THE BENTHIC FAUNA OF PINE HARBOUR MARINA

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

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Frontispiece : Aerial view of Pine Harbour Marina, with the Hauraki Gulf in the Background

ABSTRACT

An investigation into the benthic ecology of Pine Harbour Marina, Beachlands was undertaken over the period June 1994 - February 1996. The primary purpose was to provide a broadscale examination of the benthic fauna of the area, and to assess the effects of dredge spoil dumping on benthic organisms. The subtidal benthic ecology to the immediate north-west of the marina was also examined. Behavioural experiments were carried out in the laboratory to evaluate the abilities of the common cockle (*Austrovenus stutchburyi*) to rebury if left on the surface and to resurface if buried under sediment.

The intertidal benthic ecology of the area was diverse, with 89 taxa being identified. The 10 most common taxa accounted for 66% of the 39125 individuals recorded. The assemblage composition was similar to other low energy intertidal areas. The taxal assemblages were reasonably stable in time, with seasonal fluctuations in assemblage composition being related to recruitment phases. Spatially, there was variation between the transects, however the transects close to the approach channel to the marina were similar. Mid and low tide sites had similar mollusc assemblages, which changed similarly through time. High tide sites however were distinct.

The dumpground faunal assemblage changed post-dumping. Not all taxa were affected and within 6 months the dumpground was recolonised to pre-dumping levels.

The subtidal area to the west of Motukaraka Island was dominated numerically by the introduced bivalve *Theora lubrica.* Species diversity changed in an onshore/offshore direction, with a higher species diversity closer to shore.

In laboratory experiments cockles were able to resurface through sediment at burial depths of up to 10 cm, and rebury when left on the surface, in under 15 hours.

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CHAPTER ONE

INTRODUCTION

1.1 LOCATION

Pine Harbour Marina is located on the western side of the Beachlands/Maraetai Peninsula south of Motukaraka Island (36°53.5' S 175°59.3' E). The area comprises extensive gently sloping intertidal sand/mud flats with chart datum approximately 1000m seaward of the marina entrance. The approach channel to the marina traverses these intertidal flats (Fig. 1.1).

1.2 THE PROBLEM

In 1986 Pine Harbour Marina was developed in a mesotidal, low wave energy coastal environment. The entrance channel was dredged to a depth of approximately 2.4m. Removed sediment was predominantly Holocene marine sands in the outer channel and soft Miocene flysch deposits of siltstone and sandstone closer to the marina (Healy, 1994).

The marina was opened in 1988 with siltation rates for the approach channel estimated to be about 10-15mm per year resulting in maintenance dredging being required every 10-20 years (Wilkins and Davies 1986). However with the larger sailing vessels that occupy the marina requiring a minimum of 2.0m water depth to navigate safely through the approach channel at low tide, in 1993 it was considered that immediate maintenance dredging would be required. The landward section of the channel between 400 and 700m from the shore had infilled with up to 1.0m of sediment.

Dredging was carried out in the winter of 1994 with a hopper dredge situated on a barge. The sediment and rock material was dumped on the northern side of the channel, out to the 1200m markers from the entrance groyne (Fig. 1.1 ; Plate 1.1a & b). This dredge spoil was expected to be spread out towards the northern side of the marina, via littoral currents.

Plate 1.1a & b The dredging of the Pine Harbour Marina approach channel in July 1994 and resulting dumpground in January 1995.

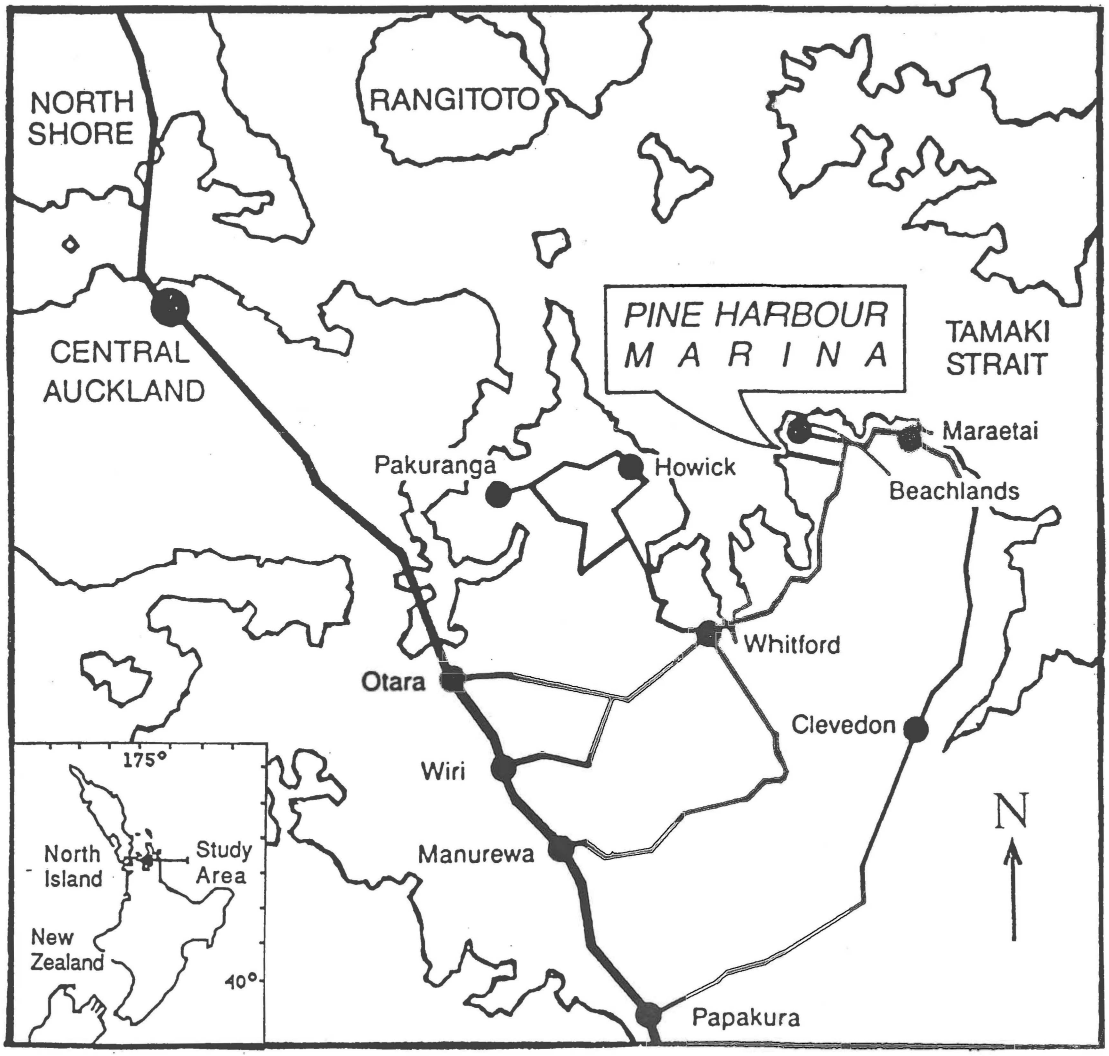


Figure 1.1 Location map showing the position of Pine Harbour Marina, Beachlands.

Under the Resource Management Act 1991 (RMA) dredge spoil dumping in New Zealand coastal waters requires a resource consent. Applications for consent are made to the local regional council which is the Auckland Regional Council in this case.

In relation to the fourth schedule of the RMA, effects on the environment by the required dredging of the Pine Harbour Marina channel should be assessed. Sections 88(4)(b) and 88(6)(a)(b) of the act require that any assessment of effects shall be commensurate with the scale of the issues.

The scale of likely effects in this case was considered to be small, although monitoring was still considered necessary.

1.3 OBJECTIVES OF THE STUDY

The principal objective of this study is to present a broad scale ecological baseline of the benthic ecology of the area. Temporal patterns in the abundances of benthic organisms both north and south of the marina are assessed. These trends are then compared to previous data compiled by Bioresearches (1985, 1986, 1988, 1989, 1991) and Kingett Mitchell Associates (1993a, b) to ascertain possible effects of spoil disposal of this and subsequent dredging on the benthic ecology of the area.

A subtidal ecological survey complements the intertidal survey data. Ancillary objectives include qualitative experimental work focusing on bivalve macrofauna especially the cockle *Austrovenus stutchburyi* which was conceived to be of public interest.

1.4 APPROACH TO STUDY

To achieve the objectives a biological monitoring program was started in June 1994. Initially this was to assess the pre-dredged benthic ecology of the intertidal area. Subsequent post-dredge sampling runs were carried out every three months with the first soon after the dredging finished (October 1994). Thus, sampling was done in late January 1995, April 1995, July 1995 and October 1995. In early March 1995 the subtidal ecological survey was investigated. Experimental investigations of bivalves were carried out in spring of 1995.

1.5 OUTLINE OF STUDY

Chapter two reviews the relevant literature on the subject of dredge spoil disposal and its effects on marine benthic ecosystems. The reasons for the need to dredge and the methods of sediment removal are reviewed. This chapter also considers the abilities of organisms to survive spoil disposal and/or recolonise the affected area. Chapter three explains the broad scale intertidal benthic ecological survey. This chapter discusses the general ecology of the Pine Harbour region in a spatial and temporal aspect. The dumpground at transects 2 and 3 is focused on in this chapter. Chapter four investigates the benthic ecology of the subtidal area adjacent to

Motukaraka Island, west of the marina entrance channel. Chapter five investigates the behavioural characteristics of the suspension feeding bivalve *Austrovenus stutchburyi* when uncovered or buried by dredging activities. Chapter six summarises and concludes the work done and makes future recomendations towards the marina's ecological standing.

CHAPTER TWO

BACKGROUND

2.1 INTRODUCTION

"The placement of dredged materials in open water disposal sites has the potential to induce a variety of short-term, acute, and longer-term, chronic environmental effects" (NRC Marine Board, 1985). This statement sums up well the effect that dredge spoil has and that it is an extremely complex problem. A broad understanding of all the parameters involved in the dumping of spoil is needed to minimise the environmental effects on benthic ecosystems.

Firstly this chapter considers the reasons for dredging and the ways in which dredge spoil can be disposed of, depending on the project's budget and local policies. The direct impacts that spoil has on the benthic and pelagic environment through chemical contamination and physical smothering are discussed next. Thirdly, recolonisation of the dredged area as well as the spoil ground via different life history stages is reviewed. The ability of organisms to survive burial under spoil is also covered in this chapter. Lastly the previous surveys carried out at Pine Harbour are reviewed as their information is important as a reference to the state of the Pine Harbour ecosystem in previous years.

2.2 REASONS FOR DREDGING

"Recreational and commercial usage of coastal waterways justifies the need for dredging to maintain sufficient water depth." (Kennish, 1991). More often than not the alteration of an estuarine hydraulic regime through construction of a marina or harbour disrupts dynamic sediment transport processes. So whether the physical alteration of the sea bed geometry is done to deepen a natural channel, or create one to facilitate passage of large vessels, the outcome is often infilling of the channel in concern. The modes of sediment transport are complex and depend on the area's physical and climatic features. In the case of Pine Harbour Marina the dominant forces of sedimentation are localised wind-driven waves of under 1m in height (Healy, 1994). The maximum depositional area of the channel is the section 400-700 m offshore as the waves are largest at high tide owing to a larger fetch. These waves come from the west and south-west and transport very fine sediments through wave-induced suspension (Healy, 1994). Thus the fact that the channel traverses the main sediment transport route is the reason for its rapid sedimentation and consequent maintenance dredging.

2.2.1 Types of Dredging Devices

Kennish (1991) recognises that there are two general methods of sediment removal; hydraulic and mechanical. Hydraulic dredges work by producing a slurry of sediment and water. This slurry is then pumped to a disposal or discharge site. Mechanical dredges lift sediment from the seabed and place it either at the dump site or on a barge or similar vessel for removal.

These dredging devices all have varying effects on the benthos of the dredged area and the spoil dumpground. All devices carry out the task of dredging, but it is often the methods of dredging and dumping that can effect the mortality of the benthos (Kennish, 1991). Suspension of sediment whilst dredging is being carried out and/or sediment is being dumped can be detrimental to infauna. As well, the rate of dumping and overall volume of sediment that is being dumped (and prevailing hydraulic conditions) effect the impacts on the benthos. NRC Marine Board (1985) states that persistent concentrations in excess of 2 $g.l^{-1}$, or deposition sufficient to produce deep burial (>20cm), or both, can prove lethal to most benthic organisms.

2.3 VIABILITY OF SPOIL DUMPING REGIMES

There are five major criteria involved when assessing the most adequate disposal option for a particular dredging activity. These are engineering, economic, environmental, social and cultural factors. Engineering involves the handling of the dredged material, the transport options and the requirements of site design and of the disposal site. The economic factors involve the cost of monitoring and the cost of disposal. Environmental factors are the physical and biological effects on the area and effects on water quality. The social and cultural factors include aesthetics, noise, traffic, history, spiritual concerns and The Treaty of Waitangi (Kingett Mitchell, 1993).

It is the proportionate weight of all of these criteria that leads to the eventual decision concerning disposal method and site. The driving factor is usually economic and all of the other factors are weighed up against this to find the cheapest practicable option. The chemical properties of the spoil are very important in influencing the method of disposal especially if the spoil has high quantities of potentially toxic compounds in its makeup (Roper & Hickey, 1994).

Beach nourishment is appropriate where an area of beach near the dredging activity has a negative sediment budget and is suffering from erosion (de Lange, 1990). Thus sediment can be dumped and allowed to move through littoral currents. However it should be of similar grain size characteristics to that of the original beach material (Komar, 1976). Dredged material is often used as a reclamation filler material. This is utilised especially where capital dredging is done in conjunction with land reclamation. The creation of wildlife habitats can also be a relevant use for dredge spoil (Kennish, 1991).

Dumping on land is another option but is rather costly and often impacts more on local residents as trucks are needed for transporting the sediment. This land-based disposal can be in two main forms. The first is to transport the spoil to an established landfill where it can be used as a capping material. The second involves utilising a specific area to contain the dredge spoil. If the spoil is contaminated this fill area has to be lined to contain any toxic compounds (Kingett-Mitchell, 1993).

Open water spoil disposal is often the cheapst form of disposal. Kennish (1991) considers two types of open water disposal. These are retentive and dispersive and these categories are dependent on the hydrodynamics of the dumpground region. In retentive site dumping the use of inerodible caps to isolate contaminants from the surrounding environment is common at sheltered sites. At dispersive sites ambient currents remove sediment and allow further disposal to take place.

The governing factor in the choice of open water disposal sites is their proximity to the dredging at hand. Paradoxically the closer the dumpground is to the dredged area the cheaper the disposal is, but also the greater the chance that the dredged sediment will find its way back to where it was dredged from.

2.4 IMPACTS OF SPOIL ON BENTHIC ORGANISMS

Dredge spoil impacts on benthic infauna in two major ways. These are the chemical impacts of a contaminated spoil and the physical impacts (such as burial and repeated smothering). Both can have an adverse effect on the infauna of a spoil dumpground but in differing ways. These adverse effects can vary from case to case due to different species assemblages. Some species are more mobile and/or more tolerant to contaminants.

2.4.1 Chemical Impacts

Kennish (1991) identifies four categories of chemical contamination associated with dredged sediments which are :

1. High concentrations of organic matter fostering anoxia and the presence of hydrogen sulphide.
2. Transition and heavy metal contamination.
3. Petroleum hydrocarbons.
4. Synthetic organic chemicals.

From a chemical analysis of the dredge spoil carried out by Bioresearches Ltd (1985, 1986) and Kingett-Mitchell Ltd (1993), it appears that in the past Pine Harbour spoil was not contaminated at any level by the above contaminants that would be overly detrimental to the infaunal benthic biota of the region.

2.4.2 Physical Impacts

The physical effects of spoil disposal include burial of organisms at various depths and the smothering effect caused by high turbidity and resulting high sediment settling rates. If the spoil being dumped is clear of contaminants (and is of a similar grain size to the dump area), then it is the method of dumping that determines the impact on the benthic infauna.

Disturbance events can be anthropomorphic or natural (Picket & White, 1985). Natural disturbance events such as predator disturbance by stingrays have been studied in Florida by Reidenauer & Thistle (1981). It was recognised that disturbed patches following stingray feeding were fully recolonised by Harpacticoid copepods within 29 hours. Shorebird and flatfish predation disturbance *in situ* caged experiments in the UK revealed that excluding predators on a tidal flat had little effect on invertebrate densities (Raffaelli & Milne, 1987). Natural disturbances may occur due to biotic and abiotic factors, these events have been reviewed by Hall *et al.* (1994). Agents of disturbance include abiotic factors such as storm-induced sediment erosion (Yeo & Risk, 1979), and deposition (Thistle, 1988). Natural biotic disturbance events include whale feeding (Oliver & Slattery, 1985) and walrus feeding (Oliver et al., 1985). Human induced disturbances include dredge spoil dumping (Kennish, 1991) and fishing effects (Jones, 1992).

The seriousness of a putative human impact can only be judged by its extent, severity, duration and magnitude relative to natural events. The patchiness exhibited by natural populations can hinder the precision of results, such that human impacts can be lost in natural variability (Hall *et al.*, 1993).

2.5 RECOLONISATION OF AZOIC SEDIMENTS BY FAUNA

There are two methods of recolonisation of fully or partially defaunated sediments. The first is pre-settlement colonisation which involves the larvae of species settling in the defaunated sediment. This method is obviously dependent on the time of year that the disturbance takes place, since the availability of larvae usually varies through the year. Some species of bivalves have reasonably short spawning seasons (<4 months per year) whereas others spawn intermittently. Also the period of larval entrainment before settlement is important in that it may determine the size of the species pool from which the larvae are drawn (Booth, 1983).

The second involves post-settlement movement either across or through the sediment (holobenthic infaunal migration) by some form of locomotion (in bivalves this can be done by shell and foot movements) (Trueman & Ansell, 1969), or by suspension in the water column by various means (Cummings *et al.*, 1993, 1995; Chandler & Fleeger, 1983). Dispersal enables the molluscs to settle away from the areas of recently metamorphosed larvae, causing age relative demographic patterns (Armonies, 1992).

In an experiment on dispersal mechanisms of meiofauna, Chandler & Fleeger (1983) found that with copepods the favoured method of colonising azoic sediment was by suspended transport. Nematodes however colonised both by settling out of the water column and by holobenthic infaunal migration at roughly the same rates, which were lower than pre-experimental background rates. More opportunistic species may colonise at levels above those of background levels (Ruth *et al.*, 1994). After a severe erosional event in Penang, Malaysia, a sand flat changed from being dominated by a gastropod to a predominantly polychaete/bivalve dominated community and species richness decreased ten-fold (Ong & Krishnan, 1994). Savidge & Taghon (1988) suggested that most colonisation by most taxa was dominated by passive advection by comparing the rates of colonisation of azoic sand and small depressions.

2.6 PREVIOUS RESEARCH FOR PINE HARBOUR MARINA

In July 1985 an environmental impact assessment was commisioned by Wilkins and Davies Ltd and Kaipara Earthmovers to assess the impact of the construction of the proposed Pine Harbour Marina. This report was compiled by Bioresearches Ltd. It briefly considered the then present ecology, pre-basin and channel infaunal biota then present and the effects of sediment disturbance on marine habitats.

In 1986 a pre-construction monitoring survey was carried out by Bioresearches Ltd. This mainly assessed the condition of the shellfish and concentrations of biocontaminants in the sediment and in the bivalves. Three post-commissioning surveys were done by Bioresearches Ltd in 1988, 1989 and 1991. These surveys again were to test the shellfish in the area for contaminants and all three surveys concluded that all concentrations of metals were well within the Food and Drug Standards and showed no increase from 1986 levels (Bioresearches, 1988, 1989, 1991).

In 1993 two reports were prepared for Pine Harbour Marina for assessment of the effects of the dredging of the approach channel and of the dumping of dredge spoil (Kingett-Mitchell Ltd, 1993a, b). Kingett-Mitchell Ltd concluded that in 1993 no influence of the marina or vessel activity was apparent and that the fauna of the area was diverse. Findings of the proposed dumpground survey identified the best practicable disposal option and that previous disposal of dredged material adjacent to the channel resulted in short term effects of a minor nature.

CHAPTER THREE

BROADSCALE INTERTIDAL SOFTSHORE BENTHIC ECOLOGICAL MONITORING AND DUMPGROUND SURVEYS

3.1 INTRODUCTION

An intertidal survey was carried out to ascertain the assemblage of the benthic fauna of the Pine Harbour Marina softshore intertidal area. This survey also focuses on the infauna of the dumpground next to the harbour approach channel.

The intertidal zone has been extensively studied due to ease of access, in comparison to subtidal areas (Estcourt, 1967; Cassie & Michael, 1968; Henriques, 1980; Roper *et al.*, 1988; Pridmore *et al.*,1990). Grange (1977) has carried out similar work in the Manukau Harbour. This study focused on the demography and benthos-sediment relationships. The spatial and temporal variation of biota on intertidal flats is important in that it attempts to put a measure on the reliability of impact/disturbance surveys. Human impacts have to be discernible from natural species fluctuations before accurate conclusions of impact assessment can be made (Underwood, 1991).

3.2 METHODOLOGY

3.2.1 Field Work

In late June 1994 the first sampling run of the intertidal survey was implemented at Pine Harbour (Table 3.1). Dredging of the approach channel was conducted between July and late August 1994. Following this a second sampling run was carried out in September. Subsequent sampling runs were carried out every 3 months.

Table 3.1 The months in which sampling runs were carried out for the broad scale benthic intertidal survey at Pine Harbour Marina.

Sampling Run	Month Carried Out
A	June 1994
Dredging of the Approach Channel	
B	September 1994
C	December 1994
D	March 1995
E	July 1995
F	October 1995

In all, 6 transects were sampled along (Fig. 3.1). These transects were located between high water and low water, normal to the coastline and each contained 3 sites, one at high tide, one at mid tide and one at low tide. Transect 1 was the northern-most transect situated approximately 300 m from Motukaraka Is. Transect 6 was the southern transect situated approximately 500 m from Waikopua Stream. Transect 3 and 4 lie on either side of the approach channel with Transect 3 occupying the dumpground (Fig. 3.1).

Four replicates were sampled per site on transects 2, 3 and 4 and three replicates were sampled per site on transects 1, 5 and 6. These replicates were taken randomly from a 5 m x 5 m grid using random number tables.

Samples were taken using a box corer with the dimensions of 22 x 22 x 11 cm giving a volume of 5324 cm^3. A spade was used to excavate the corer and the sediment was placed in a large plastic bag, labelled and then sieved over a 0.5 mm mesh which is considered to be better than 1.0 mm mesh in representing spatial variations in macrofauna (James *et al.*, 1995) (Plate 3.1). The biota were rinsed into a water-tight 2 *l* bucket using a squirt bottle to ease entangled polychaete worms off the mesh. The samples were then preserved in 10% formalin solution and dyed using a small amount of rose bengal biological dye. The 63 samples per sampling run were taken back to the University of Waikato for sorting and identification of organisms.

Plate 3.1a & b Sampling being carried out on the south side of the approach channel, Pine Harbour Marina

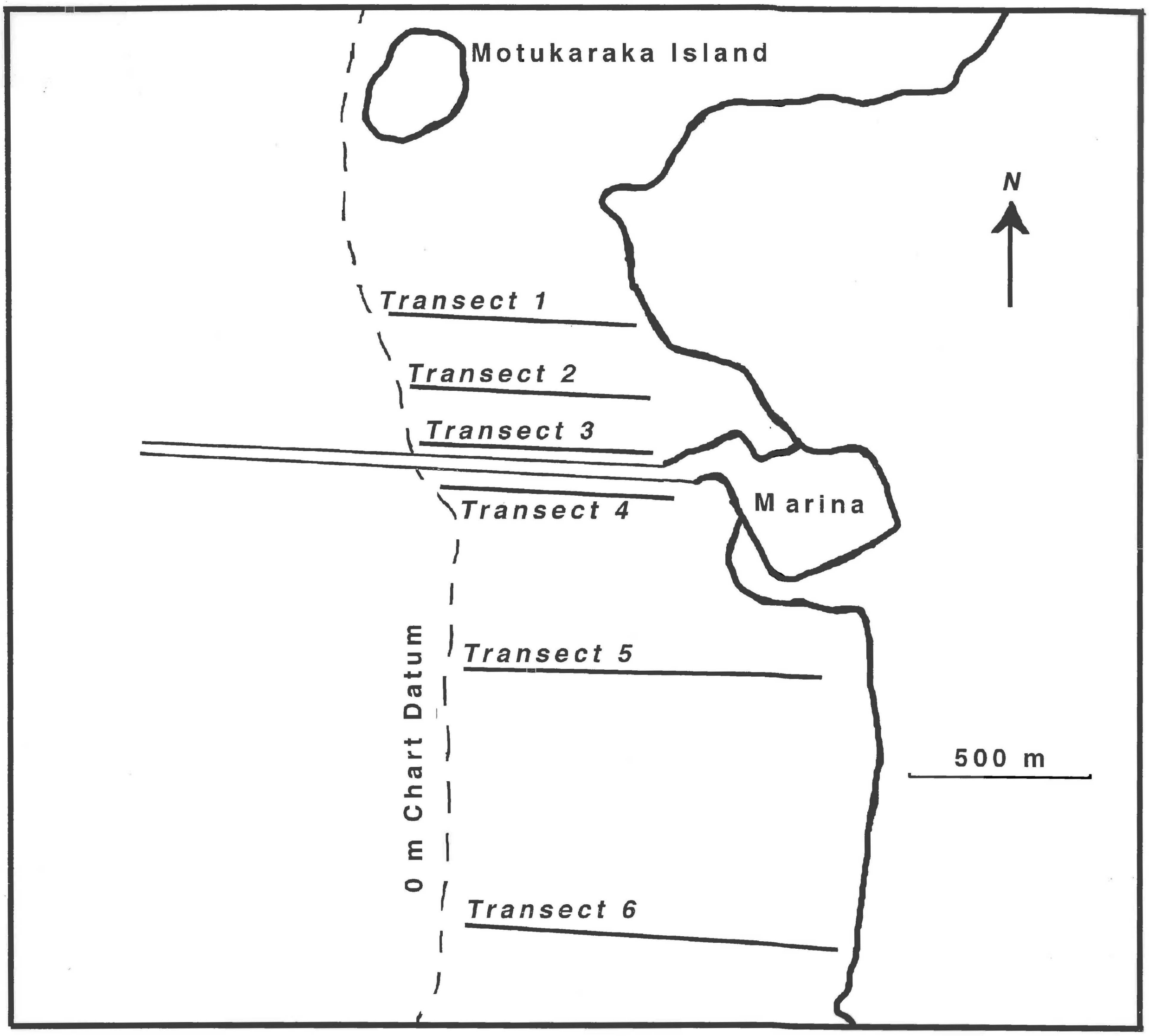


Figure 3.1 Locations of transects 1-6 on the intertidal flats at Pine Harbour Marina.

3.2.2 Lab Work

Samples were washed out over a 0.35 mm sieve to remove formalin and excess rose bengal. The resulting organisms and debris were spread on a opaque tray over a light table and all organic matter was removed. Large bivalve and gastropod molluscs were identified during sorting and the rest of the taxa were placed in a petri dish. A dissecting microscope was used to identify organisms to the lowest practicable level. A species code was assigned to each taxon but the same codes were used in the 3 different taxonomic groups (i.e. There is a sp. 1 for molluscs and a sp.1 for polychaetes. However, since all analyses are presented by taxonomic group, the distinction is clear).

3.2.3 Statistical Analysis

Multivariate ordination techniques were used to display data in fewer dimensions and to assess whether changes to assemblage structure were greater on the dumpground than elsewhere. Canonical Discriminant Analysis, Multidimensional Scaling and Principal Component Analysis (Williams, 1983; Clarke & Warwick, 1994; McArdle, 1994). Rank Sum graphs, Spearman's correlation, Berger-Parker Diversity Index and Margalef's Index were also used in the statistical analysis (Magurran, 1988).

Spearman's rank correlations were used to illustrate the correlations between transect faunal assemblages for each transect through time. A number approaching 1 indicates a high correlation between species assemblages and suggests that there has been little change through time, at a specific transect.

The Berger-Parker (BP) Diversity Index is defined as;

$$d = \mathrm{N}_{\mathrm{MAX}}/\mathrm{N}$$

Where N = the total number of individuals and $\mathrm{N}_{\mathrm{MAX}}$ = the number of individuals of the most abundant species. A reciprocal form of the index is usually used so the index increases as diversity increases. Thus a number approaching 1 indicates a low diversity and that one species is dominant (Magurran, 1988).

Margalef's Diversity Index is defined as;

$$\mathrm{D}_{\mathrm{MG}} = (S\text{-}1)/\ln \mathrm{N}$$

Where S = the number of species recorded and N = the total number of individuals summed over all *S* species. A greater index value indicates a greater diversity or species richness (Magurran, 1988).

Spearman's correlations among the fauna were done to analyse the species assemblage variation at particular transects over time. Sites and replicates on these transects were summed.

Ordination Techniques

For all analysis in this and other chapters, several multivariate ordination (dimension reduction) techniques were routinely applied. Only the results which were readily interpretable have been presented.

Non-metric Multidimensional Scaling (MDS) ordination is a multivariate technique used to represent community structure and indicate overall variability. Originally MDS was used as an informal tool to display the relationships among community samples in an easily assimilable way (Clarke & Warwick, 1994). MDS may also be used to link environmental data to biotic patterns. It is useful where single samples per site or unreplicated sampling designs are employed (Clarke & Ainsworth, 1993). Outliers in MDS graphs indicate a dissimilarity from other samples while proximity on the MDS plot indicates similar species assemblages.

