Marine ecology of Akaroa Harbour: rocky shores and subtidal soft bottoms

NIWA Client Report: CHC2004-056
May 2004

NIWA Project: ENC04511

Marine ecology of Akaroa Harbour: rocky shores and subtidal soft bottoms

Graham D. Fenwick

Prepared for

Environment Canterbury

NIWA Client Report: CHC2004-056
May 2004

NIWA Project: ENC04511

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street, Riccarton, Christchurch
P O Box 8602, Christchurch, New Zealand
Phone +64-3-348 8987, Fax +64-3-348 5548
www.niwa.co.nz

Contents

Reviewed by: *Approved for release by:*

Paul Sagar Alex Ross

Executive Summary

Baseline data and an assessment of the present ecological state of the marine environment of Akaroa Harbour are presented as a basis for resource management decisions facing Environment Canterbury.

Intertidal biota on rocky shores were surveyed using point analyses of five replicate photoquadrats at each of two shore levels along paired transects at each of three sites along the harbour's western side. Subtidal, soft-bottom benthos was surveyed by sampling six stations along the harbour's mid line, as well as four inshore stations. Three replicate samples from each station, sieved on 0.5 mm mesh, were analysed for fauna. Samples of sediment from each station were analysed for particle size composition, organic content, total nitrogen and total phosphorus, as well as for seven trace metals. Data analyses explored abiotic and biotic patterns and relationships between them.

Two species of barnacles dominated the mid and low shore biota at the exposed, outer harbour Lucas bay site, with more species present low on the shore compared with mid shore levels. At intermediate and low exposures (Cape Three Points and Tikao Bay), barnacles dominated mid shore levels, but several species co-dominated lower on the shore. Overall, communities were more diverse and dominance was less at low shore levels and at higher exposures. Low shore biotas at the most exposed and most sheltered sites were most distinctive from each other and from those on other shores. Mid shore biota at the exposed site also was quite distinctive, but there was little difference between biotas on intermediate and sheltered shores.

Subtidal sediments decreased in mud content from shallower, inner harbour stations to the deeper, outer harbour where silts and fine sands dominated. Sediment organic content, total nitrogen and zinc content varied with mud content, and there was obvious pattern to concentrations of trace metals. Thus, stations were most similar to their nearest pairing in terms of distance along the harbour and, presumably, exposure to wave and current action.

Subtidal benthic biota comprised 136 species. One third were present in just one or two of the 30 samples, and 25% were present in 10 or more of the samples. Numbers of species present increased consistently along the harbour mid line towards the open sea, but benthos diversity at inshore stations varied. Diversity of the main faunal groups was fairly consistent between stations. Mean faunal densities also increased to seaward as gastropods decreased in relative contribution whilst polychaetes, crustaceans and bivalves increased.

Faunistically, inner harbour stations were very similar to each other, but dissimilar to outer harbour stations. The biotas at outer harbour inshore stations were more similar to each other than to their respective mid harbour partners. Species differed appreciably in their individual quantitative distributions, although some general distribution patterns were apparent. Benthos distribution patterns were strongly correlated with sediment organic content, water depth and zinc or copper content.

Patterns of intertidal biota distributions appear largely controlled by exposure to wave action, although shading is probably important at Tikao Bay. The biota in Akaroa Harbour comprised species that are widely distributed around Banks Peninsula and elsewhere along the east coast of South Island. Overall, there is no evidence of human impacts on the intertidal biotas at the sites surveyed.

The subtidal soft bottom fauna of Akaroa Harbour consisted of species that are more widely distributed in the region and around New Zealand. Faunal density and diversity also were similar to those elsewhere around Banks Peninsula and in the region generally. There was no evidence of any human impacts on this benthos, but historical data and adequate control stations were lacking. Changes in the fauna along the harbour were strongly correlated with water depth and sediment characteristics. The gradual transition in the fauna along a gradient of increasing wave exposure and depth appears typical of any inshore coastal habitat, although such patterns appear poorly documented.

1. Introduction

Akaroa Harbour is a long narrow inlet formed by collapse of the seaward margin of the southern most crater of the caldera volcanoes comprising Banks Peninsula. Oriented SSE, the outer harbour is c. 1.8 km wide at its heads. Some 5 km inland, its orientation changes to N-S and it widens variously with several large embayments. Water depths range from 30 m just beyond the heads to 15 m at the curve and thence steadily to intertidal mudflats in bays some 17 km from the heads. Thus, although the heads are exposed to the full force of storm waves approaching from southerly quarters, and swells from these penetrate at least a third of the way into the harbour, the inner half of the harbour is very sheltered, with wide mudflats between steep rocky headlands. Shores along the length of the harbour grade from soft, gently sloping muds landward to vertical unbroken bedrock to seaward.

The harbour is important for several reasons and possesses considerable natural values. Maori inhabited the harbour in the past and it remains a valued area today for historical reasons and for continuation of many traditional practices, including food gathering. Today, recreation and tourism are major activities around and on the harbour. Akaroa, the major community, is the centre of this tourism activity, providing extensive accommodation, and passive and active pursuits. It is also the location of numerous holiday homes for Christchurch and Canterbury residents. Fishing continues as an important commercial activity, notably for crayfish, but finfishing is focussed more on the tourism market nowadays. Aquaculture of paua for food and pearls and of salmon are important commercial activities for the area.

Human pressures on the harbour are considerable, although not obvious. Settlements on the harbour fringes include Akaroa village, Takamatua, Duvauchelle and Wainui. Residents total some 600 people, but these communities are dominated by holiday homes and tourist accommodation, so that the effective population inhabiting the area is considerably larger. Sewage and wastewater from these communities is variously treated, but ultimately enters the harbour.

Industry in the area is quite varied and adds to human impacts. The large, steep catchment area surrounding the harbour is farmed with artificial fertilizers applied periodically to pastures. Run off from this activity almost certainly contributes to pressures in terms of sediment and nutrients. Marine farming within the harbour is another potential source of nutrients. Salmon farming, in particular, results in appreciable nett additions of nutrients to the marine ecosystem. However, inputs from these sources have been neither quantified nor evaluated relative to inputs from the open sea. There is some indication that nutrients from massive freshwater inflows into the Canterbury Bight, notably from the Rakaia River, Lake Ellesmere and perhaps Canterbury's very large aquifer system, may have significant effects on coastal and harbour planktonic ecosystems, including stimulation of nuisance phytoplankton blooms (Fenwick & Image 2002).

Given these pressures and the harbour's high human values, Environment Canterbury requested a baseline investigation of marine communities within the harbour. This report outlines quantitative surveys of rocky intertidal shores and of subtidal soft bottoms.

2. Methods

2.1. Intertidal rocky shores

Intertidal sites were surveyed during low tides on 30 October and 25 November 2003. The biota inhabiting intertidal rocky shores was surveyed at low and mid tide levels along two transects at each of three sites (Fig. 1). Five replicate 0.25 x 0.25 m quadrats were photographed at each level on each transect. Species present within quadrats and found during free searches at each site were recorded to develop general descriptions of the biota at each site and to facilitate identification of taxa within photoquadrats. In the laboratory, percentage cover by each taxon was estimated by superimposing an 8 x 8 grid over each quadrat and recording the species present at each intersection (e.g., Meese and Tomich 1992). The resulting data were consolidated into a database and analysed to identify patterns and similarities between sites.

2.2. Subtidal soft bottoms

Three replicate samples were taken from 10 stations (Fig. 1) over 29-31 October 2003 using an anchor-box dredge (area sampled = 0.06 m^2) to sample to 100 mm sediment depth. Six of these stations (Stations 1-6) comprised an array along the harbour's midline from inner to outer harbour. Another three (Stations 7-9) were adjacent to the shore opposite Stations 4-6 respectively, whilst Station 10 was located within French (Akaroa) Bay (Fig. 1). Pre-determined sampling stations were located using GPS and all replicates were taken within c. 100 m of these. The volume of mud within each dredge sample was recorded before sieving the entire contents to recover all animals retained on 0.5 mm mesh. All retained material from each station was placed in a separate labelled container and preserved in 5% formalin-seawater for subsequent processing. In the laboratory, each sample was gently washed to remove as much mud as possible and all animals separated before identification and counting. Identifications were made to family, genus or species level, as far as practical within the time available. Numbers of each identified taxon were counted and these counts were standardised to numbers per m^2 prior to analysis.

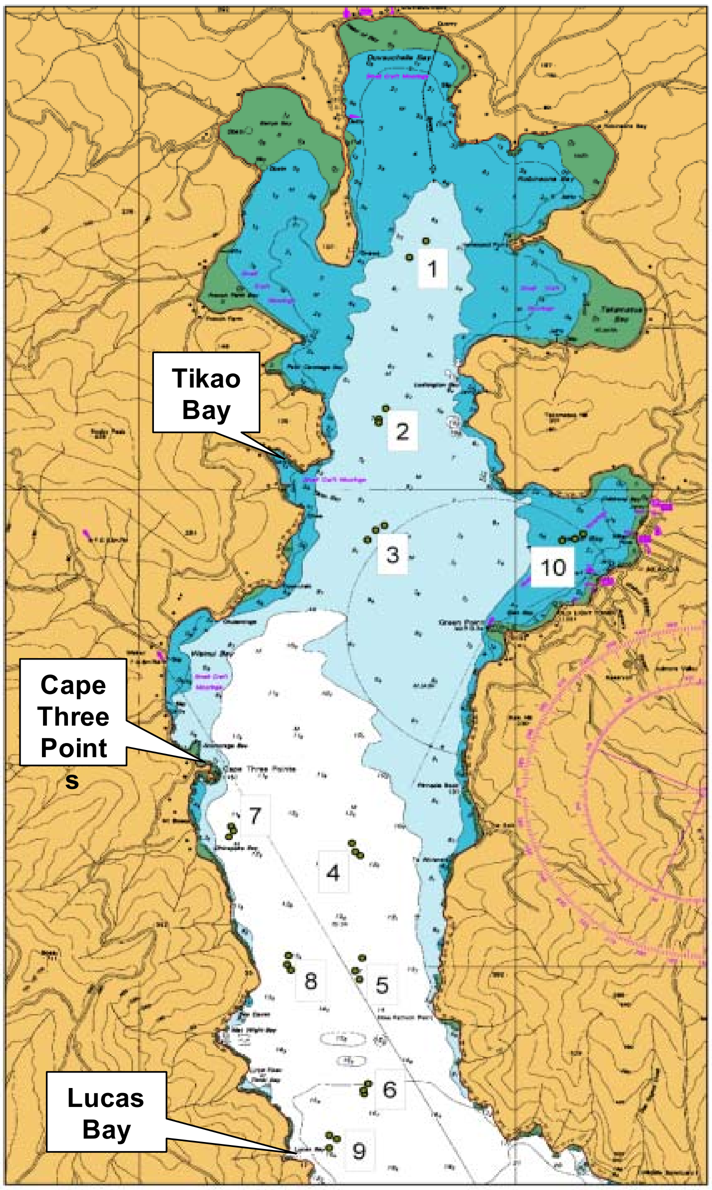


Figure 1: Location of intertidal transect sites and subtidal sampling stations (including replicates) in Akaroa Harbour (green, 0-0.5 m depth; blue, 0.6-5.0 m; light blue, 5.1-10.0 m depth) (from LINZ Hydrographic Chart NZ6324).

Three sub samples of unwashed mud were taken from all stations for sediment analyses. These analyses determined sediment particle size composition, sorting (Department of Geography, University of Canterbury), sediment organic content by loss on ignition (LOI) (500°C for four hours) (NIWA, Christchurch) and metal content for selected trace metals (ECan laboratory).

2.3. Statistical analyses

Biological data for both intertidal and subtidal surveys were analysed similarly. Each biological data set comprised a taxon (species) by samples matrix compiled into an Excel spreadsheet. Species counts were converted to numbers per m² and other initial analyses on these data were undertaken within Excel. Multivariate statistical PRIMER programmes (Plymouth Marine Laboratory) were used to compare faunal assemblages among the stations. Taxa present in only one or two replicates and small numbers (<5) were excluded because they were deemed to contribute very little to overall faunal patterns.

Square-root transformed counts of taxa in each replicate were used for these analyses. Similarities (Bray-Curtis) between pairs of samples were computed and the resulting matrix subjected to hierarchical, agglomerative clustering using group-average linking to produce a graphical representation (dendrogram) of replicates' similarities. A non-metric multidimensional scaling ordination (MDS) was used to generate an alternative map of the relative similarities of faunal assemblages at the sampling stations. The SIMPER programme also identified the contribution of individual species to the groupings developed using the cluster and ordination procedures. Two-way analysis of similarity (ANOSIM) was used to assess the statistical significance of differences in faunas between replicates at each station and between stations.

