from the turning basin (TB) and another from the inner harbour (IH). The co-ordinates of the 27 sites are shown in Table 5.2. Site 26 equals the turning basin, while site 27 equals the inner harbour site.

5.3.2 Methodology

A differential GPS was employed to relocate and sample sites monitored by Cole and Foster (1994). A Smith - McIntyre grab sampler was used to collect samples, which were then sieved over a 1 mm mesh sieve. The remaining organisms were washed, and treated with 5% formalin. The samples were then sorted and stored in 95% ethanol (Hureau and Rice, 1983).

Table 5.2 Co-ordinates for sites where samples were taken.

Site	Latitude	Longitude	Site	Latitude	Longitude
Site 1	38°41.65S	178°01.25E	Site 2	38°41.65S	178°00.95E
Site 3	38°41.65S	178°00.78E	Site 4	38°41.65S	178°00.62E
Site 5	38°41.65S	178°00.44E	Site 6	38°41.78S	178°00.78E
Site 7	38°41.92S	178°00.44E	Site 8	38°41.92S	178°00.62E
Site 9	38°41.92S	178°00.78E	Site 10	38°41.92S	178°00.95E
Site 11	38°41.92S	178°01.25E	Site 12	38°42.04S	178°00.78E
Site 13	38°42.19S	178°00.44E	Site 14	38°42.19S	178°00.78E
Site 15	38°42.19S	178°01.25E	Site 16	38°42.19S	178°01.85E
Site 17	38°41.92S	178°01.85E	Site 18	38°41.65S	178°01.85E
Site 19	38°41.65S	178°00.30E	Site 20	38°41.92S	178°00.30E
Site 21	38°42.19S	178°00.30E	Site 22	38°42.04S	178°00.62E
Site 23	38°42.04S	178°00.95E	Site 24	38°41.78S	178°00.95E
Site 25	38°41.78S	178°00.62E	Site 26	38°40.57S	178°01.34E
Site 27	38°40.22S	178°01.77E			

Identification of the biota was carried out to species level where-ever possible. Bivalves were identified, counted and measured by the length along the anterior - posterior axis. This measurement procedure was also carried out on the bivalves collected by Cole and Foster (1994).

5.3.3 Statistical Analysis

All of the following statistical analyses were undertaken using SAS version 6.07 (SAS Institute Inc., 1985).

Population Size Structure

The age composition of bivalves can be estimated by length - frequency analysis, which determines the distribution of age classes within the population. This can indicate settlement, growth and ageing (Krebs, 1978). The shape of the length-frequency histogram can indicate whether the population is young where the smaller size classes dominate, or old where large size classes dominate.

Species Diversity Indices

Assessment of individuals or the population as a whole can provide an indication of the quality of the environment being measured. Species diversity indices are the best known community structure parameter; others include species composition (Diaz, 1992). The measurement of diversity is seen as being an indicator of the well-being of ecological systems (Magurran, 1988). It is assumed that any adverse effects of pollution will be reflected in a reduction in diversity or by a change in the shape of the species abundance distribution (Magurran, 1988). Berger-Parker and Margalef's indices were chosen to measure species diversity as they are straightforward measures of the abundance and dominance components of diversity, and are easily calculated and interpreted. Diversity can be divided into two components, the total number of species and the evenness of distribution (Magurran, 1988).

The Berger-Parker index gives a simple dominance measure and expresses the proportional abundance of the most abundant species (Southwood, 1978). This can be expressed mathematically as:

$$d = N_{max} / N$$

where N = total number of individuals, and N_{max} = number of individuals in the most abundant species. Often the reciprocal form of the measure is employed as this means that as diversity increases the index increases.

Margalef's index is a measure of the species richness, and can be expressed mathematically as:

$$D_{mg} = (S-1) / \ln N$$

where S = the number of species recorded and N = the total number of individuals summed over all S species. In this study diversity is calculated for each of the 27 sites, to compare whether sites on the dump ground have higher or lower diversity than sites surrounding the dump ground. Results could be indicative of impacts to benthic biota by the dumping of dredge spoil.

Spearmans Correlation

Correlation measures the closeness of a linear relationship between two variables. If one of the variables *x* can be expressed exactly as a linear function of variable *y* then the correlation is 1 or -1 depending on whether the variables are directly or inversely related. Spearmans correlation utilises rank correlation's. Spearmans correlation was applied to detect whether sites within the dump ground have similar taxa abundance's to those sites situated outside the dump ground.

Principal Component Analysis (PCA)

Principal component analysis is a multivariate technique used for examining relationships among several quantitative variables, and is used for summarising and detecting linear relationships (SAS Institute Inc., 1985).

Each principal component is a linear combination of the original variables, with coefficients equal to the eigenvectors of the correlation or covariance matrix.

Canonical Discriminant Analysis (CDA)

Canonical discriminant analysis is a dimension-reduction technique which is related to principal component analysis. CDA derives linear combinations of the quantitative variables that summarise the between-class variation. For each canonical correlation the hypothesis is that it and all smaller canonical correlation's are zero in the population tested (SAS Institute Inc., 1985).

Multidimensional Scaling (MDS)

Multidimensional scaling is a multivariate technique applied to represent community structure. It is an informal approach to display relationships among community samples (Clarke and Warwick, 1994). Analysis follows suggestions made by Clarke and Ainsworth (1993), with data re-expressed as Bray-Curtis similarities, and then analysed using MDS.

Spatial Autocorrelation

Spatial autocorrelation can be applied to measure spatial density patterns, being described as the dependence of the values of a variable on values of the same variable at adjoining locations (Sokal, 1979). For quantitative variables, spatial autocorrelation can be measured by either Moran's I or Geary's C coefficients (Sokal and Oden, 1978). Correlograms show graphically the autocorrelation coefficients as a function of distance between pairs of localities (Hull, 1996). Correlograms of Moran's I are utilised as Cliff and Ord (1973) suggest that Moran's I is generally more useful than Geary's C.

5.3.4 Results

72 species of organisms were identified from the 1995 survey. These are given in Table 5.3, with corresponding numbers used to identify the species.

Table 5.3 Species number and corresponding species

Sps Code	Species	Sps Code	Species
1	*Amphiura aster*	44	*Halicarcinus* sp.
2	Lepidasthenia sp.1	45	Shrimp sp.2
3	*Pectinaria australis*	46	Isopod sp.1
4	*Nephtys macroura*	47	Ophiuroid sp.2
5	*Onuphis* sp.	48	Holothurian sp.1
6	Terebellid sp.1	49	Nudibranch sp.1
7	Nemertine sp.1	50	Ostracod sp.1
8	*Goniada dorsalis*	51	*Cyclasterope zealandica*
9	*Nerinopsis* sp.	52	Mysid sp.2
10	*Holothurian* sp.2	53	*Podoceris* sp.
11	Scaleworm sp.2	54	*Nucula nitidula*
12	Spionid sp.1	55	*Tellina edgari*
13	*Travisia* sp.	56	*Mactra ordinaria*
14	*Ampharete* sp.	57	*Arthritica bifurca*
15	Spionid sp.2	58	*Mylitella vivens*
16	*Cirratulus nuchalis*	59	*Dosinia dorsalis*
17	*Liljeborgia barhami*	60	*Tawera spissa*
18	*Sigalion* sp.	61	*Dosinia subrosea*
19	*Owenia fusiformis*	62	*Eatoniella* sp.
20	Glycera sp.1	63	*Tellina* sp.1
21	Maldanid sp.1	64	*Pyramidellid* sp.
22	Nemertine sp.2	65	*Dosinia* sp.
23	Terebellid sp.2	66	*Tellina spenceri*
24	*Lumbrinereis sphaerocephala*	67	*Zeocopagia disculus*
25	*Prionospio* sp.	68	*Zenatia acinaces*

26	Polychaete sp.2	69	*Dosinia lambata*
27	Cumacean sp.2	70	*Tellina* sp.2
28	Shrimp sp.1	71	*Notopaphia elegans*
29	*Magelona papillicornis*	72	*Venericardia* sp.
30	Capitellid sp.	73	Crab indet.
31	*Axiothella quadramaculata*	74	Isopod indet.
32	Amphipod sp.2	75	Isopod sp.1
33	Glycera sp.2	76	*Asychis* sp.
34	*Torrida proharpinia hurleyii*	77	*Nebalia* sp.
35	Cumacean sp.1	78	*Ampelisca* sp.
36	*Orbinia papillosa*	79	*Liocarcinus corrugatus*
37	Polychaete sp.2	80	*Pontophilus australis*
38	Mysid sp.1	81	*Dendrostomum* sp.
39	*Armandia maculata*	82	*Phyllodocidae* sp.
40	Amphipod sp.1	83	*Eulalia* sp.
41	*Lembos pertinax*	84	*Peltorhamphus novaezealandiae*
42	*Hippomedon aff mcqueeni*	85	Gastropod sp.
43	*Neommatocarcinus huttoni*		

Rank Sum Graphs

Seventy two taxa were sampled over the 1995 survey, but of these only the top 30 ranked species were graphed (Appendix Two). Of the 42 taxa that were not graphed, 32 had less than 20 individuals over the survey. The other 10 taxa had abundance's of less than 100 individuals over the survey.

Table 5.4 Taxa with less than 100 individuals over the survey.

Taxa (less than 20 individuals)	**Taxa (less than 20 individuals)**
Ampharete sp.	*Cirratulus nuchalis*
Liljeborgia barhami	*Sigalion* sp.
Maldanid sp.1	*Lumbrinereis sphaerocephala*
Polychaete sp.2	*Axiothella quadramaculata*
Amphipod sp.2	*Neommatocarcinus huttoni*
Podoceris sp.	*Dosinia dorsalis*
Tawera spissa	*Eatoniella* sp.
Pyramidellid sp.	*Zeocopagia disculus*
Dosinia sp.	*Tellina spenceri*
Dosinia subrosea	*Tellina* sp.1
Halicarcinus sp.	*Cyclasterope zealandica*
Magelona papillicornis	Cumacean sp.2
Nemertine sp.2.	Terebellid sp.2
Venericardia sp.	*Holothurian* sp.2
Tellina sp.2	*Notopaphia elegans*
Zenatia acinaces	*Dosinia lambata*
Taxa (under 100 individuals)	**Taxa (under 100 individuals)**
Glycera sp.2 (22 individuals)	Shrimp sp.1 (24 individuals)
Travisia sp. (25 individuals)	Spionid sp.2 (32 individuals)
Armandia maculata (32 individuals)	Mysid sp.2 (37 individuals)
Shrimp sp.2 (50 individuals)	Glycera sp.1 (58 individuals)
Hippomedon aff. mcqueeni (63)	*Onuphis* sp. (73 individuals)

The 30 species graphed have a cumulative total of 95 % of the total organisms sampled. Over the whole survey the most abundant species were ranked as Terebellid sp.1 having 14 % of the total organisms, *Nerinopsis* sp. and Amphipod sp.1 with 8 % each. The other 27 species showed percentage ranges from 1 % to 6 %.

The sites from the dump ground (sites 3, 6, 7, 8, 9, 10, 11, 12, 14, 22, 23, 24, 25) show that Terebellid sp.1 is the most dominant species at 7 of the 13 sites, and occurred within the top five ranked places for all sites except two. These two sites (25 and 3), both had less than 50 individuals each for the most dominant species. Nerinopsis sp. was also common in high numbers and present at ten sites over the dump ground. Amphipod sp.1 was common as well, occurring at 9 sites.

Terebellid sp.1 and *Nucula nitidula* were the two most predominant species at sites on the eastern side of the dump ground (sites 1, 15, 16, 17, 18). *Arthritica bifurca* was the most dominant species at sites 1 and 16, indicating localised variability. Low numbers of organisms were collected at site 18, with less than 50 individuals for the most predominant species.

Terebellid sp.1 occurred within the ranked top five of all species at all sites on the western side of the dump ground (sites 5, 13, 19, 20, 21) . Amphipod sp.1 and *Tellina edgari* were common at four of the five sites. Low numbers of individuals were recorded at site 20.

Local variability is present at sites throughout the survey. The bivalve species *Arthritica bifurca* is dominant at sites 1 and 2, yet has low numbers at other sites. Rank sum graphs indicate that at most sites no single species dominates.

Diversity Index

The Berger-Parker and Margalefs index were calculated for both the 1995 and the 1993 data. Sites 3 and 6 are absent for the 1993 data.

The range for the 1995 data for Margalef's index (Figure 5.4) inside the dump ground is from 4.11 to 6.30, less than the range for outside the dump ground (3.69 to 6.11). The lowest diversities for the 1995 data were from the turning basin and inner harbour with 1.82 and 3.41 respectively.

A greater range of species diversity (for sites both on and outside the dump ground) occurred in 1993 compared to 1995. Diversity at sites on the dump ground ranged from 3.71 to 6.65, whereas sites off the dump ground ranged from 3.90 to 7.47. A comparison between the two years shows that species richness is high at all sites for both of surveys.

The Berger-Parker index (Figure 5.5) (indicating the importance of the most abundant species) for sites on the dump ground ranged from 3.39 to 9.56 for the 1995 data. The sites outside the dump ground ranged from 3.44 to 8.34. The turning basin and inner harbour had the lowest diversities with 2.76 and 3.28 respectively.

On the dump ground in 1993 the Berger-Parker index ranged from 0.37 to 0.82, and sites outside the dump ground ranged from 0.28 to 3.45. Proportionally speaking most sites were similar in diversity except for site 1 which showed a greater dominance of a single species. A comparison between the two years for sites 1 to 15 indicate a large variation, with the 1995 data having significantly higher diversity than the 1993 data except at site 1. Proportionally the range is greater within the 1995 data than with the 1993 data. This indicates that the diversity has increased dramatically, but no single species is dominant, but rather a number of species are co-dominant.

Spatial patterns for the Berger-Parker index for the 1993 survey indicate that sites on the dump ground have index levels within a small range. Sites situated on the southern edge of the dump ground are slightly lower (sites 13, 14, and 15). Sites 2 and 4 on the northern edge of the dump ground were slightly higher than those sites inside the dump ground. A spatial trend for the 1995 data was noted, with sites on the southern edge of the survey being proportionally lower (sites 14, 15, 16, and 17). No other trends were noticed. This area of lower diversity was noted in the same region as for the 1993 survey.

No spatial patterns were obvious for the Margalef's index for either the 1993 or 1995 surveys.

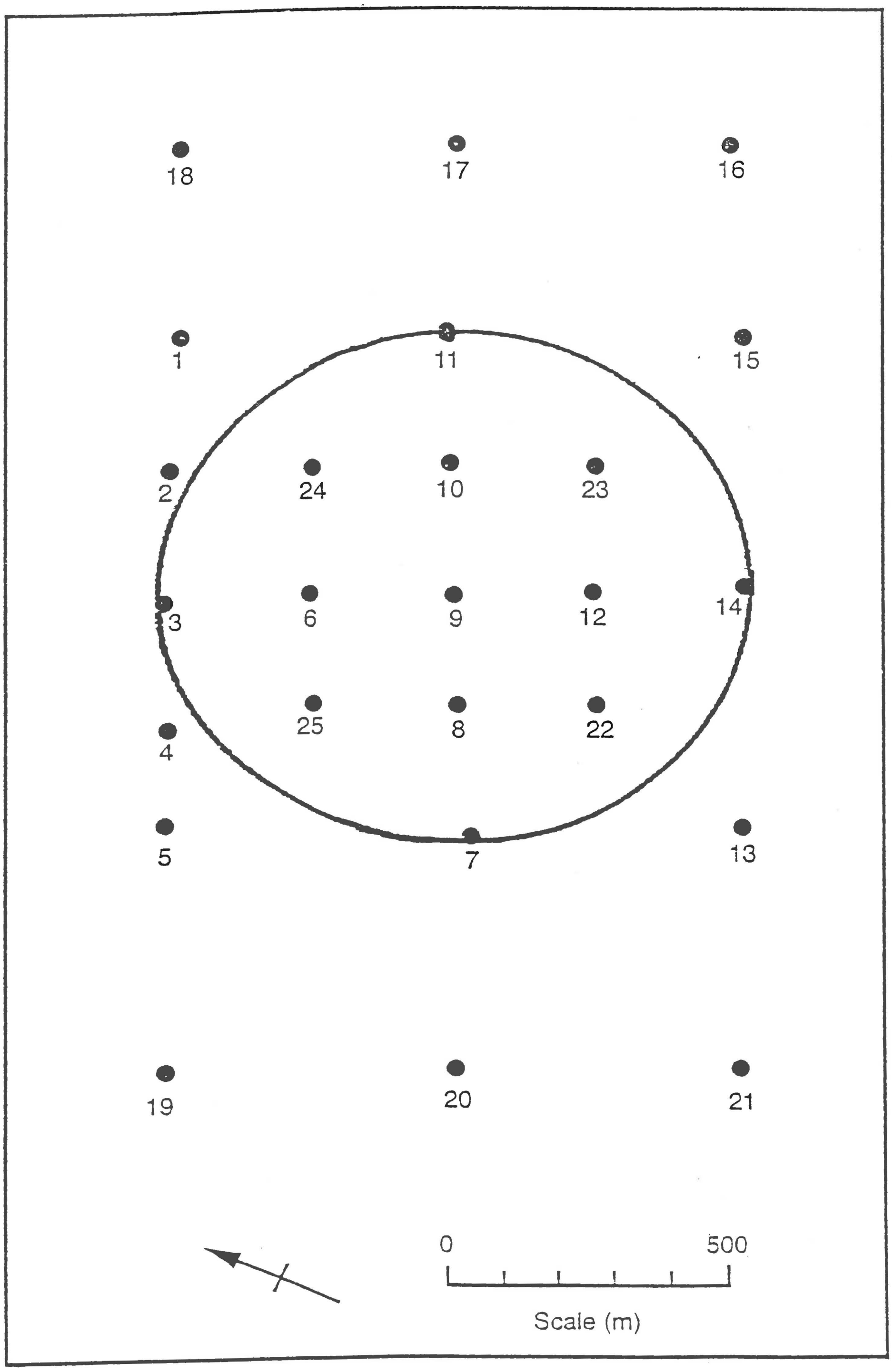

Figure 5.3 Location of the survey sites on and surrounding the dump ground.

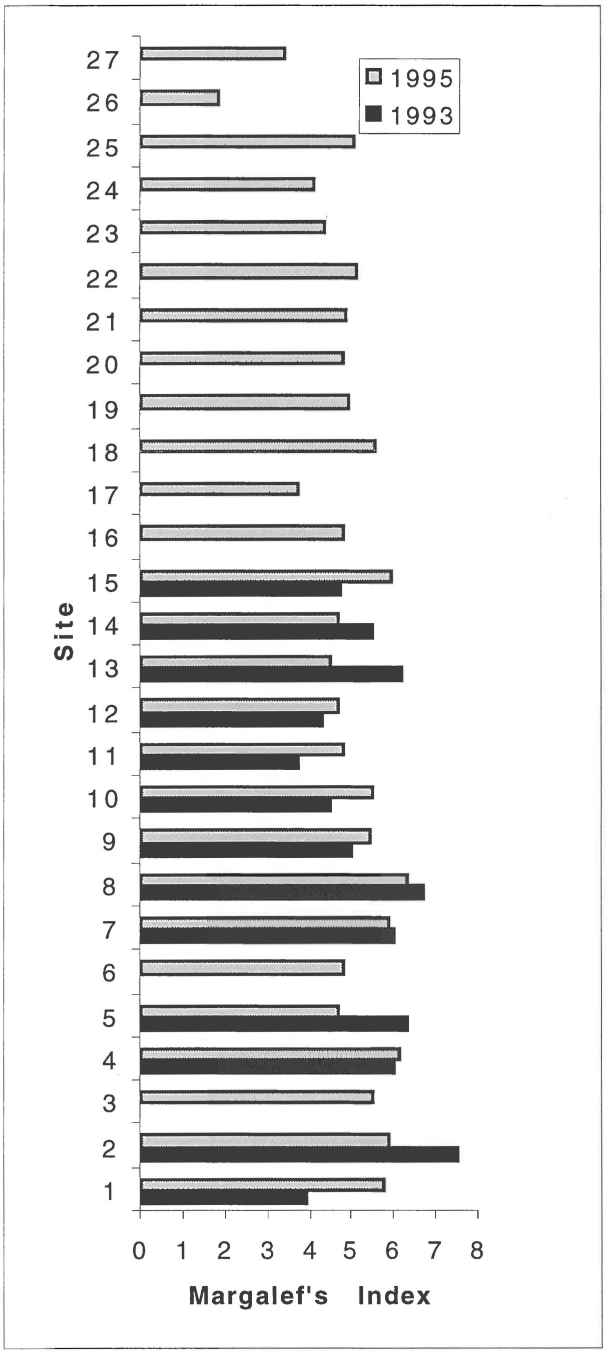

Figure 5.4 Margalef's index for species diversity for 1993 and 1995 at all sites, indicating high species diversity over the areas sampled.

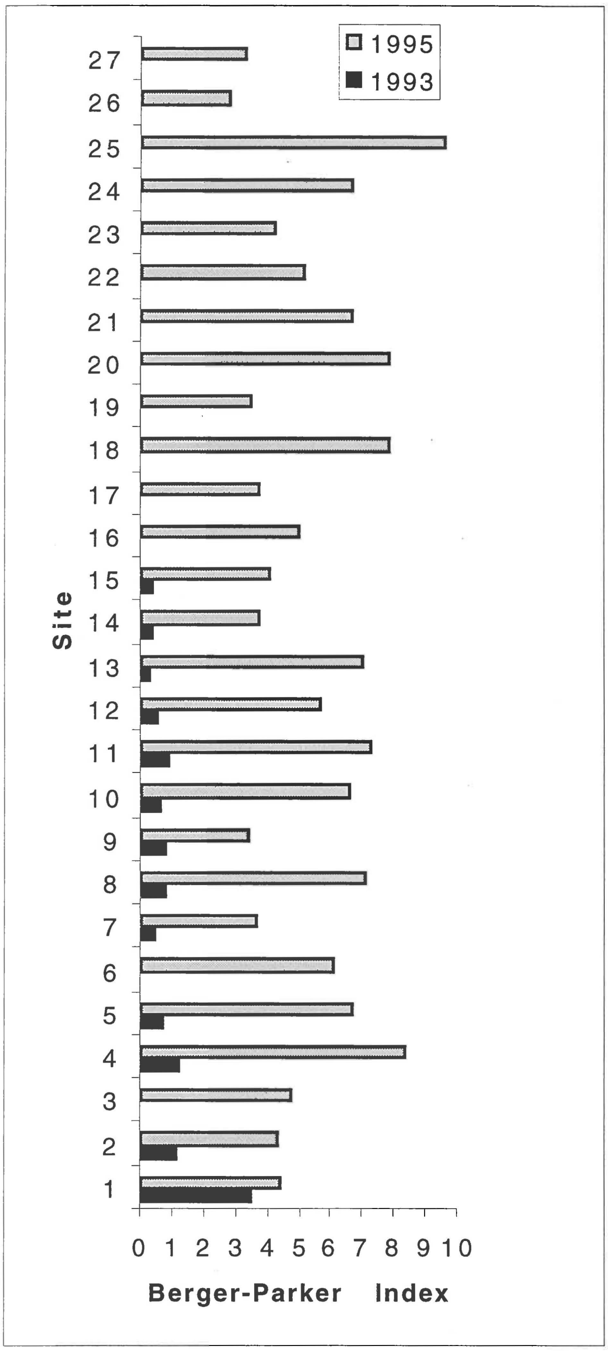

Figure 5.5 Berger - Parker index (a measure of diversity) for 1993 and 1995, indicates a clear difference between 1993 and 1995, reflecting the importance of the most abundant species had increased.