Principal Component Analysis (PCA) is the simplest eigenanalysis technique. PCA reduces the dimensionality of the data. It was used here to analyse species abundances using covariance and correlation matrices (although it seldom yielded useful or interpretable results) (McArdle, 1994).

Canonical Discriminant Analysis (CDA) is a dimension reduction technique related to principal component analysis and canonical correlation. CDA differs from PCA in that it derives linear combinations of variables that maximally discriminate between levels of a classification variable (Williams, 1983; SAS Institute Inc, 1985). For example it is used here to obtain combinations of taxa that maximally separate transects and times.

3.3 RESULTS OF THE BROADSCALE BENTHIC ECOLOGICAL SURVEYS

In the 18 survey sites monitored near Pine Harbour a total of 89 taxonomic groups or individual species was identified. The ten most common species accounted for 66% of the 39125 individual organisms recorded. The molluscs accounted for 29% (11442) of the total number of individuals found, polychaetes for 54% (20960) and crustaceans/miscellaneous taxa for 17% (6723). The most common taxa were *Austrovenus stutchburyi* (10.8%), *Prionospio pinnata* (10.1%), *Oriopsis limbata* (10%), *Nucula hartvigiana* (7.3%), *Perinereis nuntia* (6.2%), *Notomastus zeylanicus* (5.5%) and *Aonides trifidus* (5.2%).

Table 3.2 Molluscs recorded, the total number found, and their species codes for the intertidal soft shore benthic survey at Pine Harbour Marina.

Mollusc Species	Total Number Found	Species Code
Arthritica bifurca	81	sp.1
Ascitellina uriatoria	104	sp.2
Austrovenus stuchburyi	4253	sp.3
Dosinia subrosea	31	sp.4
Macomona liliana	1470	sp.5
Mactra ovata	66	sp.6
Musculista senhousia	852	sp.7
Myadora boltoni	25	sp.8
Mylitella vivens	2	sp.9
Nucula hartvigiana	2850	sp.10
Nucula nitidula	19	sp.11
Saccostrea gigas	10	sp.12
Solemya parkinsonia	1	sp.13
Paphies australis	667	sp.14
Pleuromeris zelandica	1	sp.15
Soletellina nitida	123	sp.16
Theora lubrica	1	sp.17
Xenostrobus pulex	4	sp.18
Amalda australis	21	sp.19
Cominella adspersa	10	sp.20
Cominella glandiformis	58	sp.21
Diloma subrostrata	184	sp.22
Epitonium tenellum	12	sp.23
Notoacmea helmsi	416	sp.24
Micrelenchus sp.	32	sp.25
Turbonilla sp.	34	sp.26
Xymene plebius	50	sp.27
Zeacumantus lutulentis	67	sp.28

Table 3.3 Polychaetes, the total number found, and their species codes for the intertidal soft shore benthic survey at Pine Harbour Marina.

Polychaete Species	**Total Number Found**	**Species Code**
Aonides trifidus	2040	sp.1
Aricidea sp.	595	sp.2
Armandia maculata	164	sp.3
Asychis theodori	73	sp.4
Cirratulus nuchalis	18	sp.5
Cossura sp.	87	sp.6
Scolecolepides benhami	86	sp.7
Glycera lamellipoda	381	sp.8
Goniada sp.	268	sp.9
Lepidasthenia sp.	17	sp.10
Lepidastheniella sp.	41	sp.11
Magelona papillicornis	307	sp.12
Maldanid sp.	1545	sp.13
Nephtys macroura	92	sp.14
Nephtys verilli	22	sp.15
Notomastus zeylanicus	2139	sp.16
Orbinia papillosa	773	sp.17
Oriopsis limbata	3912	sp.18
Owenia fusiformis	88	sp.19
Pectinaria australis	76	sp.20
Perinereis nuntia	2437	sp.21
Pomatoceros caeruleus	104	sp.22
Prionospio pinnata	3967	sp.23
Sphaerosyllis hirsuta	101	sp.24
Spionid spp.	1374	sp.25
Syllid sp.	230	sp.26
Travisia olens	23	sp.27

Table 3.4 Crustaceans & Miscellaneous Taxa, the total number found, and their species code for the intertidal soft shore benthic survey at Pine Harbour Marina.

Crustacean & Miscellaneous Species	**Total Number Found**	**Species Code**
Amaurochiton glaucus	23	sp.1
Platyhelminthes sp.1	10	sp.2
Platyhelminthes sp.2	11	sp.3
Amphipod sp.1	133	sp.4
Amphipod sp.2	1874	sp.5
Amphipod sp.3	87	sp.6
Callianassa filholi	29	sp.7
Cirolana sp.	67	sp.8
Corophium sp.	72	sp.9
Cumacean	425	sp.10
Elminius modestus	2	sp.11
Halicarcinus sp.	78	sp.12
Hemigrapsus crenulatus	2	sp.13

Leptochelia savignii	24	sp.14
Macrophthalmus hirtipes	371	sp.15
Nebalia sp.	13	sp.16
Paraphoxus sp.	121	sp.17
Petrolisthes elongatus	6	sp.18
Pinnotheres atrenicola	5	sp.19
Pontophilus australis	29	sp.20
Shrimp sp.	40	sp.21
Urothoe sp.	919	sp.22
Urothoides sp.	172	sp.23
Nemertea sp.1	286	sp.24
Nemertea sp.2	167	sp.25
Nemertea sp.3	45	sp.26
Nemertea sp.4	49	sp.27
Actinothoe albocincta	1329	sp.28
Fellaster zealandiae	4	sp.29
Kolostineura novaezealandiae	40	sp.30
Rhombosolea plebia	6	sp.31
Phoronis sp.	102	sp.32
Balanoglossus australiensis	4	sp.33
Myodocopina sp.	178	sp.34

3.3.1 Rank Sum Analysis

The graphs produced for the Rank Sum analysis have had the sites along each transect summed. Species codes are given in tables 3.2-3.4. Note that species codes are only unique within a taxonomic group.

3.3.1.1 Transect One

Molluscs

Initially transect one was dominated by *Nucula hartvigiana* and *Austrovenus stutchburyi* (Fig. 3.2), with *Notoacmea helmsi*, *Diloma subrostrata*, *Macomona liliana* and *Paphies australis* also prominent. Numbers of *Austrovenus stutchburyi* and *Nucula hartvigiana* remained relatively static but *Notoacmea helmsi* and *Diloma subrostrata* declined in Run B. *Paphies australis* and *Macomona liliana* numbers remained similar throughout the 18 month period at transect one. In Run F a recruitment of *Musculista senhousia* was apparent.

Polychaetes

The dominant polychaete in transect one was *Prionospio pinnata;* approximately 200 occurred per transect initially, but density declined to below 150 per transect in the last two runs (E and F) (Fig. 3.3). *Aonides trifidus* and *Perinereis nuntia* were both prominent in the initial two runs, however *Aonides trifidus* numbers then increased and *Perinereis nuntia* numbers declined. Spionid spp. was found in runs D and E in slightly higher numbers than in the other runs.

Crustaceans and Miscellaneous Taxa

Transect one during Run A was dominated by the anemone *Actinothoe albocincta* and the amphipods sp.1 and sp.2 (Fig. 3.4). *Paraphoxus* sp. and Cumacean sp. were also found in significant numbers. Run B saw a decline in the amphipods sp.1 and sp.2 and an increase in *Paraphoxus* sp. and *Actinothoe albocincta.* An increase in amphipod sp.2. was then apparent peaking in Run D and then declining by Run F. Cumacean sp. numbers followed the same trend.

Spearman's Correlations

The molluscs at transect 1 exhibited a high degree of correlation between runs. Runs C and F had the most different assemblages with regard to molluscs (Table 3.5). A similar trend was apparent with the polychaetes, which showed strong correlations between Runs. Crustacean and miscellaneous taxa exhibited large changes between runs. The correlation between runs A and the rest of the runs increases through time, indicating that the species assemblage was reverting back to the initial faunal assemblage.

Table 3.5 Spearman's Correlations between runs for the three taxal groupings at transect one.

	Run A	Run B	Run C	Run D	Run E
Run B	0.683	-	-	-	-
Run C	0.623	0.901	-	-	-
Run D	0.636	0.676	0.679	-	-
Run E	0.692	0.749	0.730	0.825	-
Run F	0.571	0.545	0.493	0.634	0.693

Transect One Molluscs

	Run A	Run B	Run C	Run D	Run E
Run B	0.648	-	-	-	-
Run C	0.694	0.723	-	-	-
Run D	0.722	0.726	0.916	-	-
Run E	0.700	0.666	0.773	0.851	-
Run F	0.781	0.726	0.878	0.878	0.815

Transect One Polychaetes

	Run A	Run B	Run C	Run D	Run E
Run B	0.424	-	-	-	-
Run C	0.545	0.579	-	-	-
Run D	0.588	0.405	0.463	-	-
Run E	0.737	0.526	0.563	0.496	-
Run F	0.565	0.418	0.630	0.494	0.670

Transect One Crustaceans and Miscellaneous

3.3.1.2 Transect Two

Molluscs

The molluscan fauna at transect two during Run A was dominated by *Austrovenus stutchburyi, Macomona liliana, Zeacumantus lutulensis* and *Diloma subrostrata* (Fig. 3.5). From Run B on there was a decline in numbers of all of these species except *Macomona liliana.* This trend continued through Run C. In Run D a recruitment of *Musculista senhousia* occurred and *Austrovenus stutchburyi* increased in numbers. The two gastropods *Diloma subrostrata* and *Zeacumantus lutulensis* were present in lower numbers in Runs B-F than in Run A.

Polychaetes

Temporal variation in polychaete species assemblage was marked in transect two (Fig. 3.6). Initially the transect was dominated by 8 taxa present in numbers of over 30 per run (*Perinereis nuntia, Prionospio pinnata, Spionid* spp., *Owenia fusiformis, Oriopsis limbata,* Maldanid sp., *Magelona papillicornis* and *Aricidea* sp). In Run B a slight increase in numbers was apparent for 3 species - Spionid spp., *Perinereis nuntia* and *Oriopsis limbata. Owenia fusiformis* declined to very low numbers (less than 5 per run) for the rest of the survey. *Prionospio pinnata* had constantly high numbers throughout the survey. *Notomastus zeylanicus* fluctuated over the 6 runs becoming dominant in Runs B and E. Numbers of *Oriopsis limbata* steadily increased through to Run E and then decreased slightly.

Crustaceans and Miscellaneous Taxa

Actinothoe albocincta, Urothoe sp., amphipods sp.2 and sp.3, and Nemertea sp.1 were present in significant numbers in Run A (Fig. 3.7). Run B saw an increase in numbers of the crab *Macrophthalmes hirtipes* and a decline in Amphipod sp.3 and and Nemertea sp.1. Run E and Run F had a marked increase in *Urothoe* sp. and amphipod sp.2. Cumacean sp. was present in Runs C-F, peaking in Run E.

Spearman's Correlations

The molluscs on transect 2 showed fluctuating correlations (Table 3.6). The correlation of all other runs with run A shows no distinct pattern. The polychaetes exhibited the same fluctuating correlation with relatively high coefficients. Crustaceans and miscellaneous however showed lower values in general, suggesting larger changes temporally. Run A and run E had very different assemblages.

Table 3.6 Spearman's Correlations between runs for the three taxal groupings at transect two.

	Run A	Run B	Run C	Run D	Run E
Run B	0.451	-	-	-	-
Run C	0.634	0.489	-	-	-
Run D	0.553	0.527	0.794	-	-
Run E	0.455	0.540	0.704	0.831	-
Run F	0.708	0.332	0.698	0.620	0.517

Transect Two Molluscs

	Run A	Run B	Run C	Run D	Run E
Run B	0.501	-	-	-	-
Run C	0.810	0.734	-	-	-
Run D	0.731	0.723	0.805	-	-
Run E	0.591	0.763	0.856	0.763	-
Run F	0.581	0.765	0.766	0.673	0.866

Transect Two Polychaetes

	Run A	Run B	Run C	Run D	Run E
Run B	0.338	-	-	-	-
Run C	0.667	0.497	-	-	-
Run D	0.357	0.453	0.552	-	-
Run E	0.221	0.355	0.592	0.553	-
Run F	0.454	0.491	0.710	0.691	0.770

Transect Two Crustaceans and Miscellaneous

3.3.1.3 Transect Three

Molluscs

Runs A and Run B had similar species compositions (Fig. 3.8). *Austrovenus stutchburyi, Macomona liliana,* and *Zeacumantus lutulensis* initially dominated the molluscan fauna. In Run D a recruitment of *Macomona liliana* and *Austrovenus stutchburyi* occurred. In Runs E and F this recruitment pulse gradually declined. *Nucula hartvigiana* numbers remained constant over the survey at this transect. Run D also saw a recruitment of *Mactra ovata* and *Ascitellina uriatoria.*

Polychaetes

Oriopsis limbata dominated transect three in Run A with over 400 individuals (Fig. 3.9). *Perinereis nuntia, Notomastus zeylanicus* and Maldanid sp. were also present in large numbers. Post dredging in Run B saw a decrease in all aforementioned species especially *Oriopsis limbata.* Following Run B *Notomastus zeylanicus* and *Perinereis nuntia* recolonised the dumpground at greater numbers than pre-dredging levels. *Prionospio pinnata* numbers were relatively constant throughout the survey.

Crustaceans and Miscellaneous Taxa

In Run A *Urothoe* sp. was dominant as well as small numbers of amphipod sp.2 (Fig. 3.10). The post-dumping survey showed a large recruitment of the isopod *Cirolana* and the crab *Macrophthalmes hirtipes.* Run C saw a increase in diversity with many species being present in low numbers and none dominant. This continued through Runs D-F although a slight increase in Cumacean sp. and Amphipod sp.2 numbers was apparent in Run E.

Spearman's Correlations

A general decrease in correlation between runs was noticed in the molluscs (Table 3.7). This trend stopped at run E, then returned to an assemblage similar to that of run A. The polychaetes displayed relatively little change in assemblage over the survey. Coefficients were high and stable. Crustaceans and miscellaneous species displayed a different trend. Very low correlations were seen at this transect. Runs B and D have very different faunal assemblages.

Table 3.7 Spearman's Correlations between runs for the three taxal groupings at transect three.

	Run A	Run B	Run C	Run D	Run E
Run B	0.531	-	-	-	-
Run C	0.328	0.625	-	-	-
Run D	0.370	0.661	0.801	-	-
Run E	0.188	0.515	0.736	0.724	-
Run F	0.606	0.512	0.438	0.448	0.420

Transect Three Molluscs

	Run A	Run B	Run C	Run D	Run E
Run B	0.542	-	-	-	-
Run C	0.619	0.802	-	-	-
Run D	0.686	0.780	0.895	-	-
Run E	0.698	0.679	0.809	0.900	-
Run F	0.619	0.762	0.873	0.867	0.891

Transect Three Polychaetes

	Run A	Run B	Run C	Run D	Run E
Run B	0.216	-	-	-	-
Run C	0.552	0.416	-	-	-
Run D	0.364	0.184	0.703	-	-
Run E	0.296	0.379	0.767	0.684	-
Run F	0.503	0.272	0.780	0.716	0.844

Transect Three Crustaceans and Miscellaneous

3.3.1.4 Transect Four

Molluscs

Transect four in Run A was dominated by *Notoacmea helmsi, Macomona liliana* and *Diloma subrostrata* (Fig. 3.11). However by Run D *Notoacmea helmsi* was not present. *Macomona liliana* and *Diloma subrostrata* numbers remained relatively constant. Species composition was reasonably diverse with many of the survey's less common species being present such as *Dosinia subrosea.*

Polychaetes

Very little temporal change was evident in polychaete assemblage composition at transect four (Fig. 3.12). Initially (Run A) *Oriopsis limbata* was highly dominant with numbers of over 800 per transect. Following this run numbers of *Oriopsis limbata* declined to about 200 except Run E which had approximately 700 individuals. All other species remained reasonably constant with an influx of Spionid spp. in Runs D and E.

Crustaceans and Miscellaneous Taxa

Initially *Urothoides* sp., Amphipod sp.2 and sp.3 and Nemertea sp.2 were the dominant taxa (Fig. 3.13). The post dredging survey saw a decline in the aforementioned taxa and an increase in *Paraphoxus* sp. and *Macrophthalmes hirtipes*. Amphipod sp.2 became dominant in Run C through Run F. *Corophium* sp. was found in numbers of over 40 per transect in Run C.

Spearman's Correlations

The molluscan fauna at transect four exhibited a fluctuating faunal assemblage (Table 3.8). This is evident from the decreasing correlation between runs indicating that the assemblage was very different by run E than it was at run A. The polychaetes however were much more stable, although still showed a decreasing correlation to run A through time. Again the same pattern was noticed for the crustacean and miscellaneous taxa. This was of a changeable faunal assemblage, where initially the transects were not well correlated, but then became increasingly similar.

Table 3.8 Spearman's Correlations between runs for the three taxal groupings at transect four.

	Run A	Run B	Run C	Run D	Run E
Run B	0.636	-	-	-	-
Run C	0.450	0.678	-	-	-
Run D	0.253	0.357	0.489	-	-
Run E	-0.639	0.261	0.280	0.669	-
Run F	0.290	0.546	0.503	0.488	0.302

Transect Four Molluscs

	Run A	Run B	Run C	Run D	Run E
Run B	0.829	-	-	-	-
Run C	0.779	0.758	-	-	-
Run D	0.759	0.726	0.776	-	-
Run E	0.652	0.693	0.601	0.625	-
Run F	0.517	0.627	0.750	0.755	0.641

Transect Four Polychaetes

	Run A	Run B	Run C	Run D	Run E
Run B	0.507	-	-	-	-
Run C	0.516	0.260	-	-	-
Run D	0.380	0.409	0.533	-	-
Run E	0.473	0.367	0.742	0.689	-
Run F	0.490	0.487	0.561	0.658	0.854

Transect Four Crustaceans and Miscellaneous

3.3.1.5 Transect Five

Molluscs

Species composition of molluscs was very constant temporally at transect five (Fig. 3.14). *Austrovenus stutchburyi, Macomona liliana, Paphies australis* and *Notoacmea helmsi* dominated the transect. Species fluctuations however did occur with *Notoacmea helmsi* declining slightly in numbers and *Musculista senhousia* recruiting in Run D.

Polychaetes

Aonides trifidus, Perinereis nuntia, Spionid spp., *Orbinia papillosa* and *Prionospio pinnata* were initially dominant (Fig. 3.15). Run B and Run C saw an increase in *Notomastus zeylanicus* numbers which then declined again. Other notable fluctuations occurred for the spionids *Aonides trifidus* and *Prionospio pinnata,* which became more dominant after Run B.

Crustaceans and Miscellaneous Taxa

Amphipod sp.2 and *Actinothoe albocincta* were dominant in Run A (Fig. 3.16). In Run D a massive recruitment of Amphipod sp.2 occurred with over 300 individuals being recorded. *Actinothoe albocincta* numbers remained relatively constant over time. Cumacean sp. were found in reasonably high numbers in Runs C, D and E, otherwise the fauna found was not as diverse as at other transects.

Spearman's Correlations

Correlations at transect 5 for molluscs were reasonably high (Table 3.9). Runs D and F were not well correlated though. A similar trend was noticed for the polychaetes. Crustaceans and miscellaneous displayed a more varied assemblage over time than the other two taxal groups.

Table 3.9 Spearman's Correlations between runs for the three taxal groupings at transect five.

	Run A	Run B	Run C	Run D	Run E
Run B	0.750	-	-	-	-
Run C	0.704	0.609	-	-	-
Run D	0.749	0.504	0.730	-	-
Run E	0.756	0.737	0.614	0.708	-
Run F	0.580	0.700	0.535	0.493	0.727

Transect Five Molluscs

	Run A	Run B	Run C	Run D	Run E
Run B	0.712	-	-	-	-
Run C	0.717	0.818	-	-	-
Run D	0.667	0.729	0.776	-	-
Run E	0.694	0.603	0.793	0.729	-
Run F	0.660	0.748	0.732	0.692	0.750

Transect Five Polychaetes

	Run A	Run B	Run C	Run D	Run E
Run B	0.347	-	-	-	-
Run C	0.442	0.528	-	-	-
Run D	0.365	0.201	0.654	-	-
Run E	0.386	0.260	0.682	0.561	-
Run F	0.668	0.230	0.488	0.494	0.433

Transect Five Crustaceans and Miscellaneous

3.3.1.6 Transect Six

Molluscs

Nucula hartvigiana, *Austrovenus stutchburyi* and *Macomona liliana* dominated the six runs with relatively constant numbers (Fig. 3.17). In Run D a recruitment of *Musculista senhousia* was recorded with numbers gradually declining through Runs E and F. *Soletellina nitida* recruited in Run C.

Polychaetes

The polychaete *Prionospio pinnata* was one of the dominant taxa initially but in Run B numbers declined to almost zero and then recovered to pre-dunping levels (Fig. 3.18). *Armandia maculata* in Run A was relatively dominant but then declined in numbers for the rest of the survey. *Oriopsis limbata*, not apparent at the begining of the survey, recruited in and remained at constant numbers. *Perinereis nuntia* and *Notomastus zeylanicus* both maintained reasonably constant numbers throughout the survey at this transect.

Crustacean and Miscellaneous Taxa

Amphipod sp.2 decreased from Run A to Run B and then an increase to over 200 individuals in Run D (Fig. 3.19). Nemertea sp.1 is present from Run C on, although only in limited numbers. Other dominant organisms in this transect were the ostracod *Myodocopina* sp. and the anenome *Actinothoe albocincta.*

Spearman's Correlations

Over time the mollusc faunal assemblage became more correlated with run A (Table 3.10). This trend is opposite to the trend expected. The polychaete fauna was stable and showed reasonally strong correlations over time. Runs B and C in the crustacean and miscellaneous taxa exhibited low correlations. Runs B and C had a very low correlation indicating a large change in faunal assemblage.

Table 3.10 Spearman's Correlations between runs for the three taxal groupings at transect six.

	Run A	Run B	Run C	Run D	Run E
Run B	0.622	-	-	-	-
Run C	0.681	0.468	-	-	-
Run D	0.737	0.507	0.618	-	-
Run E	0.744	0.454	0.584	0.838	-
Run F	0.786	0.562	0.566	0.752	0.714

Transect Six Molluscs

	Run A	Run B	Run C	Run D	Run E
Run B	0.633	-	-	-	-
Run C	0.506	0.811	-	-	-
Run D	0.451	0.666	0.782	-	-
Run E	0.567	0.834	0.719	0.705	-
Run F	0.435	0.714	0.873	0.837	0.781

Transect Six Polychaetes

	Run A	Run B	Run C	Run D	Run E
Run B	0.414	-	-	-	-
Run C	0.329	0.193	-	-	-
Run D	0.541	0.389	0.420	-	-
Run E	0.679	0.590	0.412	0.774	-
Run F	0.577	0.377	0.419	0.540	0.659

Transect Six Crustaceans and Miscellaneous

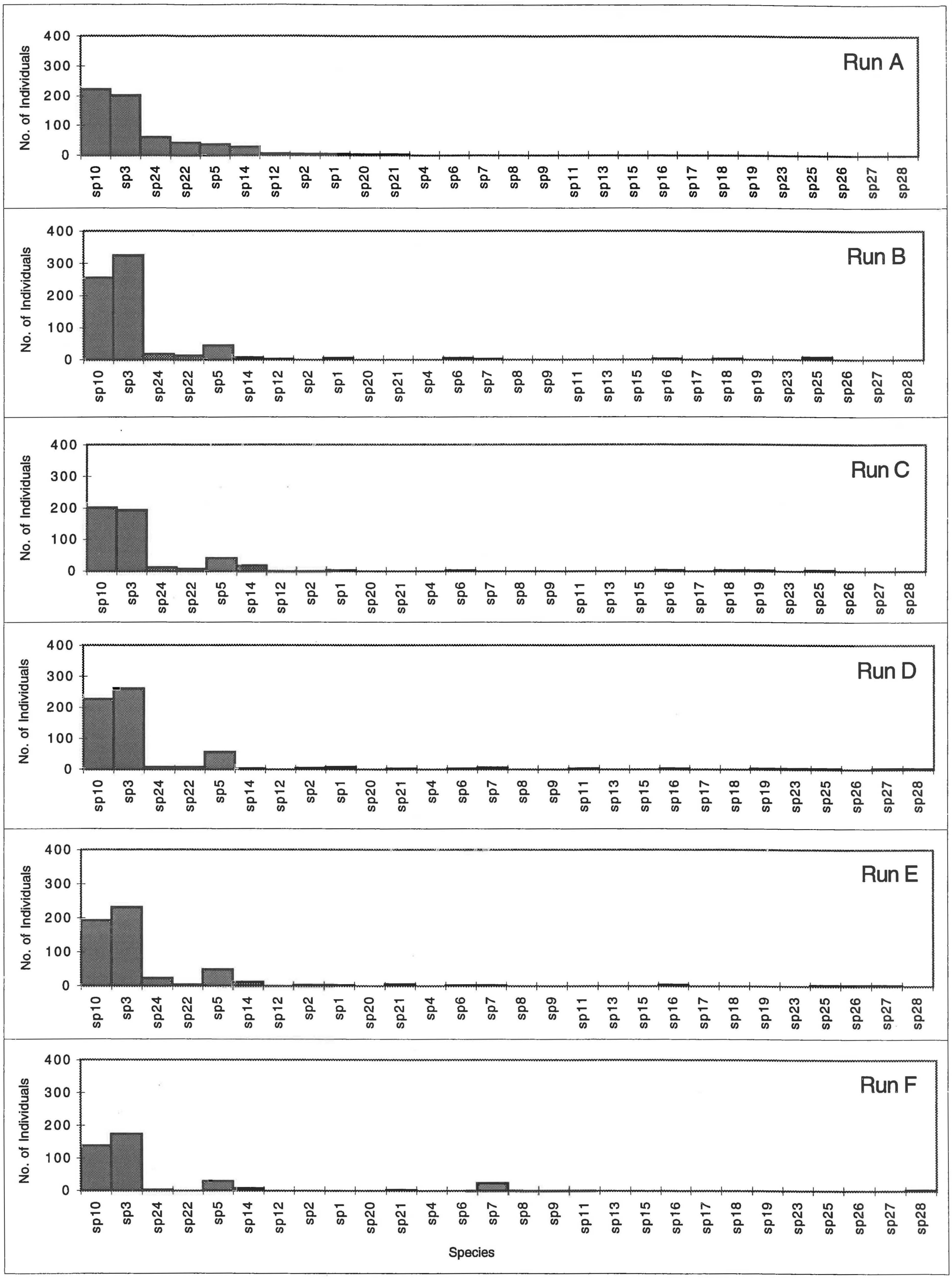


Figure 3.2 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of mollusc individuals found at transect 1, pooled across sites. See table 3.2 for species codes.

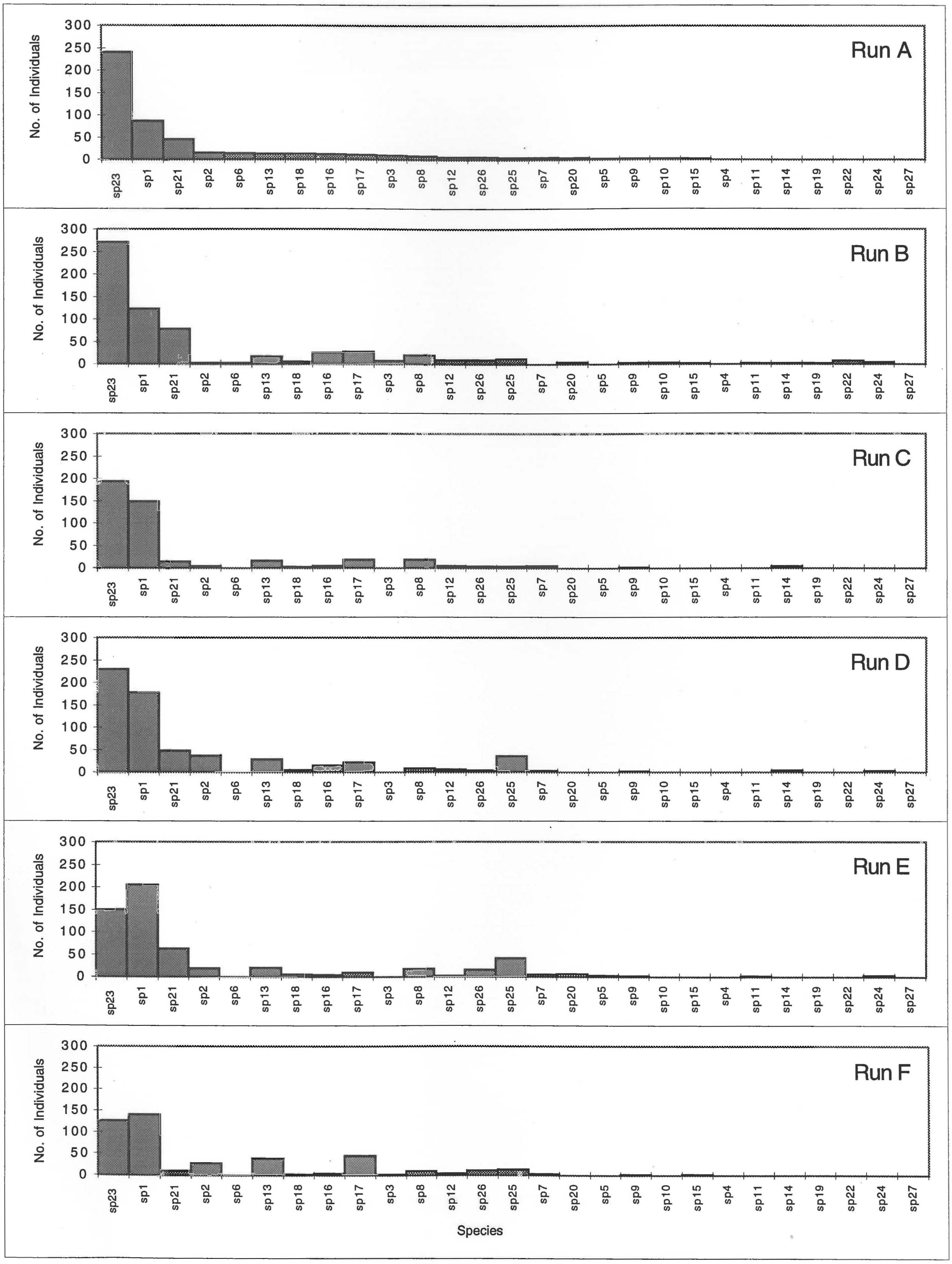


Figure 3.3 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of polychaete individuals found at transect 1, pooled across sites. See table 3.3 for species codes.