The relationships between sediment characteristics and the faunal assemblage compositions were examined by correlation and ordination following Clarke and Ainsworth (1993) and Somerfield *et al*. (1995). First, matrices of Euclidean similarity distances between stations based on standardised environmental data were computed for all possible combinations of variables. Second, an equivalent Bray-Curtis similarity matrix was produced for stations based on mean faunal densities. Next, rank correlation coefficients between the biotic matrix and each abiotic matrix were produced (BIOENV), and the highest coefficients at each level of environmental variable complexity tabulated. This identifies the combination of abiotic variables that is most strongly correlated with the faunal distribution. Finally, a two-dimensional map of stations' similarities based on environmental factors was produced by ordination of stations using multidimensional scaling (principal components analysis, the usual ordination, was not possible with the small number of stations) of similarity matrices for environmental variables to confirm any relationship between abiotic variables and the faunal distribution.

3. Intertidal ecology

3.1. Site description

3.1.1. Outer harbour site: Lucas Bay (43.872°S, 172.23°E)

Situated on the eastern head of Lucas Bay, some 4 km inside the harbour heads, the rocky shores at this site were open to high wave action approaching almost uninterrupted from the open sea. At this point, the shore comprised unbroken bedrock. The low shore rose steeply (c. 60-70º) from subtidal depths to about 2.5 m above ELWS, then gave way to a wide platform. The platform was about 6-8 m wide, almost horizontal and smooth to seaward, but rose more steeply and was increasingly dissected landwards, eventually rising via cliffs, overhanging in places, to the steep hillsides beyond.

The biota at this site changed markedly with shore level. Low on the shore, the subtidal fringe comprised dense, short *Carpophyllum maschallocarpum*, with sparse *Durvillaea antarctica* and *D. willana*. Forming an under-storey amongst these algae, a turf of coralline algae was interspersed with blue mussels (*Mytilus galloprovincialis*). This fairly luxuriant algal growth ended abruptly at about ELWS. Above this level, algae were sparse and comprised small species (e.g., *Colpomenia sinuosa* and isolated *Porphyra* sp.). Mussels (both *Mytilus galloprovincialis* and *Perna canaliculis*) dominate crevices, with barnacles (*Chamaesipho columna, Epopella plicata*) covering all rock surfaces between. Other animals were present, but generally less conspicuous. These included *Onchidella nigricans* (the black, shell-less snail), the exposed shore limpet (*Cellana ornata*) and the small mussel, *Xenostrobus pulex*. A couple of metres along the transect at midshore levels, macroscopic algae were absent. Barnacles continued to dominate and cover most rock surfaces, with *Cellana ornata* inhabiting bare rock between and abundant, minute blue littorinids (*Austrolittorina antipodum*) and sparse brown littorinids (*Austrolittorina cincta*) browsing barnacle surfaces. Black, goose-necked barnacles (*Callantica* sp.) clustered in midshore crevices, along with occasional snake-skin chitons (*Sypharochiton pelliserptentis*), small clumps of blue tube-worms (*Pomatocerus caeruleus*), sparse *Cellana ornata* and whelks (*Lepsiella scobina*), and the small limpet *Notacmaea pileoposis.*

Pools on the platform supported dense carpets of the green alga *Enteromorpha* sp., but little else. Emergent rocks between these pools were bereft of algae and animals, except sparse littorinds. These small snails increase markedly in size from seaward to landward across the platform, with larger individuals of both species approaching 10 mm long at the base of the cliffs.

3.1.2. Mid-harbour site: Cape Three Points (43.831° S, 172.909° E)

A diverse biota inhabited the unbroken basalt rocky shore at Cape Three Points, midway along Akaroa Harbour's western side. Here, the shore rises abruptly from the sublittoral and the intertidal zone is about 9 m wide, encompassing ledges, platforms and various crevice and pool habitats.

Bull kelps, *Durvillaea antarctica* and *D. willana*, dominated the sublittoral fringe on these shores over an under-storey of stunted *Carpophyllum maschallocarpum*, *Hormosira banksii* and crustose and foliose coralline algae. Kelp, *Macrocystis pyrifera*, and sea tulips, *Pyura pachydermatina*, along with various smaller red algae were also present within the sublittoral fringe. Above the abrupt end to the larger brown algae at ELWS, rock surfaces were almost completely covered by corallines, both paint and scattered clumps of dense, short foliose corallines. Other algae, notably *Adenocystis utricularis*, *Colpomenia sinuosa* and various small reds were present also. The fauna was dominated by dense populations of small, coralline-encrusted patelloid (*Patelloidea* sp.) and siphonariid (*Siphonaria zealandica*) limpets and sparse rock oysters (*Ostrea lutaria*). Within 0.5 m of this zone, the fauna changed to sparse barnacles (*Chamaesipho columna*, *Epopella plicata*), increased numbers of *Siphonaira zelandica*, with blue mussels (*Mytilus galloprovincialis*) and few periwinkles (*Melagraphia aethiops*) in crevices.

Just 1 m above ELWS, the biota was completely changed. Barnacles (*Chamaesipho columna*) dominated, covering about 60% of rock surfaces. Hard, white tubes of *Pomatocerus caeruleus* added further to the rock cover, creating microhabitats that supported siphonariid and ornate limpets (*Siphonaria zealandica*, *Cellana ornata*), with periwinkles (*Melagraphia aethiops*), mussels (*Aulacomya ater*, *Mytilus galloprovincialis*) and chitons (*Sypharochiton pelliserpentis*) closely clustered in crevices. This barnacle cover extended well up the shore, initially increasing to c. 90% cover, before decreasing and ending some 4.5 m from ELWS. Other animals also became confined to crevices and eventually disappeared from the fauna at higher shore levels. Scattered clumps of the red seaweed *Porphyra* sp. occurred towards the top of the barnacle zone, along with the small nestling mussel, *Modiolus neozelanicus*. These co-existed with the barnacles and *Cellana ornata* in a narrow band at mid shore levels above which all of these were absent.

Beyond the barnacle zone, the rock was completely bare, except for small *Austrolittorina antipodum*. These small snails increased in both size and abundance further up the shore, with numbers declining at highest levels where the largest individuals were found just below the lichen zone, along with sparse, large *Austrolittorina cincta*. There was no distinct lichen zone at the very top of this shore.

Instead, the upper limits of the littorinid zone intercepted soils and tussocks some 9 m from ELWS.

3.1.3. Inner harbour site: Tikao Bay (43.799° S, 172.920° E)

The shaded shores of Tikao Bay were very sheltered and contrast markedly with the more exposed shores to seaward. Steep hillsides to the northwest heavily shaded these shores from the drying influence of mid-day and afternoon sun, whilst the bay's sheltered situation means that the intertidal zone was not widened by wave run-up and spray.

Bedrock, irregularly dissected but mostly unbroken, rose from the sublittoral at about 30-45° through the intertidal to meet the bush line just above EHWS. Large brown seaweeds (*Sargassum sinclairi*, *Carpophyllum maschalopcarpum*, *Macrocystis pyrifera*, *Ecklonia radiata*) dominated the sublittoral fringe. Above ELWS, however, macroalgae were conspicuously absent, apart from sparse *Hormosira banksii*. At lowest shore levels, barnacles (*Chamaesipho columna*) dominated, covering up to half of all rock surfaces in irregular patches. Another barnacle (*Eliminius modestus*) occurred beneath boulders at these levels, as well as in crevices in small numbers. Crustose coralline algae (pink coralline paint) covered large areas of low shore rock surfaces, also. A few small rock oysters occurred on open surfaces, along with top shells (*Melagraphia aethiops*), tubeworms (*Pomatocerus caeruleus*) and chitons (*Sypharochiton pelliserpentis*). Crevices at these lower levels were inhabited by pulmonate limpets (*Siphonairia zealandica*) and the small black shell-less snail, *Onchidella nigricans*.

At about ELWN levels, barnacles covered up to 80% of rock surfaces and one of their predators, the whelk *Lepsiella scobina*, was common. Limpets (*Cellana ornata*, *Siphonaria zealandica*) and top shells (*Melagraphia aethiops*) were common on rock between barnacle patches, whilst chitons and tube worms were largely restricted to crevices at these levels, along with sparse large individuals of the larger limpet, *Cellana denticulata* and cats-eye (*Turbo smaragdus*).

Beyond mid shore levels, barnacle cover was slightly lower and brown patches of the short, red seaweed *Bostrychia arbuscula* appeared in between. The small nestling mussel, *Xenostrobus pulex*, and the minute snail, *Risselopsis varia*, were common among barnacles at this level. Other molluscs were reduced in abundance, however, and congregated in crevices (*Melagraphia aethiops*, *Cellana ornata*, *Lepsiella scobina*). Sparse, small littorinid snails occurred at these levels.

At slightly higher levels, barnacles disappeared from upper rock surfaces, and black lichens replaced them. A few barnacles persisted in crevices, but were absent from even these habitats by EHWN levels, just 4 m from ELWS level. The conspicuous white and yellow lichens and the complete absence of littorinid snails marked the EHWS level.

3.2. Biotic patterns

More species shared dominance of cover at low shore levels at all three sites compared with their respective midshore levels (Fig. 2). Dominance was most evenly shared at Cape Three Points, where exposure was intermediate. Notably, *Chamaesipho columna*, the dominant species at other sites and levels, was subdominant to bare rock and three other species there (Fig. 2).

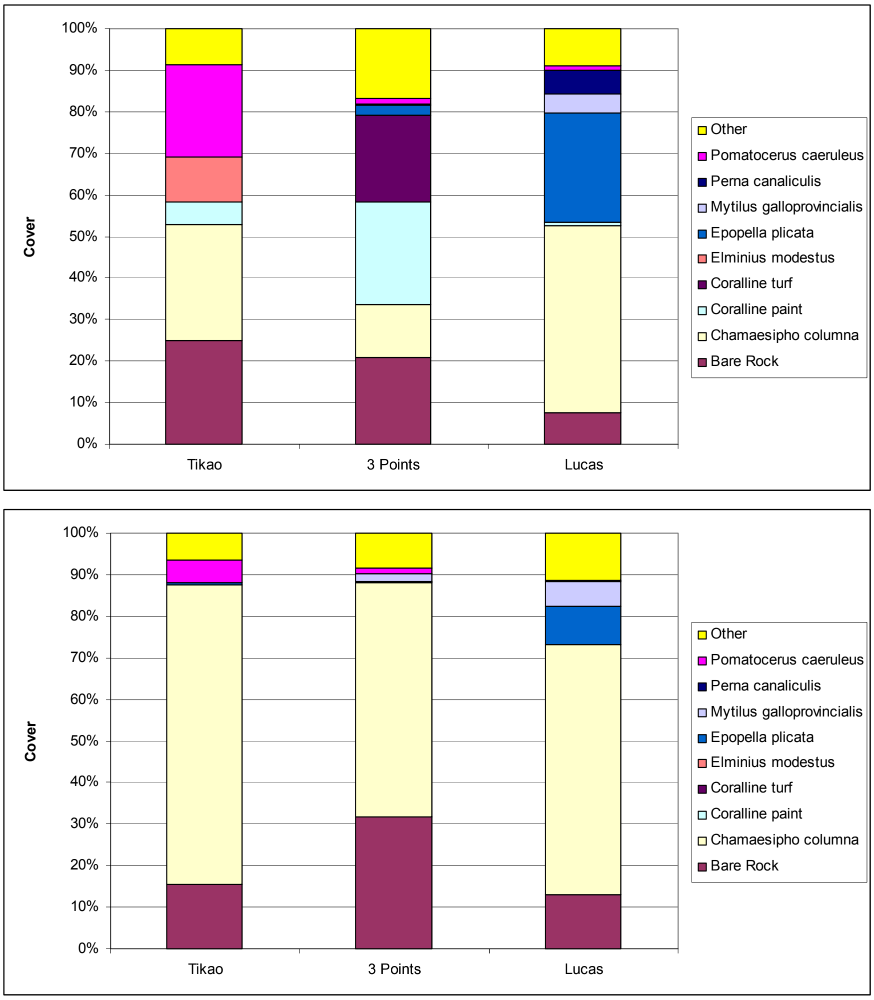


Figure 2: Composition (mean percent cover) of intertidal biota on low (top) and mid (bottom) shore levels at Tikao Bay, Cape Three Points and Lucas Bay within Akaroa Harbour.

Barnacles (*Chamaesipho columna*) dominated rock cover at both levels at most sites (Fig. 2), especially at mid shore levels. Bare rock was the second most frequent category at all sites, except at the most exposed low shore at Lucas Bay. The subdominant species differed between sites. At midshore levels, *Pomatocerus* was subdominant at greatest shelter in Tikao Bay, it shared sub dominance at intermediate exposure (Cape Three Points) and was absent at the most exposed site. *Pomatocerus* showed the converse: absence at greatest shelter, shared sub dominance at intermediate and greater dominance at greatest exposure. Its sub dominance at Lucas Bay, was, however, shared with *Epopella*, a barnacle species that was absent on midshores at more sheltered sites.

Changes in dominance of cover involved more species at low shore levels. *Chamaesipho*'s dominance was less or supplanted at Cape Three Points (Fig. 2), as various other species contributed variously to the cover. As at midshore levels, *Pomatocerus* was subdominant at the most sheltered site, but persisted as a minor component only at the two more exposed low shore sites. Another barnacle (*Eliminius modestus*) was subdominant in shelter at Tikao Bay, but absent at more exposed sites. Crustose coralline (coralline paint) was fourth in dominance at Tikao Bay, co-dominant at intermediate shelter, but only minor at greatest exposure. Coralline turf-forming algae were significant at intermediate exposure only. As with midshore levels, *Epopella* was a minor component at intermediate exposure, but subdominant at high exposure (Fig. 2). Similarly, *Mytilus* and *Perna* occurred only on exposed low shores.