Spearmans correlation

Table 5.5 Spearmans rank correlation's for the total abundance and numbers of taxa shared by sites for the 1993 data. Above the leading diagonal, the values of Spearmans rank correlation coefficient between sites for the numbers of each taxon. Below the leading diagonal the number of taxa common to both sites.

Site	1	2	4	5	7	8	9	10	11	12	13	14	15
1		0.63	0.36	0.65	0.52	0.50	0.57	0.66	0.61	0.47	0.49	0.64	0.55
2	23		0.68	0.70	0.51	0.42	0.49	0.61	0.49	0.63	0.62	0.65	0.58
4	21	20		0.56	0.55	0.39	0.31	0.31	0.29	0.67	0.52	0.47	0.49
5	27	23	22		0.68	0.57	0.73	0.67	0.45	0.64	0.76	0.74	0.65
7	27	19	20	24		0.64	0.62	0.52	0.41	0.55	0.58	0.58	0.58
8	25	17	17	21	23		0.61	0.62	0.52	0.45	0.57	0.59	0.53
9	28	21	21	28	27	25		0.72	0.64	0.42	0.70	0.68	0.61
10	30	22	21	28	27	27	32		0.69	0.42	0.66	0.69	0.63
11	33	23	23	26	27	28	32	33		0.40	0.55	0.66	0.56
12	29	23	25	27	25	23	27	28	29		0.64	0.56	0.45
13	25	22	21	27	22	22	28	27	27	27		0.74	0.53
14	28	22	20	27	26	24	29	28	30	27	27		0.69
15	27	22	22	26	25	23	29	27	28	26	25	26	

Site 11 has a low correlation range from 0.29 - 0.69. Site 4 also has a low correlation from 0.29 - 0.67. No site in particular showed high correlations with any of the other sites. Site 5 has the highest correlation of 0.45 - 0.74. Spearmans correlation over the whole survey range from 0.29 - 0.76. Common taxa were high between most sites, especially site 1, ranging from 21 - 33. Site 11 was high also, ranging from 23 - 33. These results indicate that at the time of the survey in 1993, variability over the dump ground was high. This could imply that the population was recovering from an environmental perturbation, most likely an infrequent event.

Results for the 1995 survey indicate that a quarter of all Spearmans correlations were greater than 0.70, indicating that there is a high correlation between all of the 25 sites over the grid survey, both within and outside of the dump ground. Over all the survey the range was from 0.36 - 0.89. The turning basin (26) and inner harbour (27) sites were distinct from other sites, having low rank correlations. Site 26 ranged from 0.16 - 0.49, with site 27 ranging from 0.16 - 0.45. Taxa shared by the sites was also low for site 26 and 27. Site 26 has less than 10 species in common with all other sites over the survey. Site 27 showed a higher taxa commonality range from 7 - 17.

The grid survey, for 1995 indicated that site 25 had the lowest Spearmans correlation ranging from 0.40 -0.68. Site 2 also showed low correlations with other sites ranging from 0.41 - 0.70, although most were between 0.50 - 0.60. Site 13 had high correlations with other sites ranging from 0.58 - 0.89. Site 3 also had high correlations ranging from 0.54 - 0.89. Site 3 has the lowest range of common taxa for all sites ranging from 17 to 22 species. Site 25 had between 17 - 23 species in common with other sites. Sites showing high assemblages of common taxa include site 4 which ranged from 22 - 32 species in common, and site 15 also had a high range from 22 to 32.

These results indicate that the benthic population in 1995 had recolonised since the 1993 survey, with species diversity and abundance being high. The high correlations across all of the sites indicate that there is very little difference in the taxa assemblage across sites both on and outside the dump ground. This indicates that recruitment to the dump ground has resulted in some of the dominant species across the survey being present at every site. Some of these species include *Terebellid* sp.1, *Nerinopsis* sp., and Amphipod sp.1.

Table 5.6 Spearmans rank correlations and numbers of taxa shared by sites for the 1995 data. Above the leading diagonal, the values of Spearmans rank correlation coefficient between sites for the numbers of each taxon. Below the leading diagonal the number of taxa common to both sites.

Site	1	2	3	4	5	6	7	8	9	10	11	12	13
1		0.73	0.52	0.52	0.62	0.59	0.63	0.52	0.59	0.63	0.54	0.59	0.62
2	31		0.44	0.57	0.51	0.55	0.52	0.55	0.49	0.59	0.56	0.59	0.58
3	22	20		0.50	0.55	0.61	0.49	0.55	0.52	0.57	0.54	0.36	0.63
4	30	31	22		0.71	0.74	0.69	0.76	0.49	0.75	0.73	0.58	0.77
5	26	24	20	29		0.76	0.75	0.68	0.48	0.73	0.65	0.58	0.82
6	24	24	20	27	25		0.71	0.73	0.61	0.74	0.80	0.54	0.78
7	25	24	18	27	23	24		0.66	0.60	0.70	0.58	0.73	0.79
8	28	29	22	32	28	27	26		0.64	0.68	0.65	0.52	0.76
9	24	22	19	23	20	22	22	27		0.62	0.54	0.55	0.60
10	25	26	20	29	24	24	23	26	21		0.77	0.73	0.80
11	24	25	20	28	24	25	22	27	23	26		0.56	0.75
12	25	25	17	27	21	21	24	24	21	25	22		0.71
13	25	25	21	30	26	24	23	28	22	26	26	24	
14	26	28	19	29	23	23	26	27	22	24	23	25	24
15	28	27	22	32	27	26	28	29	24	26	25	24	27
16	23	24	20	27	22	20	20	25	19	23	23	21	24
17	20	19	18	22	21	19	18	21	18	22	20	18	22
18	27	30	22	31	24	24	25	29	22	25	24	24	24
19	25	25	19	27	23	21	23	27	21	24	24	21	24
20	23	21	19	27	23	23	22	23	20	25	23	20	24
21	24	24	19	30	26	23	24	24	19	27	24	22	25
22	25	22	19	28	24	23	22	25	21	25	22	22	25
23	23	22	20	27	25	24	22	25	20	25	25	21	27
24	21	22	18	25	22	22	22	23	20	24	23	21	23
25	21	21	20	23	19	21	17	22	21	22	23	18	21
26	9	7	8	9	9	8	7	9	8	10	8	8	9
27	13	17	13	17	12	14	12	15	14	15	15	13	15

14	15	16	17	18	19	20	21	22	23	24	25	26	27
0.65	0.62	0.55	0.64	0.63	0.57	0.54	0.57	0.58	0.63	0.61	0.44	0.25	0.25
0.68	0.55	0.57	0.52	0.70	0.52	0.41	0.50	0.44	0.54	0.59	0.40	0.16	0.45
0.51	0.60	0.59	0.68	0.67	0.48	0.58	0.54	0.47	0.61	0.57	0.72	0.27	0.32
0.66	0.69	0.71	0.66	0.75	0.59	0.66	0.74	0.60	0.66	0.68	0.55	0.21	0.30
0.70	0.71	0.68	0.74	0.63	0.66	0.71	0.82	0.68	0.80	0.71	0.51	0.40	0.16
0.65	0.74	0.61	0.72	0.68	0.55	0.73	0.71	0.71	0.77	0.77	0.66	0.31	0.34
0.87	0.76	0.59	0.63	0.66	0.73	0.71	0.82	0.65	0.77	0.73	0.46	0.34	0.24
0.64	0.66	0.70	0.64	0.70	0.58	0.60	0.61	0.58	0.66	0.65	0.58	0.29	0.27
0.55	0.59	0.45	0.63	0.54	0.54	0.56	0.54	0.57	0.59	0.65	0.62	0.27	0.37
0.69	0.74	0.69	0.83	0.70	0.70	0.77	0.83	0.74	0.81	0.84	0.67	0.45	0.40
0.62	0.65	0.70	0.68	0.66	0.54	0.66	0.67	0.59	0.73	0.73	0.65	0.31	0.34
0.78	0.55	0.58	0.56	0.56	0.64	0.53	0.66	0.56	0.65	0.64	0.42	0.33	0.29
0.80	0.72	0.72	0.74	0.65	0.70	0.73	0.80	0.73	0.89	0.76	0.62	0.38	0.39
	0.69	0.61	0.60	0.68	0.74	0.64	0.77	0.62	0.79	0.66	0.43	0.37	0.35
27		0.64	0.80	0.76	0.66	0.76	0.74	0.63	0.72	0.80	0.62	0.26	0.24
22	24		0.70	0.78	0.50	0.54	0.64	0.48	0.63	0.66	0.50	0.30	0.20
18	23	19		0.73	0.56	0.71	0.77	0.71	0.76	0.84	0.68	0.26	0.30
27	29	26	20		0.57	0.62	0.68	0.51	0.60	0.70	0.57	0.23	0.28
24	26	20	18	25		0.64	0.72	0.59	0.74	0.61	0.41	0.38	0.28
21	26	19	19	22	22		0.84	0.83	0.79	0.81	0.68	0.36	0.25
24	26	21	21	24	24	26		0.77	0.84	0.81	0.57	0.40	0.26
21	25	20	20	22	22	27	26		0.80	0.75	0.57	0.35	0.34
23	25	21	20	21	23	24	25	25		0.79	0.59	0.49	0.39
21	25	20	21	22	20	23	24	23	22		0.63	0.30	0.32
18	22	18	18	20	18	21	19	20	19	19		0.34	0.37
8	8	8	7	8	8	9	9	9	10	7	8		0.36
15	14	12	11	14	13	12	13	14	15	12	15	7	

Table 5.7 Spearmans correlation between fauna at sites listed for 1993 and 1995.

Site	Correlation	Common Taxa
1	0.44	26
2	0.12	17
4	0.25	21
5	0.27	18
7	0.04	12
8	0.02	16
9	0.19	16
10	0.29	18
11	0.25	23
12	0.14	19
13	0.34	20
14	0.31	19
15	0.46	21

Correlation of the benthic biota at the same sites between the two surveys indicates that variability was high, with very low correlations for site 7 and 8, indicating a total species assemblage change between the two years. Common taxa at these sites was also low. The highest correlation's were at sites 1 and 15, which also had common taxa numbered at 26 and 21 respectively, indicating that population of the taxa at these sites had changed less than at other sites between the two surveys.

The five most dominant species in the 1993 survey were Cumacean sp.1 (10 % of total population), *Lembos pertinax* (8 % of total population), *Nucula nitidula,* and *Arthritica bifurca* (both with 7 % of total population), and *Mactra ordinaria* (6 % of the total population). This indicates that crustaceans and molluscs were the dominant taxon. The five most dominant species account for 38 % of the total population.

The 1995 data for the same sites (on the dump ground) show the 5 most dominant taxa to be Terebellid sp.1 (13 % of total population), *Nerinopsis* sp. (8 % of the total population), Amphipod sp.1 (7 % total population), *Nucula nitidula* and *Arthritica bifurca* (both with 5 % of the total population). This indicates that although the population of crustacea has decreased over time, there has been an increase in the population of polychaetes. The population of bivalves (in proportion) has decreased only slightly between the two surveys. The five most abundant species for the same sites (1, 2, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15) in 1995 accounted for 38 % of the total population (the same as in 1993).

The sites on the eastern side of the dump ground show the five most dominant taxa to be *Nucula nitidula* (13 % of the population), *Arthritica bifurca* (12 % of the population), Terebellid sp.1 (8 % of total population), *Amphiura aster* (7 % of the population), and Amphipod sp.1 (6 % of total population). Sites on the western side of the dump ground show a different species assemblage for the five most dominant taxa, Terebellid sp.1 (16 % of the population), *Nerinopsis* sp. (12 % of the total population for sites on the western side of dump ground), Amphipod sp.1 (10 % of population), *Tellina edgari* (8 % of the population), and *Gonidia dorsalis* (7 % of the total population).

The three different areas for the 1995 survey all show different species assemblages. The dominant species for sites on the eastern side of the dump ground show molluscs to be the dominant taxa (*Nucula nitidula* and *Arthritica bifurca*). *Amphiura aster* is also dominant. The sites on the dump ground have polychaetes being the most dominant taxon (Terebellid sp.1, and *Nerinopsis* sp.). Sites on the western side of the dump ground have a similar assemblage as sites on the dump ground with Terebellid sp.1 and *Nerinopsis* sp. being dominant. These different species assemblages may be indicative of localised variability, possibly influenced by sediment size.

Principal Component Analysis and Canonical Discriminant Analysis

Crustaceans

The principal component analysis for the 1993 data (Figure 5.6a) showed that 40.0 % of the total variance of the data is accounted for in the first two components. Prin 1 was influenced by Amphipod sp.1 and *Pontophilus australis* whereas Prin 2 was influenced by both Shrimp sp.1 and *Torrida proharpinia hurleyii.* Sites 15 and 11 are positively separated along Prin 1, and between them account for 80 % of the population of Amphipod sp.1, and the total population of *Pontophilus australis.* Sites 1, 2, 4, and 12 are situated negatively along Prin 2, as a result of very low abundance's of *Torrida pro. hurleyii* (ranging from <1 % to a maximum of 6 % of the total population). These four sites between them account for 80 % of the population of Shrimp sp.1. Site 9 is outlying positively along Prin 1 due to having almost 20 % of the total abundance of *Torrida pro. hurleyii.*

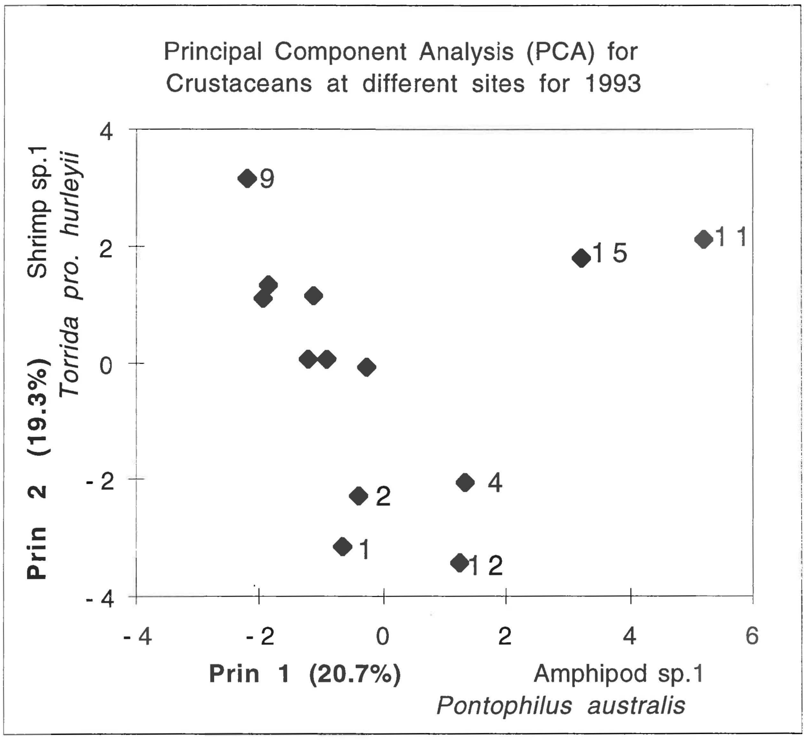

Figure 5.6a PCA for Crustaceans for the 1993 survey.
Sites separated by analysis are labelled.

The principal component analysis for the 1995 crustacean data (Figure 5.6b) shows that the first two components accounted for 41.9 % of the variance. Prin 1 was influenced by Ostracod sp.1 and *Lembos pertinax*. *Cyclasterope zealandica* and *Halicarcinus* sp. influenced Prin 2. Sites 21 and 3 were separated along Prin 1, which is influenced by Ostracod sp.1 and *Lembos pertinax* by having very low populations of each species (<1 % for each of the sites).

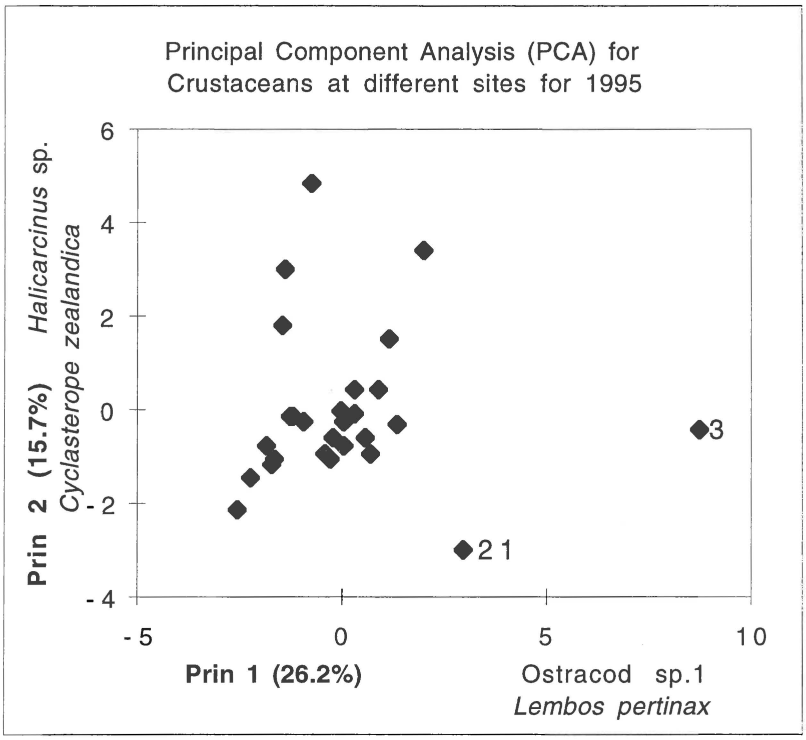

Figure 5.6b PCA for Crustaceans for the 1995 survey.
Sites separated by analysis are labelled.`

The canonical discriminant analysis (which indicates between - class variation for quantitative variables) for the 1993 data showed that Can 1 and Can 2 accounted for 80.8 % of the variance. Shrimp sp.2 and Cumacean sp.2 influenced Can 1 and Amphipod sp.2 influenced Can 2. The crustaceans for canonical discriminant analysis for 1993 at sites 1 and 11 were separated from the other sites. Site 11 was separated along both axes positively, whereas site 1 was negatively separated along Can 1. It is unknown why these sites were separated so strongly from all other sites (which are clustered). There were no distinctive taxa patterns for either sites for any of the taxa which influenced Prin 1 and Prin 2.

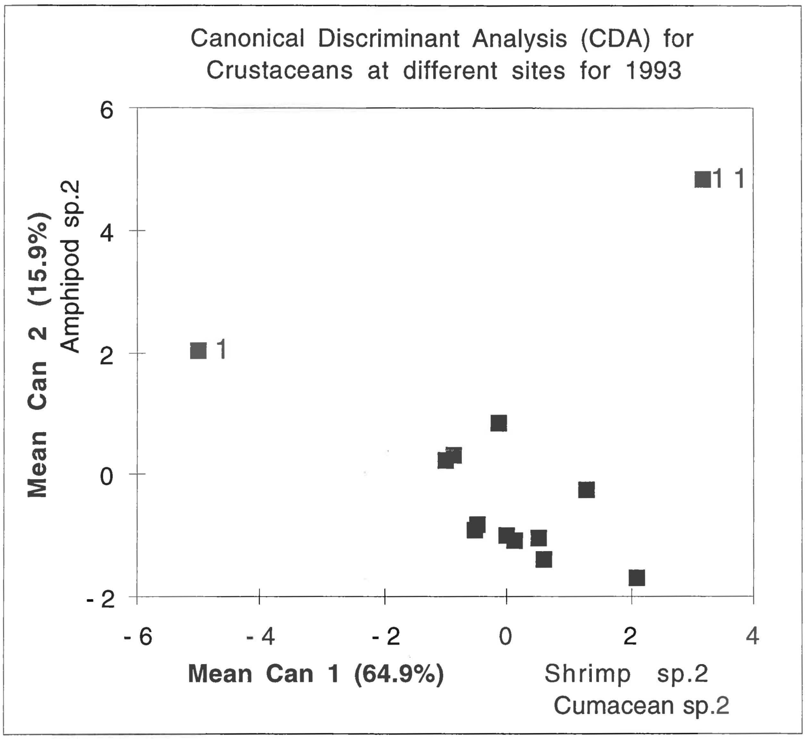

Figure 5.6c CDA for Crustaceans for the 1993 survey.
Sites separated by analysis are labelled.

The 1995 data for crustaceans indicated 45.3 % of the total variance was accounted for by Can 1 and Can 2. Can 1 was influenced by Crab indet. and *Torrida proharpinia hurleyii. Liljeborgia barhami* and Ostracod sp.1 influenced Can 2. Site 4 accounts for 60 % of the total population of Ostracod sp.1, site 11 accounted for 9 % of another 9 % of the population. No other patterns in abundance could be identified as to why site 4 was separated along Prin 1.

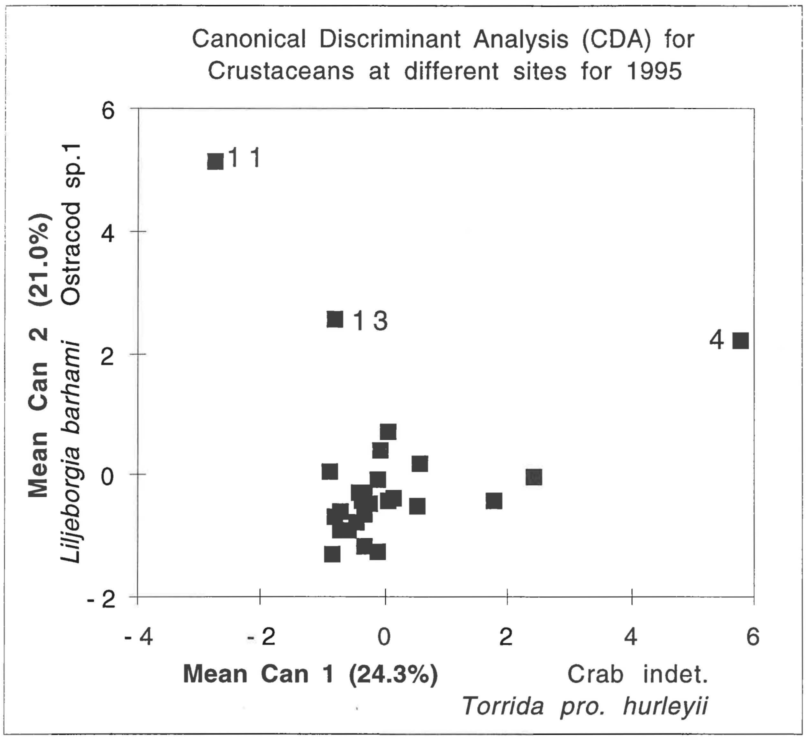

Figure 5.6d CDA for Crustaceans for the 1995 survey.
Sites separated by analysis are labelled.