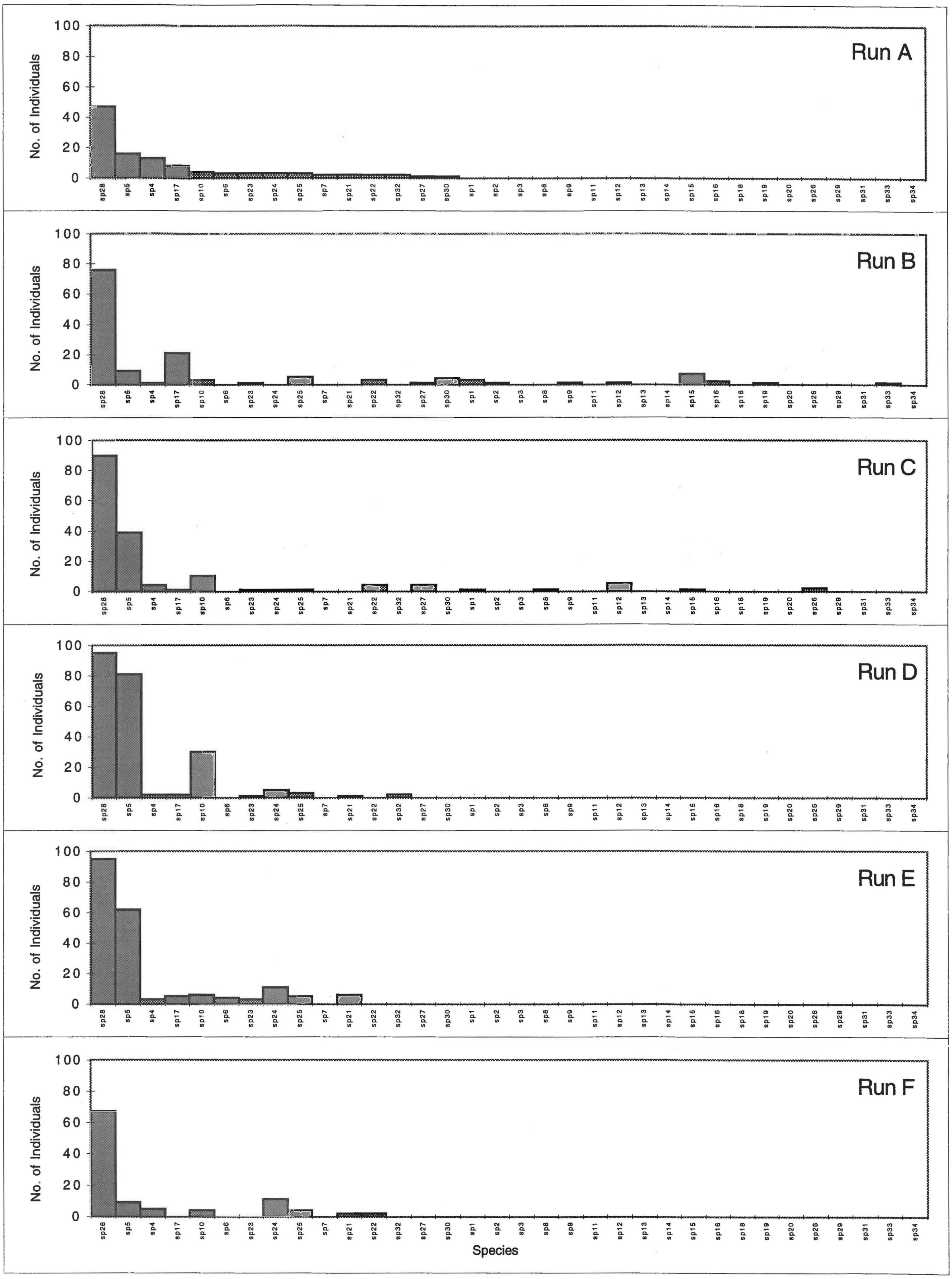


Figure 3.4 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of crustacean and miscellaneous individuals found at transect 1, pooled across sites. See table 3.4 for species codes.

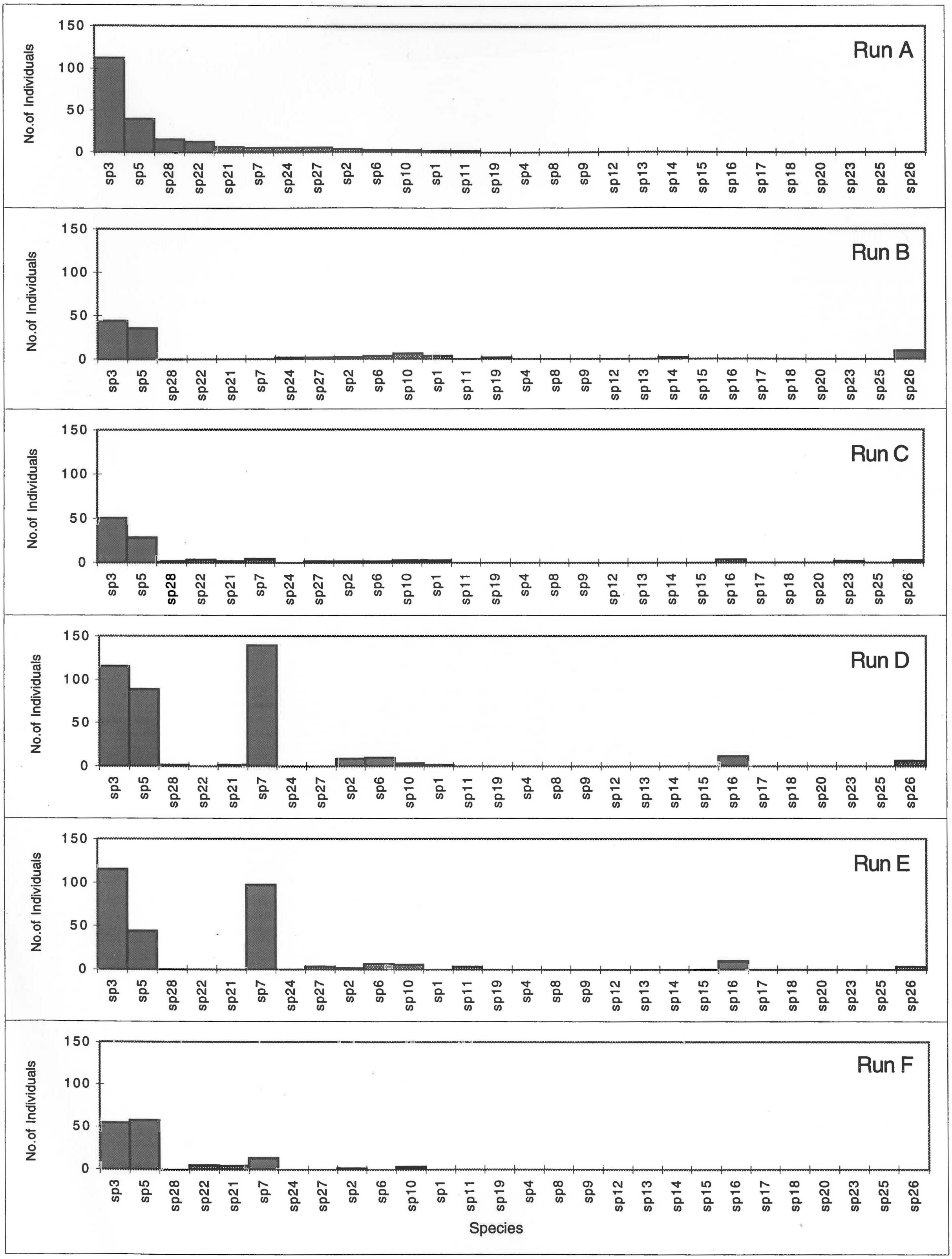


Figure 3.5 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of mollusc individuals found at transect 2, pooled across sites. See table 3.2 for species codes.

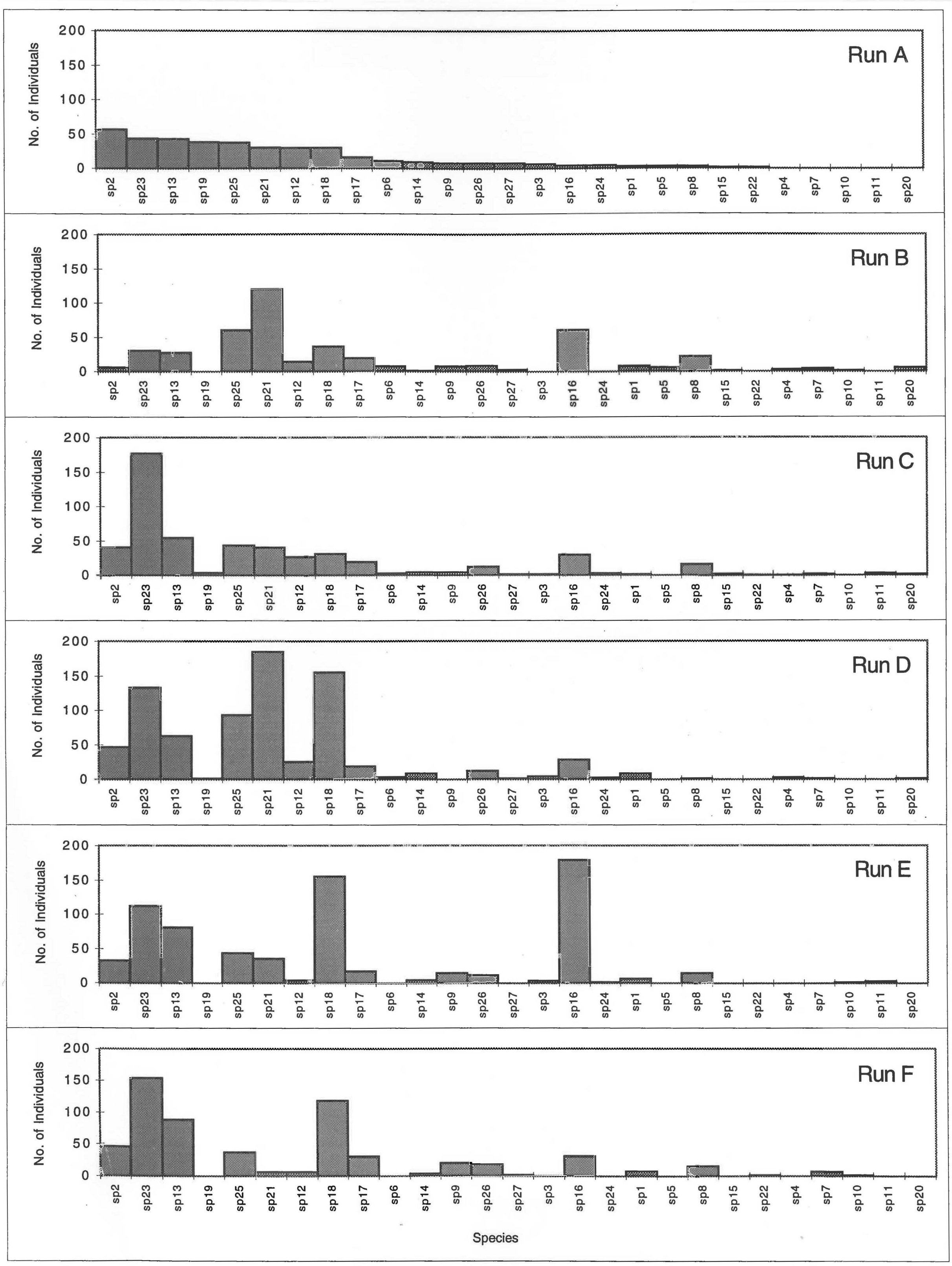


Figure 3.6 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of polychaete individuals found at transect 2, pooled across sites. See table 3.3 for species codes.

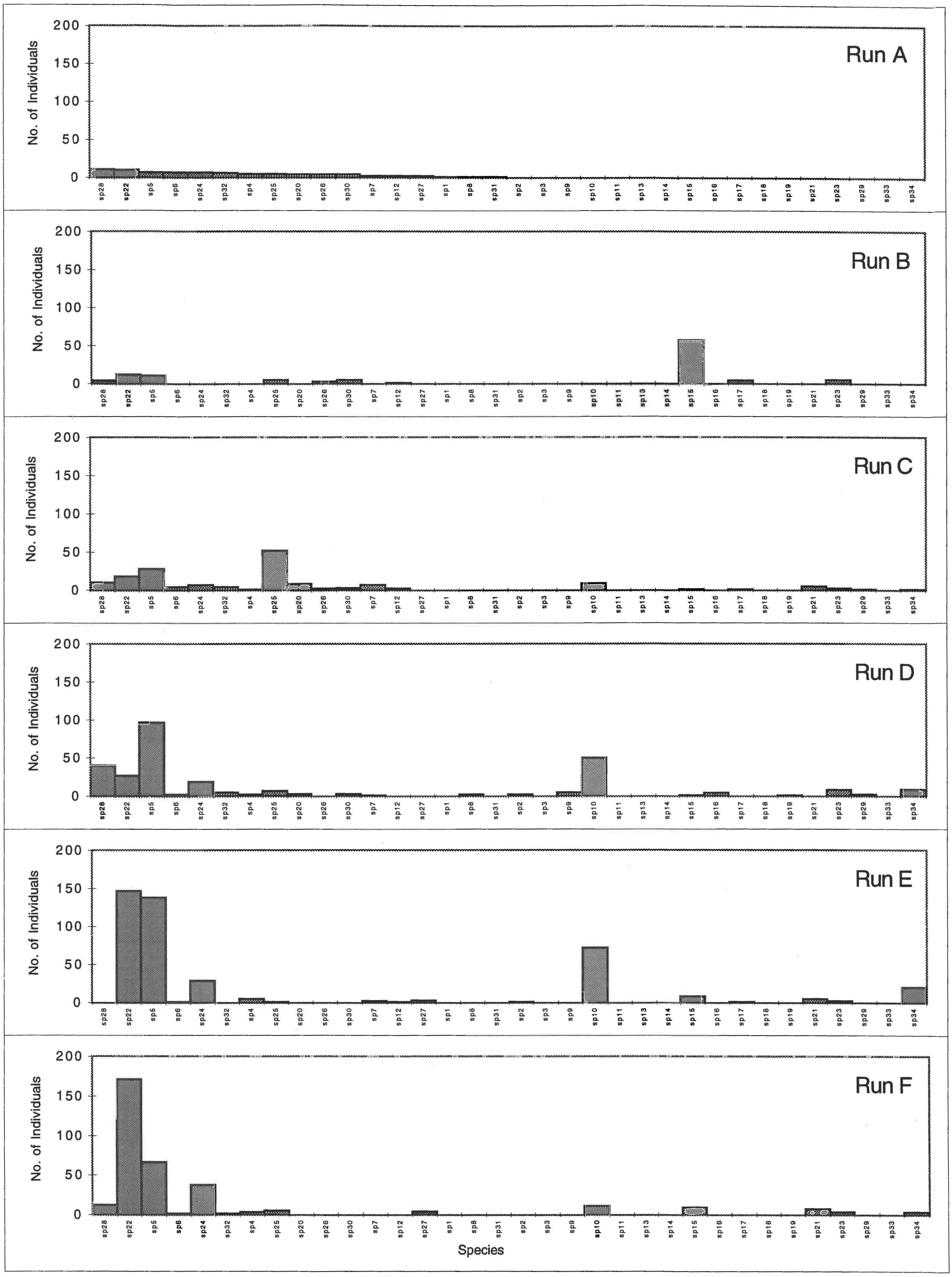


Figure 3.7 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of crustacean and miscellaneous individuals found at transect 2, pooled across sites. See table 3.4 for species codes.

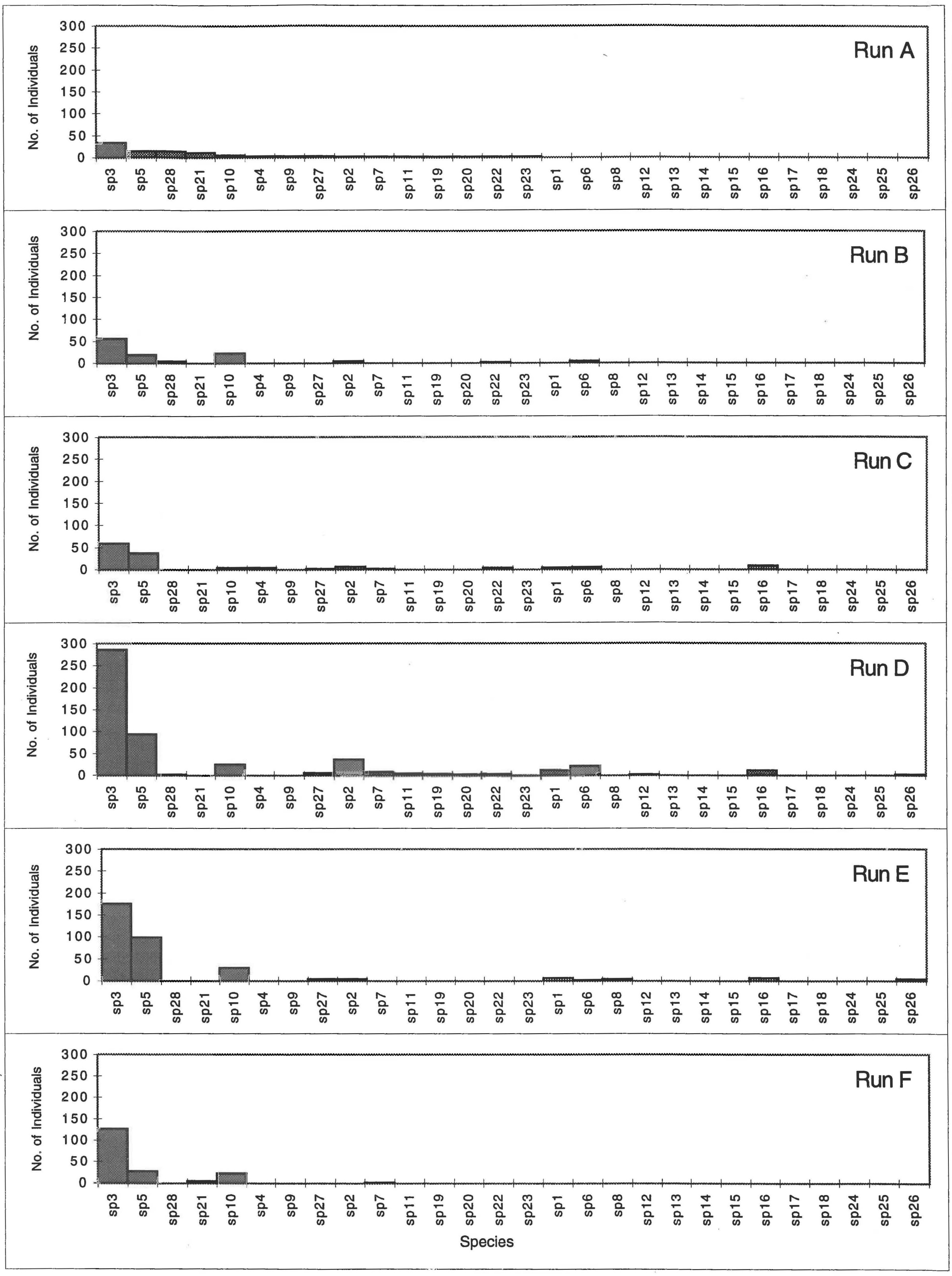


Figure 3.8 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of mollusc individuals found at transect 3, pooled across sites. See table 3.2 for species codes.

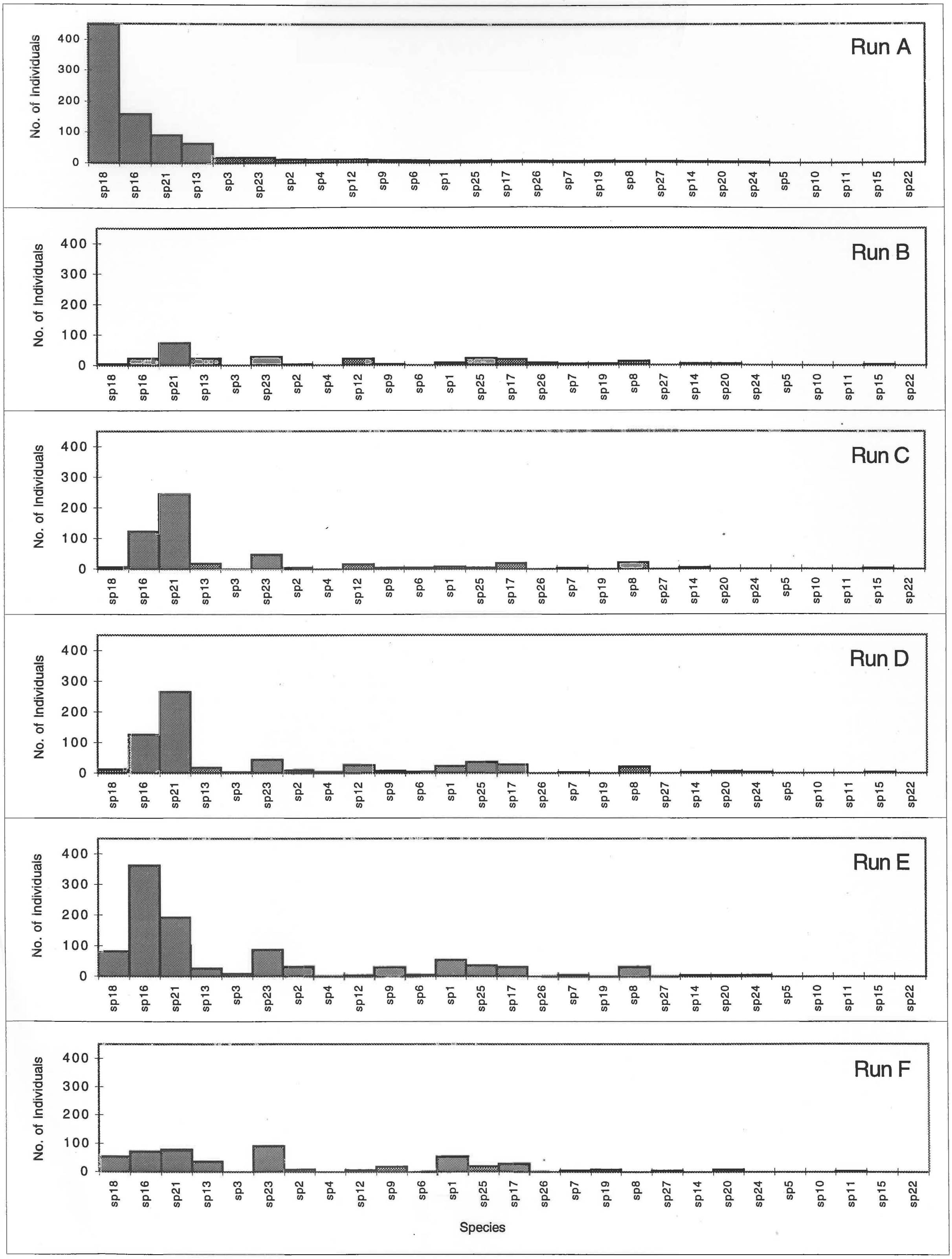


Figure 3.9 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of polychaete individuals found at transect 3, pooled across sites. See table 3.3 for species codes.

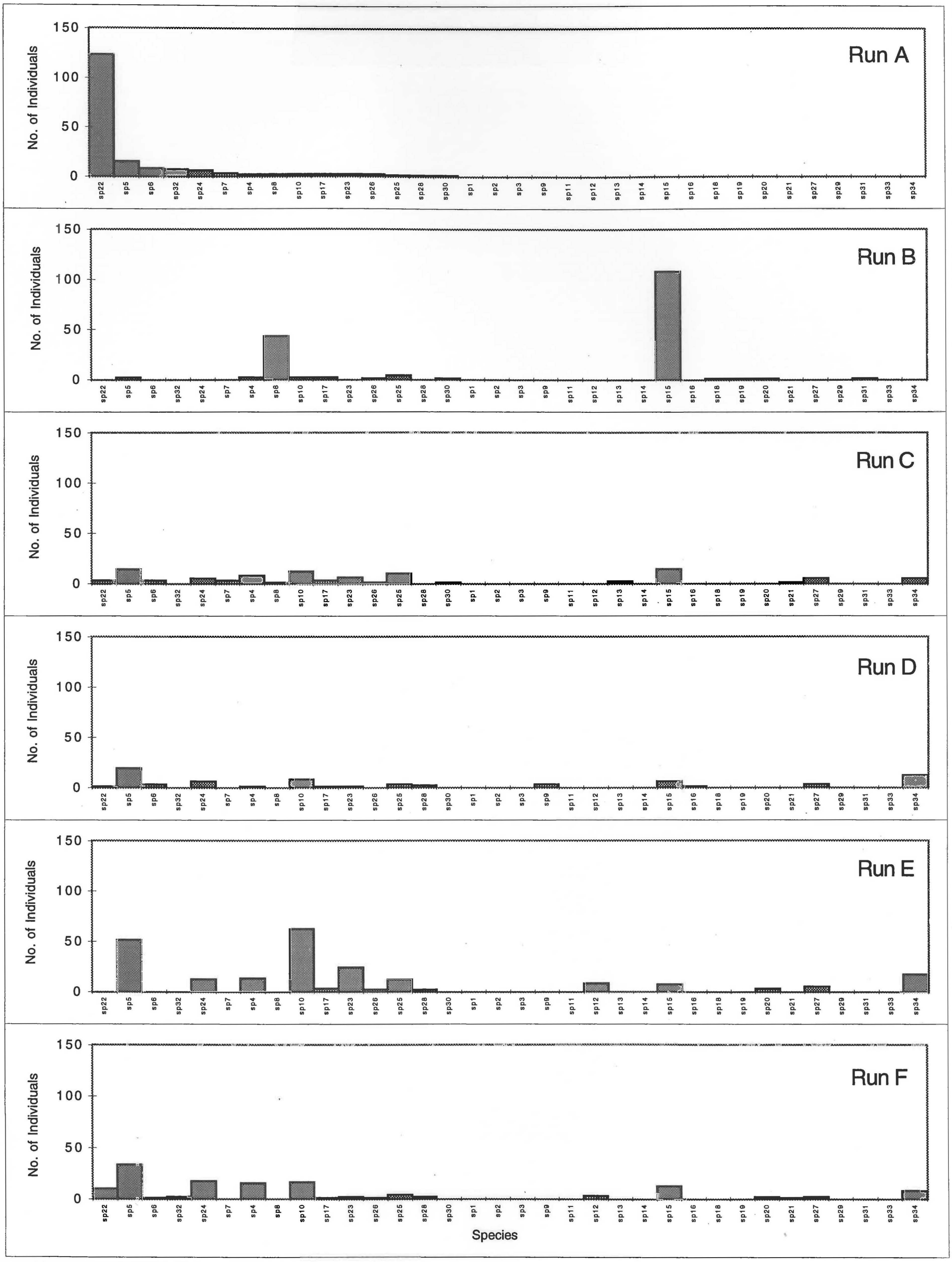


Figure 3.10 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of crustacean and miscellaneous individuals found at transect 3, pooled across sites. See table 3.4 for species codes.