Cluster analysis of sites (Fig. 3) grouped all quadrats from Cape Three Points strongly together showing that their biota was very dissimilar (c. 30% similarity) to that at other sites as well as the mid shore biota at this site. It is notable that although this low shore biota at Cape Three Points was very distinctive, there was considerable heterogeneity between replicate quadrats for this site and level.

Low shore biota at Tikao Bay also was separated out as very distinctive by the cluster analysis (Fig. 3) based on similarities (c. 35% similarity), although, again, there was considerable heterogeneity between replicates at this site. This biota also differed appreciably (similarity c. 38 %) from that at mid shore levels at this site.

There was no clear pattern at Lucas Bay. Although some of the low shore biota was very distinctive (L1L1, L1L4, L2L1, L2L4; similarity c. 45%), the rest of it was less distinctive from midshore biota at Lucas Bay (similarities >65%) and elsewhere (similarity c. 58%).

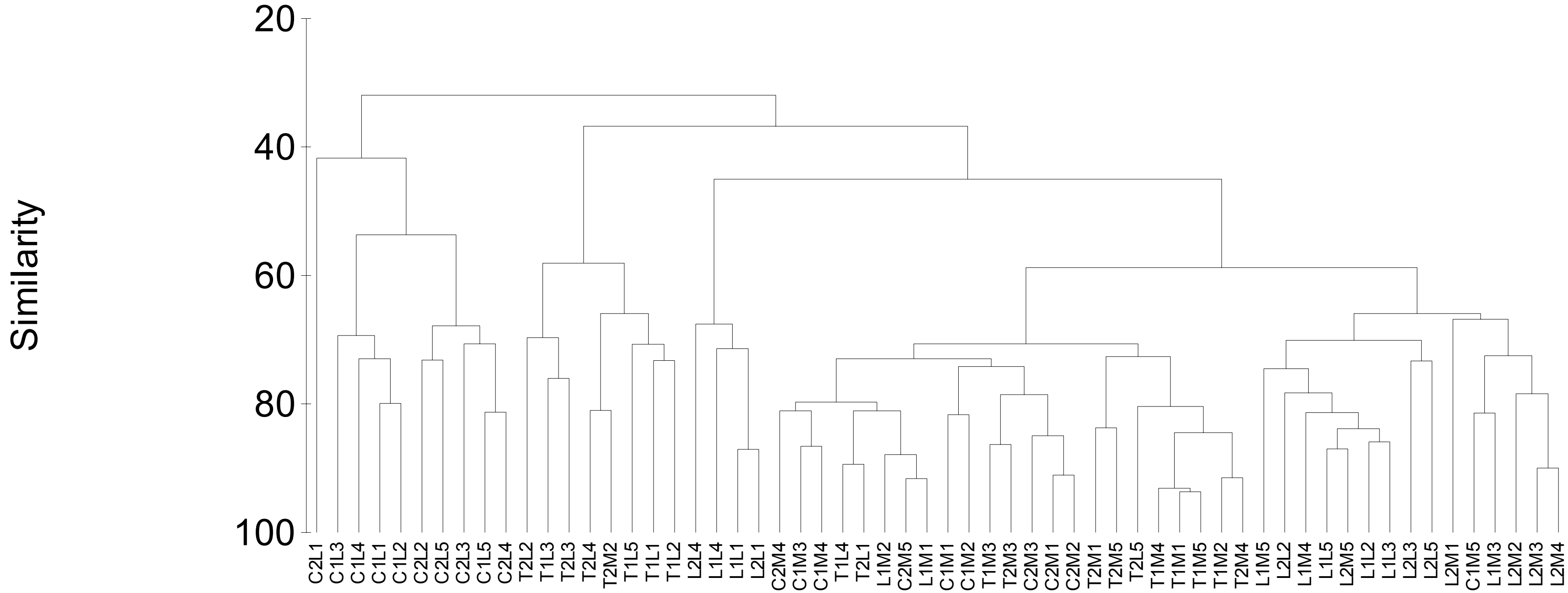


Figure 3. **Dendrogram showing similarities between biota at all Akaroa intertidal sites (C, Cape Three Points; T, Tikao Bay; L, Lucas Bay and levels (M, mid tide level; L, low tide level).**

Differences between sites were less marked for midshore biota (Fig. 3). The dendrogram grouped all Tikao Bay midshore quadrats together (along with one low shore quadrat) and placed most midshore quadrats from Lucas Bay together. However, the dendrogram indicates that the midshore biota at Cape Three Points, while grouped together, had similarities to that at some Tikao Bay mid and low shore quadrats, as well as with some Lucas Bay midshore quadrats.

The multidimensional scaling ordination of stations based on their similarities (Fig. 4) shows these relationships between sites and levels in 2-dimensional space. The arrangement here is consistent with that indicated by the cluster analysis. In particular, it reinforces the distinctiveness of low shore biotas at Cape Three Points and Tikao Bay, the overlap between Lucas Bay low shore and midshore biotas and the more general similarities of midshore biotas for all sites. Differences between all sites, pairs of sites and between levels within sites were statistically significant (Table 1).

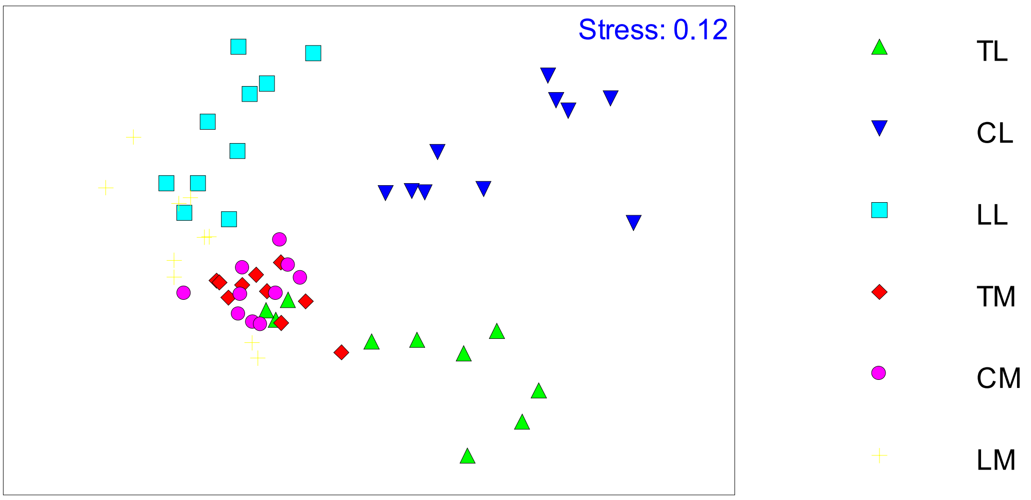


Figure 4: Multidimensional scaling ordination of replicate intertidal quadrats for each site (T, Tikao; C, Cape Three Points; L, Lucas Bay) at each shore level (L, low; M, mid tide level).

Table 1: Results of 2-way crossed ANOSIM (Analysis of Similarities) between sites and shore levels for intertidal communities in Akaroa Harbour.

		R Statistic	Significance
Differences between sites			
Global test		0.635	.001
Pairwise tests	Tikao x Cape	0.571	.001
	Tikao x Lucas	0.657	.001
	Cape x Lucas	0.690	.001
Differences between levels			
Global test		0.538	.001

4. Subtidal ecology

4.1. Sediments

Bottom sediments along the harbour mid line at inner harbour stations comprised c. 80-90% clay-fine silt, whereas this fraction decreased abruptly to seaward through stations 4 (c. 85%) to Station 6 (c. 25 %) (Fig. 5). Thus, very fine sand increasingly dominated sediments at these outer stations from Station 4 to Station 6. Station 10, located in shallower water east of Station 3, contained coarser sediments, comprising c. 65% clay-fine silt fractions. Similarly, sediments at stations (7-8) inshore (to the west) of the outer harbour stations (4-5) were dominated by coarser fractions (coarse silt-fine sand) (Fig. 5). Stations 6 and 9 differ in that sediments at the outermost mid harbour station (6) were coarser than those at the inshore Station 9, even though Station 9 was further to seaward than its mid harbour equivalent. These differences are summarised by considering the percentage non-mud (clay-coarse silt) fractions in sediments at each station (Fig. 6): mud comprised almost the entire sediment at inner mid harbour and the inner most inshore stations (1-4, 7, 10), but non-mud fractions dominated at the four outermost stations (5-6, 8-9), both in mid harbour and close to shore.

Sediment mud content was strongly related to water depth (Fig. 6), with high mud content at shallow, inner harbour stations and coarser fractions predominating in sediments at outer harbour stations. Sediment organic content (LOI) was generally low to moderate at all stations. Inner harbour stations, however, had higher organic contents than did those at mid or near shore outer harbour stations (Fig. 6). Total nitrogen varied similarly, decreasing from the bay's head towards the outer bay (Fig. 7). Thus, sediment organic content and nitrogen concentrations varied with sediment mud content and with water depth. Phosphorus, on the other hand, appears to decrease slightly from Station 1 to Station 3, thereafter increasing slightly to seaward (Fig. 7).

Metal contents of sediments showed little pattern (Fig. 7-8). Lead and zinc concentrations appear to decrease with increasing depth among Stations 1-4 and 10, but there is no obvious pattern to the concentrations of these metal amongst the other stations. There was little variation and no clear patterns in concentrations of copper, nickel, chromium (Fig. 8) and manganese (Fig. 7) between any group of stations.

Despite these differences, sediment characteristics at all stations were quite similar, with all stations clustered at high similarities (Fig. 9). A multidimensional scaling (MDS) of stations based on these same sediment characteristics produced a very similar arrangement of stations. Both analyses grouped stations into pairs corresponding to spatial nearest neighbours within the harbour (Fig. 10). Inner harbour

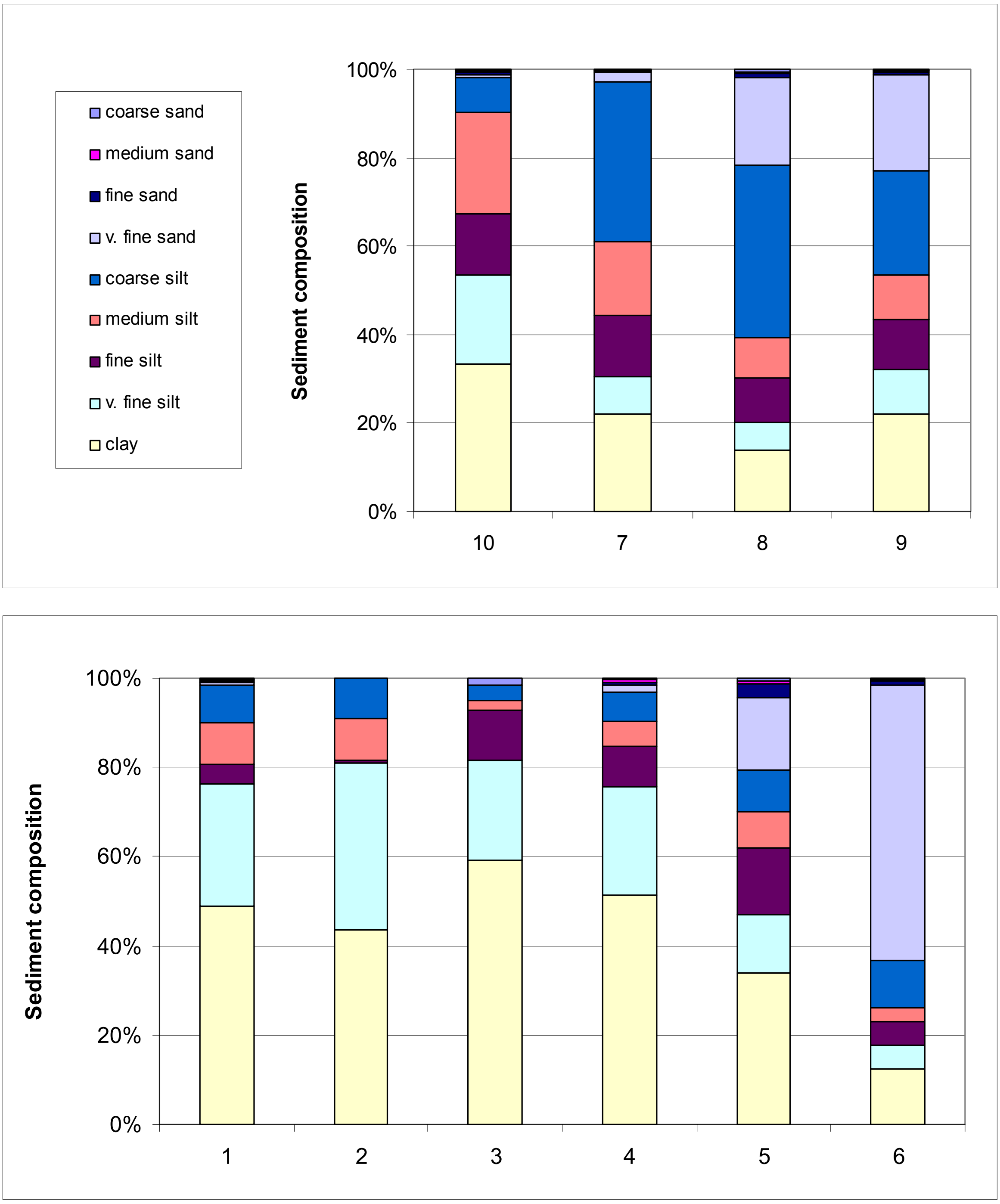
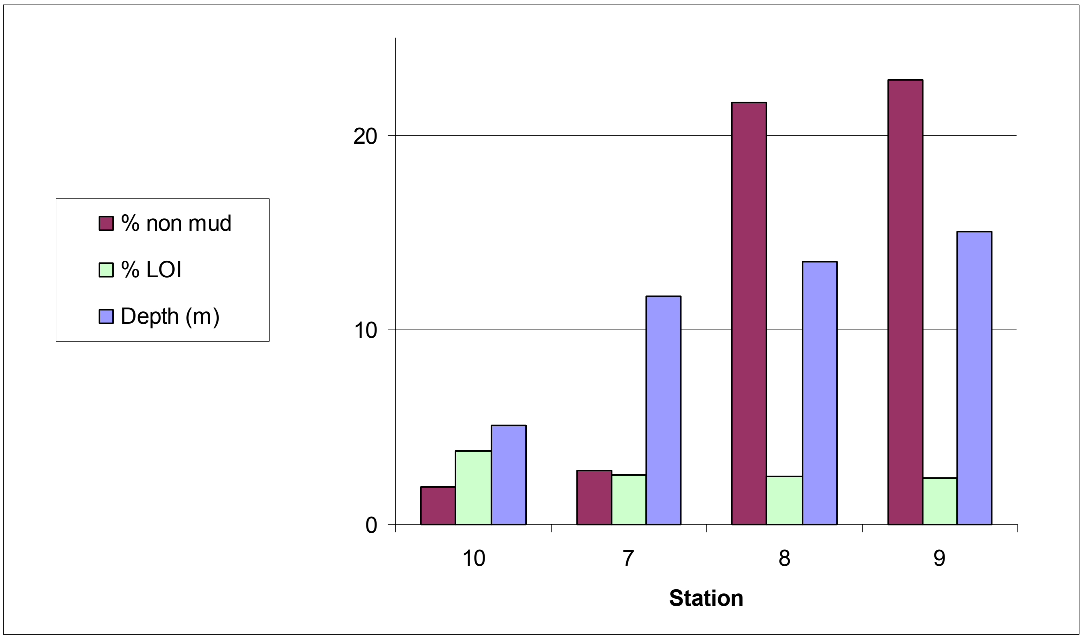