Polychaetes

Principal component analysis for the 1993 data for polychaetes (Figure 5.7a) indicates that Prin 1 and Prin 2 together account for 47.5 % of the variance. Prin 1 was influenced by *Onuphis* sp. and *Owenia fusiformis*. Spionid sp.2 and *Orbinia papillosa* accounted for the highest influence on Prin 2. Site 11 separated along Prin 2, was separated by having 12 % of the total population of *Orbinia papillosa*. Site 1 was separated along Prin 1 by having 64 % of the total population of *Onuphis* sp., and 26 % of the population of *Owenia fusiformis*. Site 12 was separated by *Orbinia papillosa*, containing 30 % of the total population. These two sites between them contain 42 % of the total population of *Orbinia papillosa*.

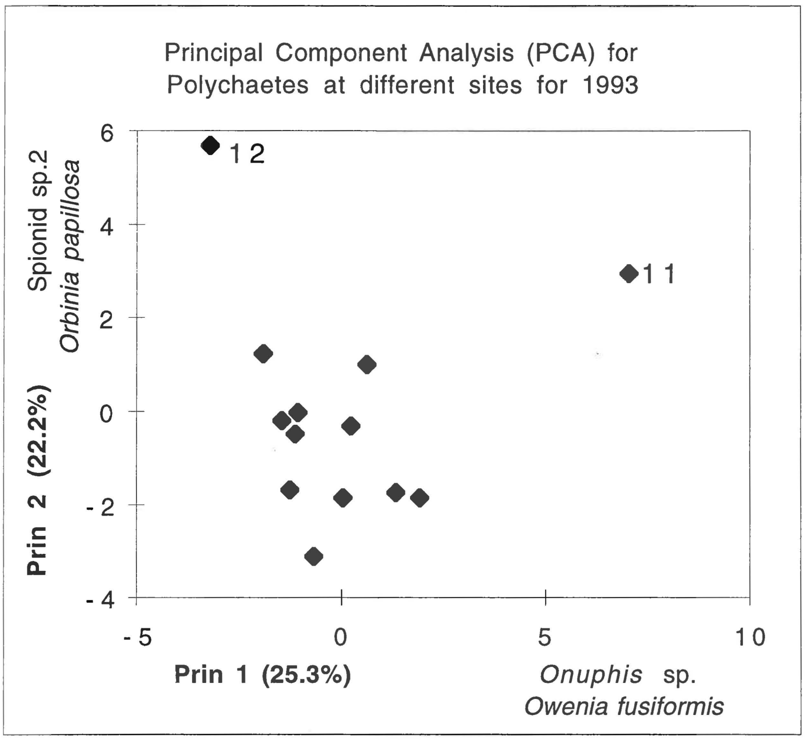

Figure 5.7a PCA for Polychaetes for the 1993 survey.
Sites separated by analysis are labelled.

The 1995 polychaete data shows that the first two components accounted for 32.5 % of the variance (Figure 5.7b). Prin 1 was highly influenced by *Lumbrinereis sphaerocephala*. Prin 2 was influenced by *Travisia* sp. and Polychaete sp.2. Site 1 was separated along Prin 1, accounting for 86 % of the population of *Lumbrinereis sphaerocephala.* Site 2 accounts for the other 14 % of the population. Site 4 was separated along Prin 2, due to *Travisia* sp. accounting for 16 % of the total population. All other sites (individually) contained only 3 and 4 % of *Travisia* sp. Site 27 had 92 % of the population of Polychaete sp.2.

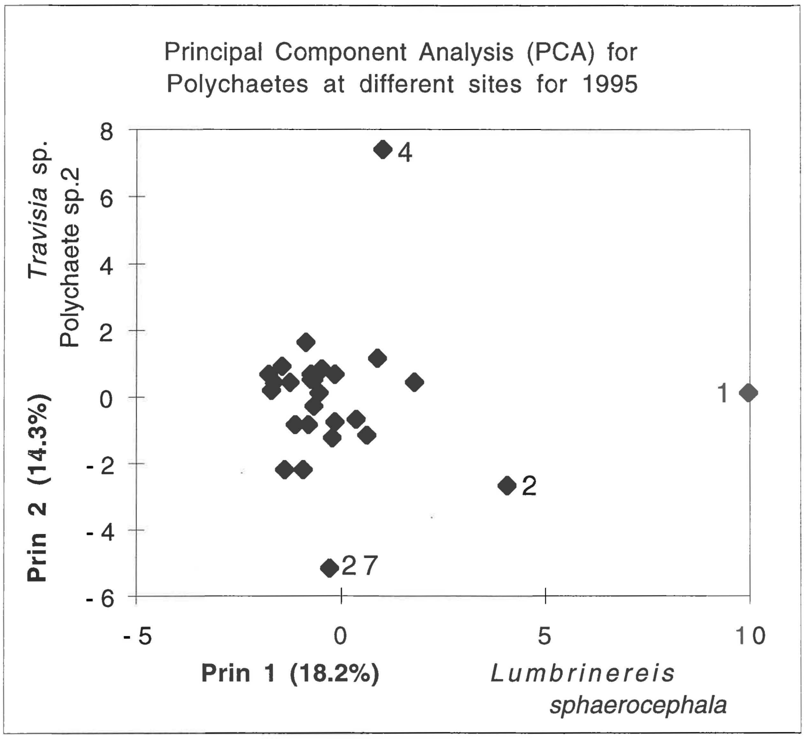

Figure 5.7b PCA for Polychaetes for the 1995 survey. Sites separated by analysis are labelled.

The canonical discriminant analysis shows that 66.9 % of the variance accounts for the first two components for the 1993 data (Figure 5.7c). Can 1 is influenced by Onuphis sp. and *Terebellid* sp.1. Spionid sp.1 and Prionospio sp. influenced Can 2. Site 12 was separated by Spionid sp.1, and *Prionospio* sp. having 24 % of the population of Spionid sp.1, and 34 % of the population of *Prionospio* sp.. Site 4 had 25 % of the population of Spionid sp.1, and 23 % of the total population of *Prionospio* sp.. Site 11 was separated by having 64 % of the population of *Onuphis* sp. and 50 % of the total population of Terebellid sp.1. Site 11 was also separated slightly along Prin 2, being influenced by Spionid sp.1 with 12 % of the total population.

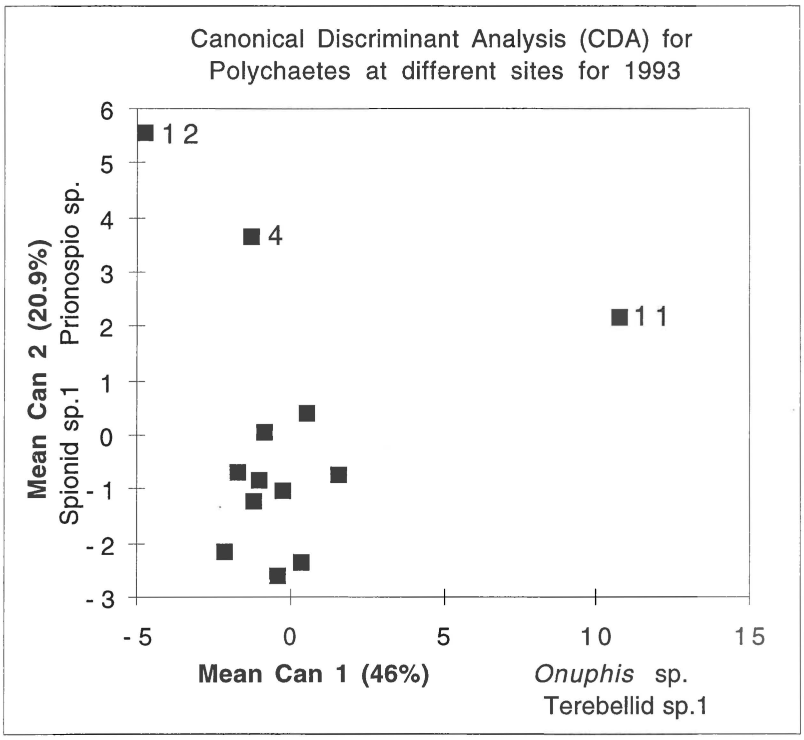

Figure 5.7c CDA for Polychaetes for the 1993 survey. Sites separated by analysis are labelled.

The first two components of the 1995 polychaete data (Figure 5.7d) accounted for 39.9 % of the variance of the data. Can 1 was highly influenced by *Lumbrinereis sphaerocephala*. Onuphis sp. and Glycera sp.1 influenced Can 2. Site 2 was separated by having 73 % of the total population of *Onuphis* sp.. Site 27 is separated for having no abundance of any of the taxa which influence Prin 1 and Prin 2. Site 1 accounts for 86 % of the population of *Lumbrinereis sphaerocephala*. The factors which separate site 12 negatively along Can 1 were unable to be isolated.

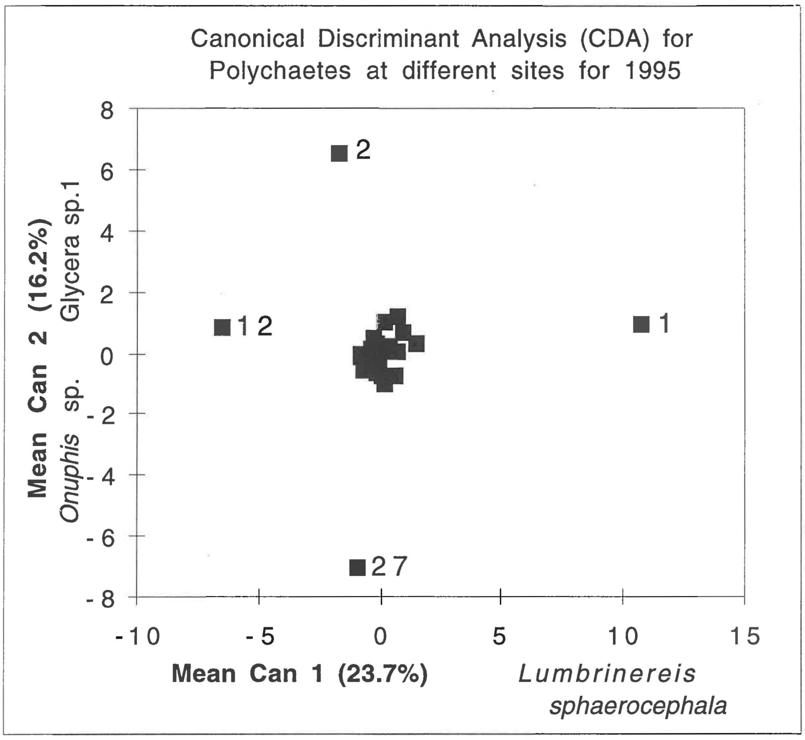

Figure 5.7d CDA for Polychaetes for the 1995 survey. Sites separated by analysis are labelled.

Molluscs

Principal component analysis of the 1993 mollusc data (Figure 5.8a) shows that 47.7 % of the total variance is in the first two components. Prin 1 was influenced by *Mylitella vivens* and *Dosinia subrosea*. Prin 2 was highly influenced by *Nucula nitidula*. Sites 4 and 12 are separated along Prin 1 by *Mylitella vivens* by having 40 % and 45 % of the total populations respectively. Both sites have an abundance of 50 % of the total population of *Dosinia subrosea* each. No other sites had a population of *Dosinia subrosea*. Sites 1 and 11 are separated along Prin 2 by *Nucula nitidula*. Site 1 contained 32 % of the population, whereas site 11 contained 43 % of the total population. The two sites between them had 75 % of the total population of *Nucula nitidula* for the 1993 survey.

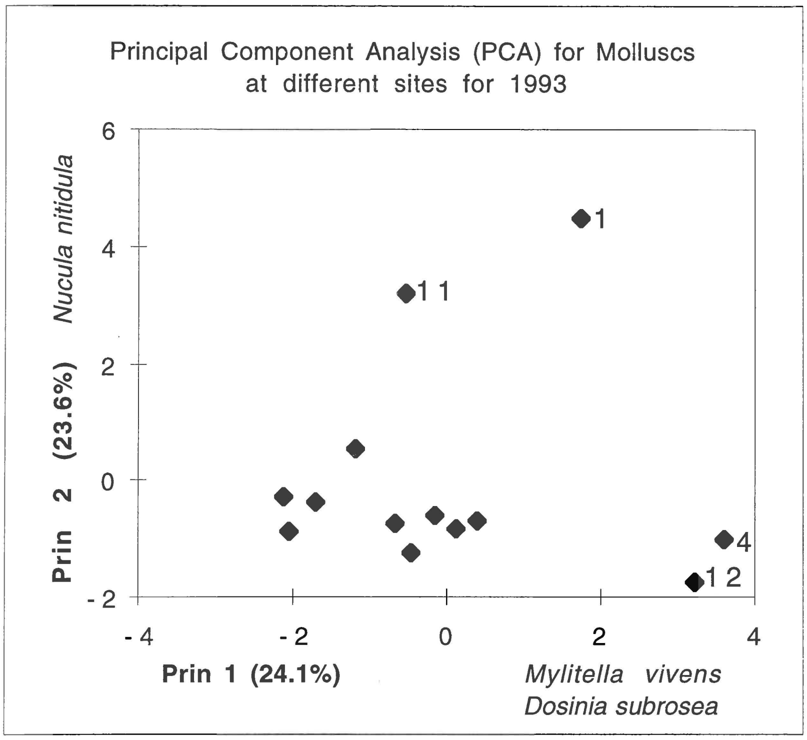

Figure 5.8a PCA for Molluscs for the 1993 survey.
Sites separated by analysis are labelled.

The mollusc data for 1995 shows that Prin 1 and Prin 2 account for 26.4 % of the variance of the data (Figure 5.8b). Prin 1 was highly influenced by *Dosinia lambata*. Prin 2 was influenced by *Mylitella vivens* and *Dosinia dorsalis*. No sites were significantly separated, although the distribution of sites was widespread along both Prin 1 and Prin 2.

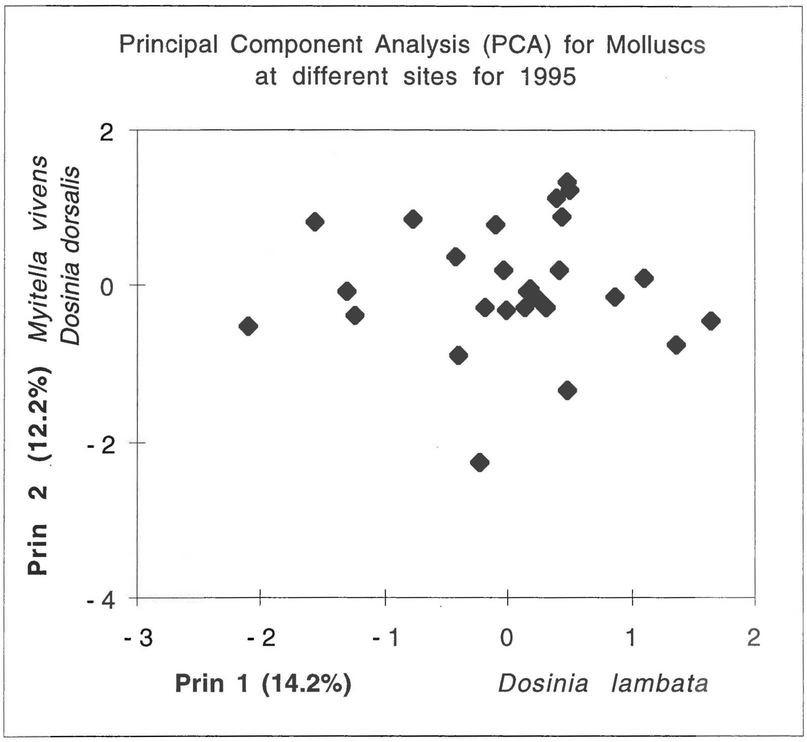

Figure 5.8b PCA for Molluscs for the 1995 survey.
Sites separated by analysis are labelled.

The canonical discriminant analysis shows that Can 1 and Can 2 account for 58.6 % variance for the 1993 mollusc data (Figure 5.8c). Can 1 was highly influenced by *Nucula nitidula*, with Can 2 being highly influenced by *Tellina edgari.* The canonical discriminant analysis confirms the results of the principal component analysis for molluscs where sites 1 and 11 were separated by their population of *Nucula nitidula*, having 75 % of the total population between them.

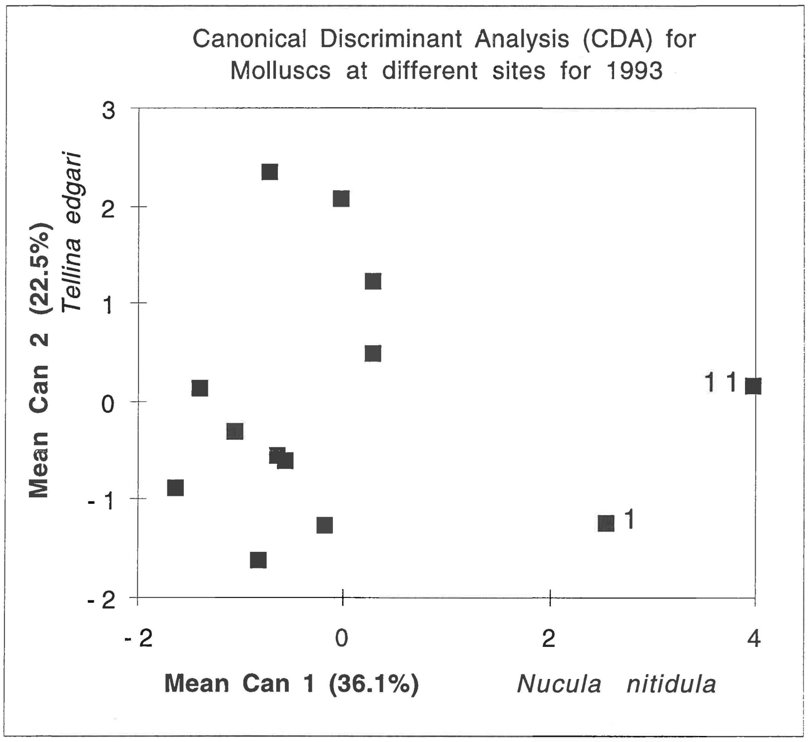

Figure 5.8c CDA for Molluscs for the 1993 survey.
Sites separated by analysis are labelled.

The 1995 mollusc data indicates that Can 1 and Can 2 account for 45.2 % of the variance (Figure 5.8d). Can 1 was influenced by *Dosinia lambata* and *Notopaphia elegans*. Can 2 was influenced by *Tellina edgari*. Site 16 was separated positively along Prin 1 as it accounted for 100 % of the population of *Notopaphia elegans* and 50 % of the population of *Dosinia lambata*.

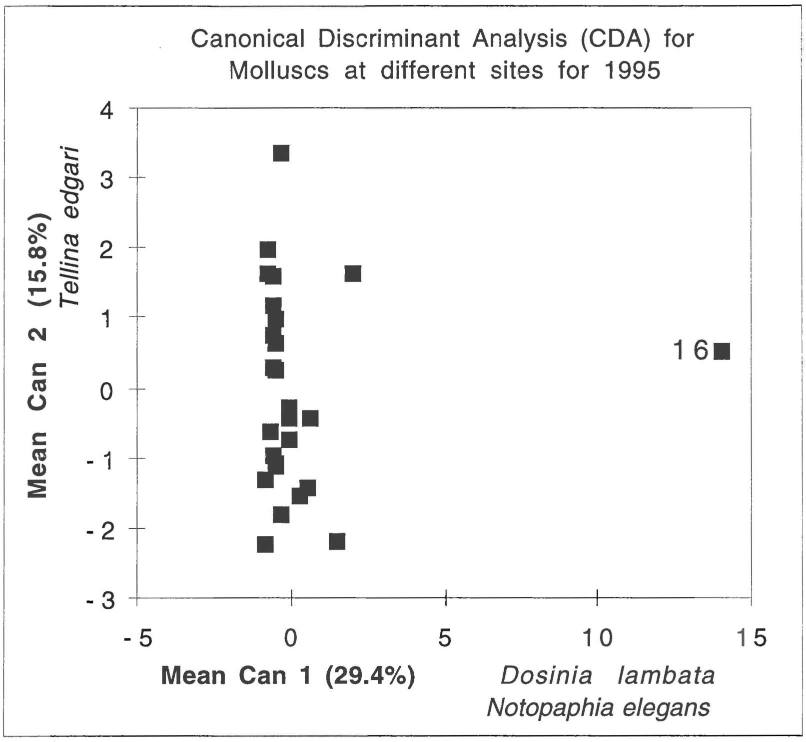

Figure 5.8d CDA for Molluscs for the 1995 survey.
Sites separated by analysis are labelled.

Site 11 was separated across all of the principal component analysis and canonical discriminant analysis for 1993; site 1 was also distinguished as being different. Site 11 had the highest abundance of individuals (496) for the survey, the average was 280 individuals. The species richness (Margalef's index) of these sites indicates no distinctive trends. The Berger-Parker diversity index indicates site 1 was separated from other sites for the 1993 data, with the abundance of the dominant taxa (*Nucula nitidula*) being important to the population at that site. Significant differences in the species assemblages at these sites are not apparent, and do not explain why they would be separated continuously by analysis.

No patterns were prominent for the 1995 data for sites or taxon and no trends were distinctive between the two surveys for either taxa or sites. Small scale local variability was present in taxon with low abundance, with these species generally being present at one or two sites only. This indicates that species with significant densities are distributed relatively evenly over the survey area.

Multidimensional Scaling

Multidimensional scaling of crustaceans (Figure 5.9a) polychaetes (Figure 5.9b) and molluscs (Figure 5.9c), (an informal approach to represent community structure) shows that for both molluscs and crustaceans, although not clustered close together there are no distinguishable outlying sites. The polychaete indicate for multidimensional scaling that sites 26 and 27 are separated from the other sites. This result was to be expected due to the different species assemblage and low abundance at these sites. Multidimensional scaling indicated that all sites over the gird survey were significantly separated.

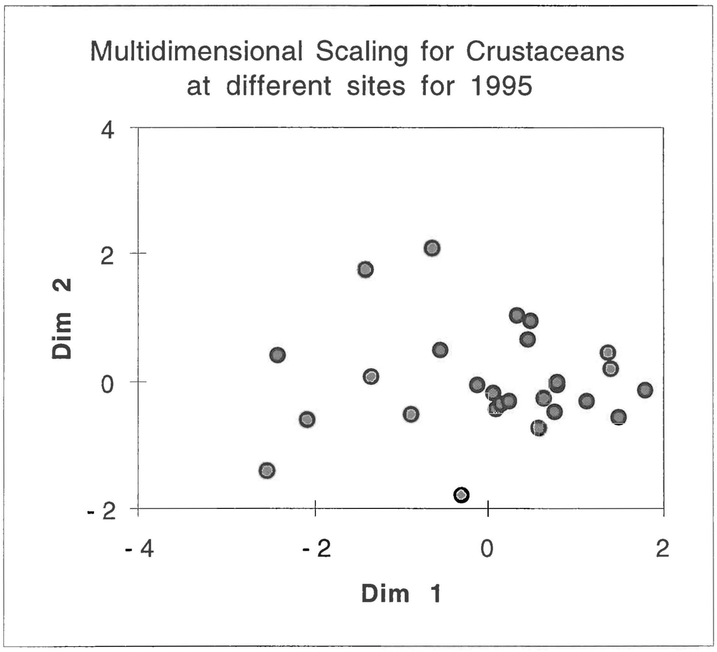

Figure 5.9a MDS for Crustaceans for the 1995 survey.
Stress = 0.13.