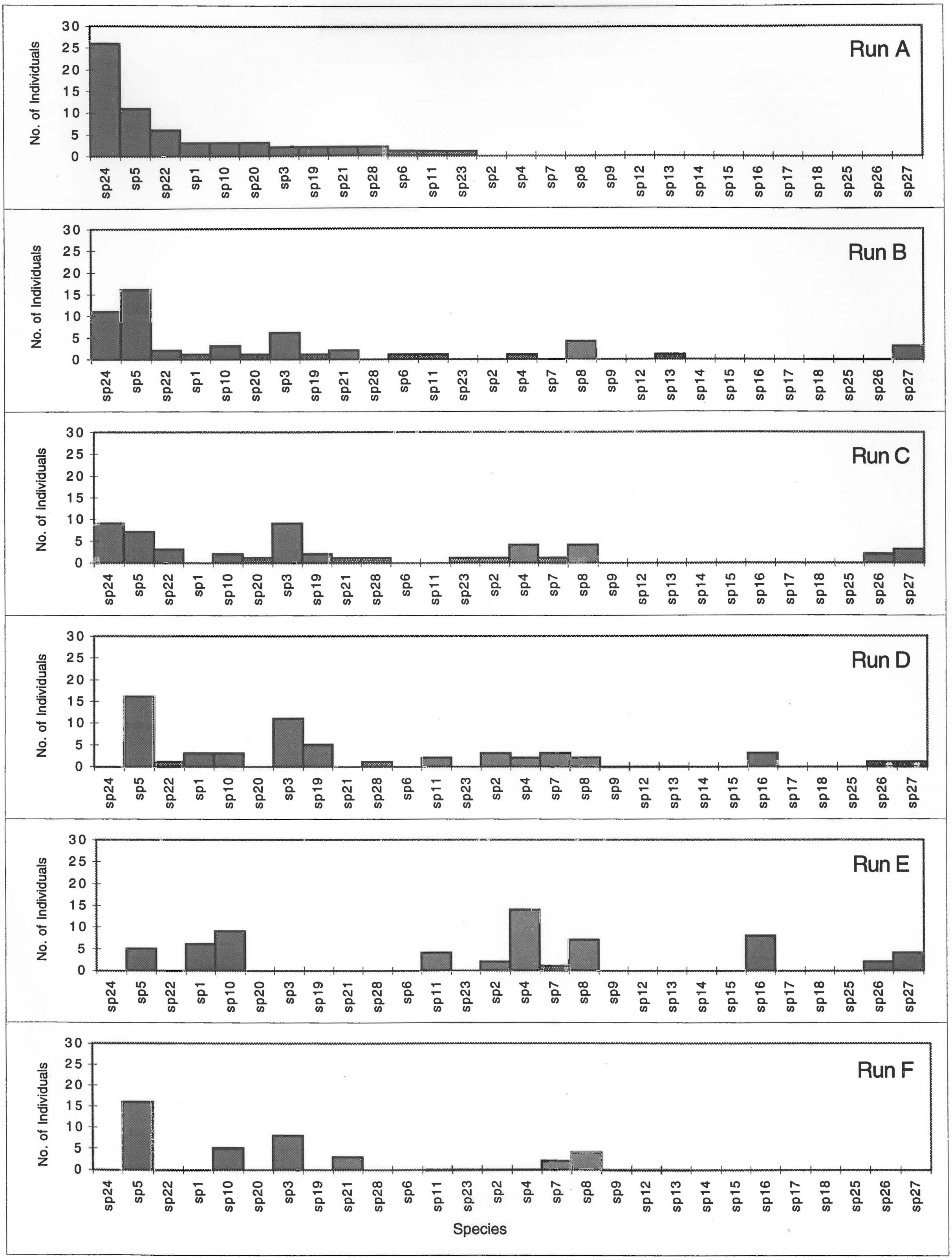


Figure 3.11 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of mollusc individuals found at transect 4, pooled across sites. See table 3.2 for species codes.

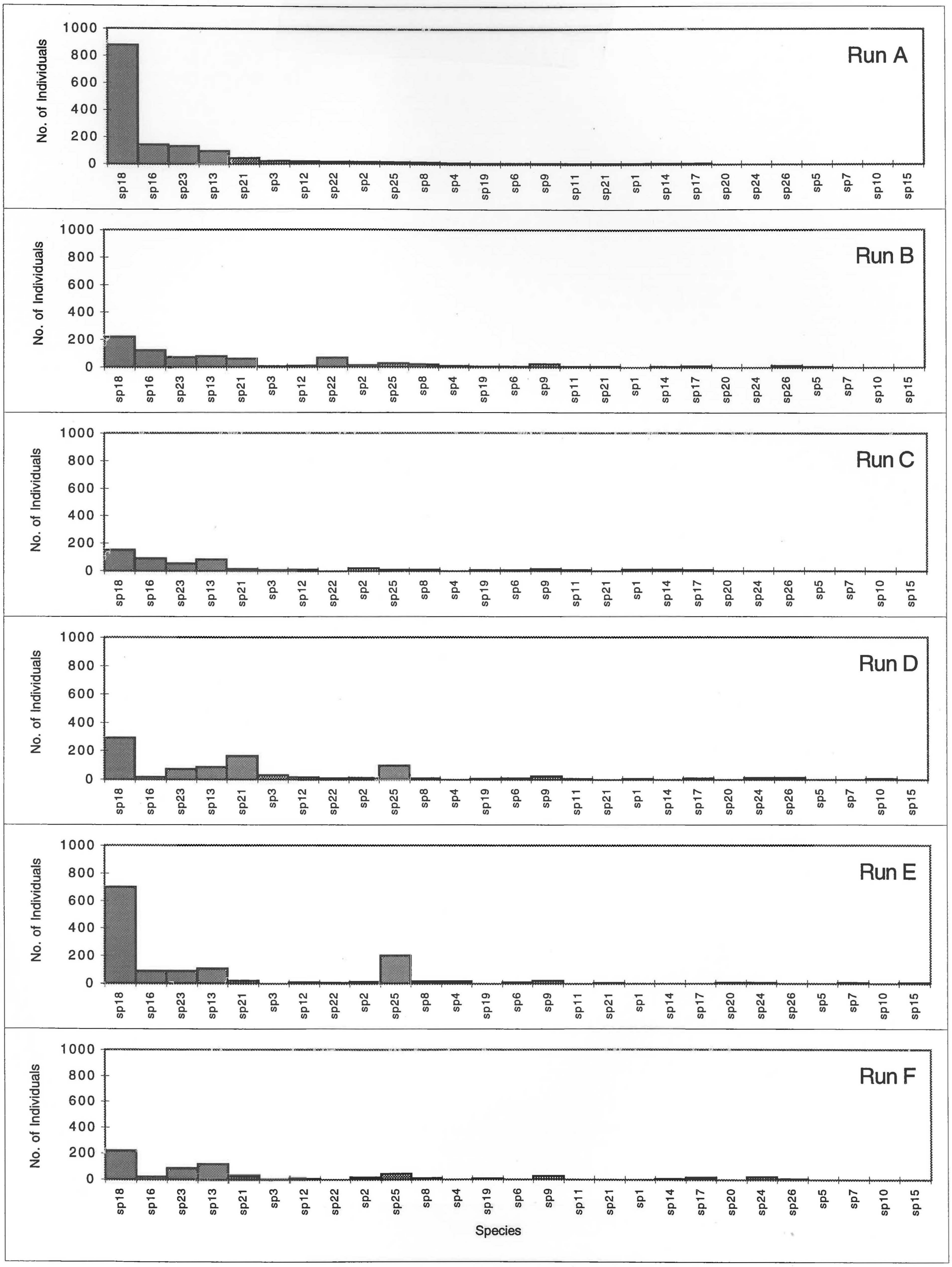


Figure 3.12 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of polychaete individuals found at transect 4, pooled across sites. See table 3.3 for species codes.

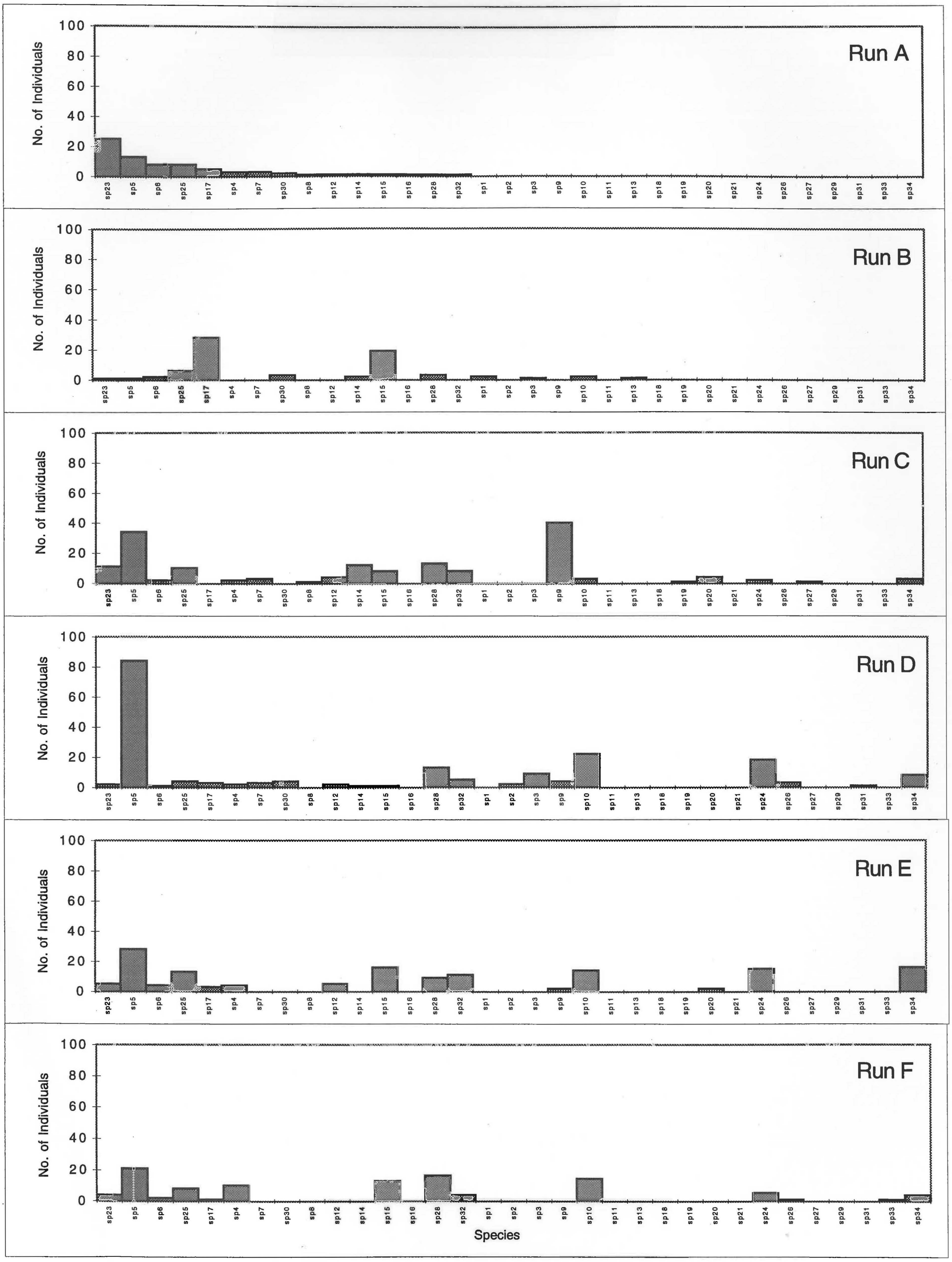


Figure 3.13 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of crustacean and miscellaneous individuals found at transect 4, pooled across sites. See table 3.4 for species codes.

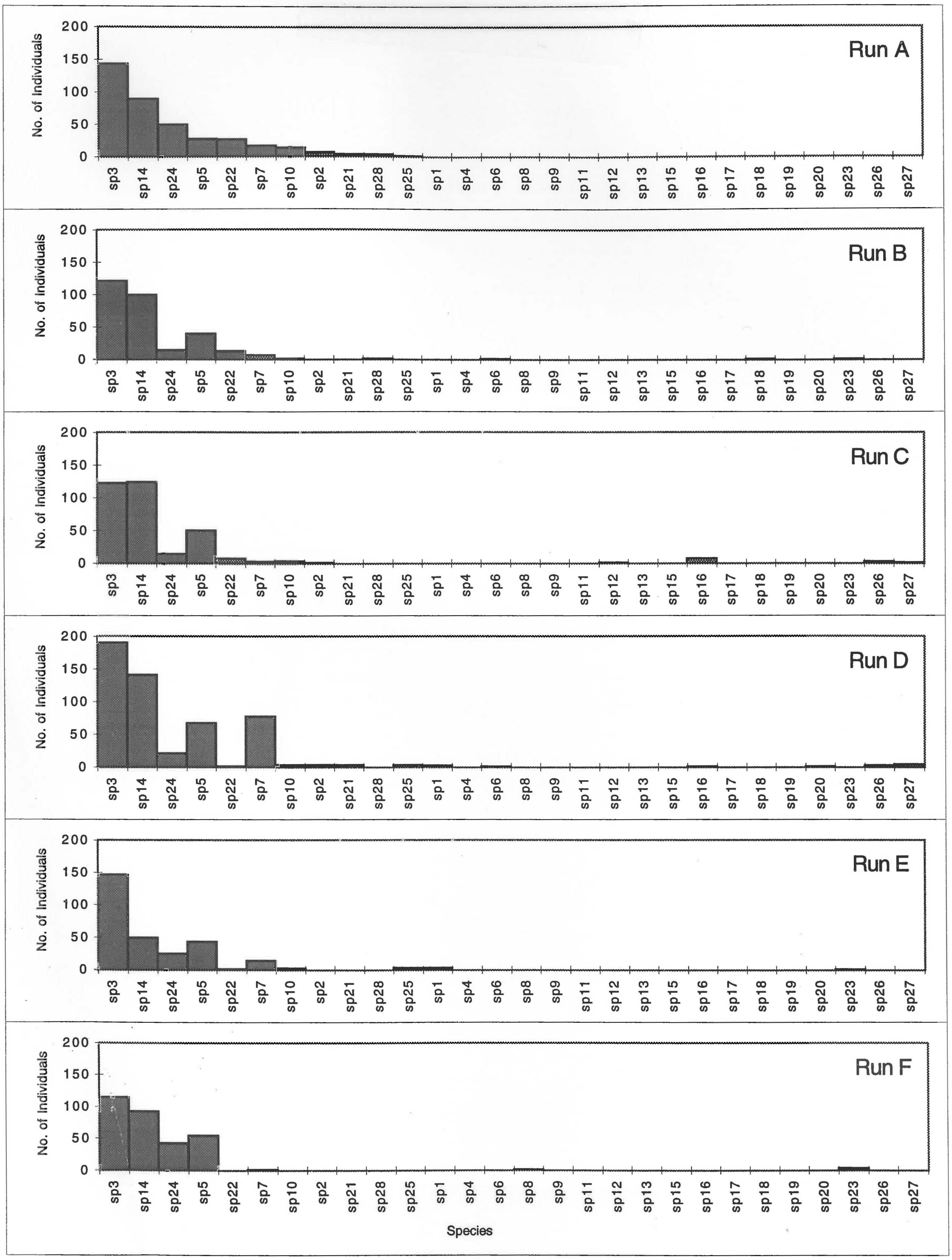


Figure 3.14 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of mollusc individuals found at transect 5, pooled across sites. See table 3.2 for species codes.

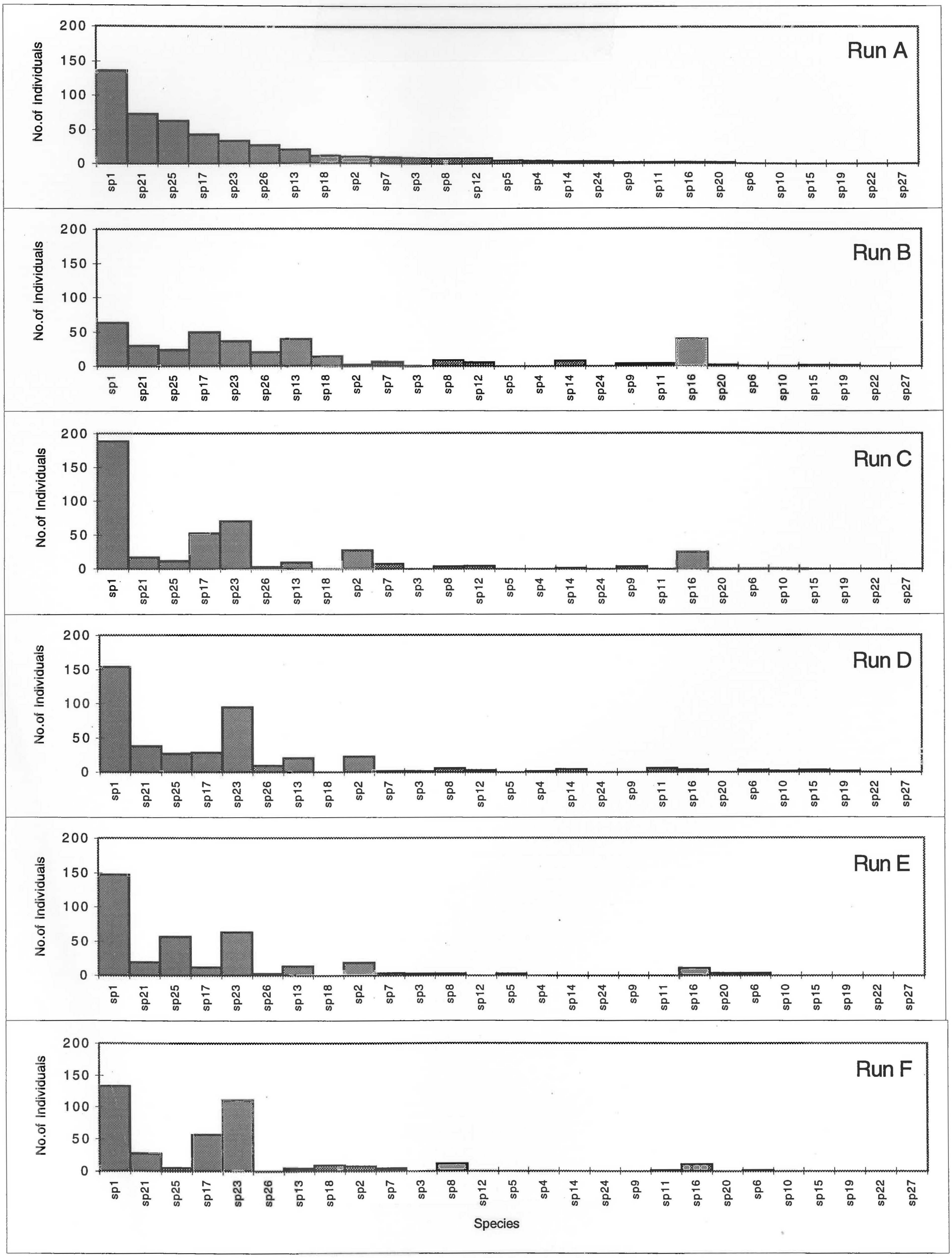


Figure 3.15 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of polychaete individuals found at transect 5, pooled across sites. See table 3.3 for species codes.

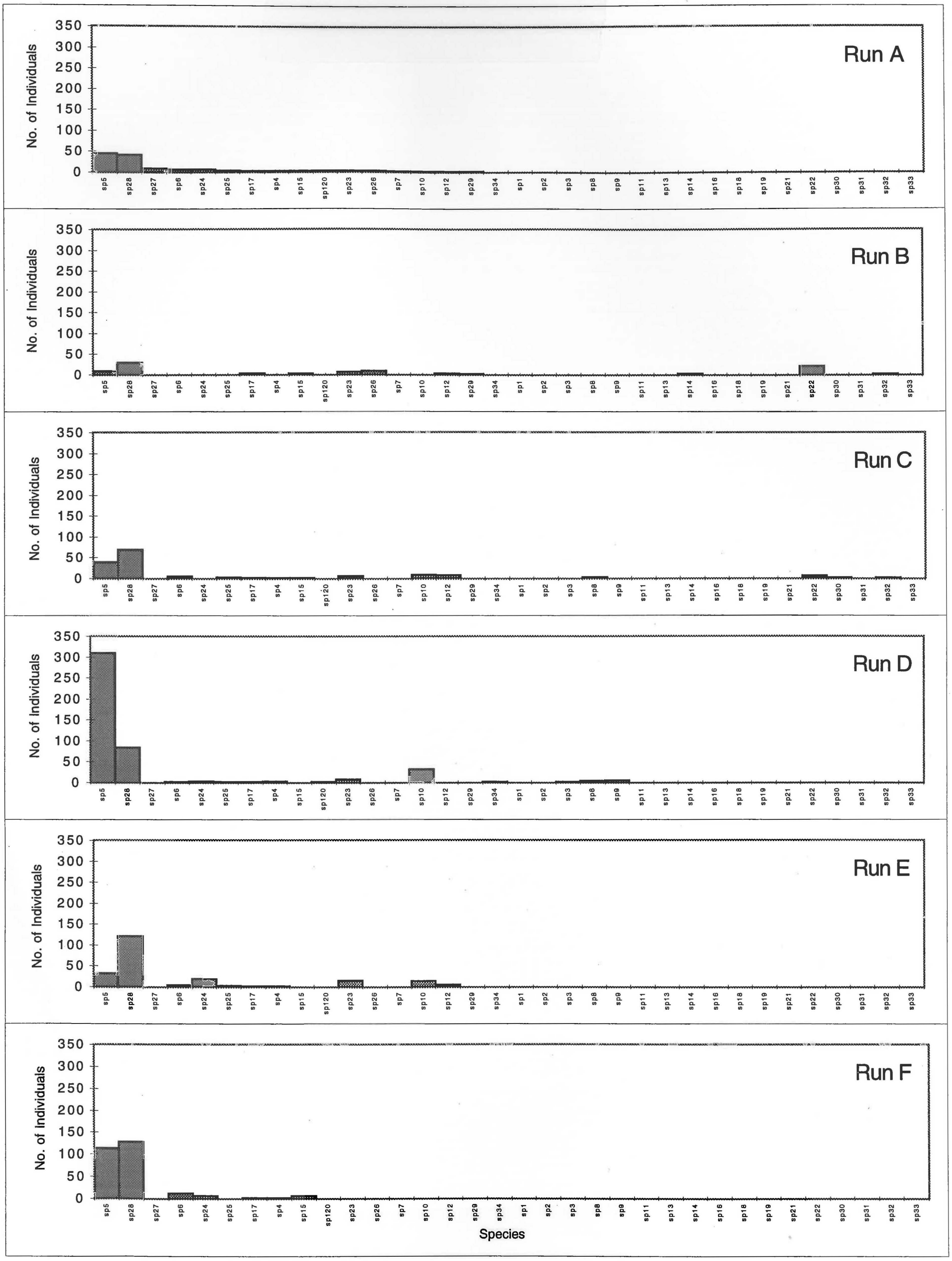


Figure 3.16 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of crustacean and miscellaneous individuals found at transect 5, pooled across sites. See table 3.4 for species codes.

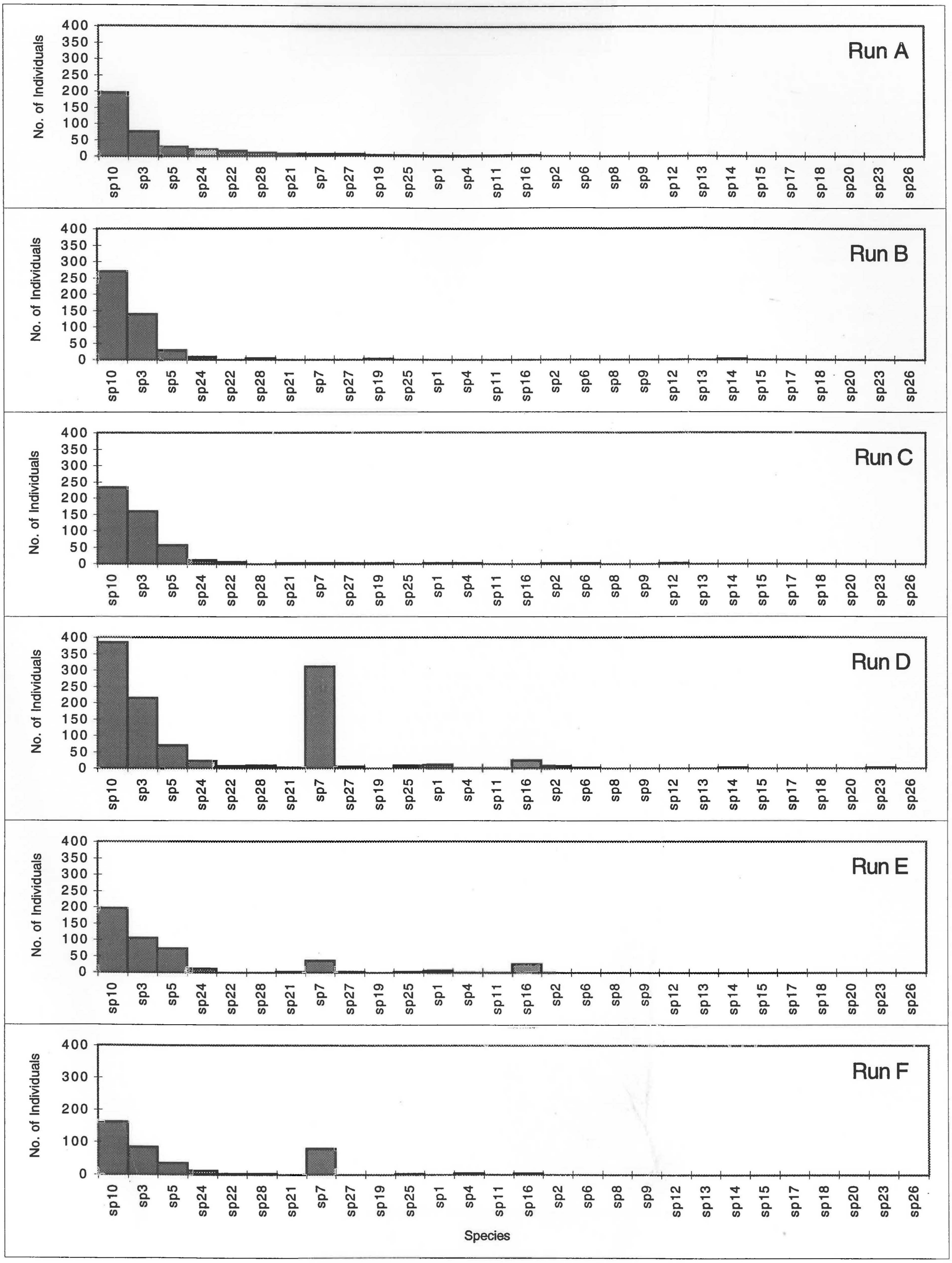


Figure 3.17 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of mollusc individuals found at transect 6, pooled across sites. See table 3.2 for species codes.

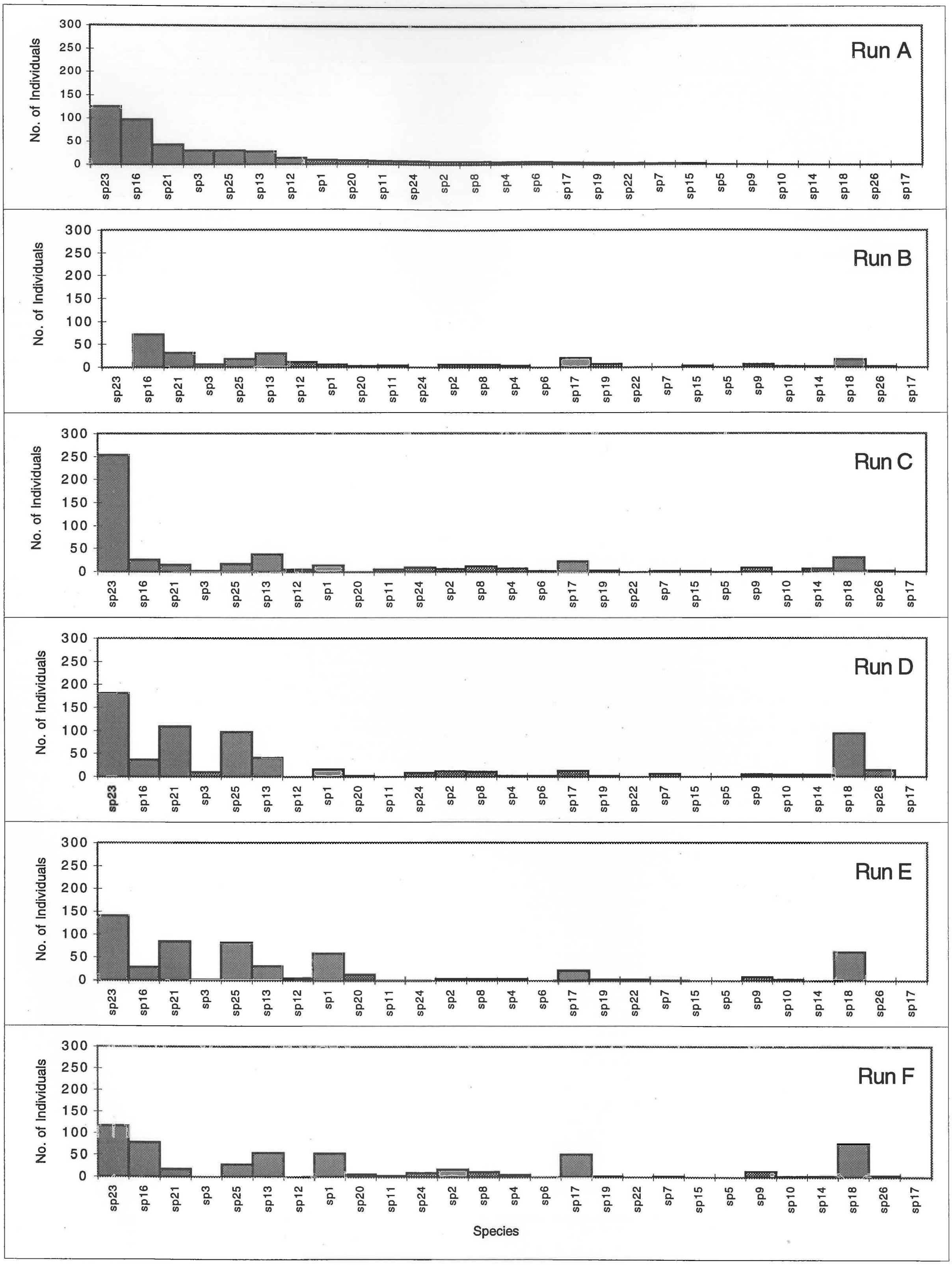


Figure 3.18 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of polychaete individuals found at transect 6, pooled across sites. See table 3.3 for species codes.