Figure 5: **Sediment particle size composition (% Wentworth fractions) at each subtidal station within Akaroa Harbour.**



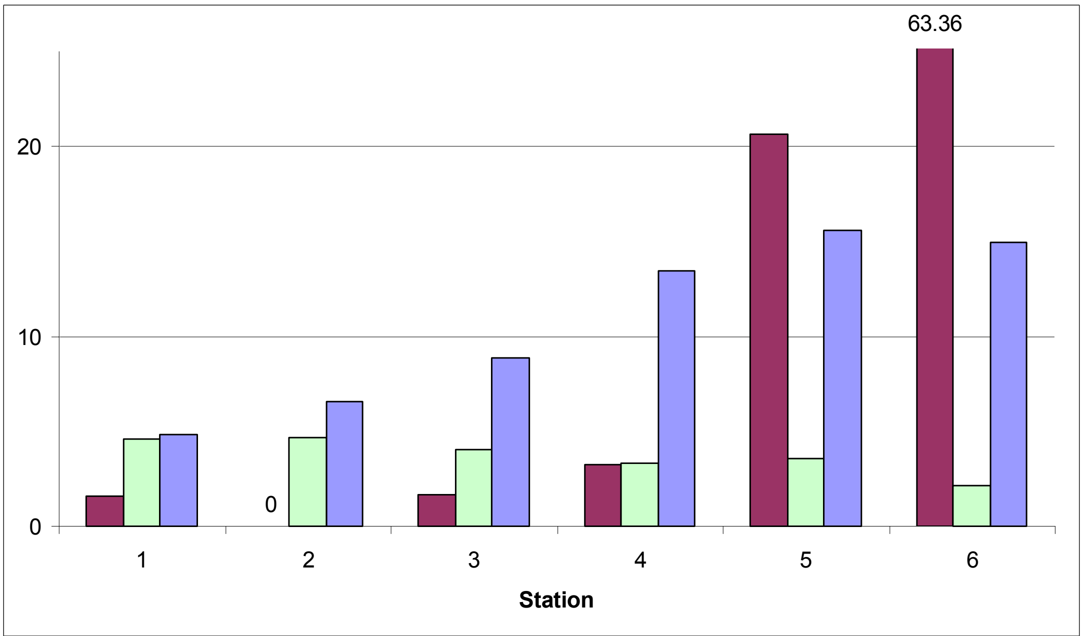


Figure 6: **Water depths (m, corrected to chart datum), non-mud and organic content (LOI) of sediments at each subtidal station in Akaroa Harbour.**

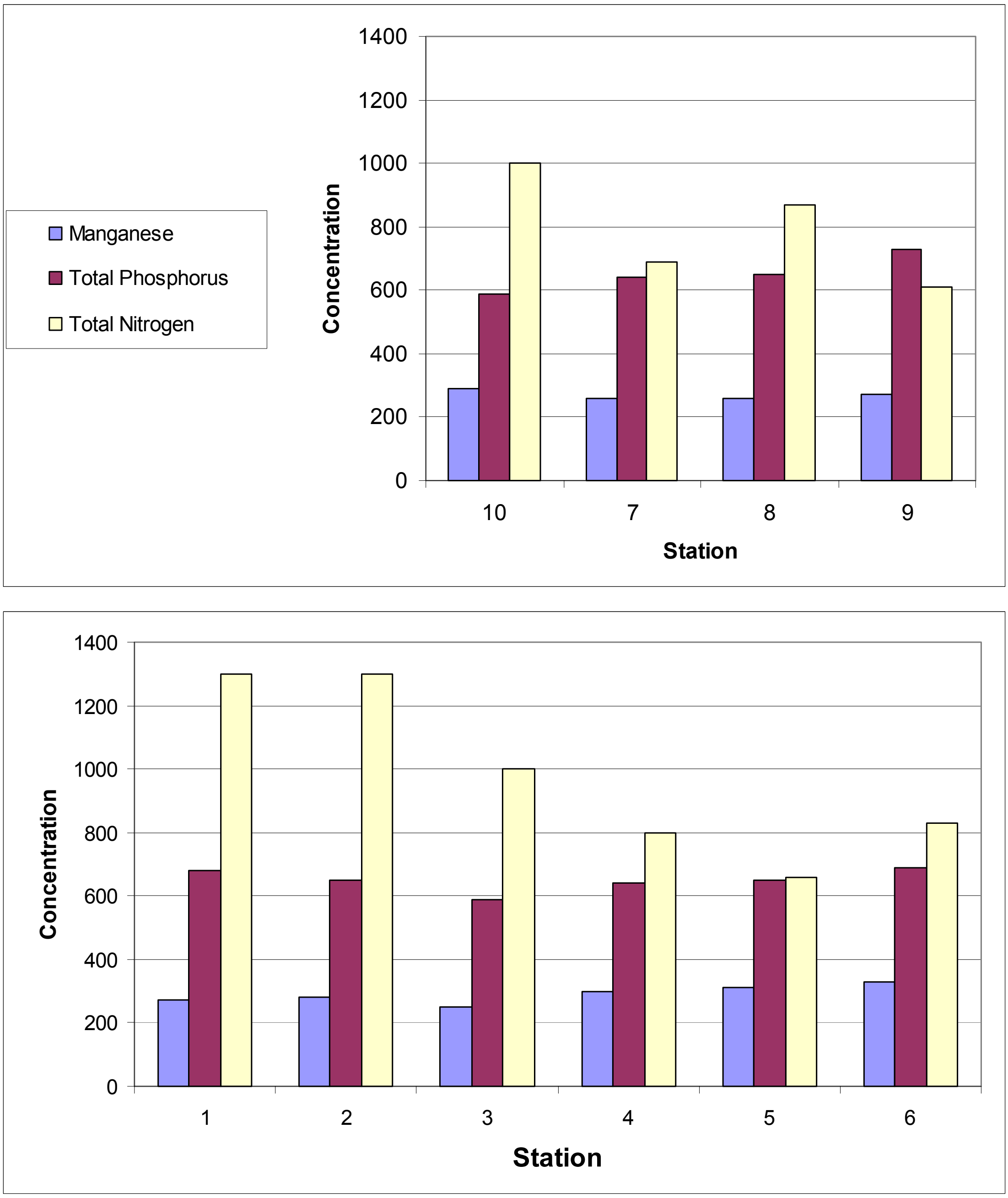


Figure 7: **Concentrations of manganese (mg/kg), total nitrogen and total phosphorus (mg/l) in sediments at each station in Akaroa Harbour.**

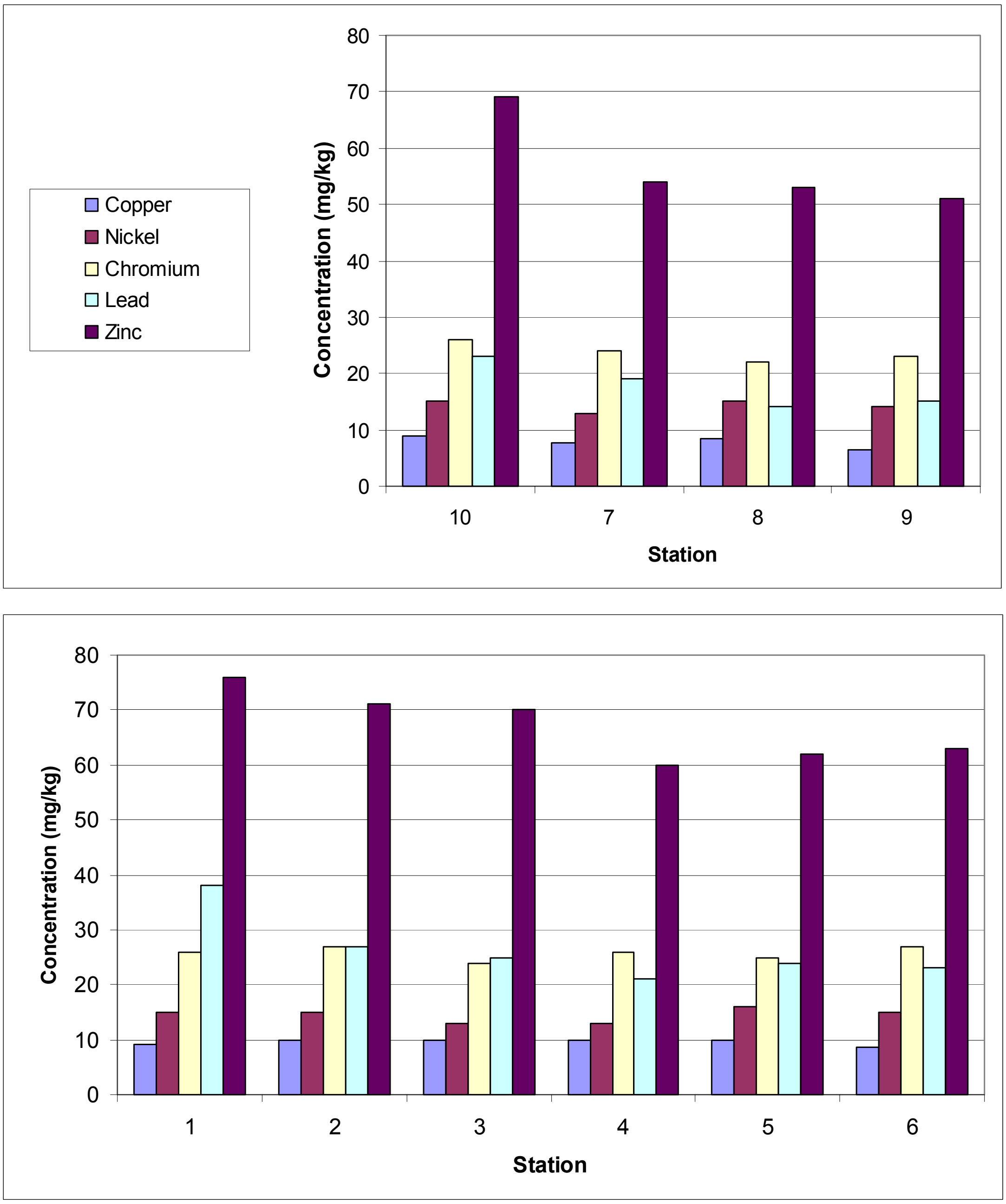


Figure 8: **Concentrations of trace metals in sediments at each station in Akaroa Harbour.**