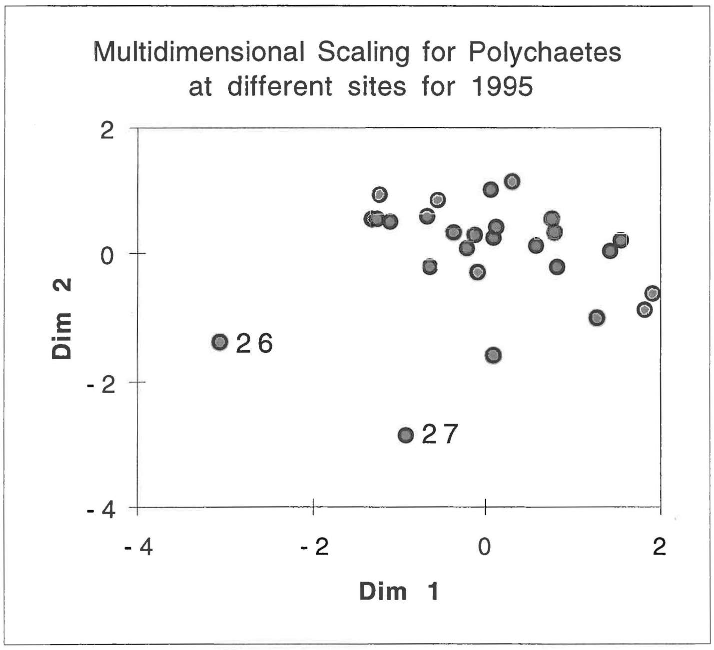

Figure 5.9b MDS for Polychaetes for the 1995 survey.
Stress = 0.14.

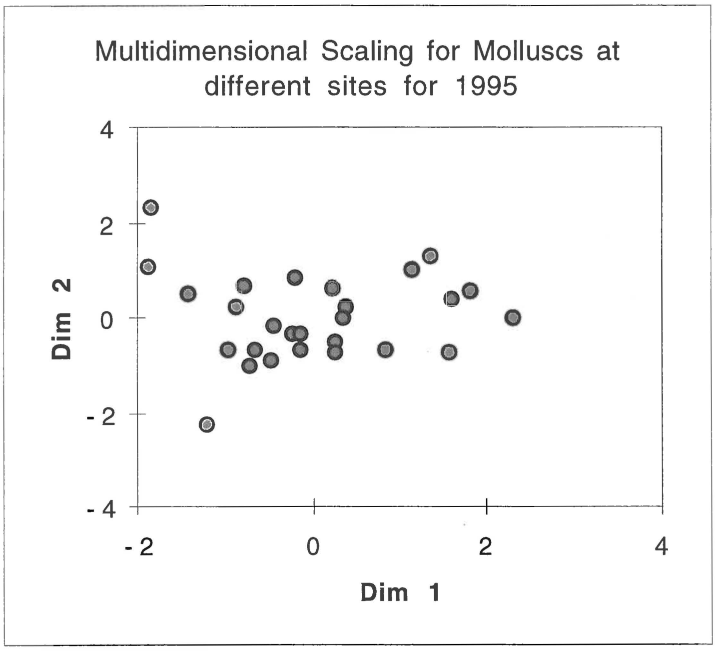

Figure 5.9c MDS for Molluscs for the 1995 survey.
Stress = 0.14.

Moran's I

Moran's I (a measure of spatial density patterns) for the 1993 survey at any distance had no significant values (Figure 5.10a). Moran's I for the 1995 data showed one significant point at a distance of 200 m (Figure 5.10b). No other distances indicated significant values.

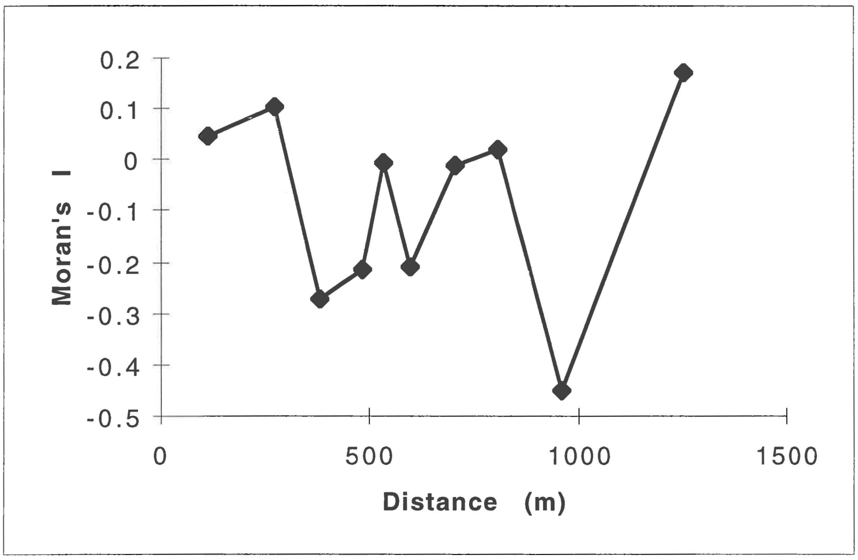

Figure 5.10a Moran's I for the 1993 survey.

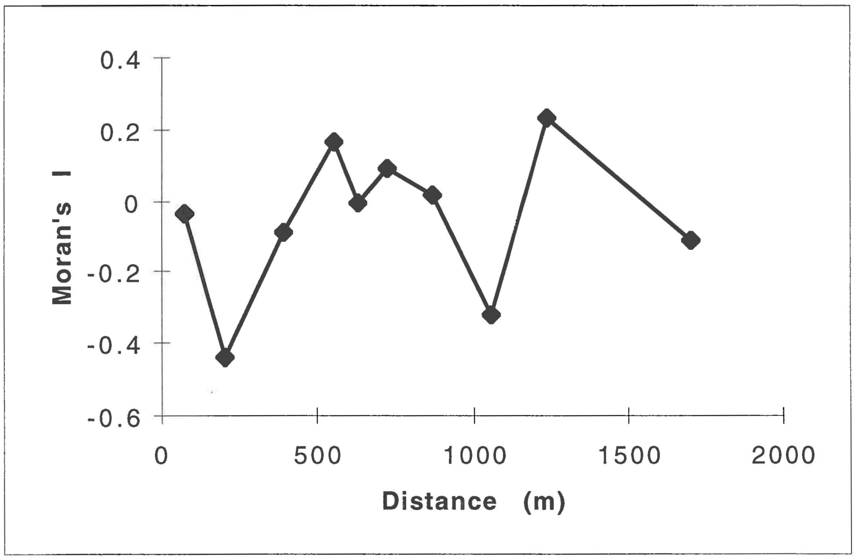

Figure 5.10b Moran's I for the 1995 survey.

Bivalves

For the 1993 survey 798 bivalves were collected in total. These were divided by size classes of which 89 % were measured from 0 - <5 mm, 8 % from 5 - <10 mm, 2 % from 10 - <15 mm, and 1 % from 15 - <20 mm. Three species of bivalve dominated the 1993 data. These species were *Nucula nitidula* (252 individuals), *Arthritica bifurca* (243 individuals) and *Mactra ordinaria* with 226 individuals. In the 1995 data 2668 bivalves were collected, of which 62 % were in the 0 - <5 mm size range, 23 % were from 5 - <10 mm, 13 % were between 10 - <15 mm, and 1 % from 15 - <20 mm. Four species of bivalve were dominant; *Nucula nitidula* (781 individuals), *Tellina edgari* (621), *Arthritica bifurca* (576 individuals) and *Mactra ordinaria* (472).

Tellina edgari

The population of *Tellina edgari* between the two years increased dramatically from 1993 where only 40 individuals were sampled, to 1995 where 621 individuals were collected. The mean length of *Tellina edgari* increased from 6.75 mm in 1993 to 8.83 mm in 1995 (Figure 5.11a). Small numbers of larger size classes in the 1995 data in the larger size classes indicate that the population is ageing.

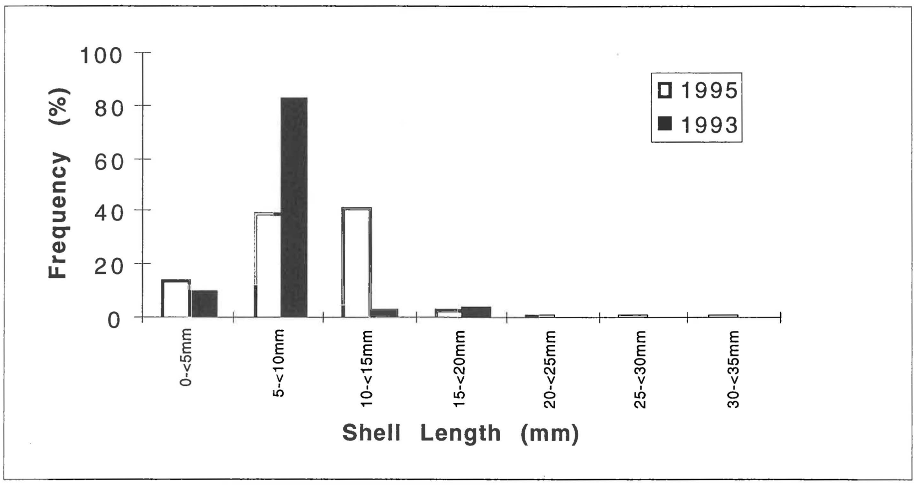

Figure 5.11a Length-frequency distribution for *Tellina edgari* between 1993 and 1995.

Nucula nitidula

Between 1993 and 1995 the abundance of *Nucula nitidula* increased. The population size increased from 1993 (252 individuals) to 781 individuals in 1995. The number of individuals that were larger than 5 mm had increased between 1993 and 1995 by 9 %. The mean length in 1993 was 2.56 mm and in 1995 was 3.33 mm.

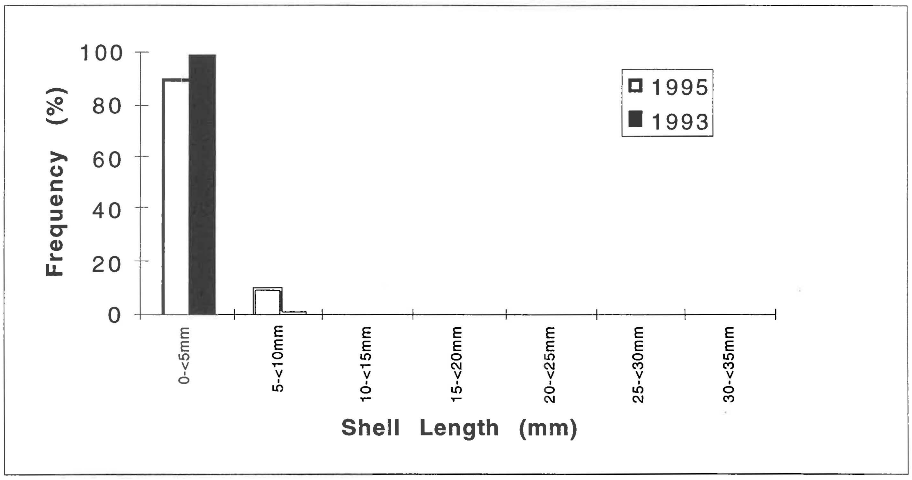

Figure 5.11b Length-frequency distribution for *Nucula nitidula* between 1993 and 1995.

Arthritica bifurca

The mean size of *Arthritica bifurca* increased in size between the two years by 0.18 mm (mean length of the sample) from 2.05 mm to 2.23 mm. Over 95 % of the population is within the first size class range for both years (Figure 5.11c).

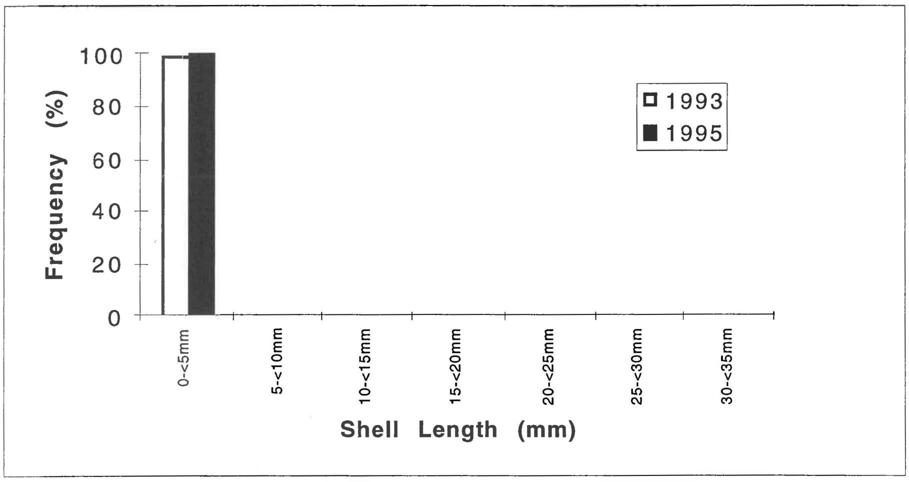

Figure 5.11c Length-frequency distribution for *Arthritica bifurca* between 1993 and 1995.

Mactra ordinaria

The mean shell length of *Mactra ordinaria* increased from 3.48 mm to 6.97, indicating that older bivalves are present on the dump ground. The distribution of the population has also changed from 1993 where the majority of the population was in the first size class range, to become more predominant in the larger size classes.

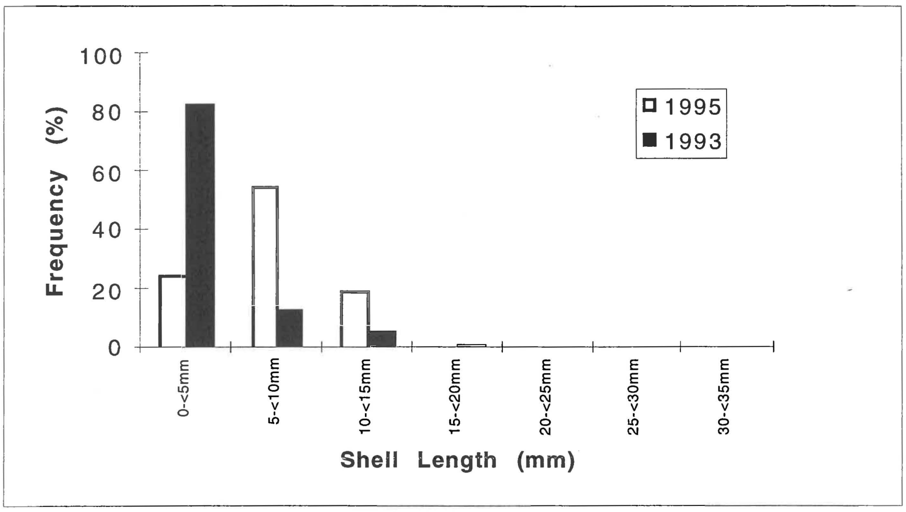

Figure 5.11d Length-frequency distribution for *Mactra ordinaria* between 1993 and 1995.

Comparison of the bivalves between the two years show that the sampled populations have increased in numbers as well as age distribution. This suggests that the 1993 population was predominantly juvenile. The population in 1995 appears to be an established aged population. The difference between the two surveys could indicate that an environmental perturbation decimated the population (before sampling in 1993), resulting in a more established population in 1995. It is possible that the environmental perturbation was an infrequent event.

Sediment / Biota Correlations for the 1995 Survey

Correlations of Berger-Parker index and Margalef's index show strong positive correlation with grain sizes 1 - 3 phi, which corresponds with medium sand to very fine sand (Table 5.8). The abundance of organisms correlates strongly to phi sizes -2 to -1, which corresponds as granule and very coarse sand. All other correlations show no significance, except for grain size 4 - 5 phi for the Berger-Parker diversity index, which shows a strong negative correlation. The positive correlation with sand sized grains was to be expected as at most sites textural descriptions fit within this range (Chapter 4).

Table 5.8 Spearmans correlation indicating relationship between sediment and biota for the 1995 survey.

Sediment Size	Berger-Parker Index	Margalef's Index	Total Abundance
-5 phi	-0.144	0.034	-0.074
-4 phi	-0.007	-0.131	-0.097
-3 phi	-0.007	-0.103	-0.111
-2 phi	-0.031	0.071	0.426
-1 phi.	-0.030	0.119	0.491
0 phi	0.050	0.100	0.244
1 phi	0.382	0.503	-0.337
2 phi	0.618	0.451	-0.132
3 phi	0.442	0.417	0.247
4 phi	-0.412	-0.130	-0.158
5 phi	-0.401	-0.228	0.0006
6 phi	-0.271	-0.069	-0.069
7 phi	-0.299	-0.130	-0.298
8 phi	-0.044	-0.072	0.039
9 phi	0.011	-0.190	-0.057

Site 11 and site 4 were both positively separated along Prin 1 (Figure 5.12). All other sites were clustered together. The sediment structure of sites 11 and 4 show little variability, although site 4 had the highest sand percentage over the whole survey. Both sites were also indistinguishable in their biota assemblages. There is no clear evidence as to which factors are responsible for separating these sites by principal component analysis

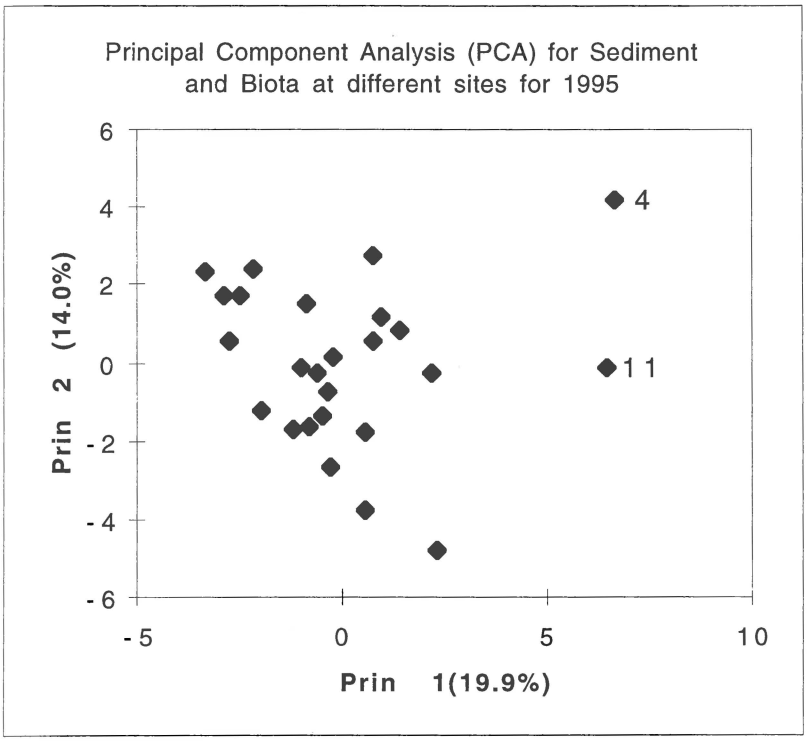

Figure 5.12 PCA for the relationship between sediment and biota for the 1995 survey.

Comparison of dominant taxa for sites on the dump ground and to the eastern and western sides indicate that sites on the eastern side of the dump ground have a different taxa assemblage. The dominant species for sites on the eastern side of the dump ground indicate that molluscs are the dominant taxa (*Nucula nitidula* and *Arthritica bifurca*). The sites on the dump ground have polychaetes as the most dominant species (Terebellid sp.1, and *Nerinopsis* sp.). Sites on the western side of the dump ground have a similar assemblage to sites on the dump ground with Terebellid sp.1 and *Nerinopsis* sp. being dominant.

A different sediment assemblage is also indicated at these sites. The sediment size was coarser, with a gravel fraction present. The textural description of these sites was sandy gravel. This sediment relationship could be an indication of the sensitivity of biota to changes in the sediment regime.

5.3.5 Discussion

Community Structure

The structure of the community assemblage indicates a stable community which is well established. The high Berger-Parker index for the 1995 survey confirms this stability and indicates the importance of individuals of one taxon to the species assemblage. Margalef's index (a measure of species richness) is also high, indicating species richness over all sites. High Spearmans correlations (measuring the correlation of abundance between sites) were calculated at most sites over the dump ground, although small scale spatial variability is present with some species dominant at only one or two sites. Rank sum graphs also show the same distribution, with no one species dominating. Commonality between taxa at all sites is high.

From the above one can interept that the dumping of dredge spoil appears to have little to no effect (that is statistically valid) on the structure, abundance and diversity (as calculated by Berger-Parker and Margalef's indices), of the species assemblages from sites on and off the dump ground. Three different interactions - competition, predation, and physical disturbance - may be responsible for the structural organisation of the community.

Relationships indicated by principal component analysis, canonical discriminate analysis and multidimensional scaling indicate no trends for the 1995 survey, with most sites showing similar species assemblage (variability occurred between taxa with low abundance's, with most of the populations located at one or two sites). This supports the idea that sites on the dump ground show little variation from those sites outside the dump ground. Spatial autocorrelation analysis also indicated no trends over distances by comparison between sites on and off the dump ground. Overall there is nothing in the multivariate analyses which indicate a concern for the establishment of benthic ecology of the dump ground and surrounding areas.

Shallow-water marine ecosystems are influenced by physical disturbances (dredging), and biological interactions (competition and predation). Competitive interactions determine the patterns of survival and occupancy of space - and therefore abundance and size of many benthic species. Predation results in predators culling their prey, resulting in reduced numbers of the prey. Physical disturbances can have a similar effect and act as predators, where vulnerable species may be removed from the habitat by a disturbance. Physical disturbances such as dredging mean that the organisms either move through the water column, or move up through the sediment after deposition has occurred. For species that are less motile, larval supply may be an important factor, as rapid recolonisation is necessary for the persistence of the local population. As dispersion of larvae is dependent on waves, currents and wind, the population at a specific site may vary enormously from time to time and season to season (Underwood, 1990).

The rich species assemblage indicated for the 1995 survey, where no one species is dominant, may be related to different species having very different resource needs and yet co-existing in the same place with little or no effect on the distribution and abundance of other species. The density of the species is kept below that at which they affect each others chance to survive and reproduce (Olafsson et al., 1994).

The two separate sites, one from the turning basin and one from the inner harbour show different results from those sites surveyed over the dump ground. These sites correlate poorly with sites on and surrounding the dump ground, have low species diversity, as well as having few species in common. This could be due to a variety of factors, for example the different sediment assemblage may influence habitat preferences. Sediments from the turning basin and inner harbour area are 100 % mud, which some species may prefer. Continual dredging of the area may also translocate part of the population. Dredging is continuous over the summer months which could influence population establishment, resulting in low densities of species at this time of year. The location of the sites in a low energy zone may also limit recruitment.

Comparison of Surveys

Some difficulties were present in comparing the two surveys. The 1995 survey was more comprehensive, with none of the difficulties with sampling which were encountered for the 1993 survey. Comparison between the 1993 survey and the 1995 survey for Spearmans correlation indicates that the species assemblage has changed dramatically, as well as an increase in population abundance. The cause of this variability may be an environmental perturbation which resulted in high mortalities of the population prior to the 1993 survey, (indicated by presence of juvenile bivalves only). The 1995 survey indicated that an established population of aged bivalves was present, evidence of a more established population.