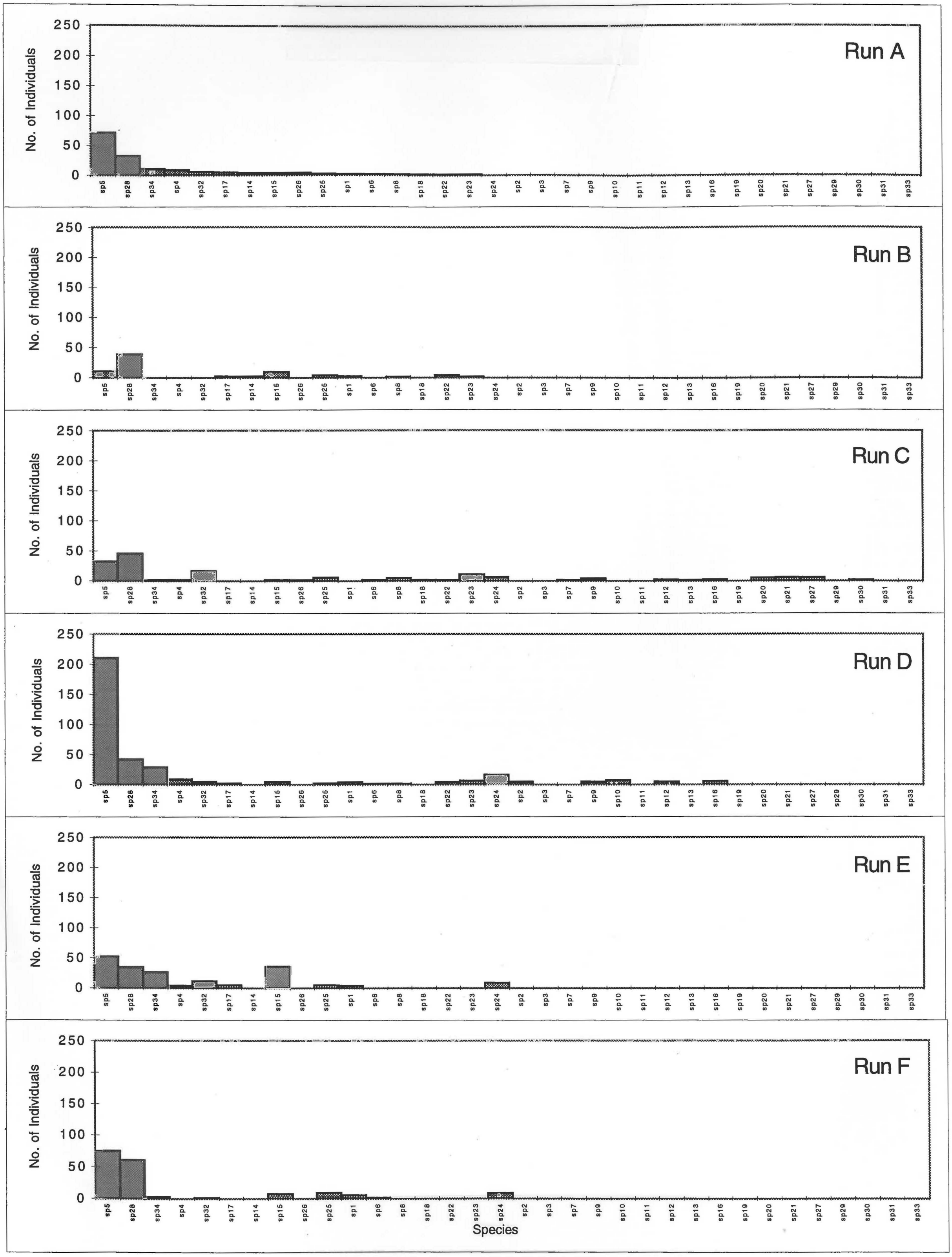


Figure 3.19 Rank sum graphs for runs A-F at Pine Harbour Marina. Bars indicate the total number of crustacean and miscellaneous individuals found at transect 6, pooled across sites. See table 3.4 for species codes.

3.3.2 Canonical Discriminant Analysis

3.3.2.1 Variation in Biota Between Shore Heights

CDA revealed a relationship between shore height and mollusc taxa present (Fig. 3.20). Sites 2 and 3 from each run are closely paired whereas site 1 did not follow the same pattern. The major species which contributed to this canonical structure for Can 1 are *Austrovenus stutchburyi* and *Nucula hartvigiana. Paphies australis* and *Macomona liliana* contribute to Can 2.

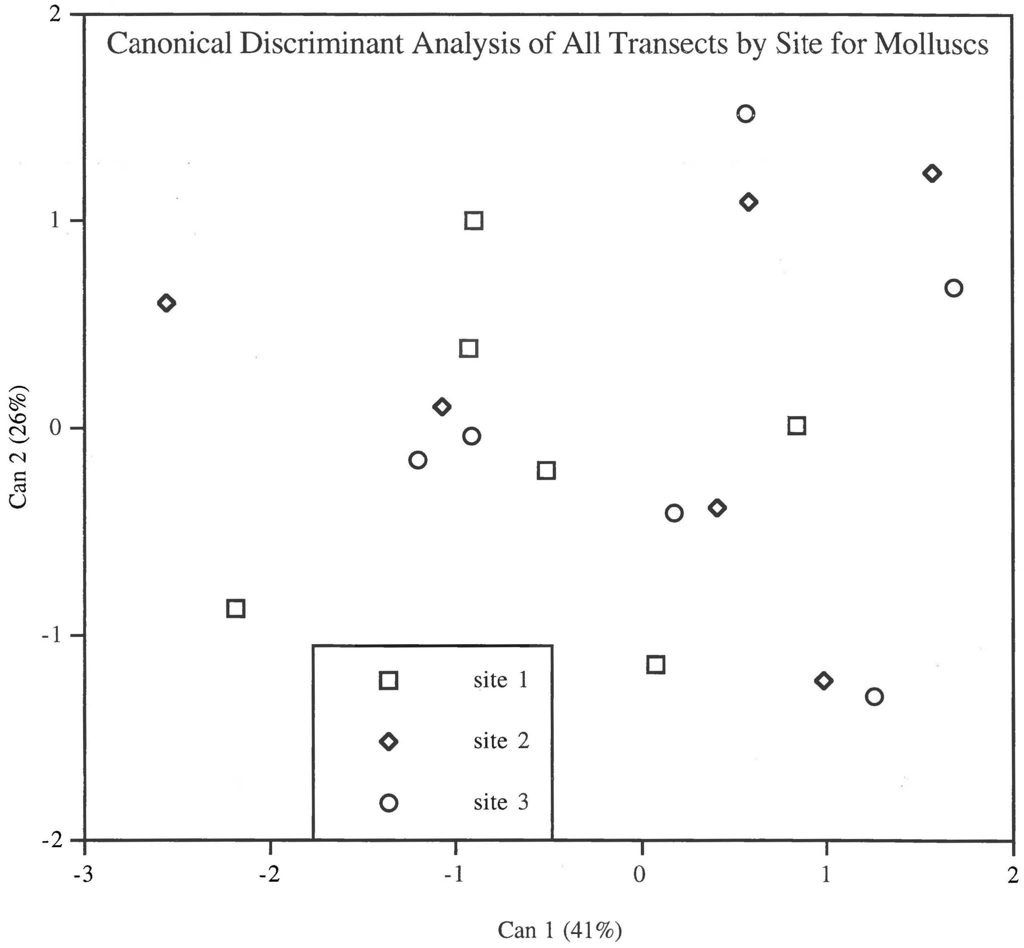


Figure 3.20 Site means for each transect from a Canonical Discriminant Analysis by site of molluscan fauna on all of the six transects 1-6 for the intertidal benthic survey at Pine Harbour.

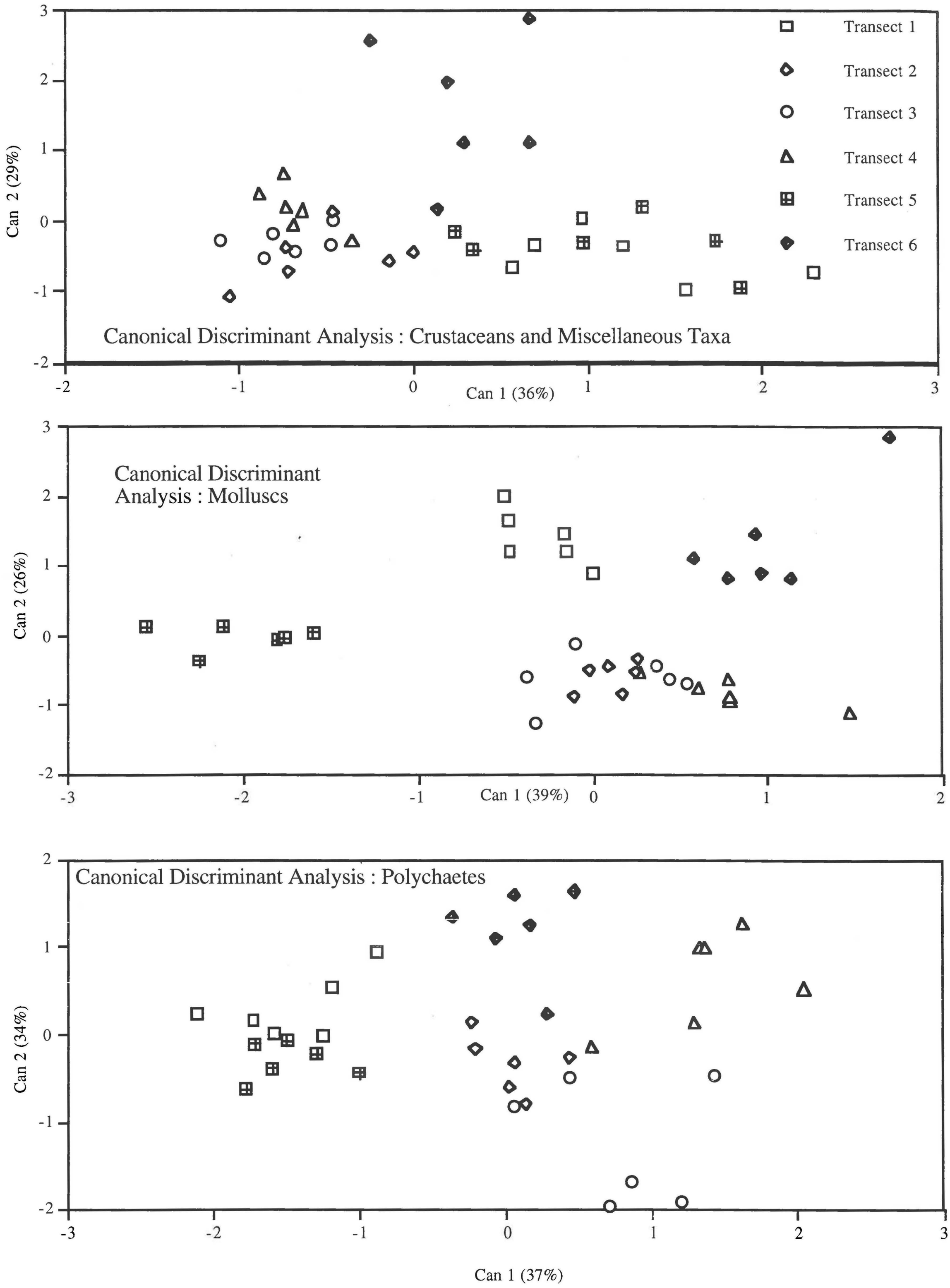


Figure 3.21a, b & c Canonical Discriminant Analysis graphs of crustacean and miscellaneous species, molluscs and polychaetes by transect for the broadscale benthic survey at Pine Harbour Marina. Each symbol represents a survey for each transect.

3.3.2.2 Canonical Discriminant Analysis of the Variation between Transects

Scores for transects 2, 3 and 4 were variable in species composition and assemblage for all three taxal catagories (Fig. 3.21a, b & c). Transects 5 and 1 had generally similar species assemblages with respect to polychaetes, crustaceans and miscellaneous taxa. However the mollusc communities at transects 1, 5 and 6 differ. At transects 2, 3 and 4 the mollusc communities were very similar in community structure. Polychaetes at transects 2, 3 and 4 show more variability between transects than molluscs and crustaceans and miscellaneous taxa.

The spacing of points (Fig. 3.21a, b &c) is indicative of the temporal variation between runs A-F. Thus closer spacing between points indicates less variation in a temporal sense at a particular transect. Thus the result of this analysis is that temporal variability is generally similar for all the transects where the data is dealt with as a whole. Temporal variation at transects 1, 5 and 6 was slightly greater than at transects 2, 3, and 4 for all three graphs.

3.4 RESULTS OF THE DUMPGROUND TRANSECT SURVEYS

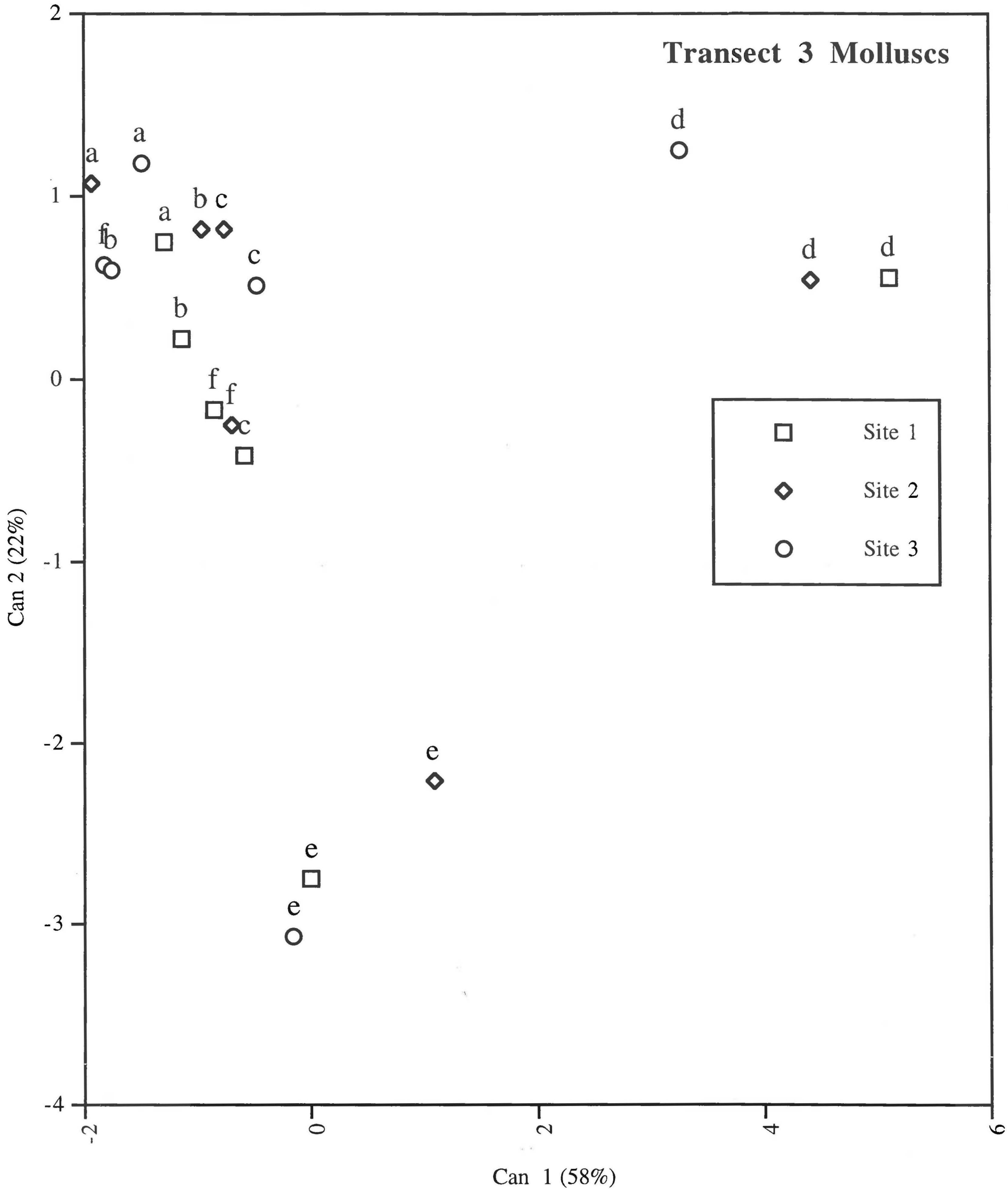
3.4.1 Canonical Discriminant Analysis by Time and Site

Molluscs

The Runs D and E are indicitive of a differing species assemblage or recruitment phase. Molluscs at transect 3 over time show a clustering of points for Runs A, B, C and F (Fig. 3.22). The major species that contribute to the canonical structure are stated below the graph. These runs correspond to a major recruitment of *Austrovenus stutchburyi* and *Macomona liliana.*

Polychaetes

A different species assemblage for polychaetes occurs initially during Run A (Fig. 3.23). This was followed by a 9 month post-dredging phase (Runs B, C and D) of little change with respect to species numbers and diversity. Run E is notable however in that there appeared to be a major event of change in polychaete community structure. During Run F the species assemblage returned to levels similar to those of Runs B, C and D.

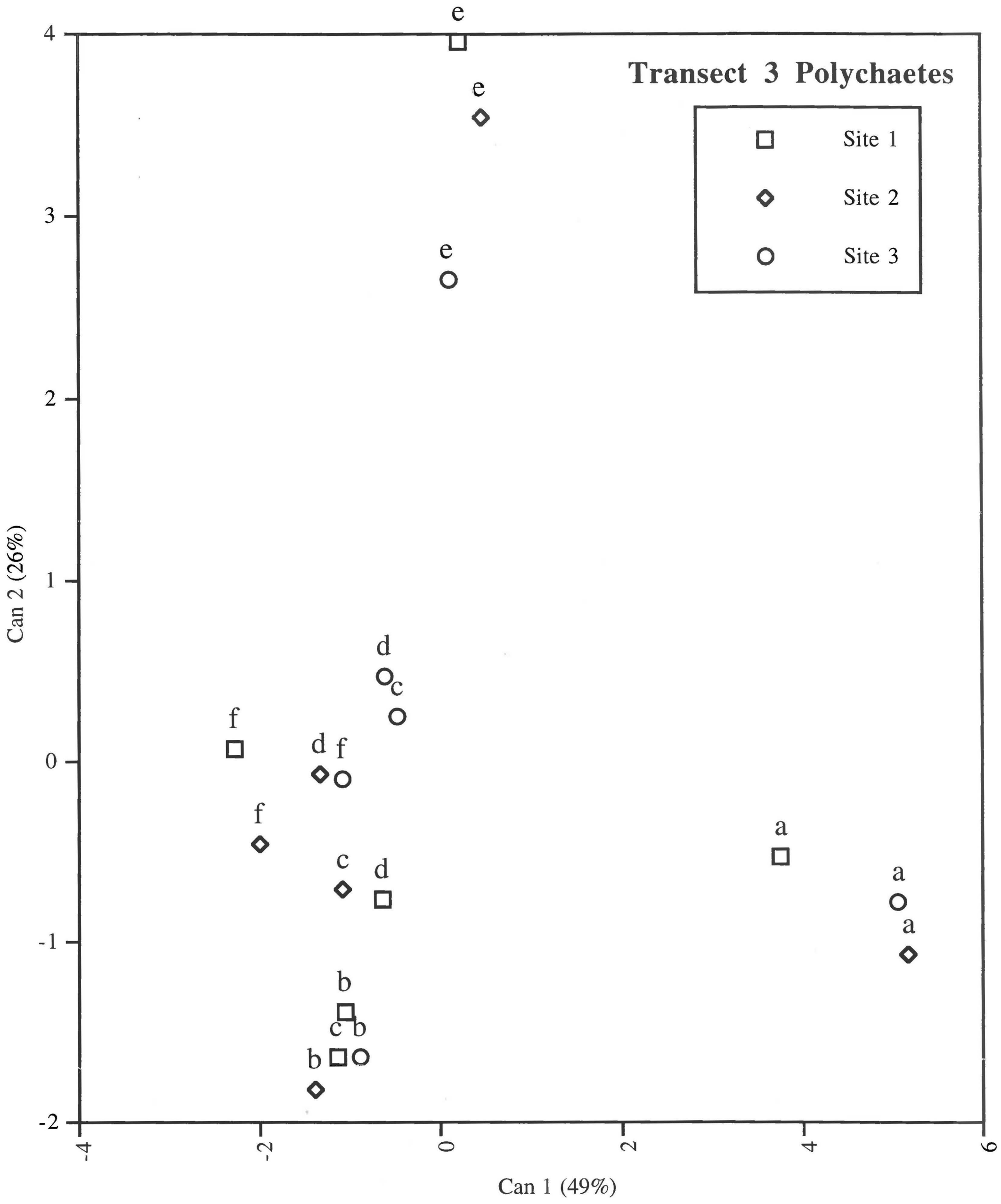


Species with major contributions to total, between and within canonical structure;

Can 1: *Arthritica bifurca, Ascitellina uriatoria, Austrovenus stutchburyi, Macomona liliana, Mactra ovata, Musculista senhousia.*

Can 2: *Macomona liliana, Myadora boltoni, Turbonilla* sp.

Figure 3.22 CDA graph indicating the variation in mollusc species assemblage over time for the dumpground sites at Pine Harbour Marina.

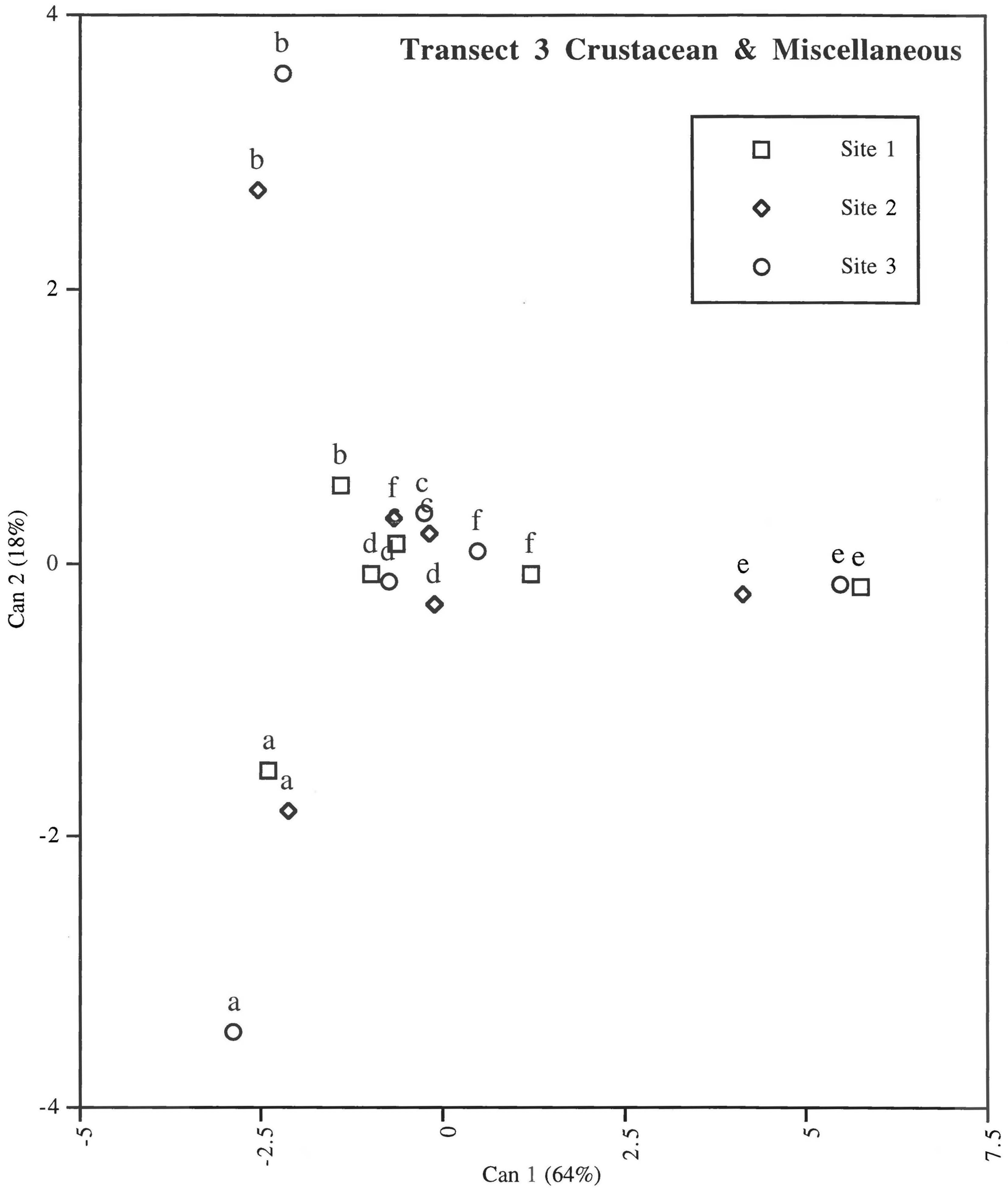


Species with major contributions to total, between and within canonical structure;

Can 1 : *Armandia maculata, Asychis theodori, Maldanid* sp., *Oriopsis limbata, Travisia olens.*

Can 2 : *Aricidea* sp., *Glycera lamillipoda, Goniada* sp., *Notomastus zeylanicus, Prionospio pinnata.*

Figure 3.23 CDA graph indicating the variation in polychaete species assemblage over time for the dumpground sites at Pine Harbour Marina.



Species with major contributions to total, between and within canonical structure;

Can 1: Amphipod sp.2, Cumacean sp., *Halicarcinus* sp., *Urothoides* sp., *Myodocopina* sp.

Can 2: Amphipod sp.3, *Macropthalmes hirtipes*, *Urothoe* sp., *Phoronis* sp.

Figure 3.24 CDA graph indicating the variation in crustacean and miscellaneous species assemblage over time for the dumpground sites at Pine Harbour Marina.

Crustaceans and Miscellaneous Taxa

Crustaceans and miscellaneous taxa indicates a change in community structure post-dredging (Fig. 3.24). Another change occurred after this (Run B) and then a six month stable period (Runs C and D). Run E again stands out as an outlier for all three sites. Run B, site 1 does not vary as much as sites 2 and 3. Run F saw a return to similar community structure as Runs C and D.

3.4.2 Community Structure, Diversity and Species Richness

Number of Species

Molluscs

The mean number of species (NSP) present on the dumpground sites through time show generally the same trends for all three sites (Fig. 3.25). The exception to this was the lack of any molluscs at site 3 during run B. The change in diversity from run A to run B other than this was not drastic (2-3 species per site). Run C showed similar results with equivalent mean numbers of species. In run D a recruitment event occurred with over 6 species per site present at all sites. Following this mean numbers of species declined to levels slightly lower than those of the pre-dumping sampling run.

Polychaetes

The mean number of polychaete species at site 1 over time showed an initial value of slightly over 6 species per site (Fig. 3.25). This then dropped slightly to 5 species per transect and then steadily increased to a value of over 11. Site 2 showed higher numbers of species initially (over 10). The post-dumping survey actually showed an increase in number of species. Run C then experienced a decline in diversity. Site 3 showed the same trends as site 1 recovering to the same amount of species present post-dredging as present pre-dredging by run D.

Crustaceans and Miscellaneous Taxa

Site 1 initially had a mean number of under 2 Crustaceans and Miscellaneous taxa. Post-dumping this mean reduced slightly and then increased to a mean of over 6 species per run (Fig. 3.25). Site 2 displayed more consistent average numbers of species, fluctuating between 3 and 5 species per run. Site

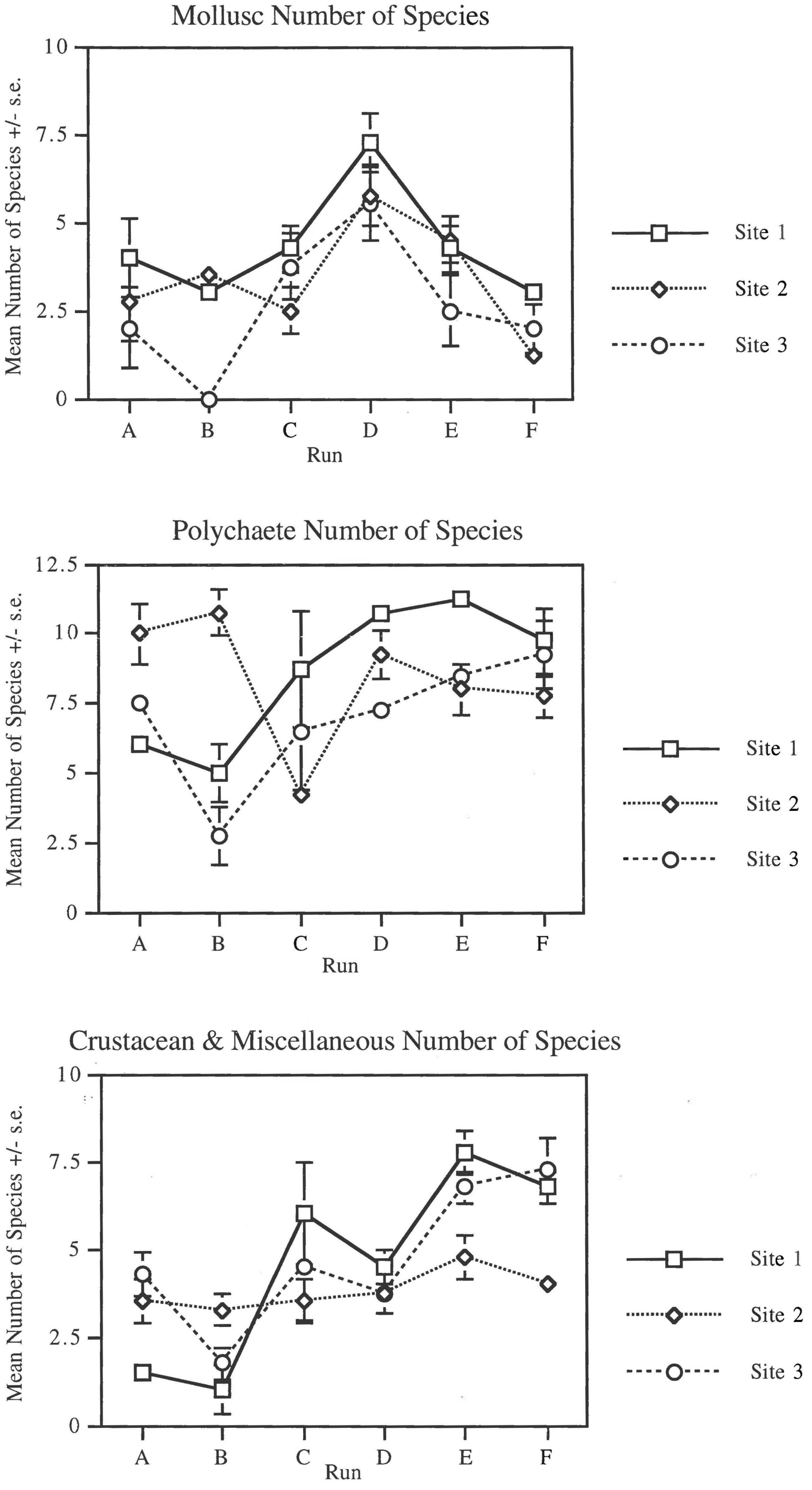


Figure 3.25 The mean number of species for the three taxal groupings at sites 1, 2 and 3 for the benthic survey at Pine Harbour over the runs A-F (18 months).