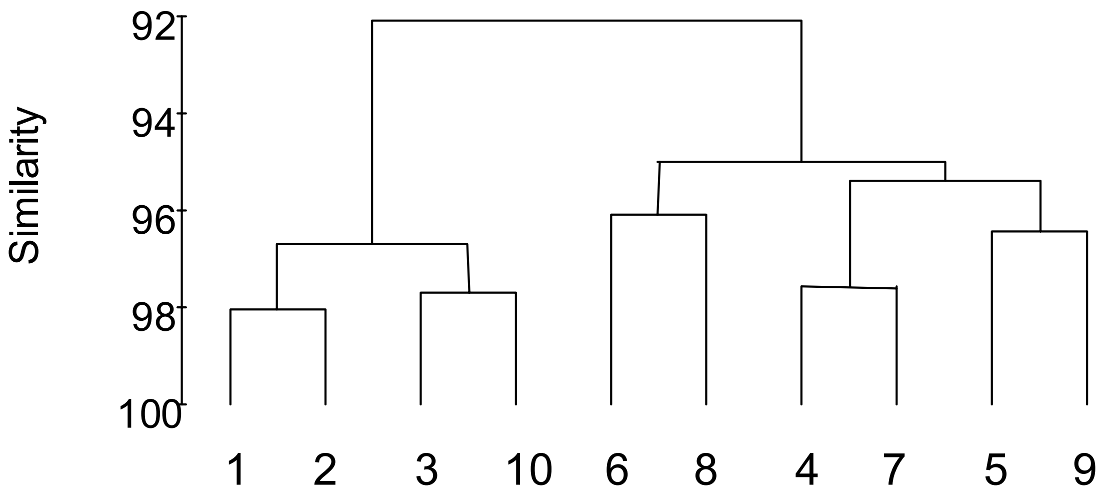


Figure 9: **Cluster analysis dendrogram showing grouping of stations in Akaroa Harbour based on sediment characteristics.**

Figure 10: **Multidimensional scaling plot of similarities between Akaroa Harbour subtidal benthic stations based on water depth and sediment characteristics.**

stations were grouped apart from the outer harbour stations and mid harbour-inshore station pairings in the sampling design were also replicated within the clustering and MDS (Figs 9-10). These findings indicate the strong influence of some along-harbour gradient in bottom sediment conditions, other than depth.

4.2. Benthos

One hundred and thirty-six taxa were identified from the 30 samples analysed for infauna from the ten stations. Of these, 22 (16%) were found in just one sample, a further 24 (18%) in just two samples (Fig. 11) and 35 (26 %) were present in 10 or more of the samples. Species occurrences by stations were similar: 34 (25%) species occurred at just single stations, another 28 (21%) were found at two stations only and 41 (30%) occurred at five or more the total 10 stations. Only nine species (7 %) were found at all stations and just two species occurred in all 30 samples.

Mean faunal densities ranged from 1906 /m^2 at Station 10 to 7727 /m^2 at Station 7 (Fig. 12). Mean densities increased steadily to seaward along the harbour midline, with inshore stations having lower mean densities than their mid harbour equivalents. Station 7 was the exception, with inshore densities almost four times higher than its mid harbour equivalent (Station 4) (Fig. 12).

Mean numbers of species comprising the benthos increased appreciably between inner and outer harbour midline stations. The total benthos diversity at inner harbour stations (1-3) was 18-19, whereas 35-58 species were found at the outer harbour stations (4-6) (Fig. 13). Numbers of taxa in the benthos tended to increase from the head to seaward along the harbour midline. There is no obvious pattern to variation in total numbers of species at each of the inshore stations and their faunal diversities are not closely follow those of their mid harbour equivalents (Fig. 13). Polychaete worms were the most diverse group at almost all stations, followed closely by crustaceans. Gastropods were generally the third most diverse group. Bivalve molluscs and other taxa tended to contribute little to overall diversity except at a few stations.

Variation of replicate densities around their respective mean values also tended to increase markedly with increasing density, although this pattern is not explored further here. Highest faunal densities found in Akaroa Harbour was 15,432 /m^2 at Station 7, but two of the three replicates at this station yielded considerably lower densities (3707-4042 /m^2). Lowest mean and individual sample densities were 1906 and 1283 /m^2 at Stations 10 and 9, respectively.

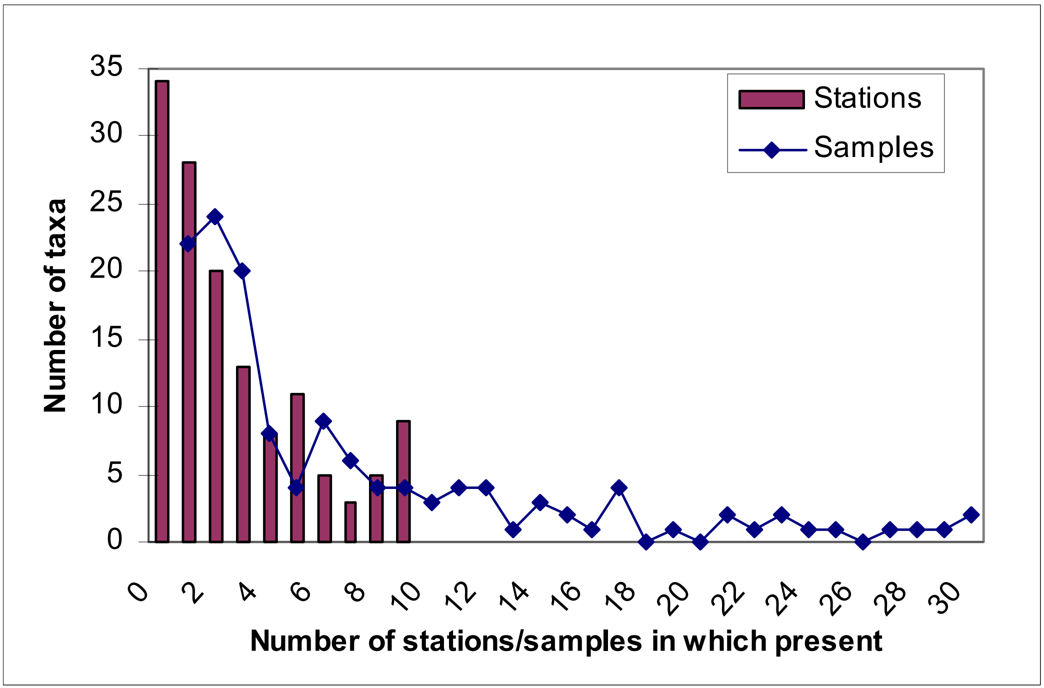


Figure 11: Numbers of species (taxa) present in different numbers of replicate samples and at different numbers of subtidal sampling stations in Akaroa Harbour.

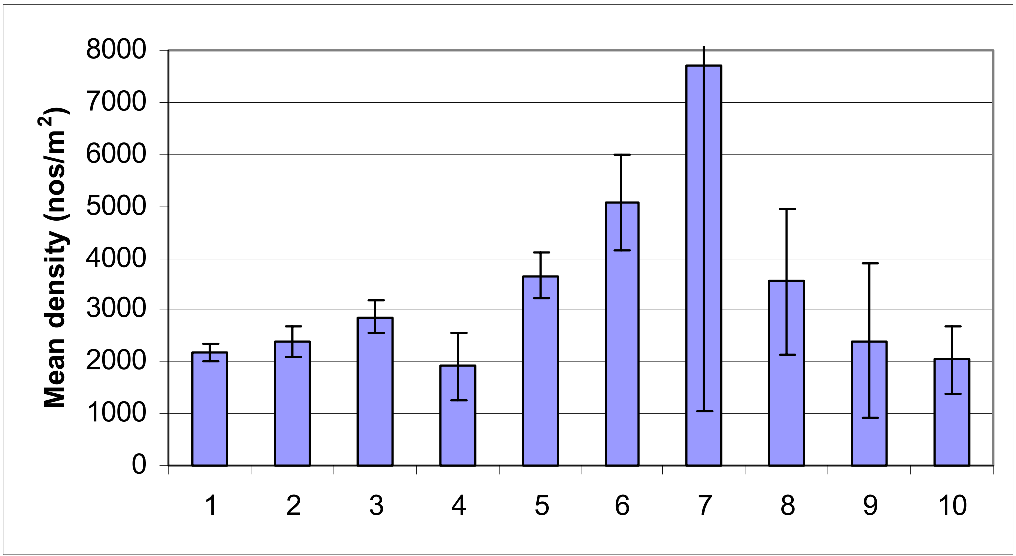
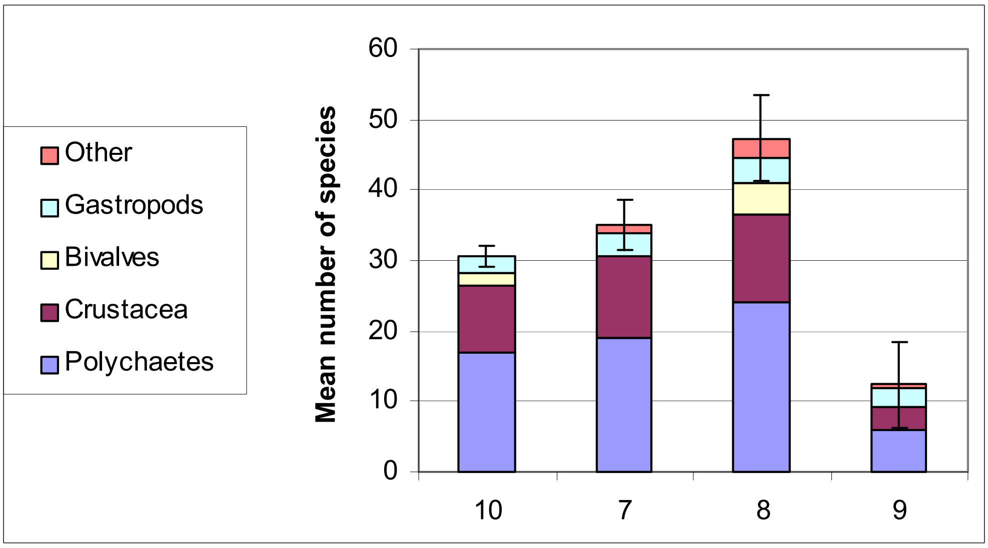


Figure 12: Mean densities (1 ± Standard Deviation) of the total benthic fauna at each subtidal sampling station in Akaroa Harbour.



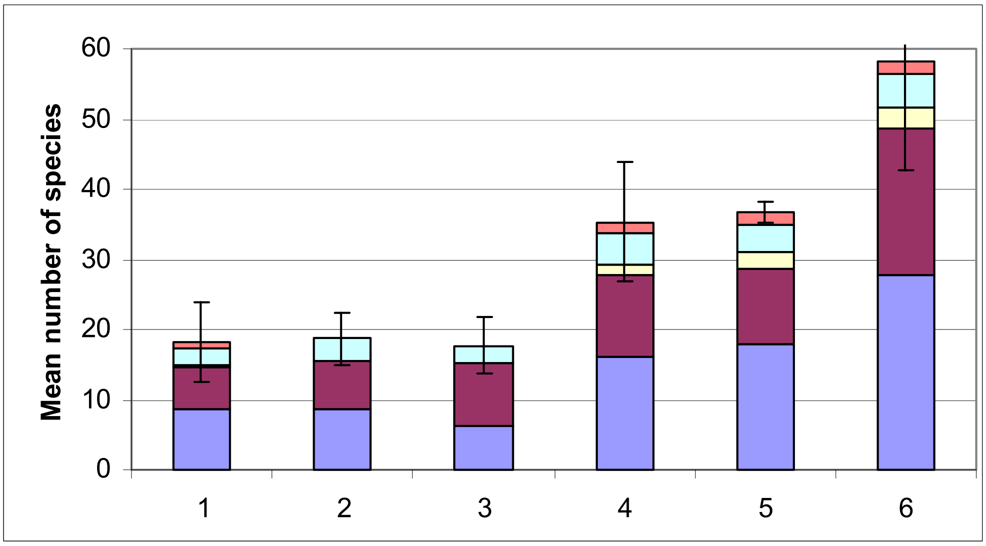


Figure 13: **Mean number of species in the total benthos (1 ±SD) and in each major taxonomic group at each subtidal sampling station in Akaroa Harbour. Stations arranged in order of distance along the harbour from inner (left) to outer (right); upper graph, inshore stations; lower graph, mid harbour stations.**

A breakdown of densities by major taxa reveals a substantial change in the taxonomic composition of the benthos along the harbour midline (Fig. 14). Gastropods dominated inner harbour stations, achieving mean densities of 1600-1800 /m^2. Their densities were markedly lower at outer harbour stations (220-370 /m^2), however. Both polychaetes and crustaceans increased in mean densities to seaward along the mid harbour (Fig. 14), largely supplanting gastropods by Station 4. Numerically, polychaetes and crustaceans were equivalent at inner harbour stations (1-4), but polychaetes were the clear dominants at Stations 5-6. It is notable that other gastropods persisted along the entire length of the harbour, and bivalves and other taxa were more common at outer sites (Fig. 14).