Another possible explanation for this may be seasonal variation, as well as variability in the dispersion of larvae over time. The survey conducted in 1993 was sampled in spring while the 1995 survey was conducted at the end of summer. Ellis and Taylor (1988) found that although recolonisation occurred continuously, at the beginning of each spring populations accelerated after the winter period of natural mortalities, slow growth, slow sexual maturation and reduced breeding, reaching peak population levels in summer. Changes between the two years could also be dependent on organic enrichment from the deposition of the dredge spoil; which as organic inputs increase species numbers and biomass also increase (Pearson and Rosenberg, 1978).

The population structure may also be controlled by the high levels of disturbance to the environment, by the deposition of dredged material which may lead to a complex mosaic of climaxes and different successional stages over time (Hall, 1994). If this was the case then the population sampled during 1993 survey could fit in the third successional stage, where a young robust community is established. Many juveniles are dominant in this successional stage, as indicated by the bivalve population for 1993. The 1995 survey would therefore fit in the fourth successional phase, known as the organisation period. A hierarchy has been established, where the number of species in each taxa is increasing and the biological and growth cycles increase (Hily, 1983). This is demonstrated by increased size classes of the bivalve population for 1995.

Animal-Sediment Relationship

The difficulty in trying to find a relationship between sediments and biota is that samples collected for grain size distributions become disaggregated, and the resulting grain size distributions may not be meaningful if the animals responded to natural, intact aggregates (Fuller and Butman, 1988). Snelgrove and Butman (1994), note that relationships based on grain size alone may not be valid, as the determining factors may include organic content, microbial content, food supply and trophic interactions. Analysis between grain size and biota for the 1995 data indicate that strong correlations occurred only for grain sizes ranging from medium sand to very fine sand, which is non conclusive of a statistically valid relationship. Carey (1991) found that high sediment heterogeneity appears to encourage higher species diversity. The differences noticed on the eastern side of the dump ground for both sediment size (sandy gravel), and dominant taxa (molluscs), in comparison to other sites (silty sand, with polychaetes being the dominant taxa), could be a result of the sensitivity of biota to different environmental regimes.

Chapter Six:

Field Experiments

6.1 Introduction

Field experiments have an advantage over laboratory experiments in that environmental variables do not need to be simulated. These variables include temperature, Eh, pH, dissolved oxygen, and fluxes that occur in the natural environment. The benefits of field experiments are that the results can be more directly applied to natural ecosystems, because the interactions with other organisms are included in the experiment. The best field experiments are carried out closest to the natural community (Connell, 1974). As field experiments are conducted in situ, there is a reduction in handling and manipulation of the samples. Field experiments involve many taxa, rather than a single species as in laboratory experiments. This means that investigations can be carried out at the population or community level.

In this chapter three field experiments are presented investigating the sensitivity of biota to environmental conditions. (i) An investigation of any changes over time, of kelp distribution on the Fouls Grounds (an area of rocky reef within Poverty Bay); (ii) The recolonisation of fauna in sediments taken off the dump ground; (iii) The burial of bivalves to measure the rate of resurfacing after burial.

6.2 Fauna of the Rocky Reefs

6.2.1 Introduction

The trends in canopy structure over time on the rocky reefs is required to be monitored as part of the resource consent. This involves semi quantitative assessment of the trends in canopy structure and percentage of cover for *Ecklonia radiata* (Figure 6.1). This impact monitoring programme is required to be undertaken once every 3 years during the summer months of January - February.

6.2.2 Method

The canopy surveys were carried out by SCUBA in January 1994 and March 1996. The 1994 survey was recorded by Cole and Foster (1994). The intention of the survey was to provide a continuous visual record of a wide range of habitats on the rocky reefs, to allow comparisons with future studies. Each site tries to range from the top of the reef to the sea floor sediments.

Spot dives at ten sites were carried out on the rocky reefs on March 18 1996. The intention of the present survey was to record any differences in canopy cover since the previous survey in January 1994. Poor visibility and video malfunctions meant that at some sites a visual record was unable to be taken. Notes were made on the location of *Ecklonia radiata* canopies and its depth.

Description of *Ecklonia Radiata* (C. Agardh) J. Agardh (from Adams 1994).

Plants large, up to 1 m or more high with a smooth, cylindrical, unbranched stipe expanding into a flattened blade with lateral lobes lying in the plane of the blade. The relative proportion of stipe to blade is very variable, as is the degree of corrugation and marginal serration; some plants are quite smooth with few marginal teeth, others extremely rugose and spiny. Holdfast a circular disc of dichotomous haptera. Colour golden brown; texture rough and pliable. Reproduction; sori in a defined, mucilaginous patch on the blade.

Habitat: on rock at or below LWS on moderately - sheltered and exposed coasts.

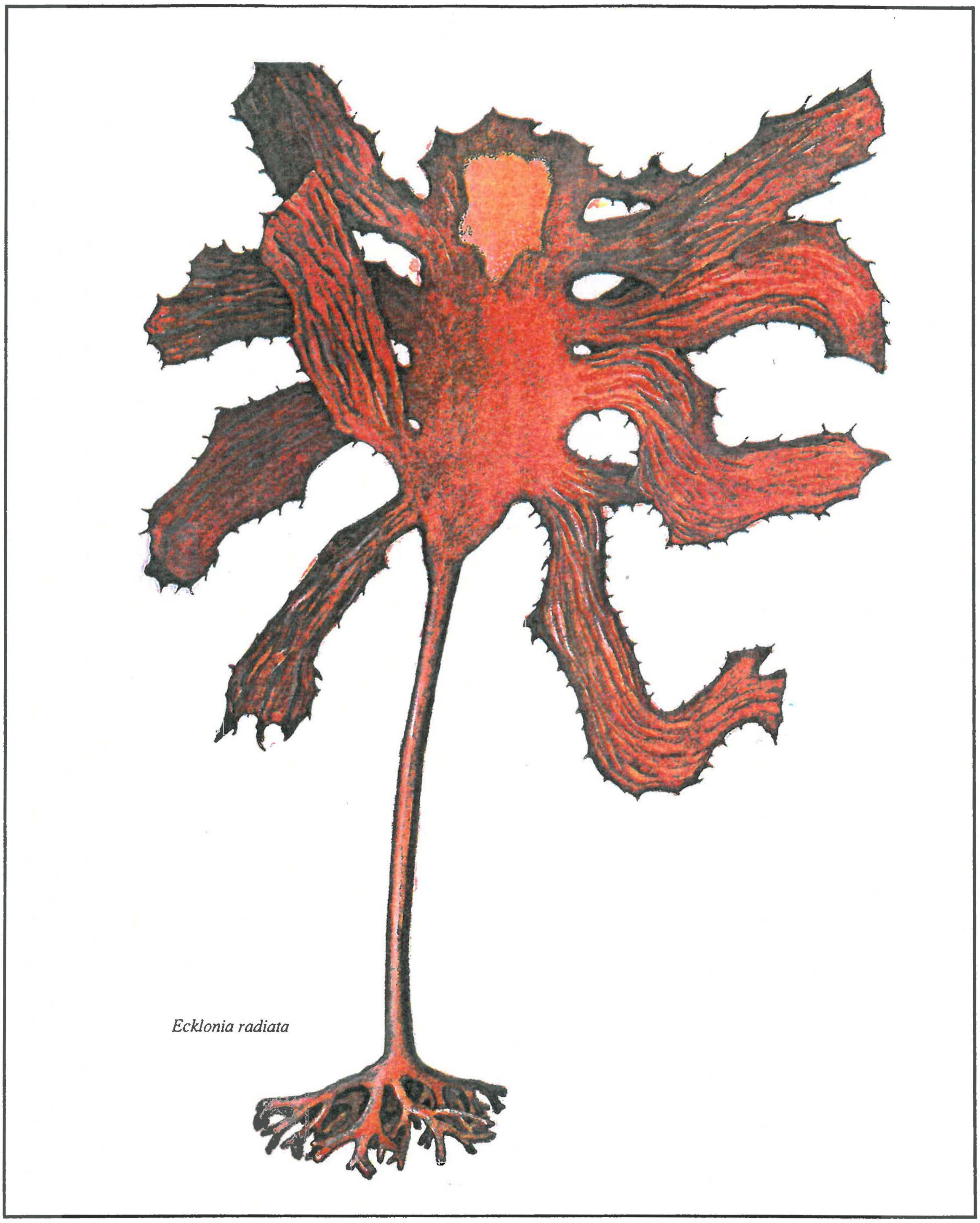

Figure 6.1 *Ecklonia radiata* from Adams (1994).

6.2.3 Results

Table 6.1 Co-ordinates of the survey carried out by Cole & Foster in January 1994.

Site	Position	Max. Depth	Kelp Presence
1	38° 41’.47S 178°00.91E	15	Absent
2	38° 41’.98S 178°01’.83E	18	Present
3	38° 41’.48S 178°00’.91E	14	Present
4	Eastern Kaiti Beach	10	Present
5	38° 41’.29S 178°00’.61E	13	Present
6	38° 41’.08S 178°00’.47E	8	Present
7	38° 41’.03S 178°00’.39E	13	Absent
8	38° 40’.98S 178°00’.78E	10	Absent
9	Western Kaiti Beach	12	Present

Summary

Descriptions of the video transects taken by Cole and Foster (1994):

Site 1: The occasional kelp plants, and grey sponges were present, with a few green algae. The benthic flora consisted mainly of large foliose coralline algae.

Site 2: At this site there were occasional kelp plants, but no clear canopies. Kelp became more apparent as shallower areas of the reef approached. At the top of the reef kelp plants had heavy hydroid growth. The kelp canopy was sparse in all areas. Sponges and swards of green algae were present. The cobble areas toward the bottom of the reef were devoid of algae/organisms. Progression down the reef showed swards of foliose green algae. The lower kelp limit was at 12 metres.

Site 3: Occasional kelp plants were present as well as massive grey sponges, and orange finger sponges. Swards of green algae were visible especially along the ridge tops. The kelp cover became moderately dense. Tongues of cobbles were present with little life on them. The lower kelp limit was at 10 metres.

Site 4: This site is situated at the meat works outfall pipe along Kaiti beach. *Carpophyllum flexuosum* (some with reproductive structures present), *Carpophyllum maschalocarpum* (occasional) and *Ecklonia radiata* in the shallows were all visible. Progressive patches of cobbles and sand occurred. Algae becomes sparse, with the increasing presence of sand. Drift algae is visible on the sand. Sand regions become abundant with sand dollars observed. The maximum depth of kelp was at 10 metres for this site.

Site 5: Occasional *Ecklonia radiata* plants, with meadows of green algae mainly on the ridges. Kelp is at a low to moderate density. Grey massive sponges and a conspicuous encrusting invertebrate, and a foliose yellow sponge were visible. Foliose corallinaceous red algae was also abundant. The maximum depth of the kelp is at 9 metres.

Site 6: There was moderate kelp abundance's at this site, with foliose green algae also present. The cobbles in the gutters between the bedrock were often devoid of life and algae. Meadows of green algae also appeared. The kelp becomes more abundant closer to the top of the reef. The lowest depth of the kelp was at 8 metres. Foliose yellow encrusting invertebrates and corallines live near the top of the reef.

Site 7: Green algae and corallines are visible on the higher parts of the reef, with cobbles in the gutters between the bedrock (finger sponges are present in some of the gutters). Swards of green algae with yellow sponges are dotted throughout. There are only the occasional kelp plants.

Site 8: Some sponges and foliose algae are present. Most of the substratum is barren with an abundance of overlying fine sediment. No kelp was present.

Site 9: *Carpophyllum flexuosum, Ecklonia radiata,* and *Carpophyllum maschalocarpum* were present in the shallows. Patches of sand and drift kelp are visible in the gutters. Foliose red or green algae were visible on the cobbles. A boat wreck became visible with *Carpophyllum flexuosum* and *Ecklonia radiata* observed. The transect progressed to show *Evechinus chloroticus*. Sand, papa and sponges became present as the edge of the reef became closer, with the occasional *Carpophyllum flexuosum* and *Ecklonia radiata*. Spots appeared of a small reddish-green algae. Sediment channels were present between reef fingers. *Carpophyllum flexuosum* and *Ecklonia radiata* were visible, with the occasional *Carpophyllum maschalocarpum.* The maximum depth of the kelp at this site was 12 metres.

Following the summary by Cole and Foster (1994) a further survey was made for the present study by Cole and Purdue (1996) following the same methodology as previously. The sites monitored are given in Table 6.2 and the observation summary below.

Table 6.2 Co-ordinates of the survey carried out in March 1996.

Site	Position	Max. Depth (m)	Kelp Presence
1	38° 41.267S 178°00.564E	16	Absent
2	38° 41.060S 178°00.295E	13	Absent
3	38° 41.021S 178°00.346E	9	Absent
4	38° 41.070S 178°00.502E	9	Present
5	38° 41.014S 178°00.643E	11	Absent
6	38° 41.115S 178°00.455E	12	Absent
7	38° 41.187S 178°00.535E	13	Absent
8	38° 41.106S 178°00.597E	9	Present
9	38° 41.219S 178°00.482E	10	Absent
10	38° 41.031S 178°00.275E	10	Present

Site 1 Showed no presence of kelp. Small white and yellow finger sponges were observed. Erect coralline algae was also present.

Site 2: No kelp was present, but bryozoans, encrusting algae, an orange encrusting sponge and ophiuroids were seen.

Site 3: Plumose green algae *Caulerpa* sp. with filamentous red algae occurred. A brown algae was also abundant -*Halopteris* sp. No kelp was observed.

Site 4: A dense cover of plumose green algae *Caulerpa* sp. covered much of the shallower areas of the reef and appeared to be growing stoloniferously. *Polymastia granulosa* occurred in the gaps, and on the sides of the channels. The occasional kelp plant *Ecklonia radiata* was observed. A dense stand of green algae appeared to collect sediments. Encrusting organisms were also present, these included sponges with the most abundant being *Polymastia granulosa*. *Callyspongia ramosa* was also present but not abundant. Erect bryozoans and turfing corallines (growing in individual clumps rather than forming a pavement) were interspersed with sponges. An unidentified plumose brown alga was also observed.

Site 5: At this site no kelp was observed. Sponges were present though, these including *Callyspongia ramosa* and *Polymastia granulosa*. Erect bryozoans and filamentous red algae were abundant.

Site 6: No reef was present at this site which was located in the shipping channel. A layer of sediment covered most of the substratum, with no visible life.

Site 7: Located on mudstones at depths to 13 metres. No sea life was visible, but a layer of sediment covered most of the substratum.

Site 8 Numerous turfing coralline algae and filamentous red algae covered most of the substratum at this site. The kelp present at this site was *Ecklonia radiata* in a low to moderate quantity. Many plants were small, indicating recruitment to the substratum.

Site 9: No kelp were present at this site. Crayfish were observed.

Site 10: Turfing coralline algae, small brown plumose alga, and small red algae *Plocamium* sp. were observed at this site. The occasional *Ecklonia radiata* was seen.

6.2.4 Discussion

The observations from 1994 - 1996 on the rocky reef indicate that kelp cover is decreasing. This decrease may be due to a variety of factors. It may be due to the disposal of dredge spoil, but deposition of spoil does not occur on the foul grounds any longer as the spoil ground was shifted 250 metres to the south in 1993. Conceivably dredge spoil may affect the kelp by the action of sea currents which may transport the fine sediments over the foul grounds. The surface currents of Poverty Bay generally move in an anticlockwise direction, but with a slow clockwise direction close to the harbour (Williams, 1959). Miller (1981) found that during flood tide the currents moved shoreward with a slight westward component. During ebb tide the current directions within 1500 m of the shore moved directly offshore. de Lange (1996) found that the direction of spoil off the dump ground moves in a south eastward direction. Overall it appears unlikely that the dumping activity has affected the kelp beds (Figure 6.2).

It seems unlikely that the sewerage outfall is having any influence on the foul grounds due to the circulation patterns in the bay, which move in an anticlockwise direction close to shore. This results in sewerage discharge being transported away from the kelp beds.

The discharge from the Turanganui River system may be impacting on the kelp cover of the foul grounds. The location of the river entrance and dispersion direction mean that the foul grounds are in the path of the discharge stream. Elements in the discharge from the river could also contribute to the declining population, for example pesticides. The high suspended sediment load may result in turbid waters, which in turn could result in a reduction in heat radiation. Devinny and Volse (1978) noted that a possilbe consequence of increased sedimetnation could be decreased survivorship of gametophytes and young sporophytes of macroalgae. Reduced light levels, due to the discoloured water may prohibit the growth of the kelp (Ryan, 1989). The decrease in kelp cover could also be due to natural variation over time.

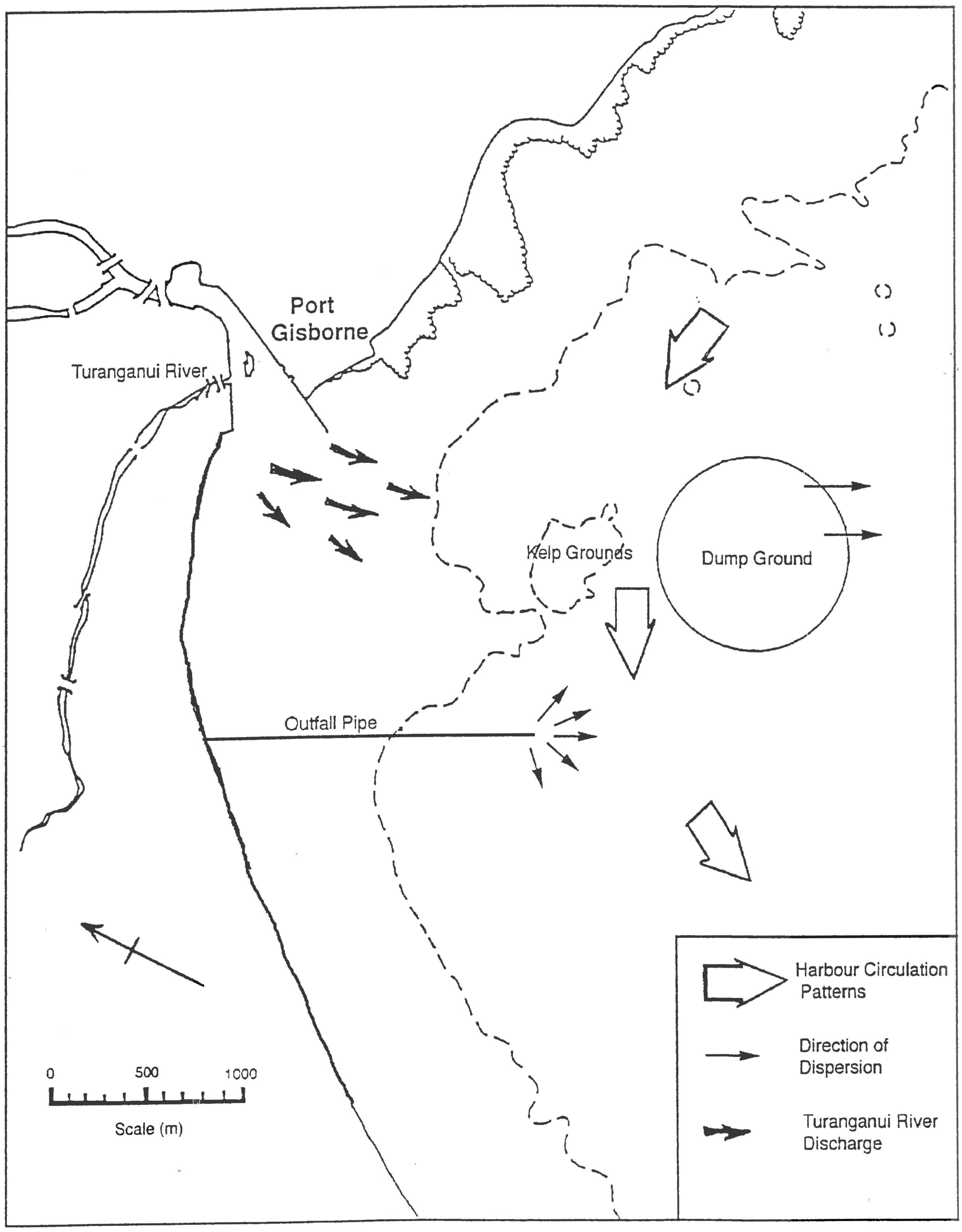

Figure 6.2 Possible factors affecting the kelp beds in Poverty Bay.

6.3 Inundation Experiment

6.3.1 Introduction

Disposal of dredge spoil can have a deleterious effect on benthic organisms as the deposition of spoil may smother them (Maurer et al., 1980). This can be dependent upon the method of disposal. Port Gisborne utilises a mechanical dredge for spoil deposition. Once burial of the biota has occurred, an important survival factor can be the speed at which biota resurface. Creese (1988) found that bivalves buried under 10 cm of sediment could resurface in the same amount of time as bivalves buried under 5 cm of sediment. Smaller bivalves also recover at a faster rate than larger bivalves.

6.3.2 Aim

To examine the effects that burial by dredge spoil dumping plays on the biota of the dump ground. It was decided to see at what depths two bivalve types *Mactra ordinaria* and *Tellina edgari* can resurface after being buried at different depths.

6.3.3 Method

Dredge spoil was collected at random sites at the centre of the dump ground using the Smith-McIntyre grab sampler. The sediment was sieved over a 1 mm sieve to remove bivalves and other organisms larger than 1 mm. Two bivalve species were retained, *Tellina edgari* and *Mactra ordinaria.* 12 *Tellina edgari* and 6 *Mactra ordinaria* were buried in each pot.

Sediment was placed in the bottom of each pot. The bivalves were then placed laterally on top of the sediment. Enough sediment was then placed over the bivalves to cover them for the required depth. The burial depths were 1 cm, 5 cm and 10 cm. Each depth was replicated five times. The pots were then submerged in sea water. The bivalves were buried as soon as possible after the removal from their natural habitat to keep their stress levels as low as possible. The experiment was left for 15 hours. Preliminary results only were obtained.

6.3.4 Results

Mactra ordinaria had a 100 % survival rate in four of the five replicates after being buried under 1 cm of dredge spoil. The numbers of *Tellina edgari* that survived were low, with the highest survival rate being 50 percent, and the lowest at 17 percent (Figure 6.3).