3 was most impacted diversity wise by the dredging with mean numbers of species dropping from above 4 to below 2 immediatly prior to dredging. Runs E and F display maximal numbers of species during the survey.

Number of Individuals

Molluscs

The mean number of individuals (NIND) present at sites 1, 2 and 3 indicate that site 3 has a non-diverse species makeup in comparison to the other sites (Fig. 3.26). The recruitment event aforementioned with maximum numbers of individuals in run D is again evident.

Polychaetes

The mean number of individuals at site 1 during run B was approximately half that of run A (Fig. 3.26). Site 2 experienced an increase in mean number of individuals post-dredging. Site 3 changed from over 130 individuals before dredging to under 10 individuals during run B. All three sites then recovered by run E, and then declined slightly during run F.

Crustaceans and Miscellaneous Taxa

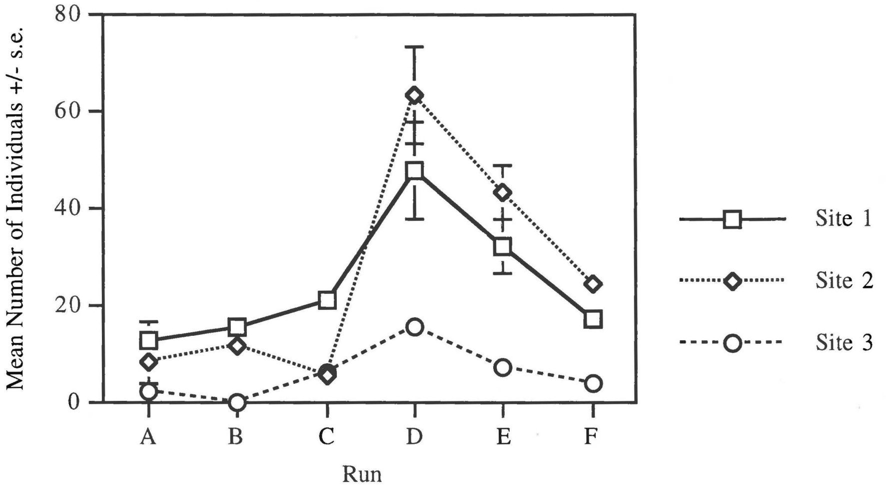
The mean number of individuals at site 1 is relatively low - less than 3 per run (Fig. 3.26). This drops even lower following dredging to under 2 individuals per run. By run E there are just under 20 individuals per run. Site 2 had initially low mean numbers of individuals (under 5). Following dredging this went up to over 20 individuals. This then declined to 5 individuals per run for runs C, D and F with over 15 individuals per site during run E. Site 3 initially had a mean of over 35 individuals per site. After dredging this value steadily decreased to just over 5 per site during run D. Numbers of individuals increased to between 15 and 20 per site during runs E and F.

Berger-Parker Index

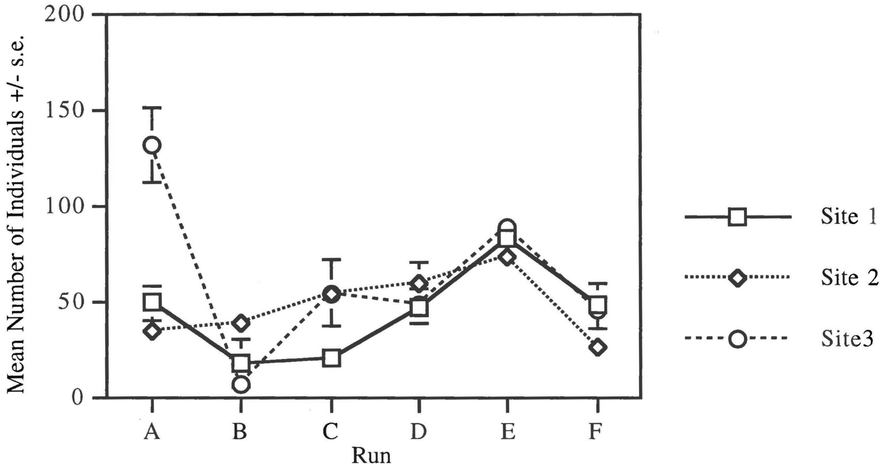
Molluscs

High values of the Berger-Parker Index occured at site 3 during runs A and C, indicating species evenness (Fig. 3.27). This equates to a high species diversity at these sites where no one species is dominant. The BP index for

Mollusc Number of Individuals



Polychaete Number of Individuals



Crustacean & Miscellaneous Number of Individuals

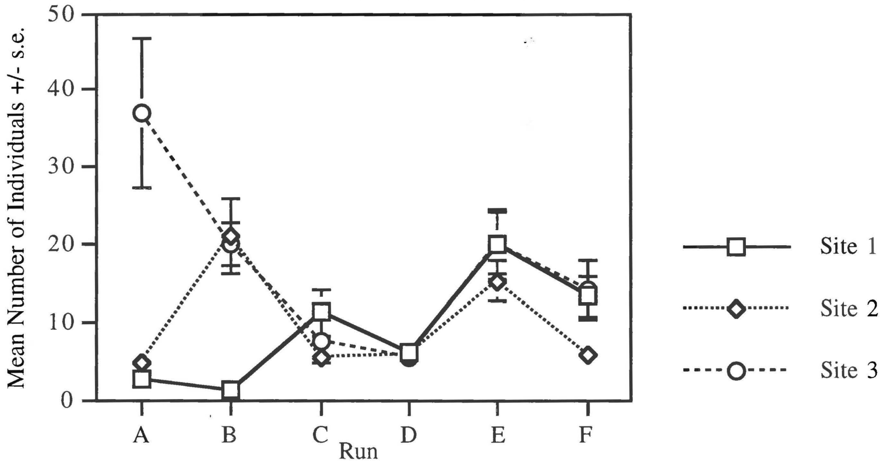


Figure 3.26 The mean number of individuals for the three taxal groupings at sites 1, 2 and 3 for the benthic survey at Pine Harbour over runs A-F (18 months).

site 2 slowly declined to a value of almost 1 by run F. This equates to a low number of species and a high number of individuals.

Polychaetes

Berger-Parker's index for site 3 changed temporally in a steady fashion from a very high dominance (by the species with the maximum number of individuals), to quite a low dominance and resulting higher diversity (Fig. 3.27). Site 1 throughout the survey displayed high diversity, peaking at run C. Site 2 was less linear in the resulting diversity index over time, run C and E had lower diversity than the other runs.

Crustaceans and Miscellaneous Taxa

The Berger-Parker index for Runs A and B was lower than the following runs. Three months after dredging diversity at all 3 sites increased (Fig. 3.27).

Margalef's Index

Molluscs

Margalef's index (Fig. 3.28) gives an indication of species richness. Site 2, run F had a very low value indicating dominance almost entirely by one species. Site 3 had high index values throughout (with the exception of run B, which had no molluscs) indicating a high species richness.

Polychaetes

Site 3 displayed a generally lower species richness in comparison to site 1 and site 2 which had rich species assemblages (Fig. 3.28). Site 2, run C had a lower than average Margalef's index value indicating a low diversity or species richness.

Crustaceans and Miscellaneous Taxa

Margalef's index illustrated the same temporal pattern with the exception of site 3, run B which had a very low species richness (Fig. 3.28).

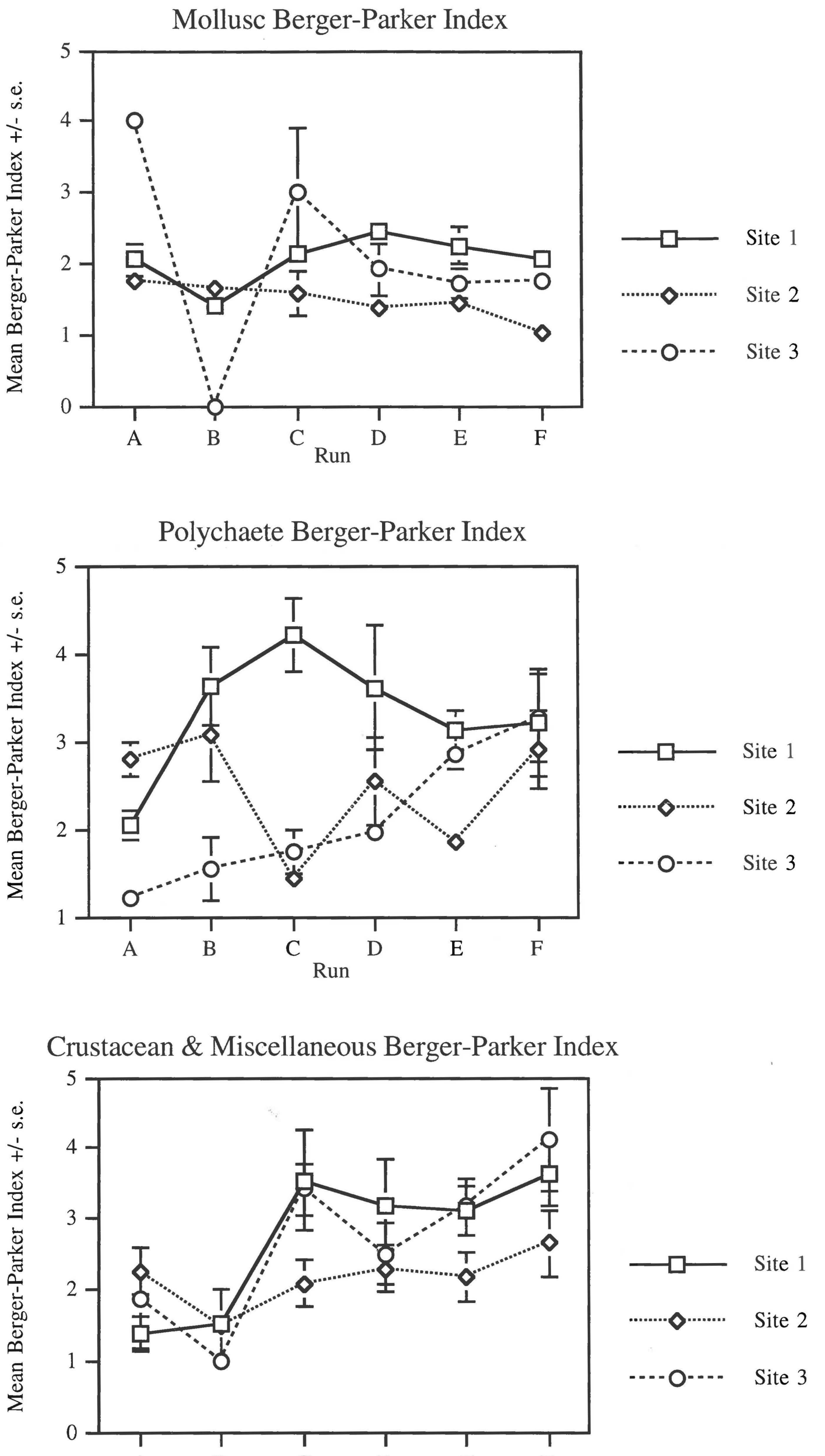
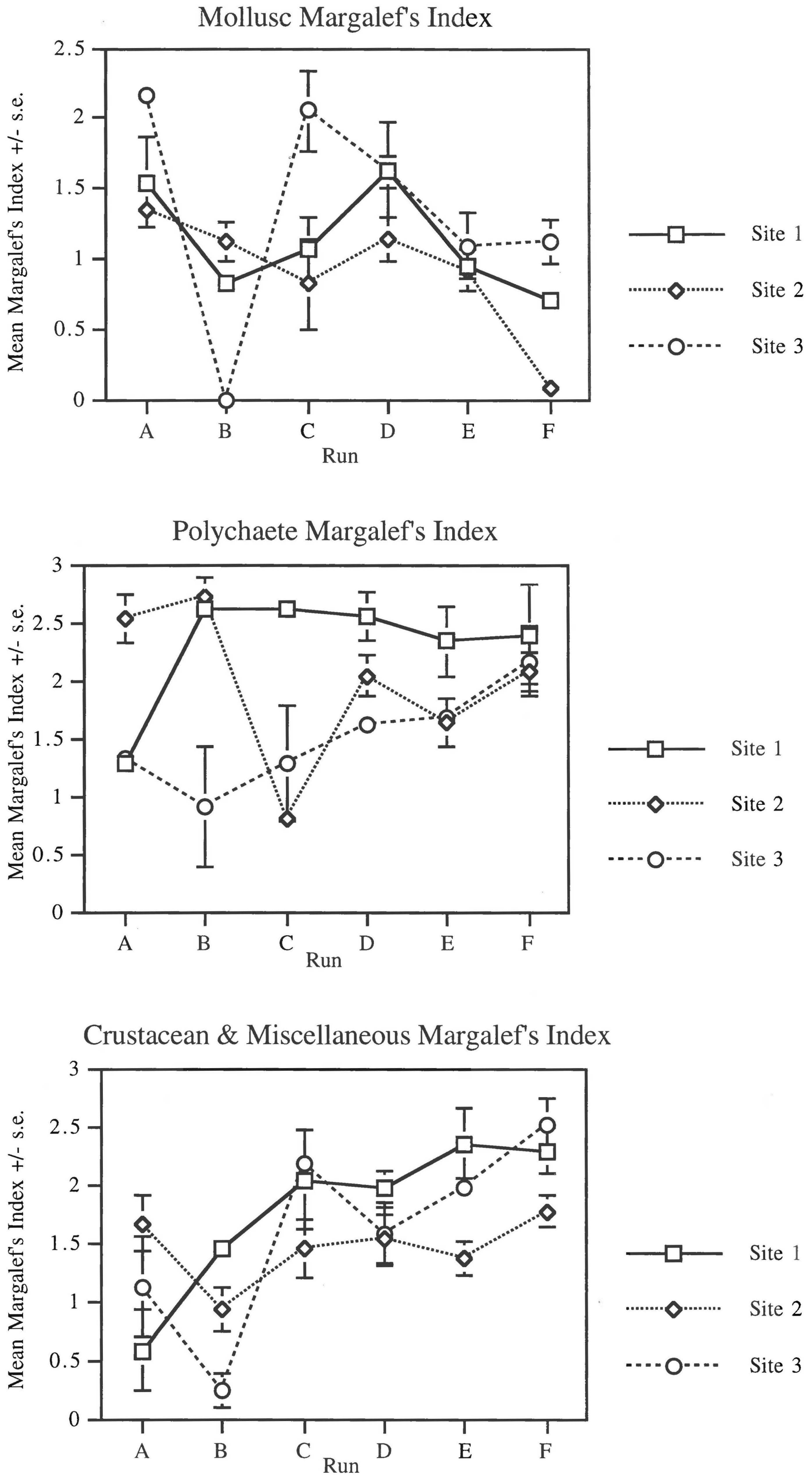


Figure 3.27 The mean Berger-Parker index value for the three taxal groupings at sites 1, 2 and 3 for the benthic survey at Pine Harbour over runs A-F (18 months).


Mollusc Margalef's Index

Polychaete Margalef's Index

Crustacean & Miscellaneous Margalef's Index

Figure 3.28 The mean Margalef index value for the three taxal groupings at sites 1, 2 and 3 for the benthic survey at Pine Harbour over runs A-F (18 months).

3.5 DISCUSSION

3.5.1 Broadscale Benthic Ecological Survey

The intertidal region to the north and south of Pine Harbour Marina contained a relatively diverse range of taxa. The polychaetes were numerically dominant in the overall survey (54%). The bivalves *Austrovenus stutchburyi* and *Nucula hartvigiana* were numerically dominant with respect to the molluscs. *Austrovenus stutchburyi* was the most common species in the survey. *A. stutchburyi,* the common cockle is abundant on enclosed softshores throughout New Zealand (Dobbinson *et al.*, 1989) and very abundant in sheltered beaches around the Hauraki Gulf (Auckland Regional Authority, 1983).

This survey yielded individuals from 89 taxa. An intertidal survey of Manukau Harbour recorded similar diversity levels with 95 taxa (Grange, 1977). A similar survey in north-western Spain recorded a total number of 93 taxa (Lopez-Jamar, 1986). Comparisons can be made with the percentages of individuals that belonged to the most abundant taxa. Sixty-nine percent of the individuals found in a survey of the Manukau Harbour belonged to eight taxa (Grange, 1977). At Pine Harbour Marina 66% of the individuals recorded belonged to 10 taxa. It therefore seems likely that Pine Harbour Marina biota is within the range of natural variation for softshore intertidal environments.

3.5.1.1 Temporal Variation at Transects

Temporal variation overall was quite marked. Recruitment phases occured but except for one site on the dumpground transect, no common taxa completely disappeared. There were also no large recruitments of species that were not found in the early sampling runs. Assemblage structure did change over time at transects 2, 3 and 4. The temporal variation of transect three will be discussed further on in section 3.5.2. Transect 2 changed midway through the 18 months of the survey with a few species becoming less common. Seasonal reproduction may have been a driving factor in the temporal fluctuations. The dumpmound was slowly spread out by environmental conditions over onto transect 2. This net accretion on the northern intertidal flat at transect 2 was 2 cm sediment depth (Hull, 1996). Over the period of the survey this probably would have been at a rate too slow to have any great impact (Ruth, 1994).

Densities of molluscs and crustaceans and miscellaneous taxa changed at transect 4, but not polychaete densities. Whether these changes result from the dumping or are the result of natural temporal fluctuations is the important question. Transect 3's species community change is likely the result of the dredging. Spatial heterogeneity or patchiness can confound temporal trends especially where too few replicates are taken from each site (Thrush *et al.*, 1994). Natural fluctuations can be mistakenly identified as human impacts. Using randomisation techniques to generate possible temporal sequences Thrush *et al.* (1994) found that these changes were often different from the observed changes and trends in density were missed. Populations that exhibit strong annual cycles are less effected by insufficient replication. (Thrush *et al.,* 1994).

Long term studies have confirmed that there are varying scales of temporal change. Buchanan & Moore (1986) found that slow steady fluctuations occurred off the coast of Northumberland on a scale of years, remaining stable for up to 6 years. Similar long term fluctuations in the Wadden Sea were thought to be caused by severe winters and long term eutrophication (Beukema & Essink, 1986). Long-term fluctuations in Scottish lochs were caused by long-term temperature changes and again nutrient input increases (Pearson *et al.*, 1986).

The meteorological conditions of the North Island did not appear to change drastically from the norm over the period of the survey which was predominantly El Nino (Glantz, 1992). This results in slightly cooler weather for the North Island with winds mostly from the western quarter. At present a change to La Nina conditions is being experienced although this is after the completion of the survey.

3.5.1.2 Shore Height Analysis

The general pattern was of similar assemblages at the low tide and mid tide sites. Change over time was quite marked and both low and mid sites changed in species assemblage in a similar manner. The high tide sites however displayed a differing trend. This was a similar amount of change over time but with different community compositions to those of the lower sites. *Austrovenus stutchburyi* accounted for a large proportion of the canonical structure on can1 and can2, as did *Nucula hartvigiana.* It is these two species that have the greatest influence on the resulting trends displayed.

On intertidal flats a position lower on the shore will result in more water cover per day. Bivalve suspension feeders can therefore obtain more food if closer to low tide. Dobbinson *et al.* (1989) found that cockles transplanted from higher up on the shore to lower down showed a significant increase in size compared to controls. It was then concluded that there were two factors influencing this shore height bivalve species distribution. Firstly the bivalves occupying lower shore heights are exposed to more plankton per tidal cycle. Secondly lower shore filter-feeders from all taxa deplete the water column of plankton while the tide is incoming.

A third factor could be that the larvae of bivalves are ingested and that in an area of high bivalve density the chances of settlement are reduced. Andre *et al.* (1993) observed that the larvae of the bivalve *Cerastoderma edule* drifting over sediment populated with feeding adults (380 ind.m^{-2}) had mean survival times of 64 s, and that 75% of the larvae were inhaled by the adults. In the Bay of Islands in spring maximal densities of Veneracea larvae (to which the cockle belongs) were found in the water column, so this is the time of year where maximum bivalve canibalism occurs (Booth, 1983).

Population demography of bivalves depends upon initial settlement of larvae and subsequent post-larval transport. High water sites tend to be dominated by smaller and younger bivalves at lower densities. These juvenile post-larval spat relocate using tidal currents buoyed up on mucous threads. These threads have a high hydrodynamic drag and enable them to be lifted from the sediment surface. The cues for this relocation can be avoidance of a contaminant or be density dependent (Cummings *et al.*, 1993; Cummings *et al.*, 1995). This demographic pattern was seen at Pine Harbour especially for *Paphies australis* (pipi). This bivalve was only recorded in significant numbers at two sites, both of which were high tide sites and contained very small pipi. It was not known however if these pipi were old but small due to their lack of water cover per day (and resulting limited feeding time and low growth rates), or if they were mucus drifting to another area. These pipi could also be drifting into these areas by chance. Pipi were not found in the subtidal survey later in this thesis and neither was there any evidence in the sample debris of small dead pipi shells. This is in contrast to the dense subtidal populations if pipi found by Grace (1972) and Hooker (1995) and Hull (1996).

Hydrodynamic conditions also have a large influence on bivalve and indeed all suspension feeding species. These hydrodynamic conditions also control the amount of settling organic matter that deposit feeders utilise. Jumars & Nowell (1984) indicate that foraging patterns of deposit feeders may be dependent upon sediment transport. In an estuarine situation proximity to the main channel effects size and biomass of bivalve populations (Vermeij, 1972; Dobbinson *et al.*, 1989). Smaller scale hydrodynamics such as eddies and variations in return flow may also control organic particle fluxes in the water column. In Otago Harbour densities of *Austrovenus stutchburyi* increase toward the lower shore but often reach peak densities at mid tide level (Dobbinson *et al.*, 1989). McArdle & Blackwell (1989) found peak densities of *Austrovenus stutchburyi* at mid tide. This relates well with the findings of this chapter with the mid and low tide sites displaying more similarity to each other than the high tide sites.

3.5.1.3 Spatial Variation Between Transects

Species community composition varied between transects. However species assemblages at some transects were more homogenous than others. Transects 2, 3 and 4 had similar community structure. These three transects are in close proximity to the approach channel and this may have an influence on the biota of the area. Differentiating between natural patchiness and patchiness resulting from disturbance is difficult as heterogeneity occurs on many scales (Hall *et al.*, 1993). Eckman (1979) found that individuals of several species exibited spatial variation at scales as small as 1 cm. He also hypothesised that bed ripples have an effect on spatial variation of benthic organisms by varying local hydrodynamic environments. As well the channel may have an influence on the settlement of larvae and could interrupt or vary post-larval transport processes. The channel and its resulting modifications to the current regime and hydrological conditions may affect the suspended organic levels in the water column. It is unknown if the boat traffic of the channel has an effect on the assemblages next to the channel.

The CDA's suggested a similarity between the faunas at transects 1 and 5 for polychaetes and for crustacean and miscellaneous taxa. These two transects are approximately equidistant from the harbour and appeared to have similar sediment compositions with much shell debris in the samples. However Snelgrove & Butman (1994) suggested that there was little evidence that sediment grain size is the primary determinant of infaunal species distributions. The molluscan fauna at transects 1 and 5 was conspicuously different than the rest of the transects. Transect six differed from all other transects in species composition in the CDA. This transect, which is the furthest from the channel, contained significantly different species assemblages.

3.5.2 The Dumpground Transect Surveys

Run E was different from other runs for all taxonomic groupings. The polychaetes also exhibited a notable difference in species composition in Run A from the remainder of the samples. The crustaceans and miscellaneous taxa differed in Runs A, E, and sites 2 and 3 of Run B.

Runs D and E exhibited a different assemblage of molluscs. This can also be seen on the species assemblage graphs as an increase in the number of species and individuals at the three sites. A major contributing species to this was a large post-settlement recruitment of juvenile *Austrovenus stutchburyi*. These bivalves were all less than 10 mm in length. It is likely that they recolonised the dumpground by means of mucous thread drifting (Cummings *et al.*, 1993) although colonisation could have been successfully completed by on-sediment movement (Cadee *et al.*, 1994) (see Chapter 5).

The size of the impacted area is important in determining the rate of colonisation. Ruth *et al.* (1994) in Florida found using *in situ* microcosm tests that after six weeks 29 taxa had recolonised a variety of microcosm sizes. Only one bivalve was found in the largest microcosm size used. Taking into account the sample size used in this survey and the microcosm size used by Ruth *et al.*, it seems that *A. stutchburyi* are very numerous and mobile at Pine Harbour. Gastropods, although mobile, were not conspicuous recolonisers of the dumpground. Many of the gastropods found near Pine Harbour are scavenging carnivores, and their low abundances may have been due to lack of available food on the dumpground.

The polychaete infauna of the dumpground had initially large numbers of polychaetes in the order of 40-140 individuals per site. These numbers then declined in Run B. There was a peak in the number of individuals at all sites during Run E. This was due to increases in numbers of *Oriopsis limbata*, Maldanid sp. and *Notomastus zeylanicus*. Although not quantified, the large size of these animals suggests that the probable method of colonisation was post-settlement movement (see Smith & Brumsickle, 1989; Cummings *et al.*,1995).

Colonisation events by crustacean and miscellaneous taxa produced a change in species composition immediately post-dredging. There followed a stable period of six months. Run E stands out again and this is mainly due to an increase in *Macrophthalmes hirtipes* and cumacean sp. Site 1 during Run B appears to be less affected by the dredging and stabilised in infaunal composition earlier than the other two sites. This site was at the edge of the dumpground. Diversity rises steadily during the survey with respect to this taxon class suggesting that polychaetes of many taxa are competent post-larval colonisers.

3.6 CONCLUSIONS

A. A similar number of taxa were found at the Pine Harbour Marina area as other surveys in New Zealand and overseas. There are similarities in species composition between the Manukau Harbour and the Hauraki Gulf. Two thirds of the individuals found belonged to the 10 most abundant taxa.

B. There were generally quite stable species assemblages in the overall survey. Community composition did fluctuate but mainly at the dumpground transect. During Run E there appeared to be a general increase in species numbers, especially at the dumpground transect. This recruitment is likely to be post-settlement and larval recruitment as many of the organisms found were mature, but some found in the later surveys were small.

C. Mid tide and low tide sites had similar molluscan infaunal assemblages, which changed similarly through time. The high tide sites however were significantly different.

D. Overall, transects 2, 3 and 4 had similar community compositions, while transects 1 and 5 were also very similar, but different from the others.

E. At the dumpground the number of species and individuals declined post-dumping. However, not all taxa were affected, and much colonisation occurred within 6 months.

CHAPTER FOUR

SUBTIDAL SURVEY

4.1 INTRODUCTION

A subtidal survey of the area northwest of the entrance channel was carried out at Pine Harbour in an effort to ascertain species assemblages and distribution (Fig. 4.1). This survey was not done to assess effects of dredge spoil disposal. There has been more research carried out on intertidal communities than subtidal communities and this is probably due to the accessability of intertidal areas. Grange (1979) identified assemblages of subtidal fauna in the Manukau Harbour, categorised them by their community scores and related this to the prominent sediment type.

4.2 METHODOLOGY

Generally the same methods that were used in the intertidal sampling runs were used subtidally except that a diver-operated hand sampler was used with SCUBA gear. The hand sampler employed was considered better than a grab sampler for the survey as the depths were very shallow (6 m maximum depth) and accuracy is somewhat less when grab samplers are used. If the sediment texture is large or compacted sampler artifacts may also arise with such remote sampling techniques. Also the occurrence of a lot of shell material can hamper a grab sampler.

In March 1995 25 samples of 0.01 m^3 were taken from sites on a grid pattern positioned by differential GPS (Fig. 4.2). Transect A is the shoreward transect and transect E is the furthest offshore. The samples were placed in large plastic bags underwater, tied off and labelled. They were sieved over 1mm mesh onshore to remove sediment and the remaining organisms were fixed in a solution of approximately 10% formalin and rose bengal. The samples were transferred to water tight buckets for transport. All samples were sorted at the University of Waikato and identified to the lowest possible taxonomic level.