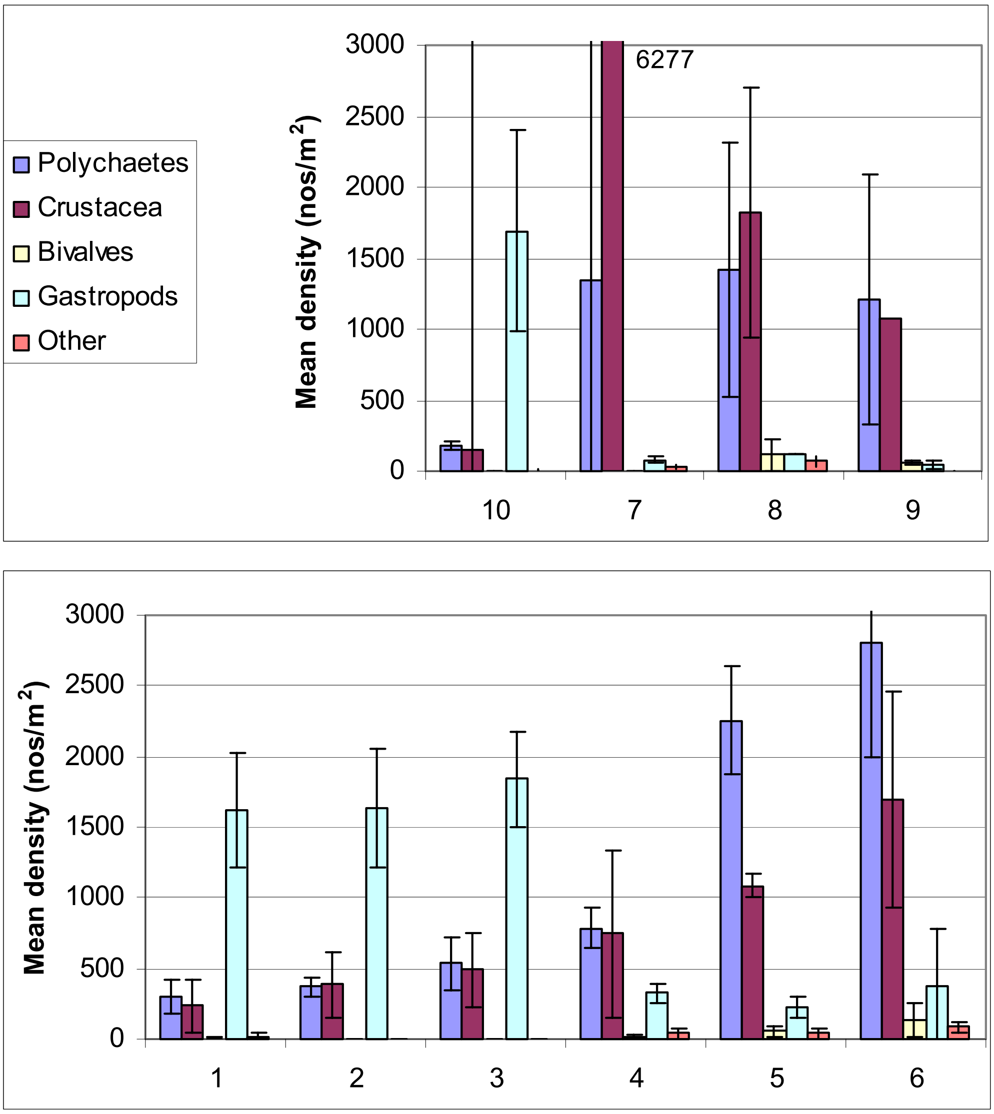


Figure 14: Mean densities (1 ±SD) of each major taxonomic group at each subtidal sampling station in Akaroa Harbour. Stations arranged in order of distance along the harbour from inner (left) to outer (right); upper graph, inshore stations; lower graph, mid harbour stations.

Inshore stations of the outer harbour had quite different benthos and the pattern of benthos change also differed. Crustaceans dominated at inshore Stations 7 and 8, overwhelmingly so at Station 7, but polychaetes barely dominated at Station 9 (Fig. 14). Also, crustacean densities decreased markedly between successive stations to seaward, whereas densities of polychaetes and other taxa varied less. In comparison, the fauna at Station 10, just off Akaroa township (Fig. 1), was very similar to that at Station 3, its mid harbour equivalent.

4.3. Biotic patterns

The cluster analysis of stations based on species density data (Fig. 15) split samples into two groups sharing about 35% similarity: inner harbour samples (Stations 1-3 and 10) and outer harbour samples (Stations 4-9). Sample 1.2 was split off from the other inner harbour samples, including the other two replicates from that station, at 58 % similarity. Comparison of this sample against other Station 1 replicates revealed that it contained more species (23 cf. 12 and 20), including 11 crustaceans (cf. 2-5), and at slightly lower total faunal densities (2030 /m^2 cf. 2167-2341 /m^2), presumably accounting for its lower similarity. The other inner harbour samples formed two groups, one containing the two other Station 1 replicates and those from Station 10, plus one from Station 2 (Fig. 15). The second group comprised just Station 2 and 3 replicates. Thus, Stations 1 and 10 were more similar to each other faunistically, than to other inner harbour stations, and the faunas at Stations 2 and 3 were most similar to each other.

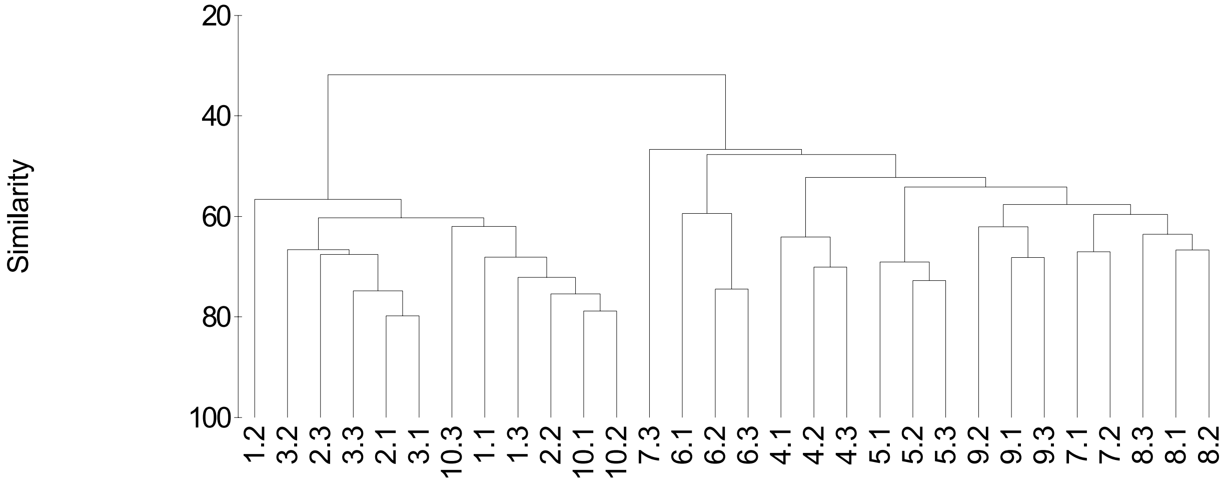


Figure 15: Cluster analysis dendrogram showing levels of similarity (%) between replicate samples from all Akaroa Harbour subtidal benthic stations.

Outer harbour samples clustered tightly at c. 50 % similarity (Fig. 15) and were further grouped according to station, with the exception of one sample from Station 7 (7.3). Comparison of the faunas in Station 7 replicates showed that sample 7.3 differed appreciably from the other two in very high densities of the amphipod *Ampelisca chiltoni* and tanaid sp. B (see Fig. 14). Among the other outer harbour stations, the inshore stations (Stations 7-9) are closely grouped at c. 58% similarity. These were most similar to Station 5 samples (54% similarity), Station 4 samples (52% similarity) and Station 6 samples (47% similarity) (Fig. 15). It is notable that the inshore stations were grouped with themselves, rather than with their respective mid harbour pairs.

The multidimensional scaling plot replicated this arrangement, presenting inter-sample similarities in two-dimensional space (Fig. 16). Here, the separation of inner harbour from outer harbour sites is reinforced. Notable also is the separation of Sample 1.2 as an outlier (discussed above) and the transition along the mid harbour sequence of stations from 1 and 10, mostly to the right, through 2 and 3, to the left, indicating something of a faunal transition, despite the intra-station variation. A stronger separation and sequence is apparent for the outer, mid harbour stations: Station 4 samples are grouped to the middle of the plot, closest to the inshore stations, whilst those for Stations 5 and 6 comprise a diagonal series to the left (Fig. 16). Above Stations 5-6 are the inshore station samples, again grouped by station, with the exception of the outlier Sample 7.3.

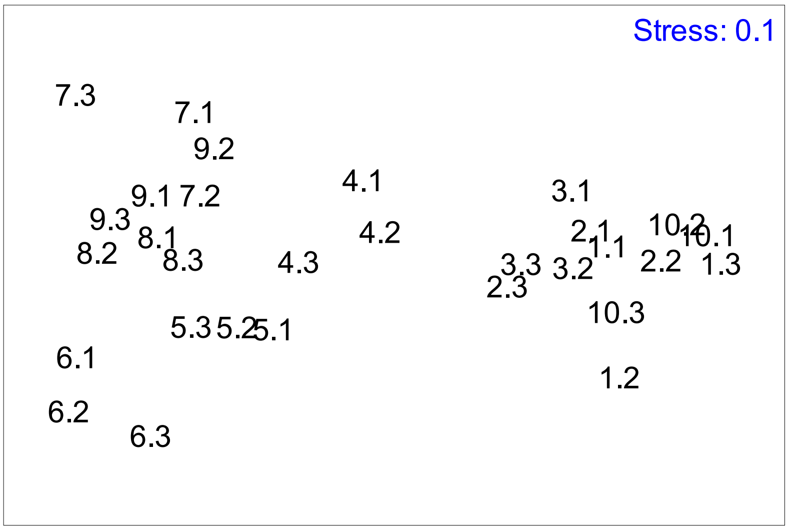


Figure 16: **Multidimensional scaling representation of relationships between infauna from all replicate samples taken from the Akaroa Harbour benthic stations.**

Differences between stations were not statistically significant (ANOSIM, Table 2) when variation between replicates was considered. Differences with relative shelter (Stations 1-3 & 10, shelter = 1; 4 & 7, shelter = 2; 5 & 8, shelter = 3; 6 & 9, shelter = 4) also were not statistically significant for these groups (Table 2).

Plots of mean densities at each station for species contributing most to differences between stations (by SIMPER routine), also the most abundant species, indicate how these patterns relate to distributions of key species (Fig. 17). The polychaete worm *Terebellides stroemii* was ubiquitous, present in moderate densities (100-1220 /m^2) at all stations, with some tendency for densities to be higher within the outer compared with the inner harbour. *Zeacolpus symmetricus*, a gastropod mollusc, occurred at most stations, but its abundance at inner harbour stations (1580-1800 /m^2) was very high compared with outer harbour stations (30-250 /m^2). Further, within the outer harbour, it was more abundant in mid harbour (130-240 /m^2) compared with inshore (25-70 /m^2). The opposite pattern is apparent with the large amphipod, *Ampelisca chiltoni* (Fig. 17). This species was all but absent within the inner harbour (Stations 1-3, 10; 0-40 /m^2), but common to very abundant in the outer harbour (Stations 4-9; (170-3300 /m^2). Densities of *Ampelisca* were highest inshore, although this was not consistent. Restricted to inshore, outer harbour sites was the large tanaid crustacean, tanaid sp A. Indeed, it was virtually absent from all other stations, but present at densities of 410 to 2370 /m^2 at the three exposed inshore stations (Fig. 17).

Table 2: Results of 2-way ANOSIM (Analysis of Similarities) between stations (n = 3) and stations grouped by relative exposure (Stations 1-3 & 10, shelter = 1; 4 & 7, shelter = 2; 5 & 8, shelter = 3; 6 & 9, shelter = 4) for subtidal benthic communities in Akaroa Harbour.

		R Statistic	Significance
Differences between stations			
Global test		0.503	0.002
Pairwise tests	All station pairings	-0.111 – 1.000	0.100 – 0.700
Differences between shelter levels			
Global test		0.42	0.049
Pairwise tests	1 x 2	0.5	0.067
	1 x 3	0.5	0.067
	1 x 4	0.5	0.067
	2 x 3	0.0	1.000
	2 x 4	-0.5	1.000
	3 x 4	0.0	0.667

Several of the other common benthic species tended to be less abundant inshore and more abundant in the outer harbour, although changes in densities were not large (Fig. 17). These included *Proharpinia* sp. A (lower densities at Stations 1, 5, 10), *Sthenolepis*? sp., *Aglaophamus verrilli*, *Abyssoninoe galatheae* and ?*Sinoediceros* sp. (least abundant at Stations 1-3, 10). The mud crab, Macrophthalamus hirtipes, was distributed similarly, although its densities were lower at the most exposed or deepest stations (Fig. 17). A group of two polychaetes (*Paraprionospio* sp. and *Glycinde dorsalis*) and a cumacean (*Diastlylopsis thilenuisi*) were absent from inner harbour sttons, present at most outer harbour stations, and very abundant at the outer-most mid harbour station (6). *Heteromastus filiformis*, an opportunistic capitellid polychaete worm, had a similar distribution pattern, except that it was most abundant at two outer harbour stations, one in mid harbour (6), the other inshore (7) (Fig. 17).