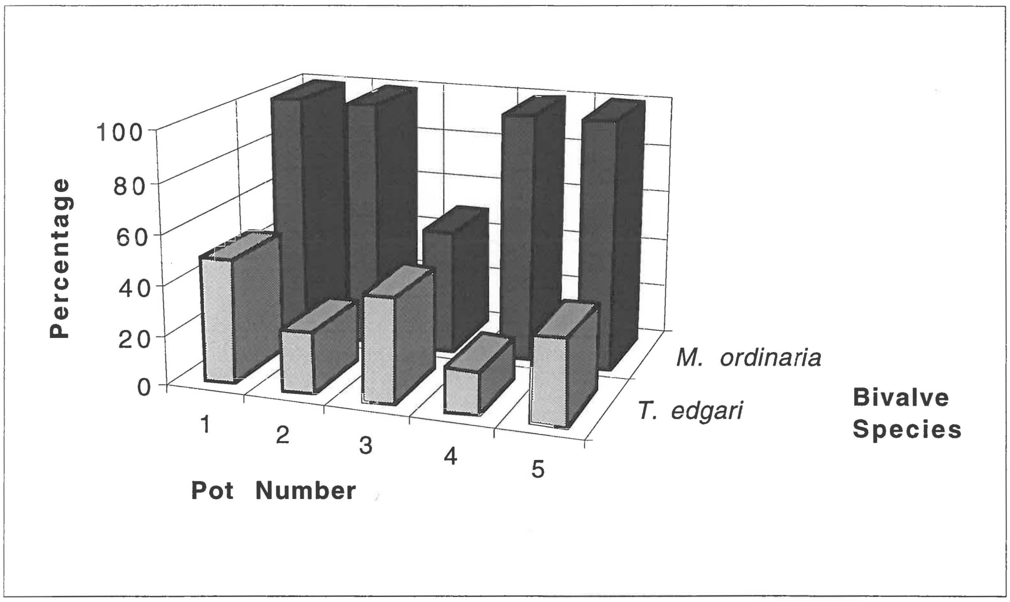

Figure 6.3 Showing the percentage of bivalves at the surface after being buried in 1 cm of sediment.

After burial under 5 cm of dredge spoil *Mactra ordinaria* had survival rates between a maximum of 50 % and a minimum of 17 %. Three of the five pots showed a 50 % survival rate. *Tellina edgari* survival rate reached a maximum of 25 % and a minimum of 8 % (Figure 6.4).

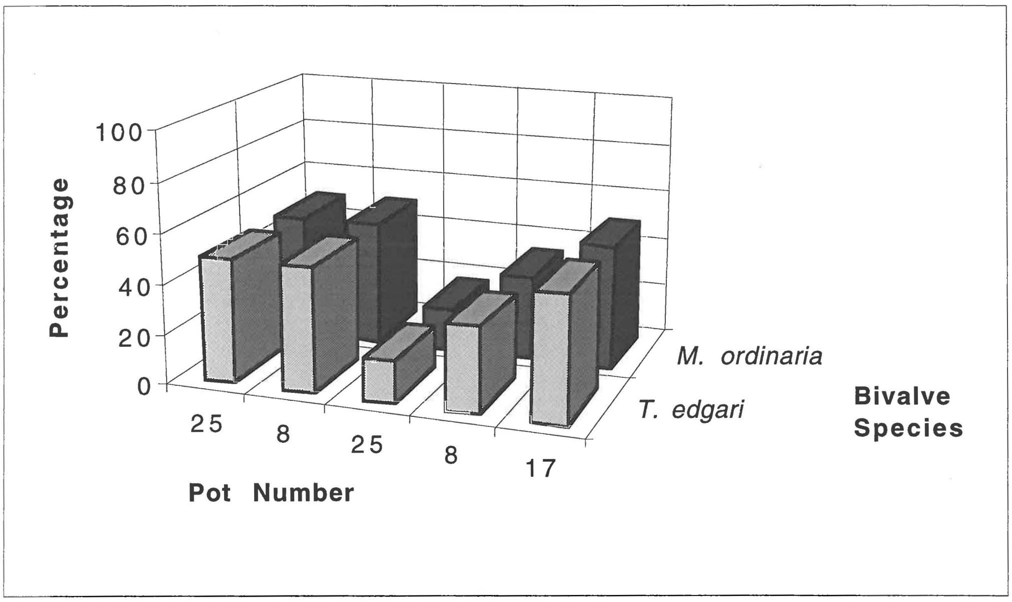

Figure 6.4 Showing the percentage of bivalves having made it to the surface after being buried in 5 cm of sediment.

After being buried under 10 cm of sediment both of the bivalve species started to show variable results. The maximum survival rate for *Mactra ordinaria* was 33 %. The minimum survival rate was 0 %. *Tellina edgari* showed a maximum survival rate of 25 % in two pots, with no survival in two pots (Figure 6.5).

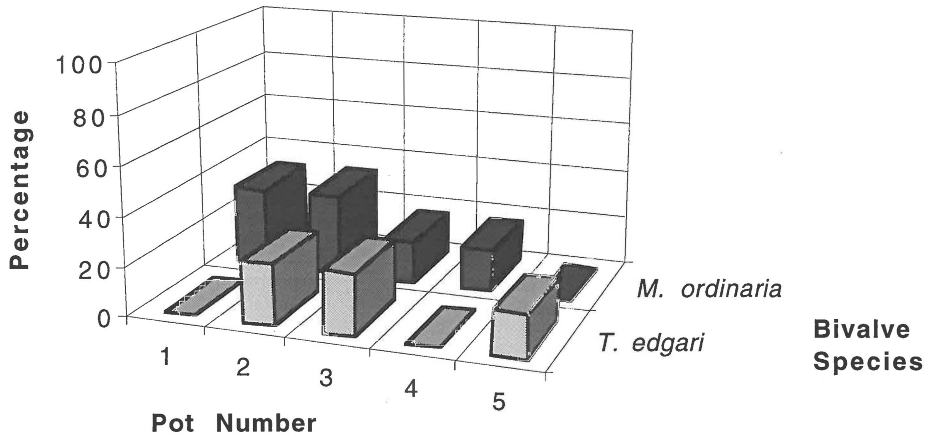

Figure 6.5 Showing the percentage of bivalves who made it to the surface after being buried under 10 cm of sediment.

Figure 6.6 illustrates the total survival rate of *Tellina edgari* from experimental pots at all depths was lower than *Mactra ordinaria*. This ranged from 34 % for 1 cm burial, 17 % for 5 cm burial, and 13 % for 10 cm burial. There was a steady decrease with increasing burial depth. *Mactra ordinaria* stared out with a high survival rate at 1 cm depth of 90 %. This dropped for the 5 cm burial depth to 40 %. At 10 cm depth the survival rate was only at 20 %. This is a drop of 70 % as burial depth increases.

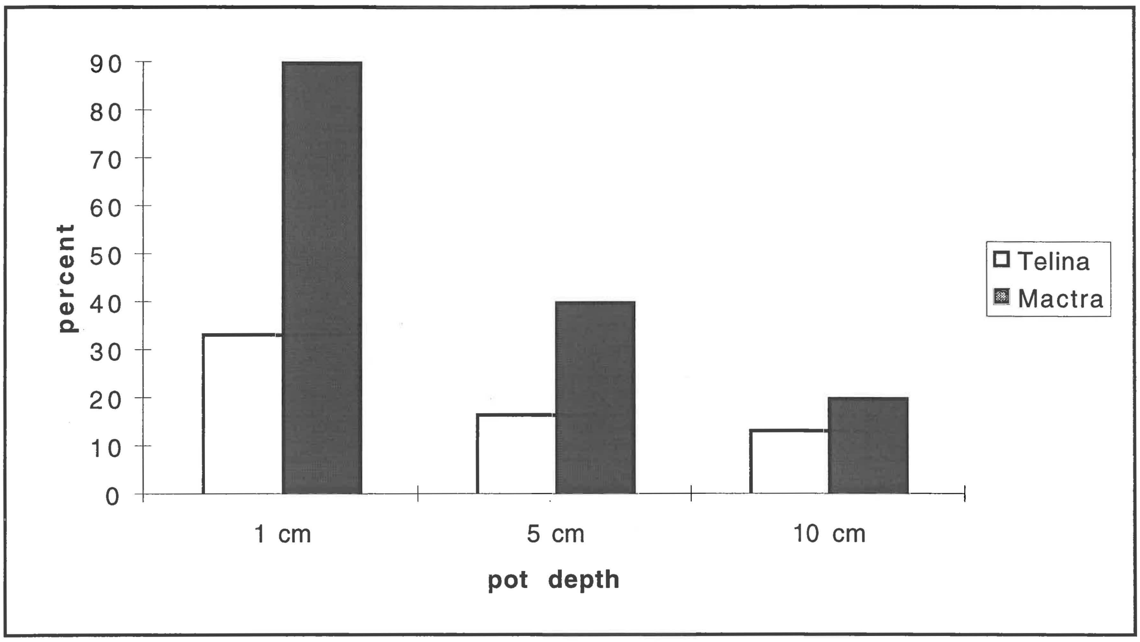

Figure 6.6 Showing the mean number of bivalves that made it to the surface for each species and burial depth.

6.3.5 Discussion

These results clearly show that as the burial depth increases the number of bivalves that resurface also decreases. These low survival rates may be due to the experimental conditions and stress imposed when removed from their original habitat. The low survival rate may also be due to the bivalves being buried laterally rather than in a upright position as the bivalve would initially experience a large resistance to movement, which would decrease once an upright position was reached (Chang and Levings, 1978). *Tellina edgari* appears to be the more sensitive of these two bivalve species, possibly due to the broad shell of *Tellina edgari.* which could result in severe resistance to upward movement in a stable substrate such as sand (Chang and Levings, 1978).

The continual burial that occurs to the biota on the dump ground may influence species which are predominant on the dump ground. Those species which have characteristics which make them less sensitive to being buried, for example greater motility, may have an advantage over those that do not.

6.4 Recolonisation Experiment

6.4.1 Introduction

The recolonisation of defaunated sediments, both natural and artificial by dispersing macrofauna (greater than 0.5 mm) has been investigated frequently. Fegley (1988) has demonstrated that above sediment transport is both frequent and ubiquitous, in both shallow and deep water habitats. Dispersion has been observed to occur laterally via bedload and suspended load pathways over substrata ranging from muddy to sandy composition. The species found in the water column are similar to those found in the top 1 cm of the substratum (Cumming Et al., 1995, Eskin and Palmer, 1985, Palmer and Gust, 1985, and Sibert, 1981).

The greatest source of recolonising meiofauna (less than or equal to 0.5 mm) is often presumed to be from within the sediments, rather than through the water column (Fegley, 1988). It has been demonstrated by Chandler and Fleeger (1983) that in muddy sediments, above sediment transport is of at least the same importance as within sediment transport for the recolonisation of defaunated sediment. Some of these investigations have found that recolonisation rates can be very rapid. Ambient densities have been reached in one to three days, with little or no change in the relative abundance of the colonising species (Reidenauer & Thistle, 1981; Sherman & Coull, 1980; Sherman et al .,1983). Some studies have also found that recolonisation rates can be slow, with ambient densities being reached in several weeks, or changes occurring in the relative abundance of the colonising species (Alongi et al.,1983; and Chandler & Fleeger, 1983).

6.4.2 Aim

The aim of the recolonisation experiment was to compare recolonisation rates on various sediments after they had been defaunated.

6.4.3 Method

Sediment was collected using the Smith-McIntyre grab sampler. The sediment was then sieved over a 0.5 mm sieve to remove biota over 0.5 mm in size. Enough sediment was collected to fill eight containers.

Four different sediments were to be used experimentally. Sediment from the old dump ground; sediment from the present dump ground; sediment from the turning bay; and sediment from a control site off Kaiti beach. It was found that the turning bay sediment was unable to be used due to its fine particle size, resulting in the sediment not settling, even when left over night. This meant that the sediment would have been scoured out due to wave action once buried. All of the containers were sealed after filling with defaunated sediment. The control sediment was taken from 1 m water depth, beyond the shoreline of Kaiti Beach.

The containers were transplanted into a site offshore of Kaiti Beach. An offshore reef area protects the area from the large southerly swells. This is a region of relatively calm conditions, and easy access.

Two lots of 12 containers (190 mm in diameter and 190 mm in depth) each were threaded with ties, and then all tied together by rope. Each of these lines had four containers of the three sediment types threaded on randomly. At each end of the rope weights were connected to help hold the containers in place once buried in the sea sediment. Each container was taken down to the sea surface by SCUBA, to an approximate depth of 4 - 7 metres. A trowel was used to bury the containers into the sandy sea bottom. The containers were buried up to the lip. Once all of the containers were buried and weighted down, the lids of the containers were removed.

After eight days one of the lines of 12 containers was recovered. The containers were then lidded to prevent loss of sediment during the recovery process. The containers were then bought to the surface sequentially. The container sediment was sieved and collected fauna treated with approximately 5 % formalin. The samples were then sorted into species, with the fauna removed and stored in 95 % ethanol. The other twelve containers were to remain for thirty days, to measure the rate of colonisation of the sediments for a longer period.

6.4.4 Results

Only eleven of the twelve containers could be recovered after eight days. None of the containers after thirty days could be recovered.

The number of individuals that recolonised the sediments was low, with the highest replicate having five individuals. The lowest number of individuals in a replicate was one. The mean number of species for each site is documented in Figure 6.8.

Table 6.3 Showing the number of species and individuals for each sediment type.

Sediment origin	No. of species	No. of individuals
CS 2	3	3
CS 3	2	3
CS 6	3	4
CS 9	3	4
OD 1	3	3
OD 4	3	4
OD 7	2	2
OD 8	2	5
DG 1	1	1
DG 7	3	3
DG 8	1	3

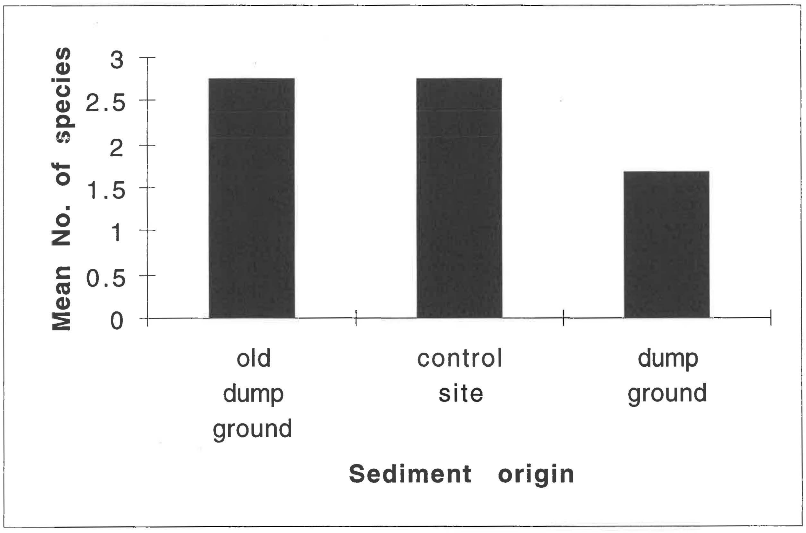

Figure 6.7 Showing the mean number of species for each sediment type.

Only a few individuals had recolonised any of the sediment types. The old dump ground and control sediment showed the same mean for the number of species (Figure 6.9). The dump ground was lower showing a mean of only 1.7 species.

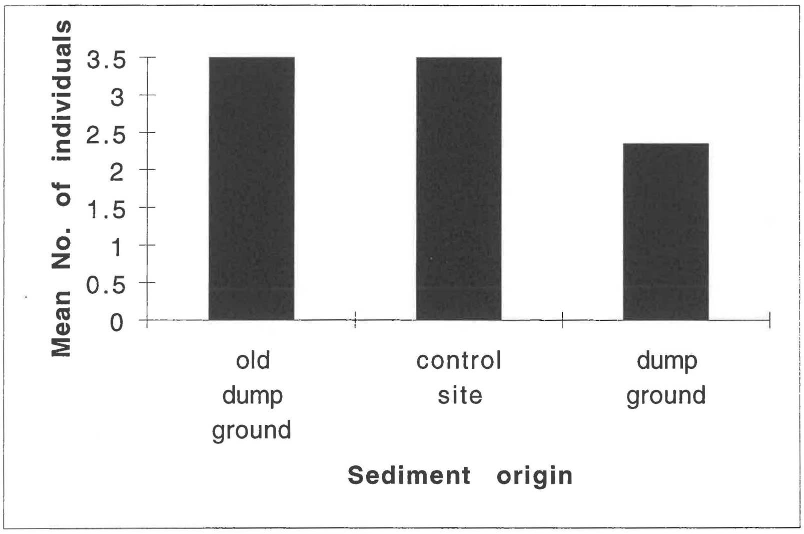

Figure 6.8 The mean number of individuals for each sediment type.

The mean number of individuals is only slightly higher than that for the mean number of species. The old dump ground and control sediment showed the same value. The dump ground sediment once again had the lowest number of individuals.

6.4.5 Discussion

The recolonisation of sediments from the dump ground had lower numbers of both individuals and species in comparison to the control sediment, and sediment from the old dump ground. As the recolonisation rate was so low for all sediment types no conclusions can be drawn from the results as they are not statistically valid.

Chapter Seven:

Summary and Recommendations

7.1 Introduction

The primary objective of the survey was to describe comprehensively the benthic biota of the dump ground and the surrounding region, as well as sensitivity of the biota in relation to sediment regimes, enabling future studies to refer to the present study as a baseline survey. Secondary objectives were to measure heavy metal limits, and draw conclusions about the changes in distribution of *Ecklonia radiata* on the kelp beds over time, as well as changes on the dump ground over time.

7.2 Heavy Metal Concentrations

The heavy metal concentrations over the dump ground and within the turning basin and inner harbour area were at low levels, and well below the resource consent. This indicates that the benthic biota are not affected by current levels of heavy metals on and surrounding the dump ground.

7.3 Benthic Survey

The results from the benthic survey after identification to the lowest taxonomic level indicate that the biota of the dump ground is abundant and diverse, showing high levels of species richness. No difference in species abundance and diversity (both Margalef's and Berger-Parker indices) was detected between sites on the dump ground and sites surrounding the dump ground. This implies that the dumping of dredge spoil has no effect on the diversity and abundance of the benthic population living on the dump ground.

Comparison between the survey conducted in 1993 and the survey conducted in 1995 indicate diversity and species richness over time has increased. The presence of only juvenile bivalves in the 1993 samples indicates that the population may have being recovering from a environmental perturbation due to the occurrence of an infrequent event. The assemblage of species implies that the community was stable at the time of sampling for the 1995 survey, with an ageing population of bivalves present, also indicative of an and established population.

Analysis of the relationship between sediment size and biota by Spearmans correlation and principal component analysis indicate a relationship between sand sized particles and diversity indices (both Margalef's and Berger-Parker). Species assemblage of the most dominant taxa from sites on the dump ground, sites to the east and west of the dump ground, indicate that a different species assemblage (dominantly molluscs) is present on the eastern side. Sites on the dump ground and to the west of the dump ground are dominated by polychaetes. It is noted that the sediment is slightly different on this side of the dump ground, being described as coarse sand to granule sized sediment. Sediments on the dump ground and to the west of the dump ground are described as silty sand. This suggests that biota could be sensitive to different sediment regimes.

7.4 Field Experiments

Video transects of the rocky reef area indicate that the distribution of *Ecklonia radiata* has decreased over time. This reduction may be due to elements in the discharge from the Turanganui River. It seems unlikely that the dumping of dredge spoil has caused this decline since the position of the dump ground was shifted to the south by 250 m in 1993. Currents present in the harbour would not transport sediments of the present dump ground onto the kelp beds.

The experiment carried out on the inundation of *Mactra ordinaria* and *Tellina edgari* indicate that *Tellina edgari* was the bivalve species more sensitive to burial under sediment, with mortalities occurring under a 1 cm burial depth. An experiment on recolonisation of defaunated sediment types proved inconclusive, due to low recolonisation levels.

7.5 Future Studies

Understanding of the benthic biota on and surrounding the dump ground would be better understood if regular sampling was carried out. It is felt that seasonal variation may be a factor in population assemblages on the dump ground, which could be assessed in future investigations. Further experiments into the effect burial plays in the role of population distribution would be beneficial. Crustaceans, polychaetes and molluscs may all respond differently to the continuous dumping of dredge spoil over the summer months. More detailed investigations on the kelp beds need to initiated, to prove conclusively which factors are causing the decrease in kelp abundance.

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Appendix One:

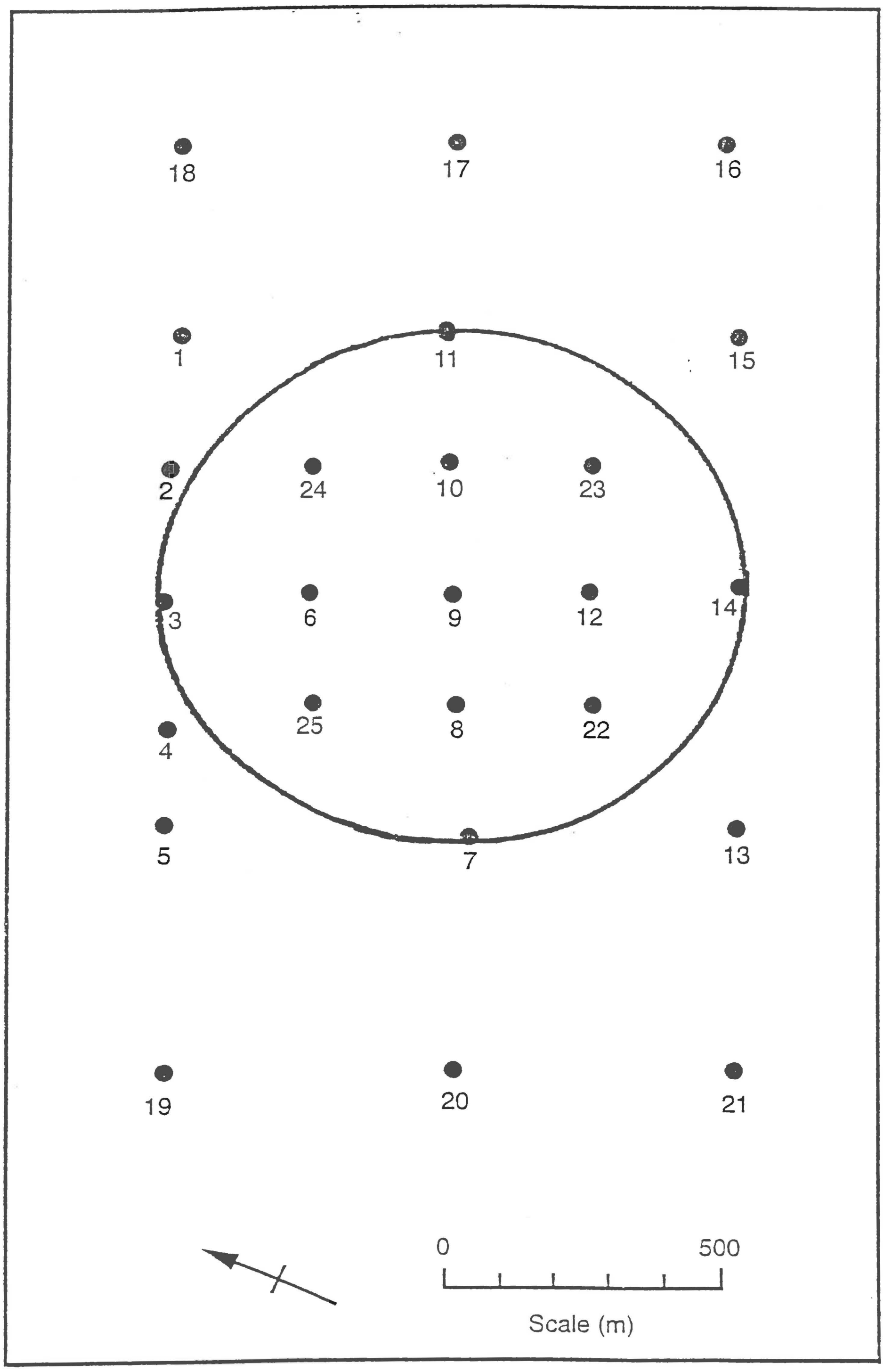

Figure One: Location of the survey sites on and surrounding the dump ground.