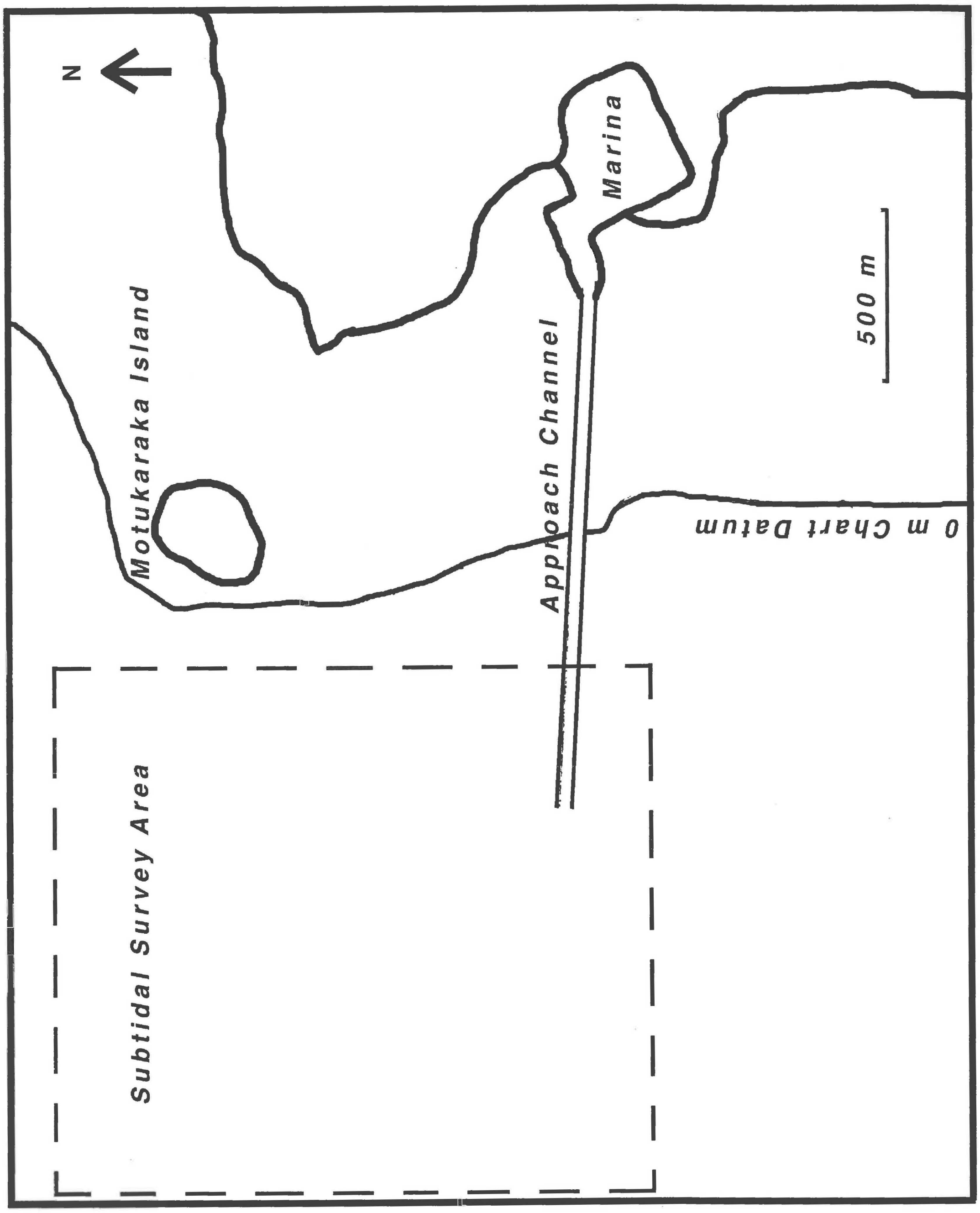


Figure 4.1 Location map of subtidal survey north-west of Pine Harbour Marina

Data were analysed using the methods outlined in chapter three. Spatial autocorrelation techniques were also used, to examine patchiness at the scale sampled. This technique tests whether the observed value of a variable at one locality is dependent on values of the variables at neighbouring localities (Sokal & Oden, 1978; Upton & Fingleton, 1985; McArdle & Blackwell, 1989). Analysis of sediments from some sites was carried out (Hull, 1996).

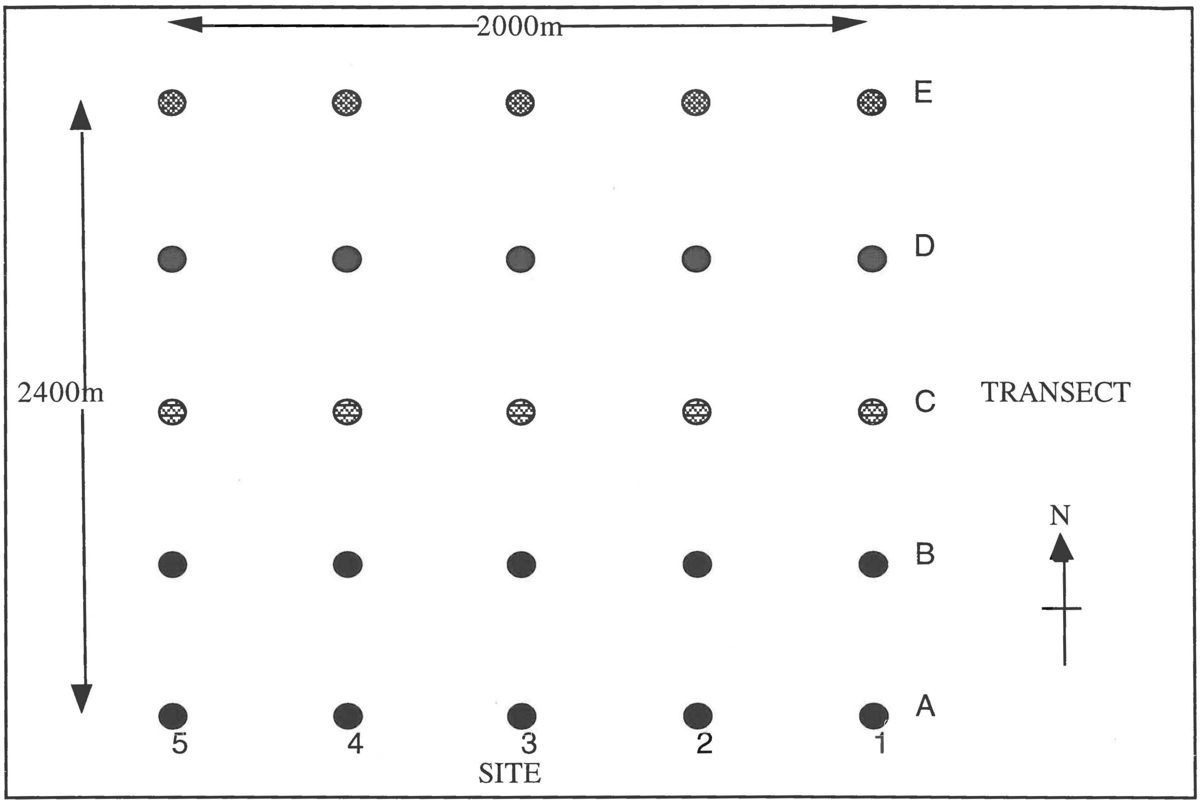


Figure 4.2 Subtidal sampling survey diagram illustrating the position of sites sampled. Motukaraka Is. is to the east of the diagram and Pine Harbour is to the south-east (see also Fig.4.1).

4.3 RESULTS

Forty-seven taxa were collected from the 25 sites surveyed, with an average of 14 species and 182 individuals at each site (Table 4.1). Species 1, *Theora lubrica* was by far the most abundant with over 3000 individuals (Fig. 4.3). Species 39, the amphipod *Urothoe* was the next most abundant taxon and the polychaetes *Cirratulus nuchalis* and *Cossura* sp. were also quite prominent in the survey. The amphipod *Urothoe* was dominant at site D1 with a total of 210 individuals. *Cirratulus nuchalis, Nephtys macroura* and *Cossura* sp. were often found together in similar numbers throughout the whole survey. The species diversity of the area was slightly higher at the inshore transects A, B and C (Fig. 4.4).

Table 4.1 Species List for the species found in the subtidal survey at Pine Harbour

Polychaetes
Ameana sp.
Armandia maculata
Asychis theodori
Cirratulus nuchalis
Cossura sp.
Glycera lamellipoda
Goniada sp.
Lepidasthenia sp.
Lumbrinereis brevicirra
Maldanid sp.
Nephtys sp.
Notomastus zeylanicus
Oriopsis limbata
Pectinaria australis
Podarke augustifrons
Prionospio pinnata
Scale worm
Syllid
Bivalves
Arthritica bifurca
Dosinia subrosea
Mactra ovata
Musculista senhousia
Nucula hartvigiana
Pleuromeris zealandica
Theora lubrica
Zenatia acinaces
Gastropods
Amalda australis
Xymene plebis
Crustaceans
Amphipod sp.1
Amphipod sp.2
Amphipod sp.3
Callianassa filholi
Cumacean
Isopod
Leptochelia savignii
Macropthalmes hertipes
Myodocopina sp.
Ostracod
Paraphoxus sp.
Pontophilus australis
Shrimp sp.
Urothoe sp.
Urothoides sp.
Nemerteans
Nemertean sp.1
Nemertean sp.2
Echinoderms
Ophiuroid sp.
Arachnoides zealandica

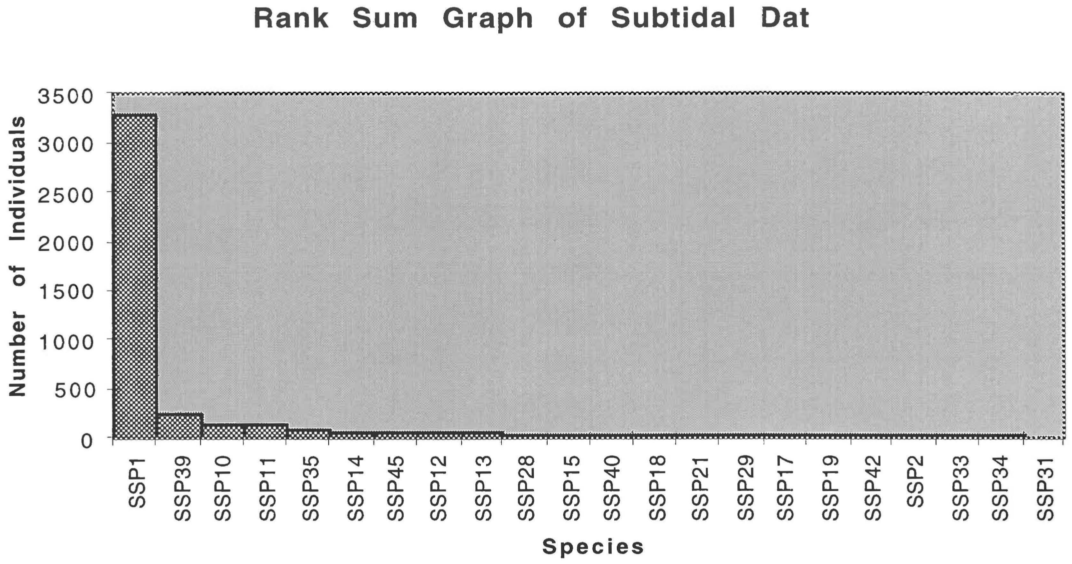


Figure 4.3 Rank sum graph illustrating the rank abundance of the species found in the subtidal survey adjacent to Pine Harbour

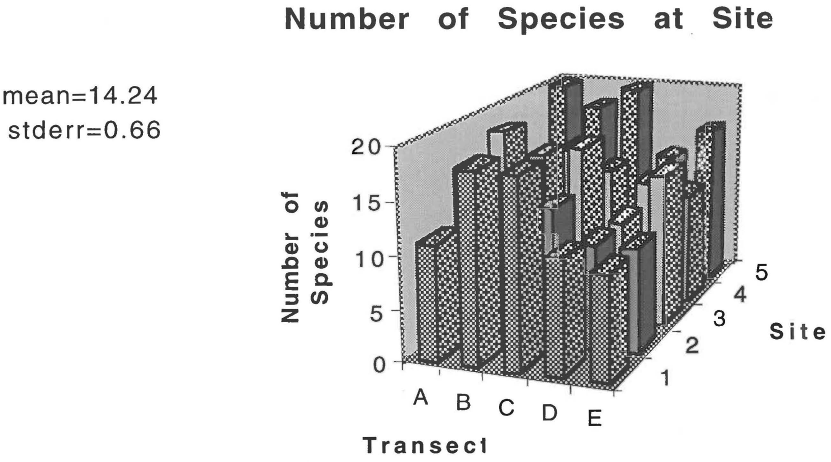


Figure 4.4 Number of Species found at the various sites sampled in the subtidal survey at Pine Harbour

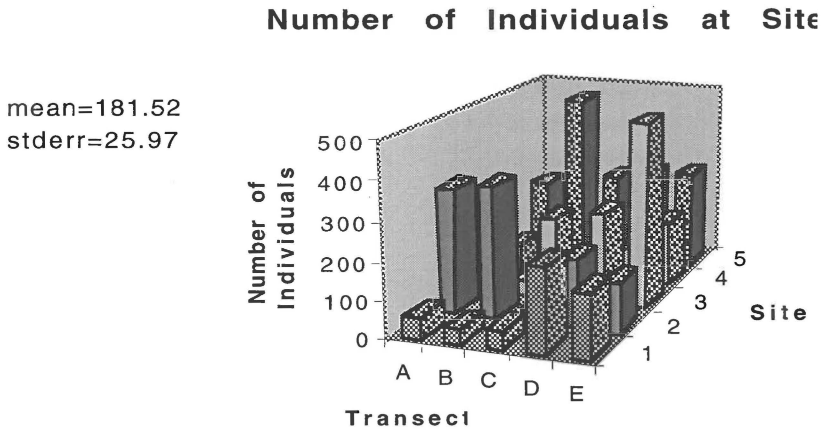


Figure 4.5 Number of Individuals found at the various sites sampled in the subtidal survey at Pine Harbour

Transects B and C have higher overall Berger-Parker index values than the other transects. This corresponds to low dominance. Site B1 has a very high index value. This corresponds to a very diverse species assemblage (Fig. 4.6).

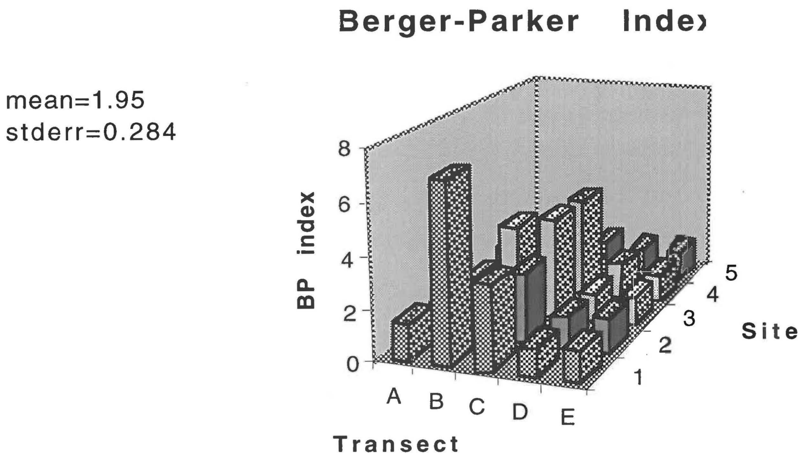


Figure 4.6 Berger-Parker Index for the species found at the various sites sampled in the subtidal survey at Pine Harbour

Species richness of the area changes in a onshore-offshore gradient (Fig. 4.7). Transects A, B and C have D_{mg} values above the mean value. However species richness decreases at transects D and E, shown by D_{mg} values below the average value.

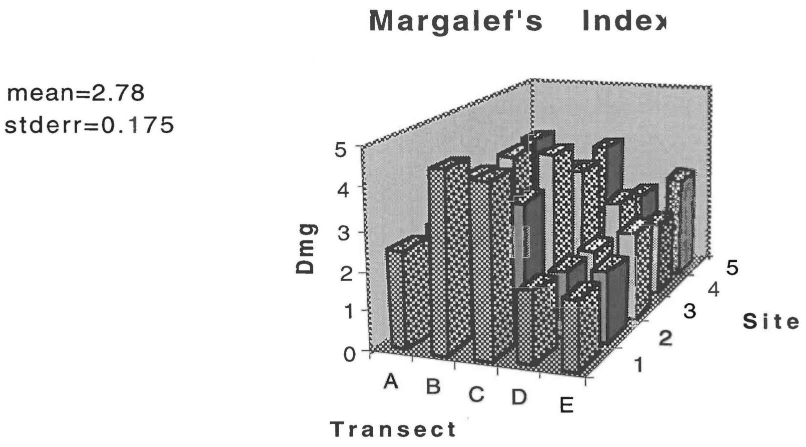


Figure 4.7 Graph of Margalef's Index for the species found at the various sites sampled in the subtidal survey at Pine Harbour

The spatial analysis of densities of *Theora lubrica* produced statistically non-significant values of Moran's I indicating a very patchy distribution at the scale in which the area was sampled.

Multidimensional Scaling identified 2 sites (A1 and D1) as being outliers (Fig. 4.8). These sites had low similarity value with all other sites. Site D1 was an outlier due to very low numbers and diversity of all species except the amphipod *Urothoe* (210 individuals). The site A1 also had high numbers of this species (39 individuals) and low numbers of other species.

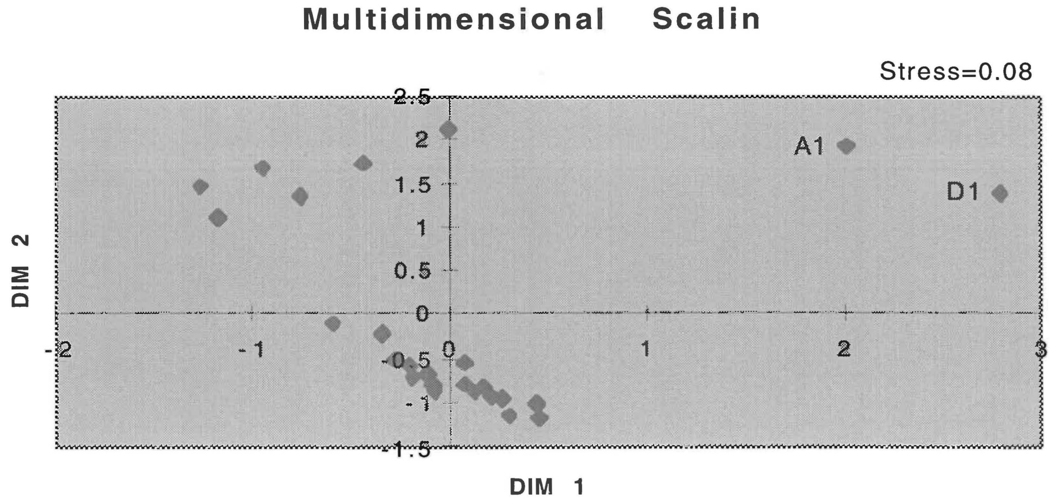


Figure 4.8 MDS for the various sites sampled in the subtidal survey at Pine Harbour

The numerically dominant species in the survey was *Theora lubrica* (Fig. 4.9). This bivalve was present in high numbers reaching densities of over 400 per 0.01m^3. Other abundant species were the polychaetes *Cirratulus nuchalis*, *Cossura* sp., *Lumbrinereis* and the scale worm sp. which were present in almost all of the samples (Table 4.1) The polychaete *Nephtys macroura* was also widely distributed as was the crab *Macrophthalmes hirtipes*.

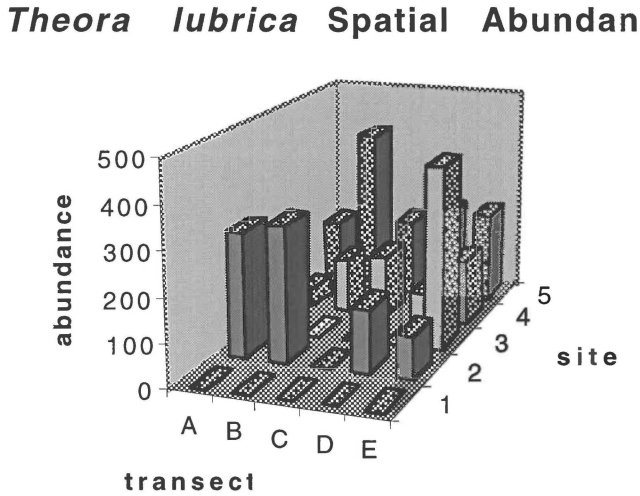


Figure 4.9 Spatial abundance of *Theora lubrica* in the subtidal survey at Pine Harbour

Sediment analysis of a select few sites was carried out and except for site D1, the general sediment composition of the area was of a ratio of **1:35:64** for gravel, sand and mud respectively. Site D1 had a higher sand ratio of **0:88:12**, whereas site D2 had a ratio of **0:10:90**.

4.4 DISCUSSION

No benthic data is available for the subtidal area adjacent to the marina although work has been done assessing the biota of the harbour channel. Bioresearches (1985) found that the area of the proposed marina channel below extreme low water spring tides was dominated by *Theora lubrica*. Other dominant species found in the Bioresearches work were the maldanid *Axiothella quadrimaculata* and the spionid *Boccardia polybranchia, Nephtys* *macroura* and *Goniada* sp. Dominant crustaceans were *Macrophthalmes hirtipes*, *Pagurus* sp. and *Pontophilus australis.* In 1993 Kingett-Mitchell Consultants surveyed the channel biota and found that bivalve mollusc density was low in the channel except for the bivalve *Theora lubrica.* Using a similar sized sampling device to that used in this survey, maximum abundances of 39 and 37 *Theora* in samples were found. Abundances of *Theora* found in samples taken in this survey are roughly 10 times those in the channel in 1993. This bivalve was first introduced into New Zealand from Japan in 1972 (Dromgoole & Foster, 1983). Other introduced bivalves *Musculista senhousia*, (Willan, 1985) and *Crassostrea gigas* (Dromgoole & Foster, 1983) occur near Pine Harbour. *C. gigas* and *T. lubrica* have also become established in California (Willan, 1985). The "export" of foreign species from New Zealand has also occurred. The gastropod *Philine auriformis* has been observed in the southern portion of San Francisco Bay since the summer of 1992, and is colonising other areas of this coastline (Gosliner, 1995).

Theora lubrica was very abundant at some sites, although absent at site one on all of the transects. Moran's I indicated a very patchy distribution of *Theora lubrica*. Site one, A to E were not characteristic in their depths as all were between 4 and 6 metres below mean low water. Thus water depth is not a driving factor in this distribution pattern. Sediment type, noted when the samples were taken, was significantly different at some of the sites of the survey. The abundance of *Urothoe* at site D1 may be correlated with the high proportion of sand at that site. Fenchel & Kolding (1979) state that amphipods of the genus *Gammarus* show zonation patterns which correlate with salinity, degree of exposure (low tides), depth and substrate. Levin (1994) recognises that the details of the relationship between patchiness and diversity are far from clear, but heterogeneity can contribute to diversity.

The diversity of the area showed general trends of becoming less diverse offshore. This may may be due to the change of depth, which is only slight, or a change in sediment type. Sediment type did not appear to change from a diver visual perspective but may have been varied enough in an onshore-offshore gradient to effect diversity. Rainer (1981) suggested that much spatial variation in subtidal estuarine benthic communities was due to physical factors such as sediment size and type and current speed. However, a recent review by Snelgrove & Butman (1994) points out that there is little evidence to support links between fauna and sediments. These physical factors in this survey are not constant over all the sites. Grange (1979) identified two communities dominated by two different species by their physical characteristics. Many of the taxa found by Grange are also found at Pine Harbour but widespread taxa such as *Owenia fusiformis* and *Amalda australis* in Manukau Harbour are infrequent subtidally at Pine Harbour.

The Berger-Parker Index shows that although *Theora lubrica* is in very high numbers it does not dominate the species assemblage at all sites. This is evident by the comparison of the *Theora lubrica* graph with the Berger-Parker Index graph. At transect E, the Berger-Parker index is close to one at all of the sites and yet the abundance of *Theora* varies from zero to over 400. Thus it seems that if *Theora* is not present, another species dominates the community.

Again the same onshore offshore pattern is noticed in Margalef's species richness index. Transect D and E further off-shore in the survey are generally below the mean index value. This again may be associated with an increased water depth or a change in sediment type.

4.4 CONCLUSIONS

The subtidal benthic infaunal community to the west of Motukaraka Island varies slightly in species assemblage in an on-shore off-shore direction with species diversity higher closer to shore. The bivalve *Theora lubrica* is very abundant and very patchily distributed.

CHAPTER FIVE

BEHAVIOUR OF THE COMMON COCKLE *AUSTROVENUS STUTCHBURYI*

5.1 INTRODUCTION

The physical effects of dredging involve the smothering of individuals and relocation of biota. For the fauna to return to its original state either the benthic organisms must make their way to the surface or the sediment can be colonised by immigration. This immigration can be by either pre- or post settlement methods. These modes of recolonisation are species-specific and often more mobile species are better suited to recolonising the dumpground (Maurer *et al.,* 1980). Infaunal organisms need maintain contact with the surface in order to feed and respire. An alternative anaerobic metabolism is available when in a hypoxic environmental situation (Carroll & Wells, 1995). Where conditions exist leaving cockles exposed on the surface of the sediment, mechanisms enabling reburial are needed to avoid predation by birds, fish or whelks.

Trueman & Ansell (1969) describe the process by which a bivalve completes a digging cycle. Firstly the foot makes a probe downward and this usually raises the shell. Secondly the siphons close preventing water passing out at adduction. The foot continues to maximum pedal extension. Thirdly rapid adduction of the valves causes water to be ejected from the mantle cavity through the pedal gape increasing pressure in the haemocoele causing maximum dilation in the foot. Fourthly the contraction of the anterior and posterior muscles results in the shell being pulled into the sand. Cockles feed and respire through two siphons which are extended when the two adductor muscles are relaxed and the valves are parted. Around high tide up to 3 litres of water and food can be processed per hour by an individual (Belton, 1984).

This experiment was designed to investigate the abilities of cockles (*Austrovenus stutchburyi*) to make their way back to the surface. Cockles were the focus of this study as they are a food source and are often taken by humans. *Austrovenus stutchburyi* are seldom buried more than 10-20 mm below the sediment surface and are limited by short siphons (Belton, 1984). Thus this type of bivalve is very susceptible to the impacts of dredge spoil.They were the most abundant taxon in the survey (see Chapter 3) and are amenable to laboratory manipulation. The experiment was in two parts; the first investigated the ability of cockles to rebury when placed on the sediment surface, while the second investigated the depth of sediment through which cockles could migrate to regain contact with the surface. These experiments were carried out in late 1995.

5.2 EXPERIMENTAL METHODOLOGY

5.2.1 Experiment One : Reburial

Austrovenus stutchburyi were collected from the north side of Pine Harbour from around the half tide level and brought back to the University of Waikato. They were then placed in a salt water tank with a layer of native sediment collected fron the same place and left to acclimatise. Twenty-seven, 2 *l* plastic containers were set up with salt water circulating through them and a layer of approximately 4 cm of sediment was placed in each container. This sediment had been collected from the marina and had been sieved over 2 mm mesh to ensure all cockles bigger than 2 mm were removed. In each of nine of the containers 10 cockles were placed upright with the anterior end uppermost. Thirty of these 90 cockles were less than 15 mm across, thirty were 15-20mm and thirty were 20-25mm. This made three replicate containers for each size class. The same procedure was carried out for cockles positioned on their sides and upside down with siphons buried in the sediment. The experimental design was thus 2 factor (size and orientation) orthogonal, with 3 replicate containers for each combination of cockle size and orientation (Plate 5.1).

For the first hour observations were made of the number of cockles buried every 15 minutes, then for the next three and a half hours, every half hour. A final observation was made 14 and a half hours after the beginning of the experiment. Cockles were taken to be buried if more than three quarters of the animal was submerged in the sediment. This was taken to be a natural position as in the field large numbers of cockles were observed only partially buried.

5.2.2 Experiment Two : Resurfacing

Cockles for this experiment were collected from Raglan Harbour and brought back to the University. These cockles were then left in a tank with circulated salt water for three days to acclimatise. Six, 2 litre containers were filled with 4 cm of sediment and 10, 25-35 mm cockles were buried in a natural position in each container. In three of the containers 5 cm of sediment was added and in the other three containers 10 cm of sediment was added. Every hour the containers were inspected for evidence of siphons indicating the presence of cockles at the surface of the sediment. A last destructive inspection was done 29 hours after the start of the experiment as it was noted that cockles at the surface do not always begin filtering and thus their siphons might not show.

Plate 5.1 Experimental setup for the reburial experiment showing containers and circulation system

5.3 RESULTS

5.3.1 Experiment One : Reburial

Effects of Orientation

After the first hour 2 or 3 individuals of the 15 mm size class in each treatment had retreated into the sediment irrespective of orientation. After 1 hour fewer cockles placed in a normal orientation were buried than those on their sides or upside down, a pattern which continued throughout the experiment (Fig 5.1). After 14.5 hours nearly all of the cockles had retreated into the sediment.