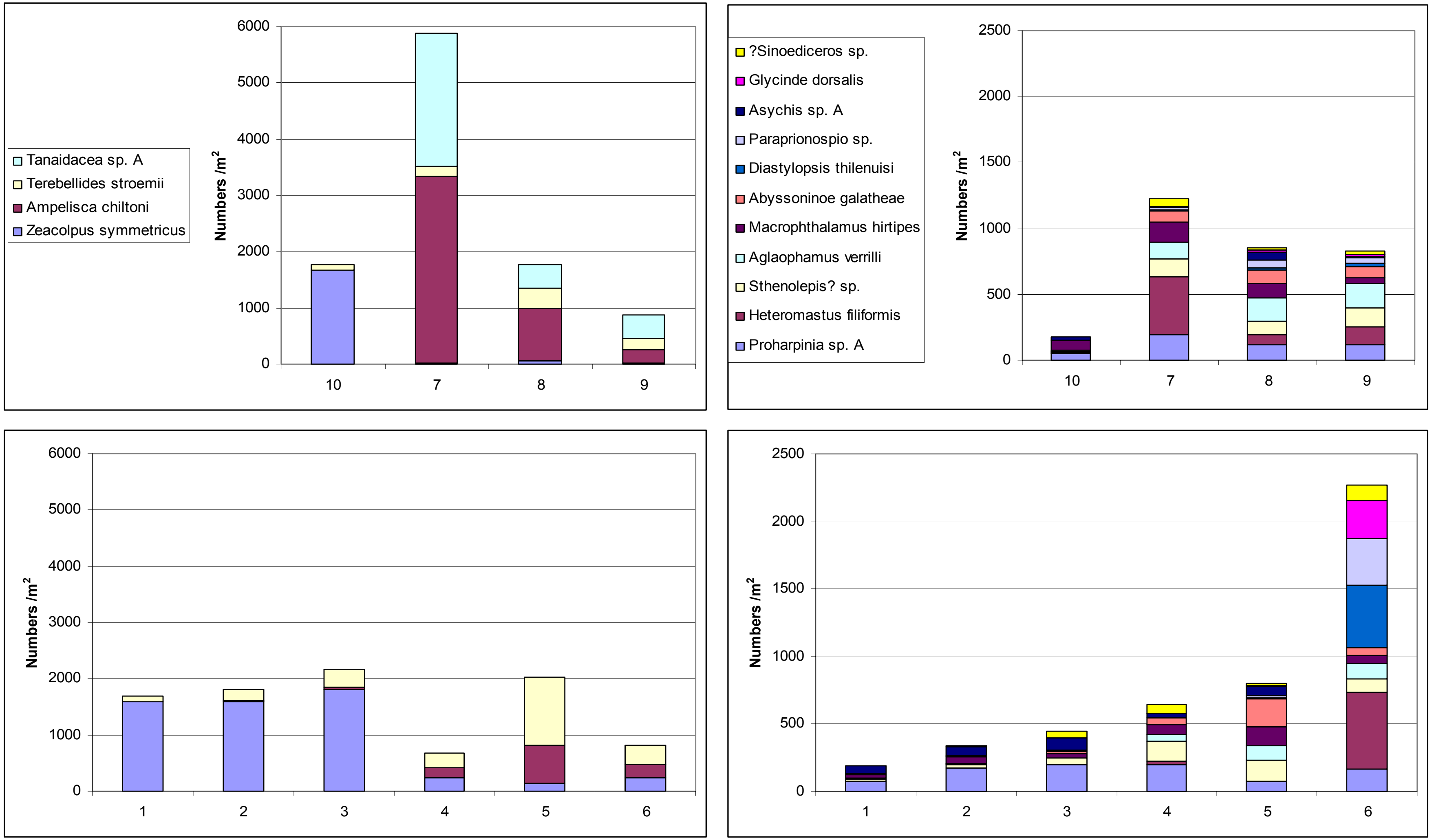


Figure 17: **Man densities of the 15 most abundant species (identified as greatest contributors to dissimilarities between faunas at each station by SIMPER routine) in Akaroa Harbour.**

Correlations between faunal patterns at each station and abiotic (physico-chemical) factors were examined by measuring correlations between faunal and abiotic similarity matrices for combinations of 1-5 factors (Primer's BIOENV routine). Results are summarised in Table 3. The distribution of fauna or community pattern was most strongly correlated (r_s = 0.856) with the combination of three factors: water depth, sediment organic and zinc contents. Water depth was the single factor most strongly correlated (r_s = 0.723) with community pattern amongst the stations. However, when sediment organic content (LOI) was combined with depth, the correlation increased appreciably (r_s = 0.830) and is similar to the highest correlation achieved with combinations of four or five abiotic factors (Table 3). Thus, water depth and sediment organic content appear to be the strongest influences on faunal distribution and community composition within Akaroa Harbour.

Table 4: Combinations of abiotic factors with highest Spearman correlation co-efficients between mean faunal and abiotic similarity matrices (Primer's BIOENV routine).

	Best variable combinations			
No. of variables	**Best combination**	**Second best combination**	**Third best combination**	**Fourth best combination**
1	Depth 0.723	Organic content 0.695	Zinc 0.623	Total nitrogen 0.455
2	Organic content Depth 0.830	Organic content Zinc 0.810	Organic content Copper 0.792	Organic content Clay 0.757
3	Organic content Depth Zinc 0.856	Organic content Depth Copper 0.853		
4	Organic content Depth Zinc Cadmium 0.856	Organic content Depth Zinc Nickel 0.855	Organic content Depth Cadmium Copper 0.853	Organic content Depth Zinc Copper 0.853
5	Organic content Depth Zinc Cadmium Nickel 0.855	Organic content Depth Zinc Cadmium Copper 0.853	Organic content Depth Zinc Nickel Chromium 0.852	

5. Discussion

5.1. Intertidal biota

The three shores surveyed during this investigation were subjected to quite different levels of exposure to wave action, one of the strongest determinants of intertidal biotic zonation patterns. Wave action, however, represents a complex of factors that are mediated by the hydrodynamic conditions. These include sedimentation, plankton and nutrient supply, and dissolved oxygen concentration, as well as probability of drying for intertidal habitats. Shore level adds a further dimension for intertidal organisms. It should be noted that shading from direct sunlight is also an important factor around parts of Banks Peninsula and Akaroa Harbour. The Tikao Bay site receives partial shade from afternoon sun during much of the year, potentially altering the biotic zonation pattern towards that expected under greater exposure. The extent to which this occurs is unknown, but the site does appear to be shaded for much of the day, except during the height of summer.

Lucas Bay was most exposed because of its more seaward location. The Cape Three Points site was moderately exposed, even though on the lee side of the point itself. Conditions at Tikao Bay were very sheltered, in comparison. The exposure levels at Cape Three Points, the intermediate site, should not be regarded as equidistant from the other two sites along an exposure gradient; exposure levels at Cape Three Points appeared more similar to those at Lucas Bay than to those at Tikao Bay. Also, some situations in Akaroa Harbour are more exposed (e.g., at the heads) and others are even more sheltered (e.g., bedrock shores at French Farm) than Lucas Bay and Tikao Bay, respectively. Thus, the changes in biota observed between the three sites represent three points along a wider exposure gradient, but do encompass levels of exposure reaching shores in some parts of the harbour.

Several changes in biota with differences in shore level are apparent from this investigation. There is a tendency for higher cover of rock surfaces by the biota at lower shore levels (biomass almost always increases at lower levels on shores, but this is probably poorly correlated with cover). Cover is dominated by fewer species at higher shore levels and there are more species present at lower levels on these shores. Barnacles overwhelmingly dominated mid shore levels, but their dominance was substantially reduced on low shores.

Changes in biota with wave exposure also are apparent. The number of species contributing to cover increased with increasing wave exposure at both shore levels, although these changes were small. With the exception of the barnacle *Chamaesipho columna*, most species were replaced by another as exposure changed.

The multivariate analyses confirmed these observations. Low shore biotas were quite distinctive from each other and from their midshore biotas. At Lucas Bay, however, there was some overlap between low and mid shore biotas. Further, low shore biotas at all three sites were similar, especially those at the two more sheltered sites (Tikao Bay and Cape Three Points).

The intertidal biota in Akaroa Harbour comprised species that are widely distributed around Banks Peninsula (Knox 1953, Fenwick 2003) and elsewhere along the east coast of South Island (Morton & Miller 1968). None of the shore communities seemed particularly remarkable as nationally significant habitat. However, the rich biota more generally present at Cape Three Points and its accessibility suggests that this site may merit special attention. There was no evidence of human impacts on the intertidal biotas at the sites surveyed either from the data collected or from casual observation at each site, although no control sites were included in the investigation.

5.2. Subtidal sediments

Bottom sediments changed markedly along the harbour mid line from almost complete mud to very fine sand. Sediments closer inshore were generally very similar to those in mid harbour. Notably, the transition from mud to sand occurred along a gradient of increasing depth and increasing wave moment due to wave action and currents. Generally, finer sediments are expected in deeper water, but, here, the increase in hydrodynamic energy more than offset the expected change, so that shallow water mud was replaced by coarser sediments in more exposed deeper water to seaward.

Superimposed on this gradient of deceasing mud with increasing depth is a general decrease in concentrations of organic content (LOI), total nitrogen and several trace metals. Sediment organic content and metal concentrations are usually directly correlated with sediment mud content, so these findings are not unexpected.

Stations were grouped into pairs at very high similarities based on sediment characteristics by the multivariate analyses. These analyses also confirmed the close similarities of inner harbour stations and of outer harbour mid-inshore pairings, as well as confirming the distinctiveness of inner versus outer harbour sediments, providing further evidence of an along-harbour gradient in sediment characteristics.

There was no clear evidence of human impacts on sediments within Akaroa Harbour in the absence of historical data for a comparable, unimpacted situation. The absence of such baseline data means that any assessment will be very tentative. Of particular relevance is the impact of agriculture on Banks Peninsula on fine sediment discharge and accumulation within benthic habitats. Although forest removal and agriculture may seem to have resulted in high sediment loads in Banks Peninsula run off and caused the high turbidity so characteristic of near shore habitats, satellite imagery suggests another origin. Highly turbid water appears to become entrained within a narrow, high energy zone close to shore along much of the Canterbury Bight, and this appears to be carried along the peninsula's southern coast and around its eastern margin by the prevailing Southland Current, presumably assisted by wind waves at times. Much of this sediment washes into the various bays and harbours, where it may either settle out or be re-suspended and transported elsewhere by wave action and currents (Dingwall 1974).

5.3. Benthos

Total faunal diversity in Akaroa Harbour was similar to that reported for other locations around Banks Peninsula. Knight (1974), using very different sampling methods and 0.4 mm mesh sieves to separate fauna, found 114 species in Lyttelton Harbour; two studies in Pegasus Bay using 0.5 mm sieves found 100-101 species (Knox et al. 1978; Fenwick 1999 and; surveys of three bays around Banks Peninsula reported 108 species (0.5 mm mesh; more species were present, but not identified) (Fenwick 2002b). Fifty-eight species only were reported from Little Akaloa by a study that also used 0.5 mm sieves (Davidson 1989). Another investigation surveyed the benthos within the Port of Lyttelton operational area (i.e., subjected to dredging periodically), reporting just 29 taxa, but many of these were identified to family only, with no attempt to distinguish species. Thus, diversities found in Akaroa Harbour are slightly higher than those found in the region generally.

Diversity of benthos elsewhere around New Zealand varies, largely as a result of the geographic extent and habitat diversity of sampling, as well as mesh size and resolution of identifications. In Hawke Bay, 100 species were reported (0.5 mm mesh) (Knox & Fenwick 1981), 126 were found in Manukau Harbour (1 mm mesh) (Grange 1979) and 240 in the vicinity of Otago Peninsula (1 mm mesh) (Rainer 1981). One survey of a larger geographic area further off shore found 456 taxa (1 mm mesh) (Probert & Grove 1998).

Benthos densities in Akaroa Harbour varied widely (samples: 1283-15,432 /m^2), with an overall consistent increase in mean density (2033-7727 /m^2) with increasing depth towards the open sea. The densities themselves were very high compared with those in the Lyttelton port operational area (260-1760 /m^2) (Fenwick 2003), but, with the exception of highest densities in one replicate sample from Station 7, were consistent with benthos densities elsewhere around Banks Peninsula (850-7700 /m^2) (Davidson 1989; Fenwick 2002) and in Pegasus Bay (2696-11,085 /m^2) (Fenwick 1999). Benthos densities in Akaroa Harbour also were similar (7000-10,500 /m^2) to those found in relatively uncontaminated waters 4-5 km offshore from a sewage outfall in Hawke Bay (Knox & Fenwick 1981). Densities reported in sewage-polluted situations, however, were substantially higher (>23,000 /m^2) (Knox & Fenwick 1981).