Appendix One: Results from pipette analysis, RSA and sieving of gravels, combined to give distribution over all phi sizes for each site.

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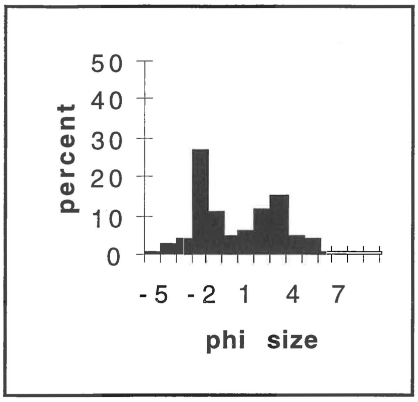

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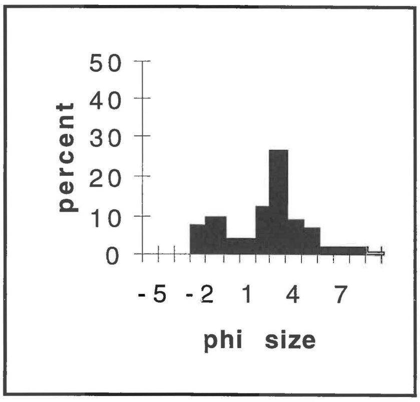

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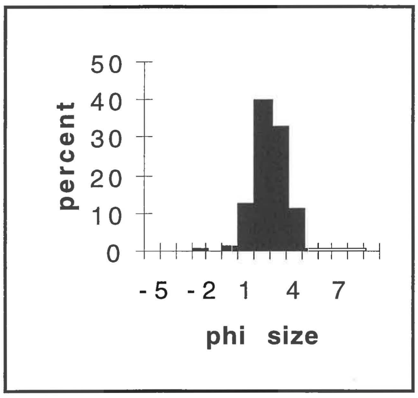

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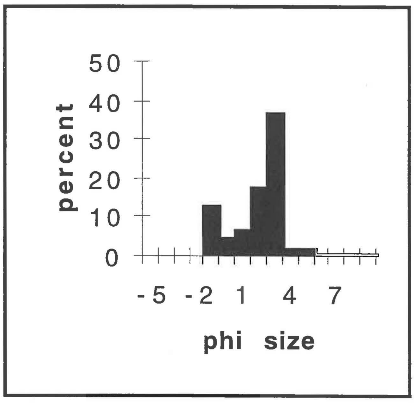

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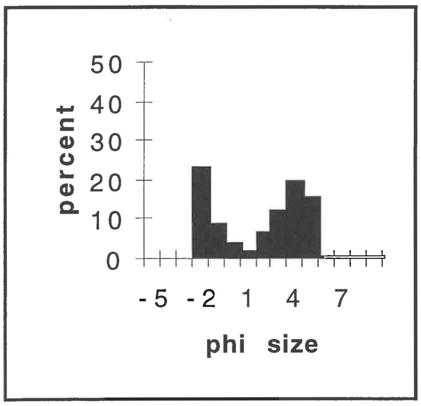

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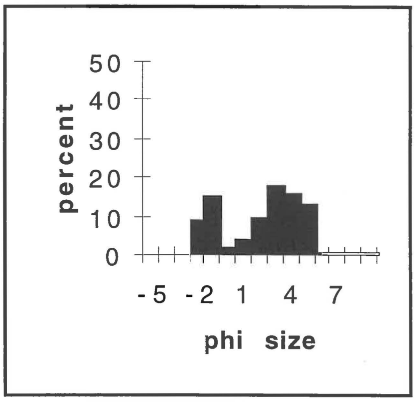

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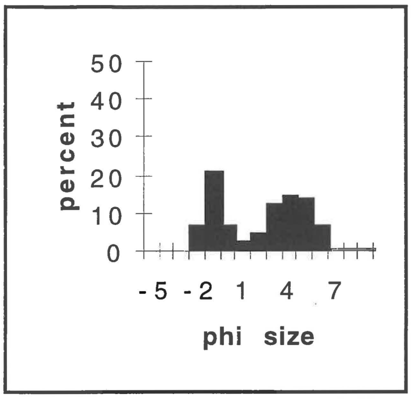

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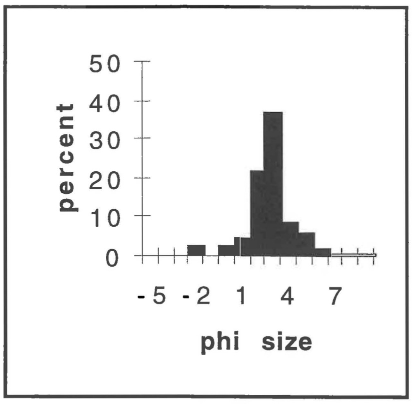

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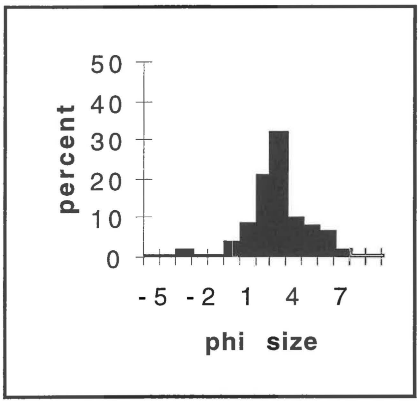

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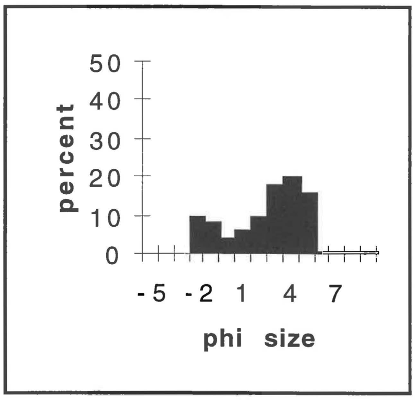

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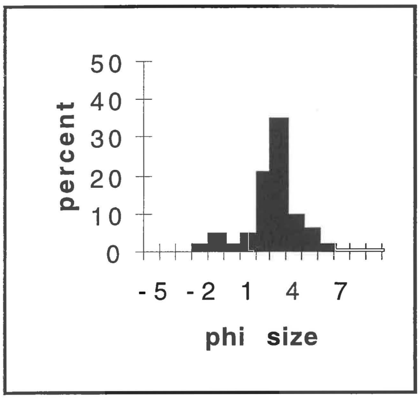

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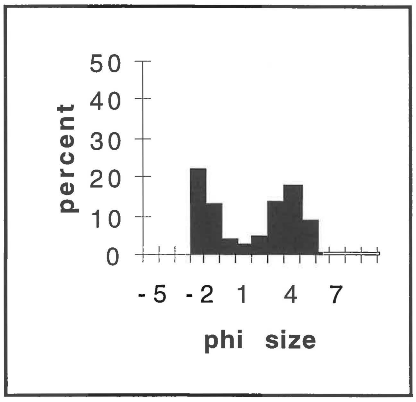

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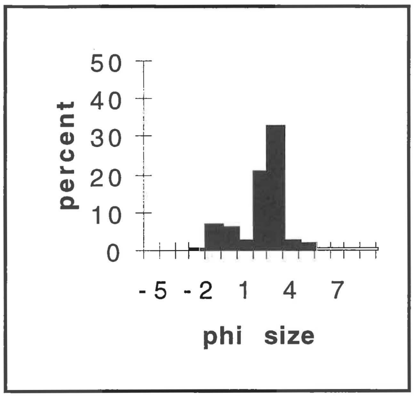

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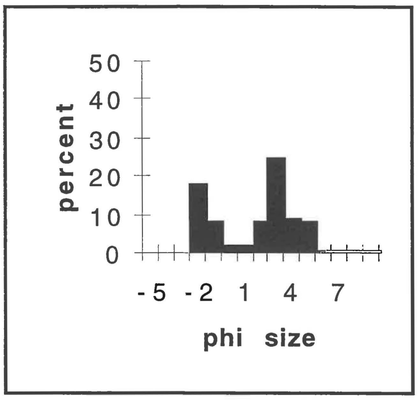

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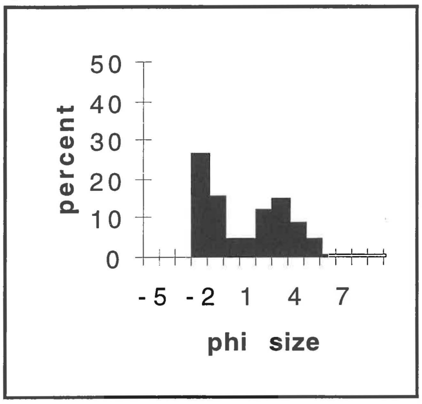

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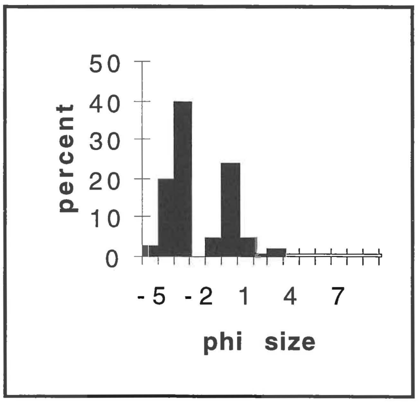

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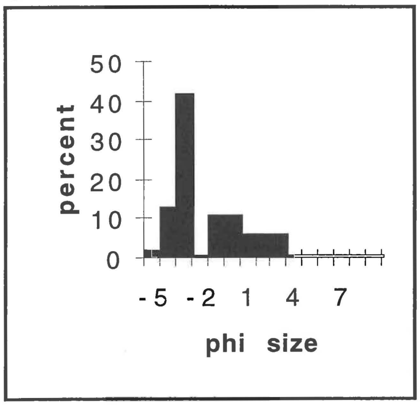

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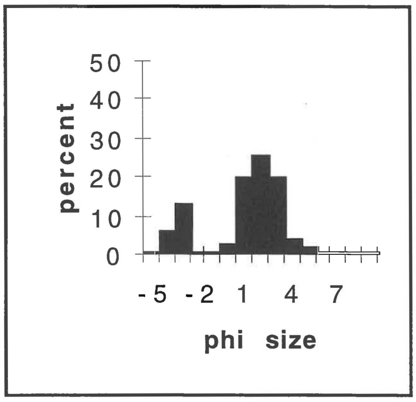

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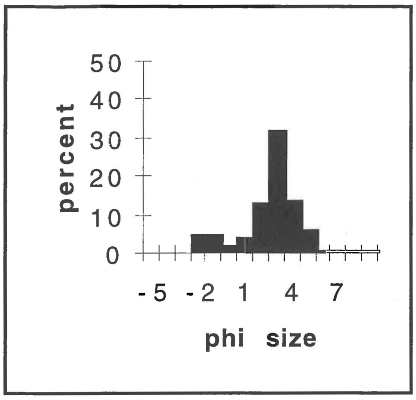

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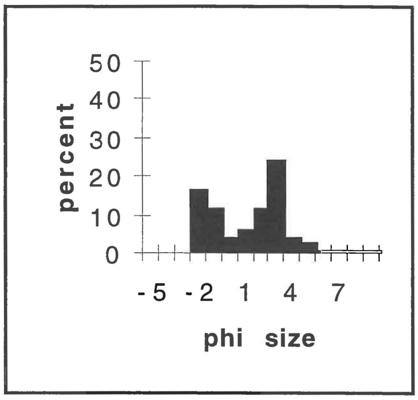

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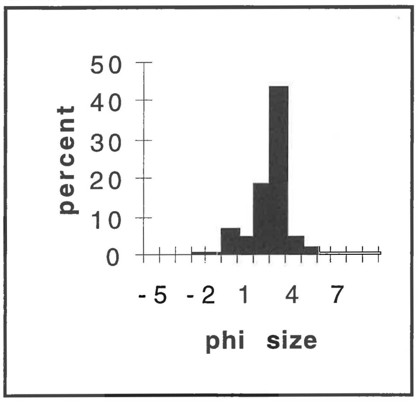

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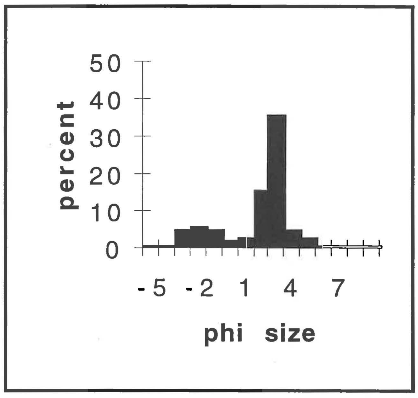

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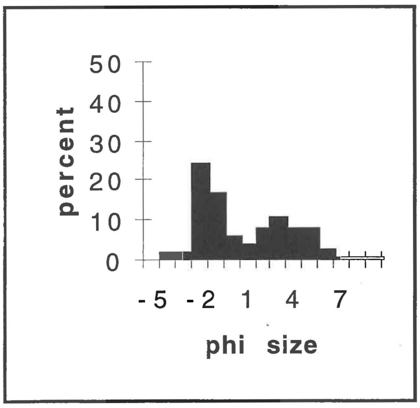

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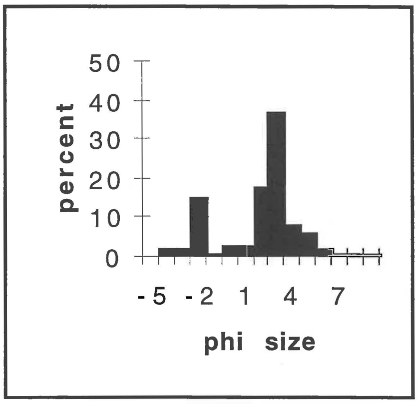

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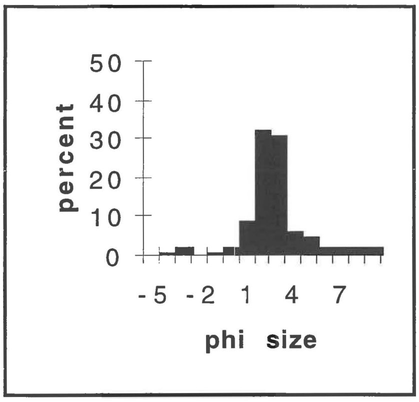

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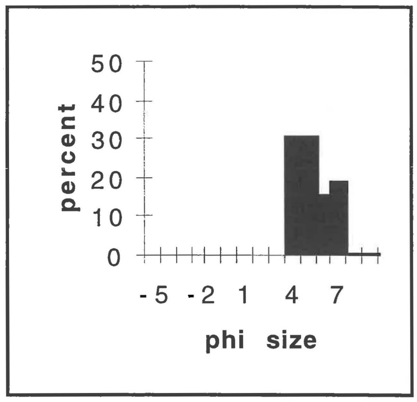

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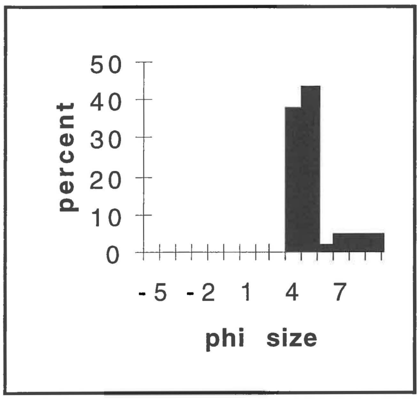

Appendix Two:

Table One Species number and corresponding species

Sps Code	Species	Sps Code	Species
1	*Amphiura aster*	44	*Halicarcinus* sp.
2	Lepidasthenia sp.1	45	Shrimp sp.2
3	*Pectinaria australis*	46	Isopod sp.1
4	*Nephtys macroura*	47	Ophiuroid sp.2
5	*Onuphis* sp.	48	Holothurian sp.1
6	Terebellid sp.1	49	Nudibranch sp.1
7	Nemertine sp.1	50	Ostracod sp.1
8	*Goniada dorsalis*	51	*Cyclasterope zealandica*
9	*Nerinopsis* sp.	52	Mysid sp.2
10	*Holothurian* sp.2	53	*Podoceris* sp.
11	Scaleworm sp.2	54	*Nucula nitidula*
12	Spionid sp.1	55	*Tellina edgari*
13	*Travisia* sp.	56	*Mactra ordinaria*
14	*Ampharete* sp.	57	*Arthritica biturca*
15	Spionid sp.2	58	*Mylitella vivens*
16	*Cirratulus nuchalis*	59	*Dosinia dorsalis*
17	*Liljeborgia barhami*	60	*Tawera spissa*
18	*Sigalion* sp.	61	*Dosinia subrosea*
19	*Owenia fusiformis*	62	*Eatoniella* sp.
20	Glycera sp.1	63	*Tellina* sp.1
21	Maldanid sp.1	64	*Pyramidellid* sp.
22	Nemertine sp.2	65	*Dosinia* sp.
23	Terebellid sp.2	66	*Tellina spenceri*
24	*Lumbrinereis sphaerocephala*	67	*Zeocopagia disculus*
25	*Prionospio* sp.	68	*Zenatia acinaces*
26	Polychaete sp.2	69	*Dosinia lambata*
27	Cumacean sp.2	70	*Tellina* sp.2
28	Shrimp sp.1	71	*Notopaphia elegans*

29	*Magelona papillicornis*	72	*Venericardia* sp.
30	Capitellid sp.	73	Crab indet.
31	*Axiothella quadramaculata*	74	Isopod indet.
32	Amphipod sp.2	75	Isopod sp.1
33	Glycera sp.2	76	*Asychis* sp.
34	*Torrida proharpinia hurleyii*	77	*Nebalia* sp.
35	Cumacean sp.1	78	*Ampelisca* sp.
36	*Orbinia papillosa*	79	*Liocarcinus corrugatus*
37	Polychaete sp.2	80	*Pontophilus australis*
38	Mysid sp.1	81	*Dendrostomum* sp.
39	*Armandia maculata*	82	*Phyllodocidae* sp.
40	Amphipod sp.1	83	*Eulalia* sp.
41	*Lembos pertinax*	84	*Peltorhamphus novaezealandiae*
42	*Hippomedon aff mcqueeni*	85	Gastropod sp.
43	*Neommatocarcinus huttoni*		

Figure Two: Rank sum graphs for 30 most dominant species.

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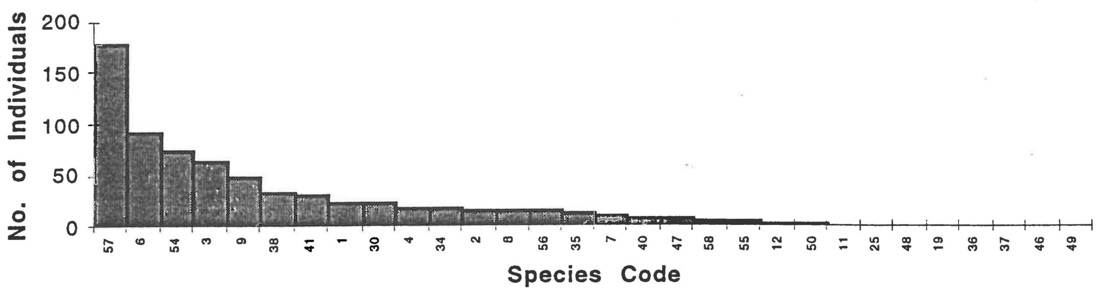

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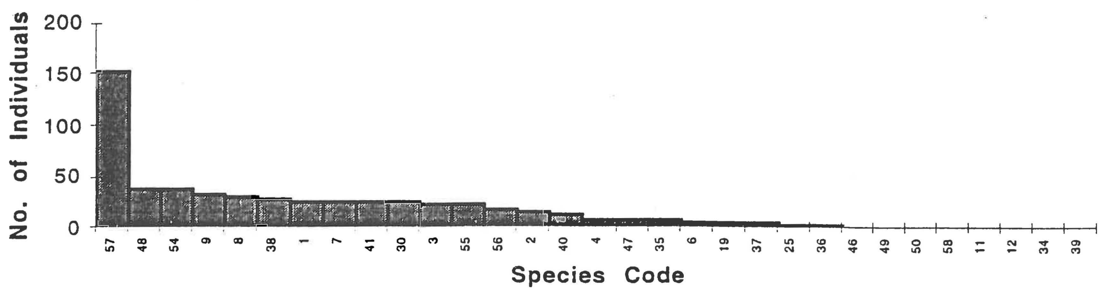

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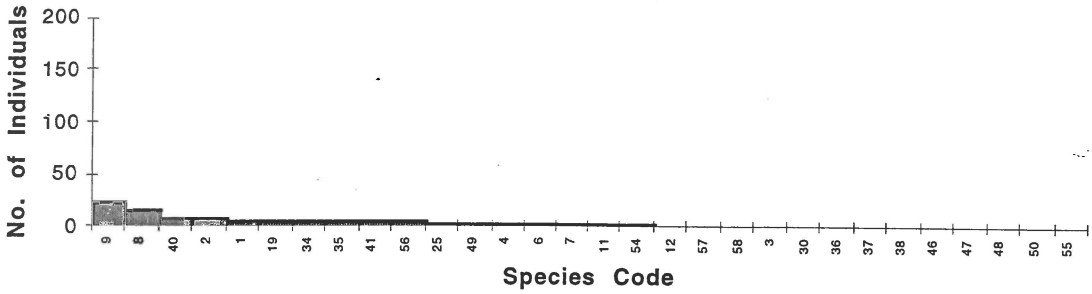

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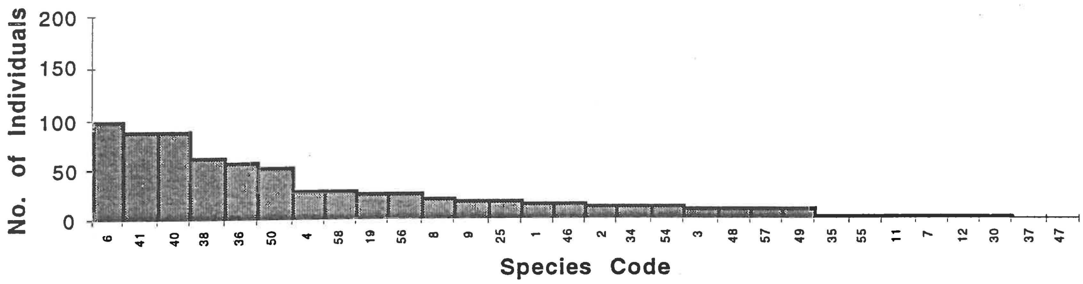

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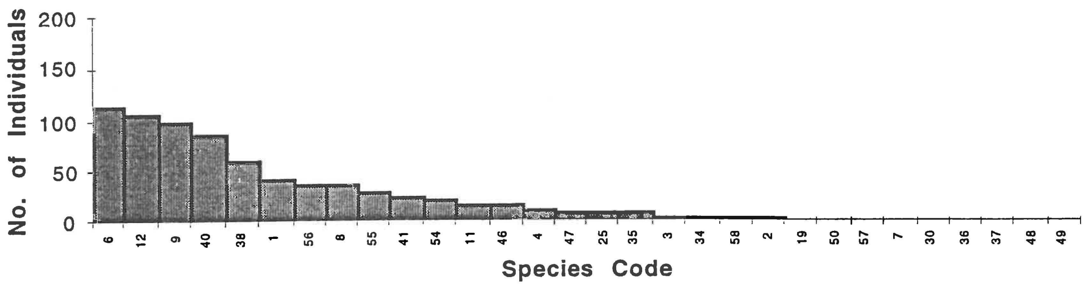