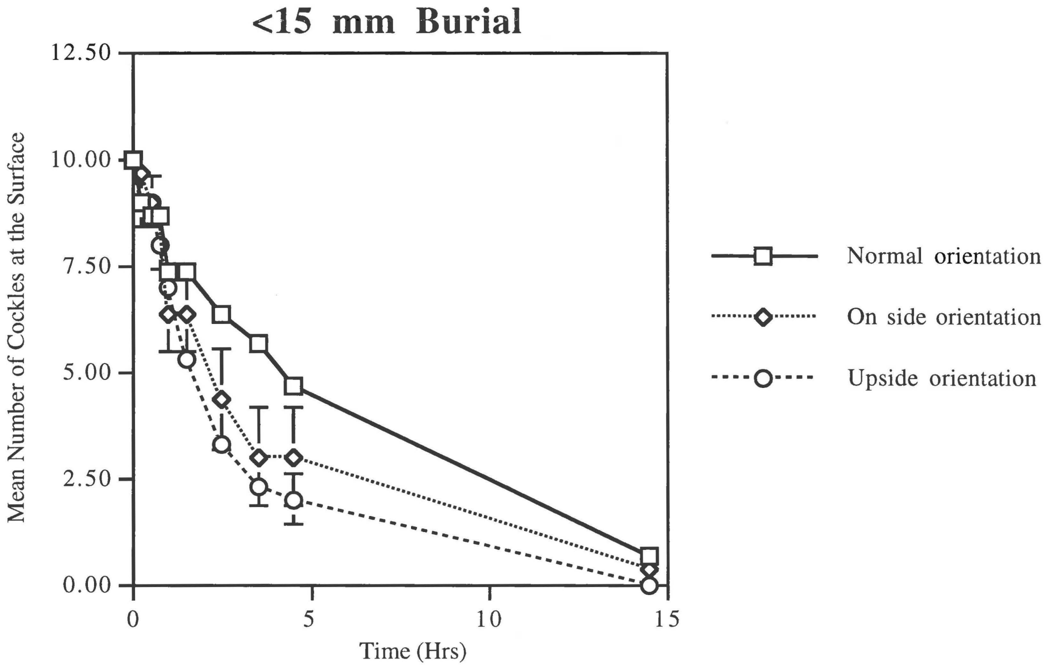


Figure 5.1 Number of <15 mm Cockles at the Sediment Surface Over Time

For the 15-20 mm size class (Fig. 5.2), the three orientations all followed the same trend although there was large variation between replicates as can be seen by the size of the error bars. Almost all individuals buried into the sediment by 14.5 hours. There was no clear difference between orientations.

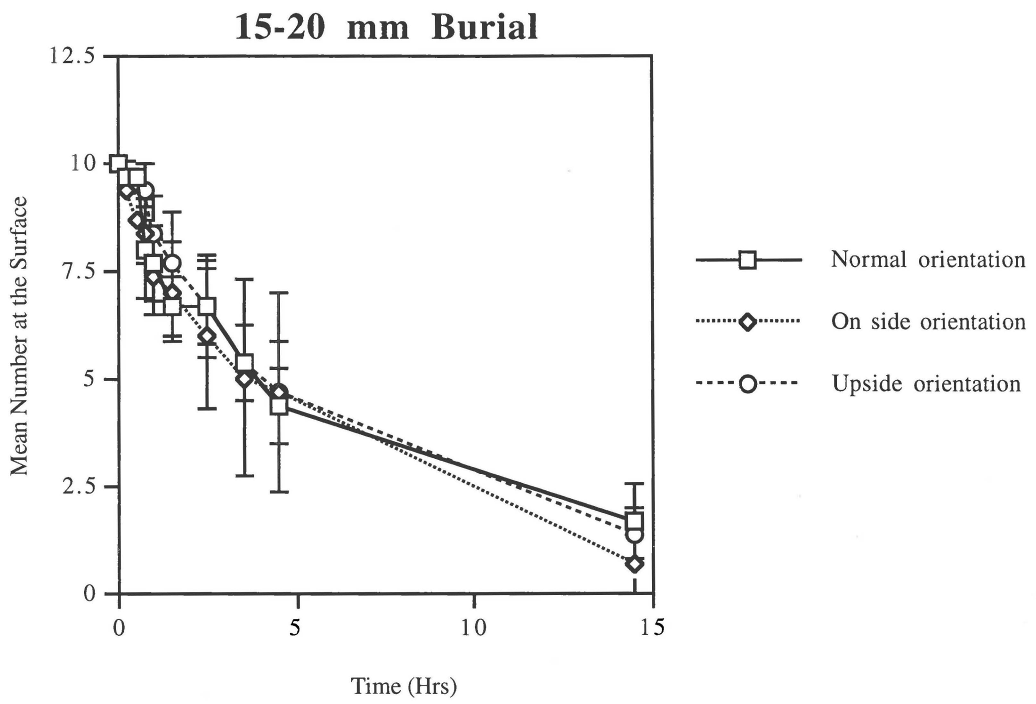


Figure 5.2 Number of 15-20 mm Cockles at the Sediment Surface Over Time

The 20-25 mm size class buried more slowly than the other 2 size classes (Fig. 5.3) and did not have the same completeness of burial, with a mean of 5 individuals left on the surface when placed in a natural position.

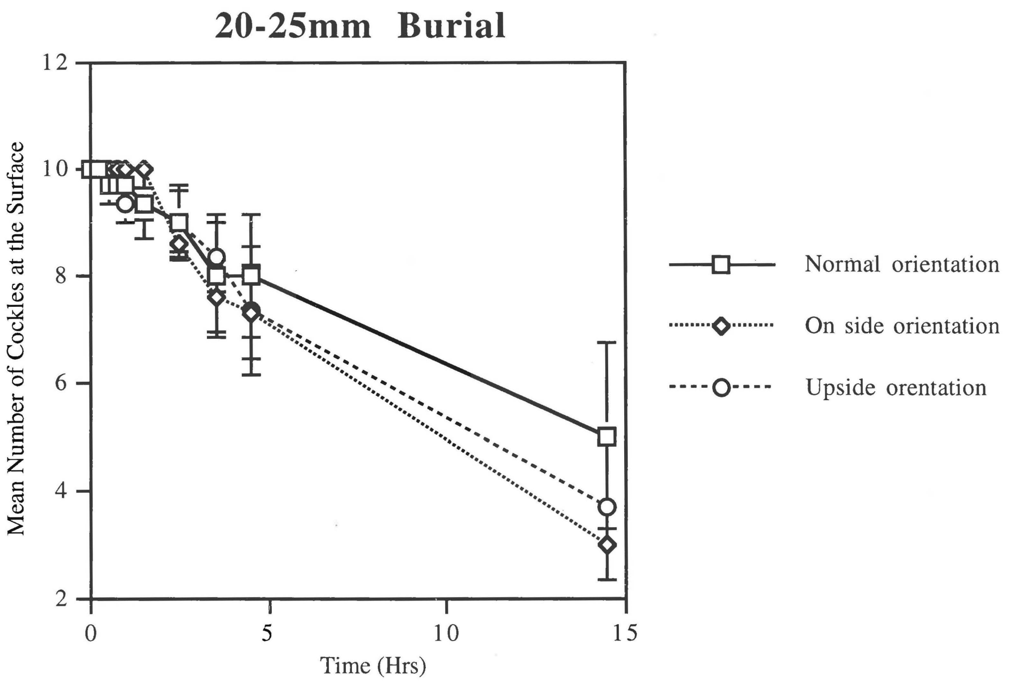


Figure 5.3 Number of 20-25 mm Cockles at the Sediment Surface Over Time

Effects of Size

Smaller cockles buried faster than large ones in all orientations. When placed in an upside-down orientation cockles less than 15 mm across buried rapidly and were all completely buried after 14.5 hours (Fig. 5.4).The proportion of 20-25 mm cockles buried at any time was roughly half that of the <15 mm cockles.

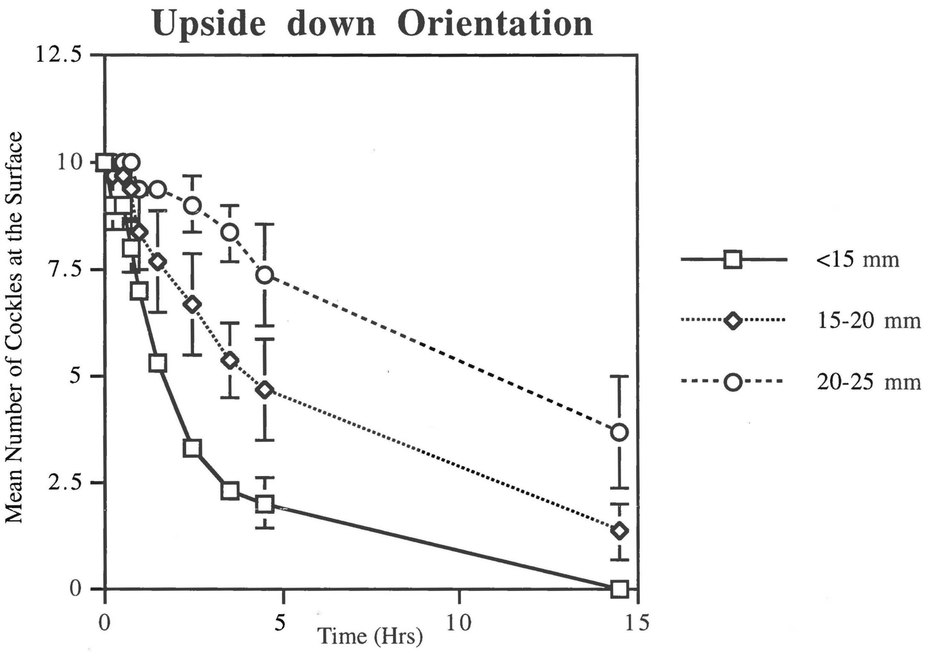


Figure 5.4 Number of Cockles of Differing Sizes at the Surface over Time

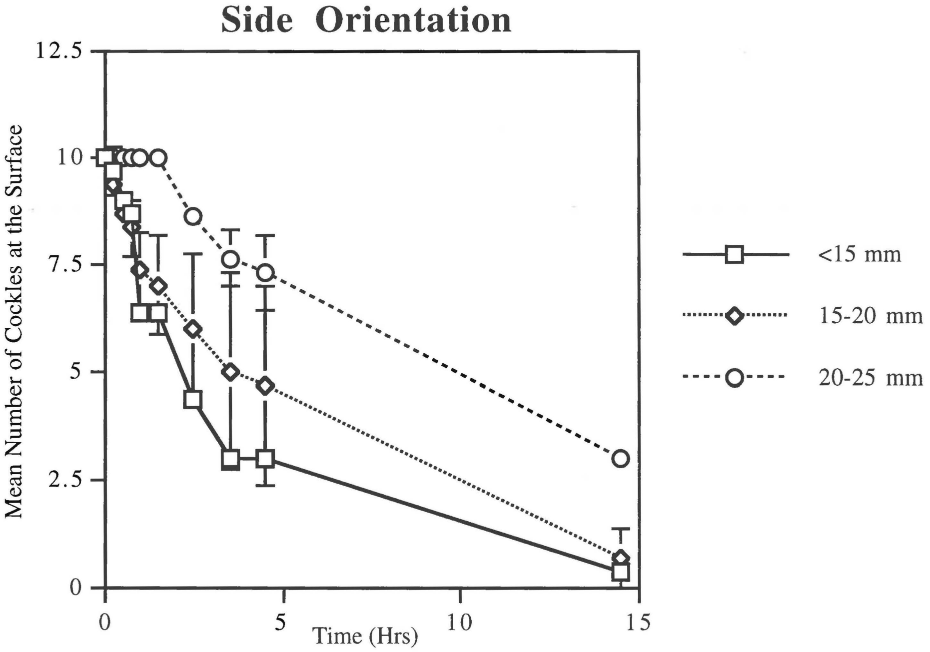


Figure 5.5 Number of Cockles of Differing Sizes at the Surface over Time

When cockles were placed in a natural position (Fig 5.5) the smaller two size classes acted in a similar manner with half of the numbers in the treatments burying by 5 hours, but the larger cockles remained on the surface and many individuals started filter-feeding.

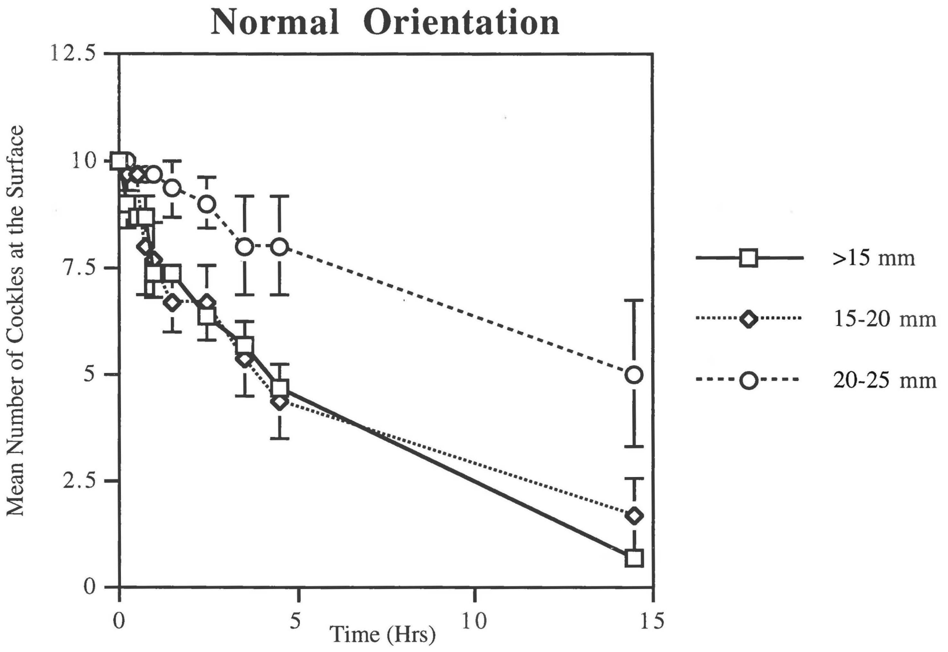


Figure 5.6 Number of Cockles of Differing Sizes at the Surface over Time

5.3.2. Experiment Two

This experiment investigated the ability of cockles to move upwards through sediment. More cockles resurfaced more quickly when buried under 5 cm than under 10 cm of sediment (Fig. 5.7). When destructively sampled after 29 hours a mean of 8.55 and 5.78 cockles were at the surface in 5 and 10 cm burial depths respectively (Fig. 5.8).

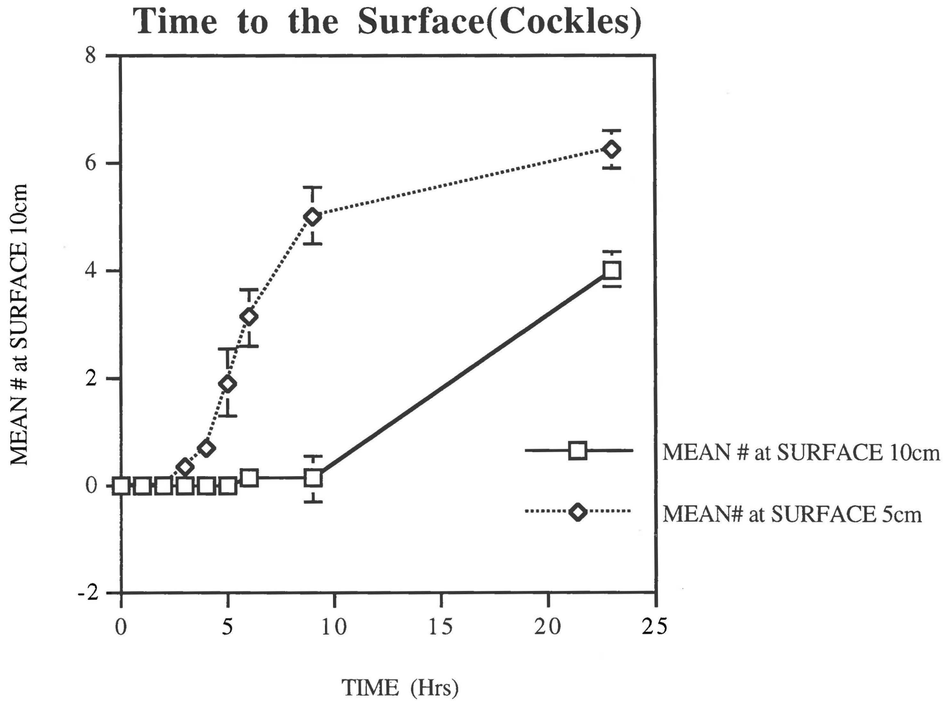


Figure 5.7 Time Taken for Cockles to Reach the Surface of the Sediment

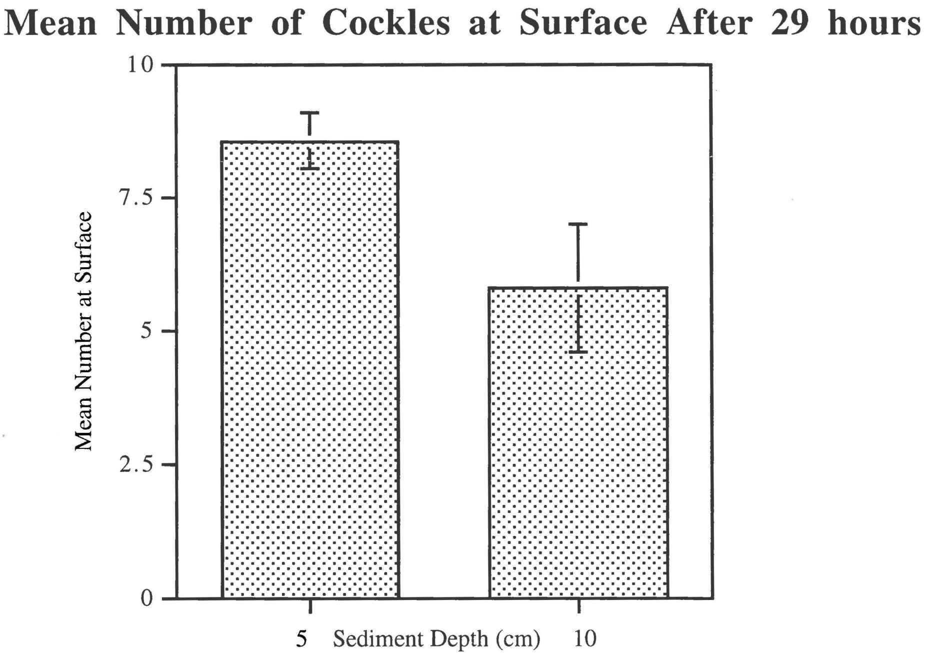


Figure 5.8 Number of Cockles at the Surface After Destructive Sampling

5.4 DISCUSSION

Cockles of smaller sizes were more mobile than larger ones. This seemed to be of a progressive nature with the 15-20 mm size class producing results between those of the smaller and larger size classes. Creese (1988) found that in *Paphies australis* (Pipi) the smaller individuals were more mobile than larger ones and more of them successfully reburied themselves. Most animals in his treatments had buried in 12 hours. However *P. australis* placed in an upside-down position, did not have the reburial capabilities that cockles have. Creese (1988) noted that larger animals died in the upside-down treatment although some smaller individuals did manage to bury in 1-2 weeks. This is probably due to the physiology and shape of the animal. Pipis placed upside down may not be able to locate their foot in the sediment. In this experiment the large cockles (20-25 mm) when placed in an upright position did not bury rapidly and a majority of them actually started feeding, with only about a quarter of their shells buried. Occasionally in the field at Pine Harbour large cockles were seen almost fully exposed.

Smaller cockles were very mobile. Before burial, many of the cockles travelled up to 30 cm horizontally often knocking other less active cockles out of the way in the process. This method of post larval transport could result in smaller cockles moving in the order of metres in a week and is evident in the field as 'tracks' seen at low tide. Pressures causing this movement may be crowding or physical factors such as salinity, temperature or sediment characteristics. It could be that they naturally roam.

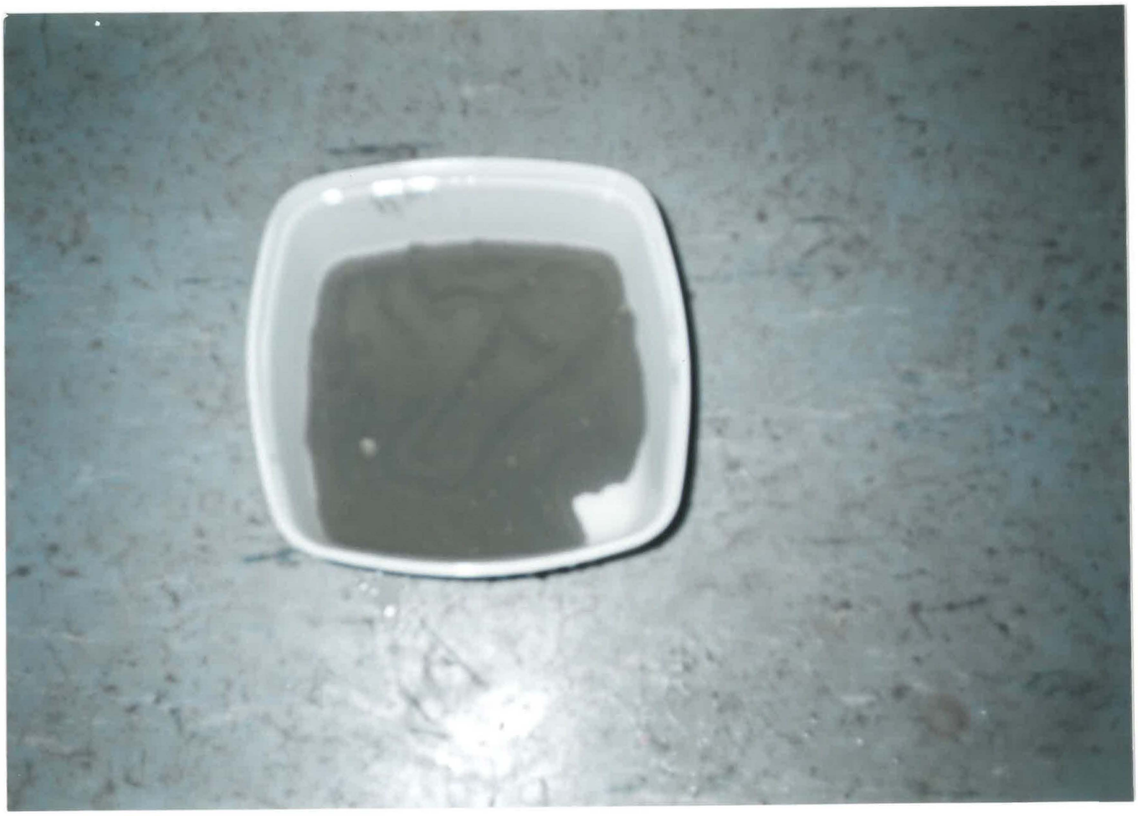


Plate 5.2 Cockle "tracks" from movement on the surface prior to burial

McLachlan (1995) related speed of burial to shell shape and ornamentation in that the slowest burrowers were characterised by rounded shapes and the fastest by flattened shapes. This view is supported by Carroll & Wells' (1995) research which found that *Austrovenus* was a slower burrower than both *P. australis* and *P. subtriangulatum.* However this burrowing speed was also directly related to foot muscle size, which also seems to be an important factor in determining burial and burrowing speeds. Ease of penetration depends on the manner in which penetration force is applied. Brown & Trueman (1991) recognise that sudden pressure (of the foot) causes an increase in interstitial pore volume and drawing in of water resulting in increased resistance to penetration. Thus many bivalve molluscs begin burrowing with rapid probing of the substratum. Some cockles in this experiment were seen to do this.

Chang & Levings (1978) studied the heart cockle *Clinocardium nuttallii.* They used very large individuals for their experiments (50-70 mm) and buried them under 0.1-20 cm of sediment. The heart cockle resurfaced more rapidly after superficial burial. These results are quite similar to the present study even though a different taxon is used and size is different.

Although not tested, it is possible that the recovery rate of cockles buried under 20 cm of sediment would not be very high. Maurer *et al.* (1995) speculates that greater pressures created by the weight of the sediment might prevent bivalves from opening their shells. Pore water pressures and overburden pressure would be much higher at 20 cm depth than at 5 cm depth. Selby (1993) states that overburden pressure at any given point in a saturated sediment is a result of total vertical pressure exerted by all of the particles and water above the point, minus the pore water pressure; thus it stands to reason that at some depth pressure will be too great to resurface.

The burrowing activity of a species will depend not only on the physical characteristics but also on the health of the individuals involved. At certain times of the year, perhaps due to temperature and food availability, bivalves may be in a better state to burrow through dredge spoil. Carroll & Wells (1995) state that burrowing of *Austrovenus* in hypoxic environmental conditions is supported by anaerobic energy production. This may be when a cockle is buried or when it is exposed during low tide. Cockles are more efficient at this anaerobic metabolism than other surf clams from higher energy environments. This probably correlates with having to withstand extended periods of hypoxia due to emersion.

5.5 CONCLUSIONS

Due to the dredge used in the Pine Harbour dredging removing spoil in the order of cubic metres with each movement, it seems unlikely that *in situ* cockles could survive the spoil dumping. However post larval recolonisation methods for this species are quite rapid. Cockles left on the surface through dredging would most likely be fully buried after 2 tidal cycles.

Elevated levels of turbidity caused by dredging would cause a fine layer of settling sediment. This may have some impact on the cockles adjacent to the dumpground. Also the spread of sediment from the dumpground could have an effect although this spread was at a rate far slower than the surfacing abilities of the cockles. Thus cockles over most of the beach adjacent to the spoil mound could easily cope with the inundation rates.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

6.1 BROADSCALE BENTHIC ECOLOGICAL SURVEY

The Pine Harbour Marina intertidal area has a species assemblage similar to that of other low-energy intertidal areas in New Zealand. The area had a diverse range of species but was dominated by a small number of taxa. Sixty-six percent of the individuals found belonged to the 10 most abundant taxa.

Species assemblages were quite stable at each site although the fauna of the dumpground showed a conspicuous fluctuation. Recruitment processes were seen to be in effect on the intertidal area near Pine Harbour. These were both pre-settlement and post-metamorphic processes. The dumpground was rapidly recolonised.

Species assemblage of molluscs were similar at mid and low tide levels, but high tide levels were distinct.

Variation between transects was quite prominent. Transect 2, 3 and 4 had similar assemblage compositions. Transects 1 and 5 were also similar to each other in species assemblage, while transect 6 showed slightly different species assemblages than the other transects.

6.2 DUMPGROUND SURVEY

Dumpground sites exhibited decreases and in some cases, increases in number of species and individuals immediately after dredging. This was dependent upon site and taxal grouping. Some species were more heavily impacted than others. Numerical recovery occurred within six months after the dredging. By run E, the dumpground supported a greater densitiy of individuals than pre-dredging.

6.3 SUBTIDAL SURVEY

The subtidal area to the west of Motukaraka I. is dominated by the infaunal bivalve *Theora lubrica* which exibited a very patchy distribution. The species assemblage was diverse and changed in an onshore-offshore direction, with species diversity increasing closer to shore.

6.4 BEHAVIOUR OF *AUSTROVENUS STUTCHBURYI*

Smaller cockles were more mobile than larger ones. They were able to rebury and make their way to the sediment surface if buried. This depended on the depth of sediment they were buried under. The maximum depth of burial at any size for low levels of mortality would be not more than 15-20 cm. Depths above this would produce mortalities reaching 100%. Cockles that are placed on the surface by the dredging activity would most likely bury within two tidal cycles irrelevant of orientation.

6.5 RECOMMENDATIONS

The dumping of sediment intertidally at Pine Harbour Marina does have an impact the environment, but this impact on the marine biota of the area is negligible. As a disposal option, dumping intertidally is appropriate in terms of minimal impact on the environment and cost. However, due to unfavourable sediment transport conditions leading to further sedimentation of the channel, the main objective of the dredging has not been sufficiently met. Therefore this form of disposal would only be efficient in these circumstances if the spoil was placed far enough away to ensure that it does not reach the channel.

The next most cost-efficient method is offshore disposal. Kingett-Mitchell (1993) initially proposed six disposal options. After side-casting with a backhoe, the next two cheapest disposal options were offshore. However these offshore methods are roughly three times the total cost per m^3 removed. Biological monitoring has been done on the North Rangitoto dump site (which is a possible option) and it was found that historical disposal on this site had limited impacts. This method of disposal although slower and more expensive, does have the advantages that dredged sediment would not re-enter the channel.

6.6 SUGGESTIONS FOR ADDITIONAL WORK

Further monitoring surveys of the biota may need to be carried out depending on the eventual spoil disposal option chosen. If further intertidal dumping is decided upon, this work should incorporate the information gathered in this thesis to help ascertain possible impacts. The dumping intertidally of dredge spoil is less frequent than subtidal dumping. This makes analysis of impact more accessible. No diving or remote sampling techniques are needed.

Additional research could be done on the behavioural ecology of the cockle. Shore height transplantation experiments could compliment the work already carried out by Dobbinson *et al.* (1989). Other experiments on the abilities of cockles to reach the surface at extreme depths of burial could be investigated. Interesting work could be done quantifying post-larval movement of cockles, in the water column and over the sediment surface. This could be then related to spatial distribution and size/frequency analysis at various shore heights. Basic observational experiments could be carried out on the behavioural characteristics of the bivalves of the region. These experiments would involve putting the bivalves through various tests of burial and surfacing and noting any patterns.

Further research could be carried out on the ecology of the introduced species of the area, especially the bivalves. The proximity of Pine Harbour to the major trade route in and out of the Ports of Auckland makes it a likely candidate for introduced species, and their spread.

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