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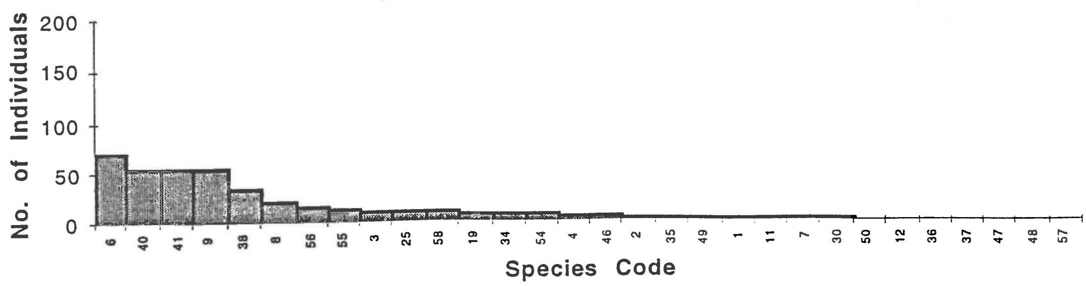

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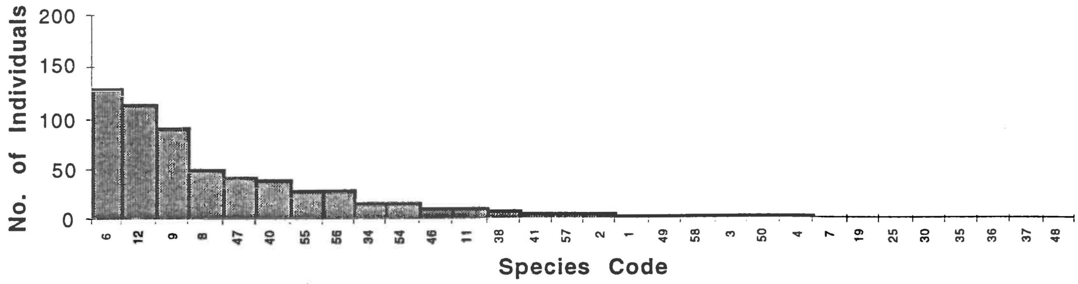

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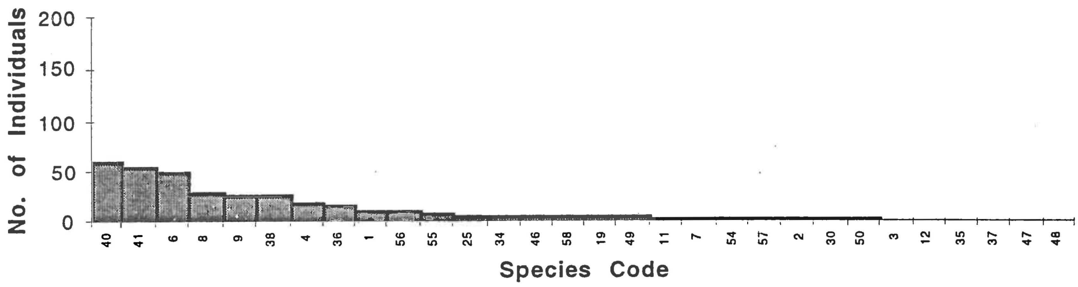

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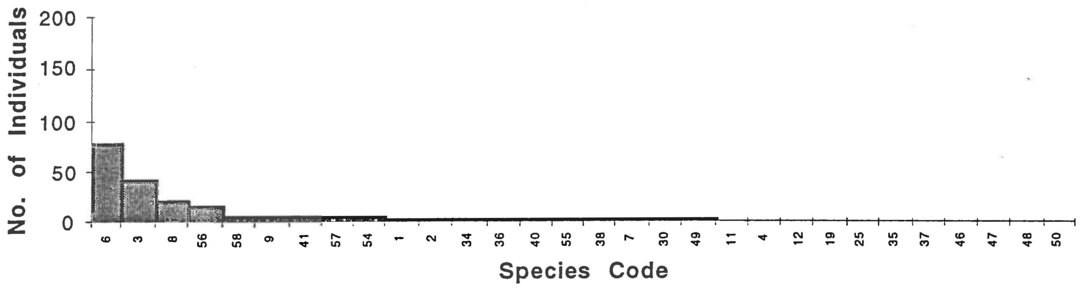

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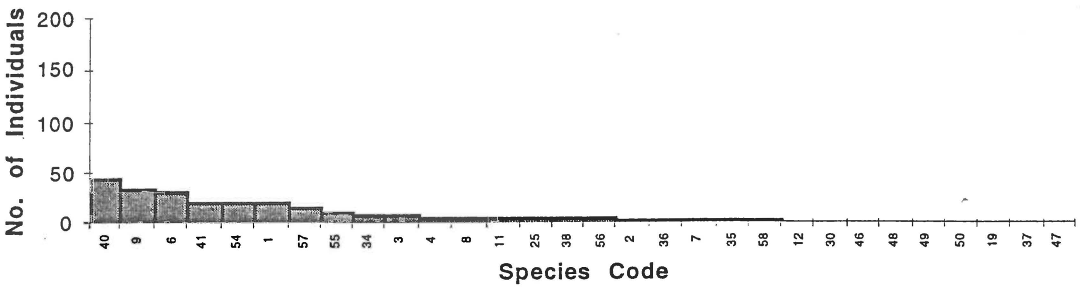

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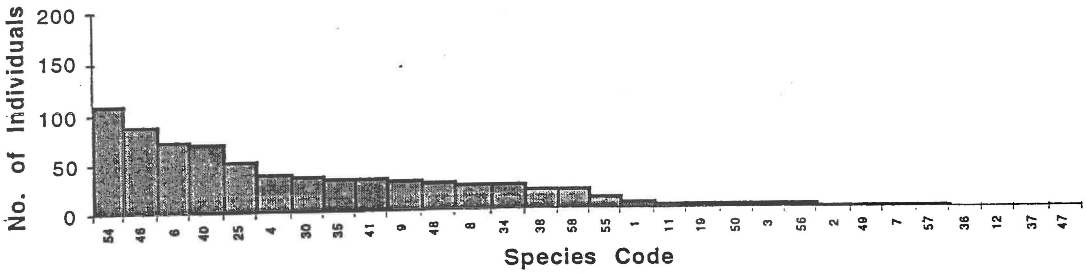

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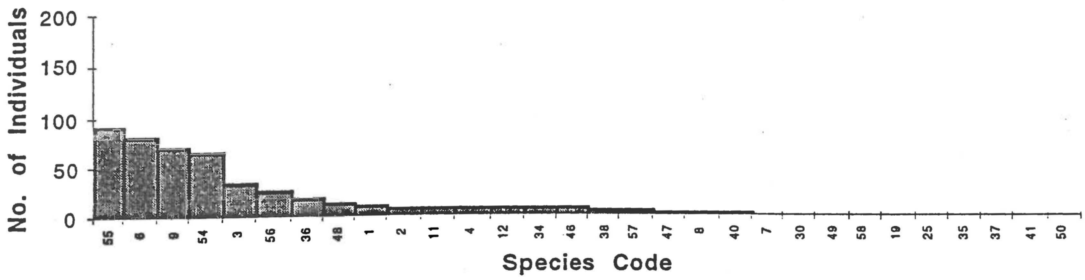

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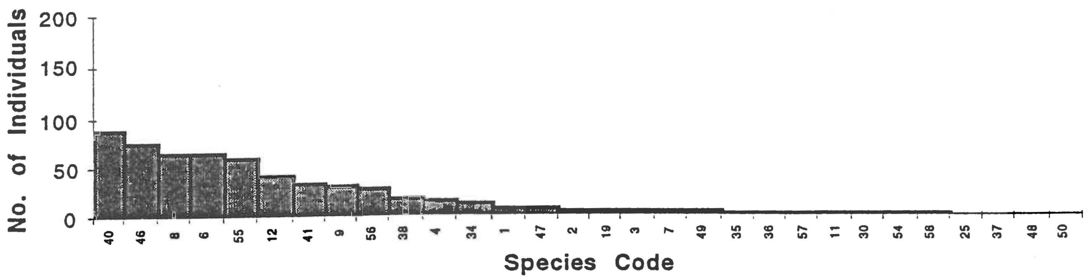

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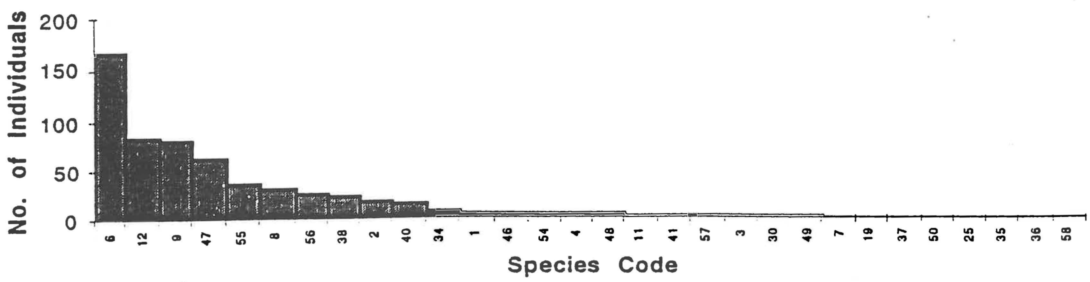

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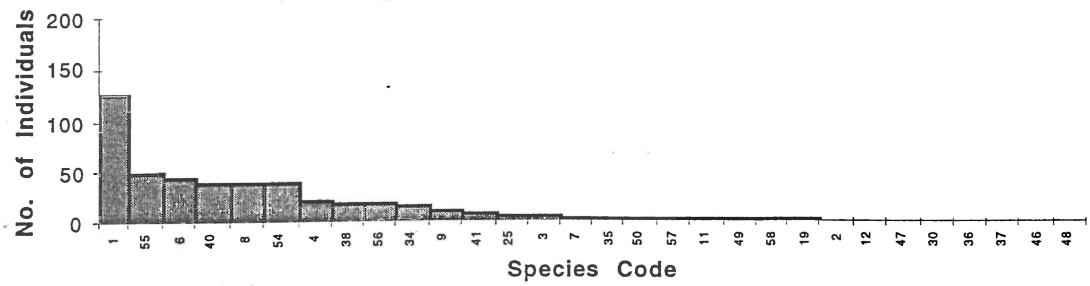

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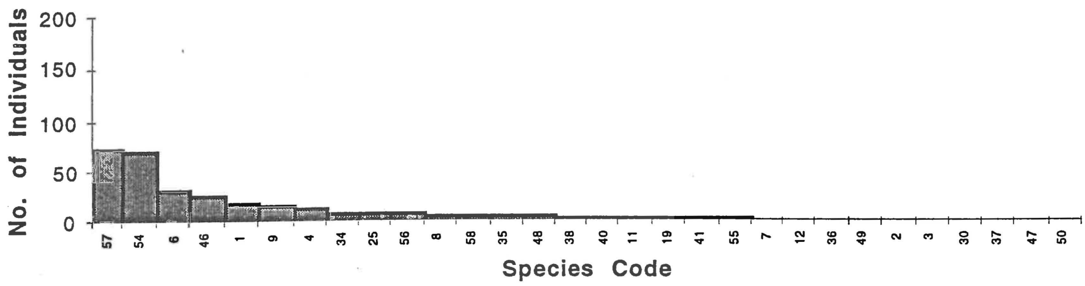

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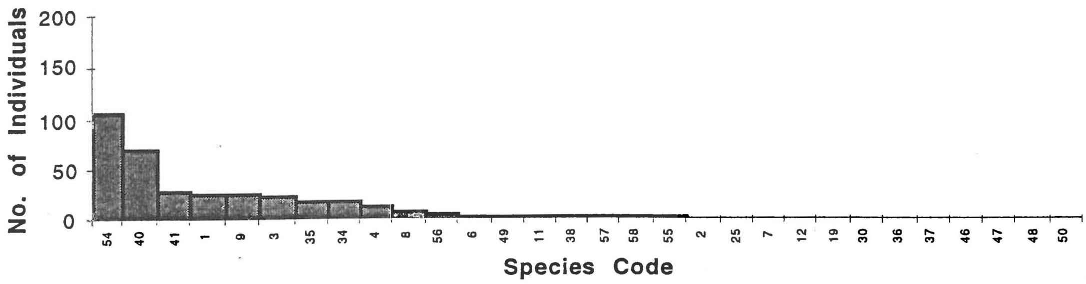

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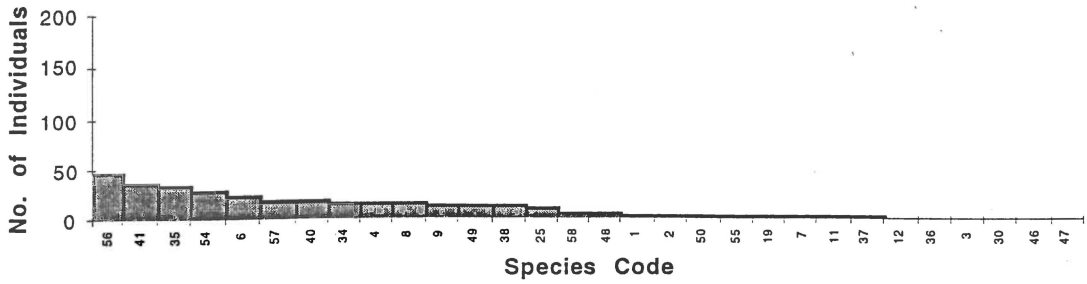

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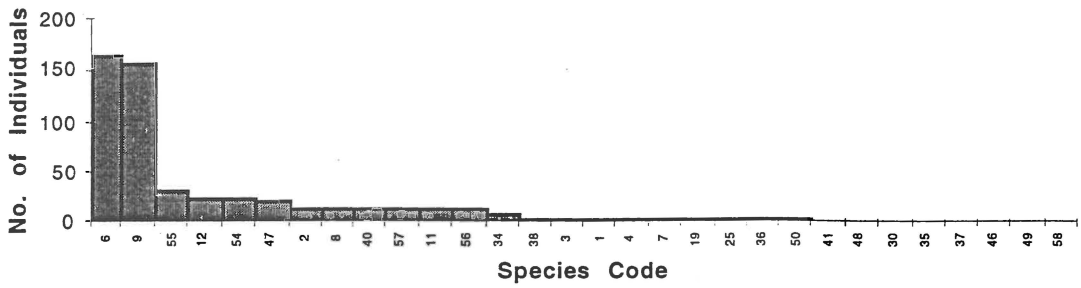

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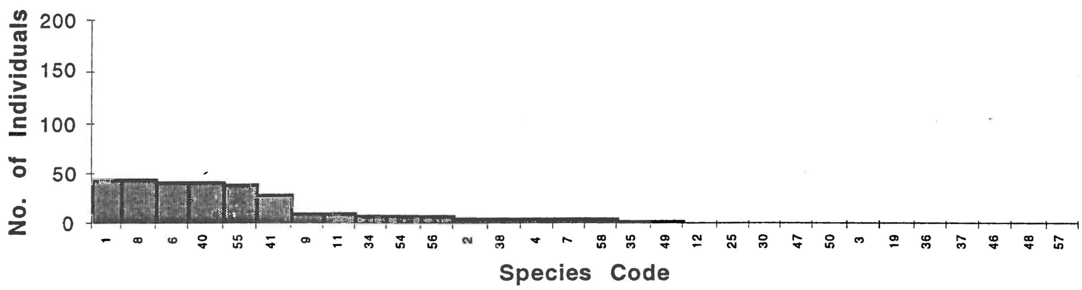

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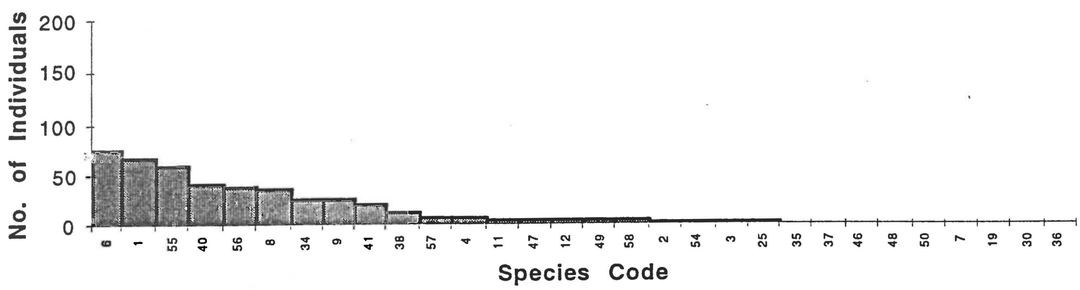

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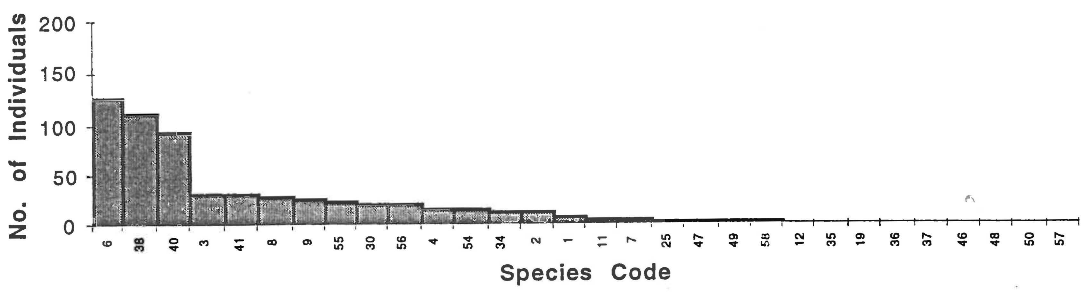

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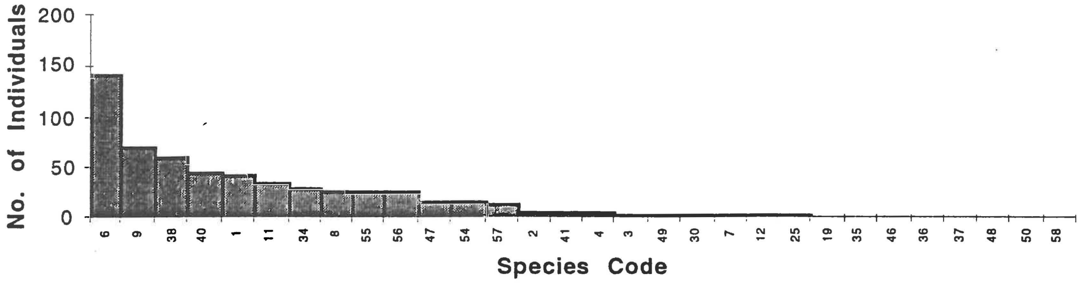

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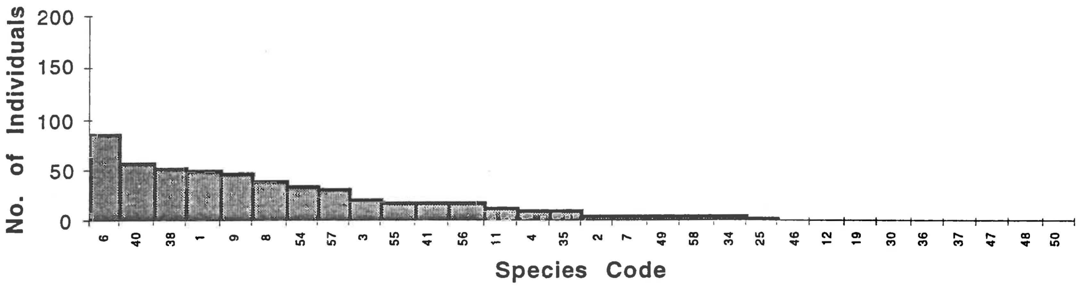

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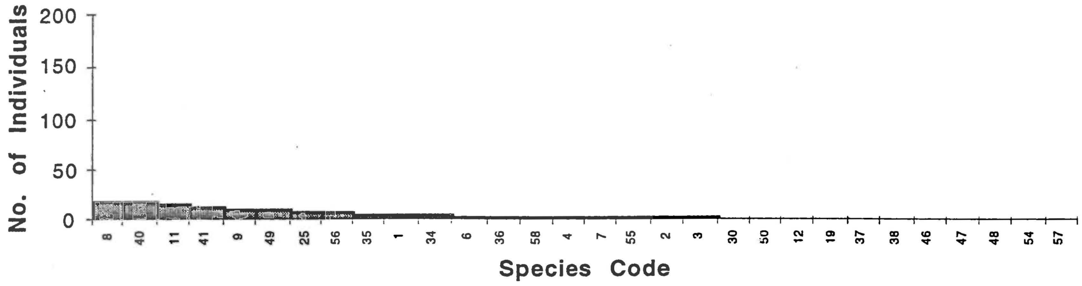

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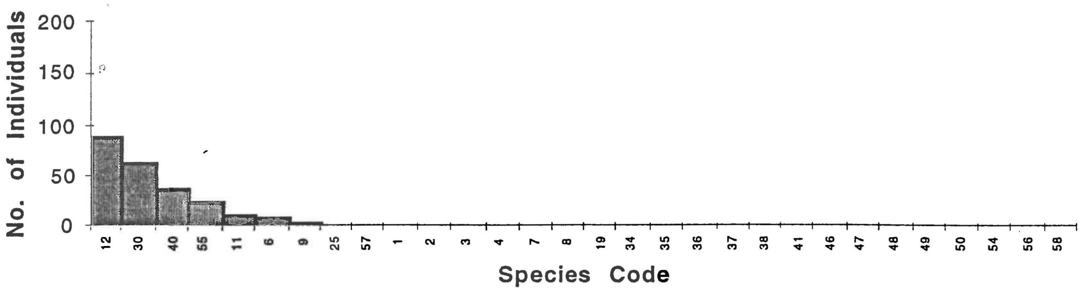

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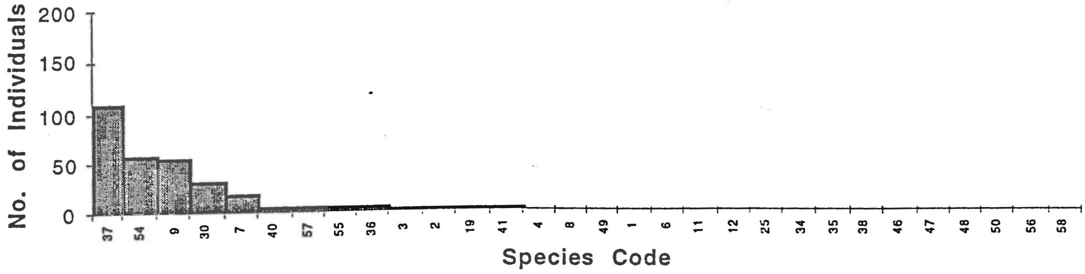
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Species Code