Comparisons with the fauna identified from investigations elsewhere indicate that several Akaroa Harbour benthos species are widely distributed, although no detailed review is attempted because of differences in names and identifications. Although sampling methods and taxonomic resolution of identifications differed between the various investigations, Lyttelton Harbour and Akaroa Harbour share many common species. For example, Knight (1974) reported almost half of the species that dominated the Akaroa benthos during this survey (*Aglaophamus verrilli*, *Paraprionospio* sp., *Terebellides stroemii*, *Macrophthalamus hirtipes*, *Ampelisca chiltoni*, *Zeacolpus symetricus*, *Proharpinia* sp.), as well as many other less abundant species.

The general similarity of benthos with situations beyond Akaroa Harbour, notably species composition, diversity and density, suggest that the subtidal benthos here has not been altered greatly by human impacts. Perhaps the best comparisons are with the heavily enriched benthos in Hawke Bay described by Knox & Fenwick (1981). That study described changes in benthos along an on shore-offshore gradient long which organic inputs, depth and mud content of sediments all increased. Despite the multiple effects influencing the benthos in Hawke Bay, shallower, in shore stations were clearly heavily impacted by organic enrichment from an intertidal, wastewater outfall. Clear indications of this were apparent in the relatively low benthos diversity adjacent to the outfall combined with extremely high densities of a single opportunistic worm species, *Heteromastus filiformis*, rather than mobile crustaceans that are more typical of surf zones on soft shores (e.g., Knox *et al*. 1978; Fenwick 2002).

Analyses conducted here identified appreciable changes in benthic community composition with distance towards the harbour entrance that was strongly correlated with changes in water depth and sediment characteristics. These changes appear to represent a transition in community composition rather than a change from one distinct faunal assemblage to another. In particular, many of the abundant species that accounted for much of the difference between stations occurred at all stations. The essential differences between stations, therefore, were changes in the relative abundances of species and the addition of more species with increasing depth and distance to seaward, rather than a complete replacement of one set of species by another set.

Faunal transition with distance from shore appears to be a common feature off open coasts (Know & Fenwick 1981; Fenwick 1999) and the exposed beaches of small embayments (Fenwick 2002). However, such faunal transitions along larger embayments appear poorly documented. Most previous investigations focussed strongly on identifying communities in the classical sense of fixed assemblages and comparing these between regions. There appears to have been little attempt to understand patterns and the under-lying drivers of these patterns. In his survey of Lyttelton Harbour, Knight (1974) identified something of a transition in his two exclusively subtidal communities (the *Hemiplax hirtipes-Virgularia gracilima* and (the *Zeacolpus vittatus-Pectinaria australis* communities) inhabiting the harbour's muddy and sandy regions, but their occurrence within the harbour is difficult to deduce. Similarly, faunal transitions are apparent in Manukau Harbour (Grange 1979) and in Otago Harbour (Rainer 1981), although not explicitly recognised nor described.

6. Acknowledgements

This project would not have been possible without the generous and enthusiastic assistance of several people. Dr Leslie Bolton-Ritchie (ECan) assisted with sampling design, fieldwork and identified and counted all polychaete worms. Olivia Johnston (University of Canterbury) and Marty Flanagan (NIWA) also contributed substantially to the fieldwork. Anna Bradley (NIWA) sorted the samples and Isla Fitridge (NIWA) identified the molluscs and various other groups. Catherine Chagué-Goff (NIWA) analysed sediment samples for organic content, and the ECan laboratory completed analyses of sediments for metals, nitrogen and phosphorus. Carol Whaitiri pulled my draft into a professional looking report and Paul Sagar offered some very useful suggestions for improving the final report. My sincere thanks to you all.

7. Literature cited

Clark, K.R.; Ainsworth, M. 1993: A method of linking multivariate community structure to environmental variables. *Marine Ecology Progress Series 92*: 205-219.

Davidson, R.J. 1989: The bottom fauna from three subtidal locations around Banks Peninsula, Canterbury, New Zealand. *New Zealand Natural Sciences 16*: 87-95.

Dingwall, P.R. 1974: Bay-head sand beaches of Banks Peninsula, New Zealand. *New Zealand Oceanographic Institute Memoir 15*: 1-63.

Estcourt, I.N. 1967: Distributions and associations of benthic invertebrates in a sheltered soft-bottom environment (Marlborough Sounds, New Zealand). *New Zealand Journal of Marine and Freshwater Research 1*: 352-370.

Fenwick, G.D. 1999: The benthos off South Brighton, Pegasus Bay: a preliminary assessment. *NIWA Client Report CHC99/53*. 27 p.

Fenwick, G.D. 2002: Marine benthic fauna of three bays around Banks Peninsula. *NIWA Client Report CHC02/51*. 26 p.

Fenwick, G.D. 2003: Port of Lyttelton ecological monitoring: May 2003. *NIWA Client Report CHC2003-079*. 26 p.

Grange, K.R. 1979: Soft-bottom macrobenthic communities of Manukau Harbour, New Zealand. *New Zealand Journal of Marine and Freshwater Research 13*: 315-329.

Knight, G.S. 1974: Benthic community structure in Lyttelton Harbour. *New Zealand Journal of Marine and Freshwater Research 8(2)*: 291-306.

Knox, G.A. 1953: The intertidal ecology of Taylor's Mistake, Banks Peninsula. *Transactions of the Royal Society of New Zealand 81(2)*: 189-220.

Knox, G.A.; Fenwick, G.D. 1981: Zonation of inshore benthos off a sewage outfall in Hawke Bay, New Zealand. *New Zealand Journal of Marine and Freshwater Research 15*: 417-435.

Knox, G.A.; Fenwick, G.D.; Bolton, L.A. 1978: A preliminary quantitative study of the benthic fauna off Spencerville, Pegasus Bay. *Estuarine Research Unit Report No. 17*: 1-42.

Morton, J.; Miller, M. 1968: The New Zealand seashore. Collins, London. 638 p.

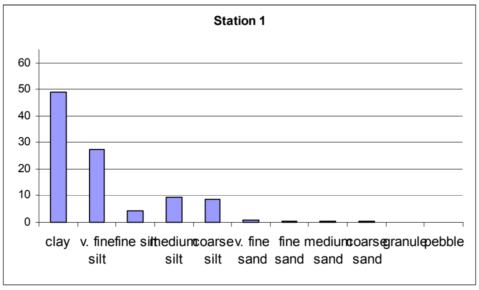
Probert, P.K.; Grove, S.L. 1998: Macrobenthic assemblages of the continental shelf and upper slope off the west coast of South Island, New Zealand. *Journal of the Royal Society of New Zealand 28(2)*: 259-280.

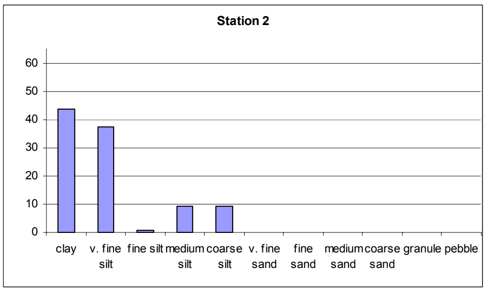
Rainer, S.F. 1981: Soft bottom benthic communities on Otago Harbour and Blueskin Bay, New Zealand. *New Zealand Oceranographic Institute Memoir 80*: 1-38.

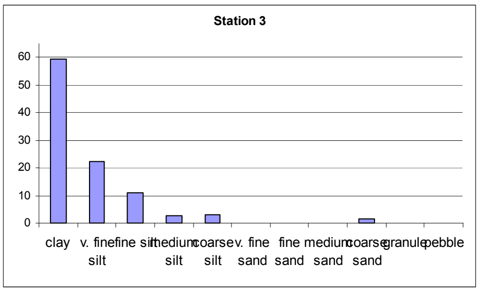
Roper, D.S.; Smith, D.G.; Read, G.B. 1989: Benthos associated with two New Zealand coastal outfalls. *New Zealand Journal of Marine and Freshwater Research 23*: 295-309.

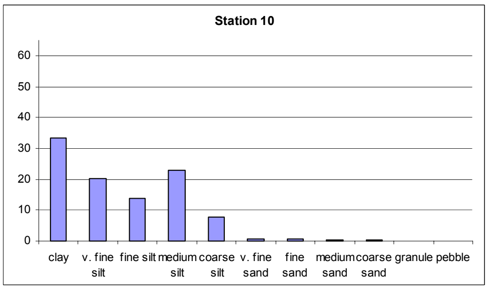
Somerfield, P.J.; Rees, H.L.; Warwick, R.M. 1995: Interrelationships in community structure between shallow-water marine meiofauna and macrofauna in relation to dredgings disposal. *Marine Ecology Progress Series 127*: 103-112.

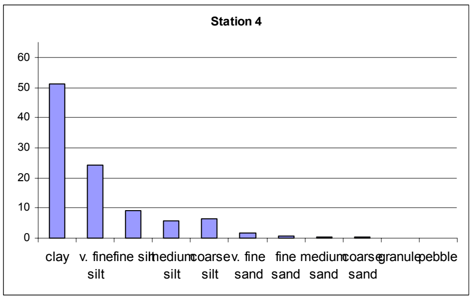
Appendix 1: Size frequency (weight) distributions of particle size analyses for subtidal bottom sediments at each station in Akaroa Harbour (Wentworth size classes).

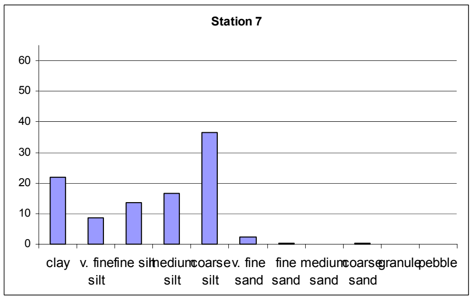


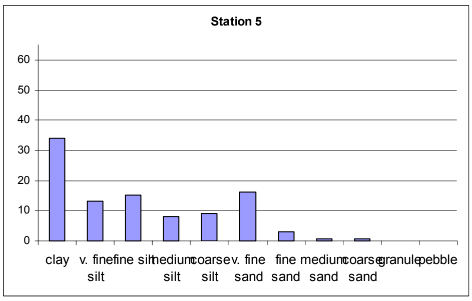


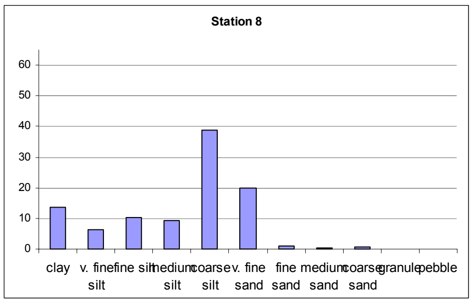


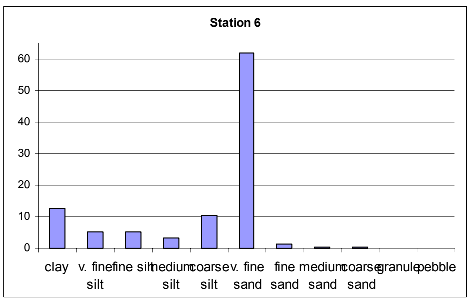


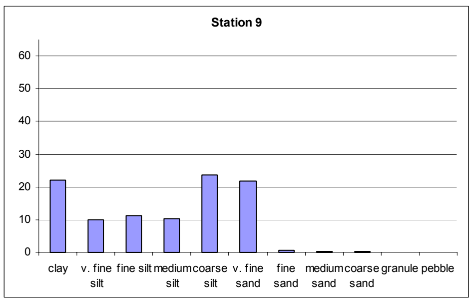












Appendix 2: List of taxa found during the survey of subtidal stations in Akaroa Harbour.

Phylum	Class	Order	Family	Species
Annelida	Polychaeta		Ampharetidae	*Lysippides* sp.
Annelida	Polychaeta		Ampharetidae	*Sosanides* sp.
Annelida	Polychaeta		Aphroditidae	*Aphrodita* sp.
Annelida	Polychaeta		Capitellidae	Capitellid sp.
Annelida	Polychaeta		Capitellidae	*Heteromastus filiformis*
Annelida	Polychaeta		Capitellidae	*Notomastus* sp.
Annelida	Polychaeta		Cirratulidae	*Aphelochaeta* sp.
Annelida	Polychaeta		Cirratulidae	*Tharyx* sp.
Annelida	Polychaeta		Flabelligeridae	*Diplocirrus* sp.
Annelida	Polychaeta		Glyceridae	*Glycera lamelliformis?*
Annelida	Polychaeta		Glyceridae	*Glycera ovigera*
Annelida	Polychaeta		Glyceridae	*Glycera* sp.
Annelida	Polychaeta		Goniadidae	*Glycinde dorsalis*
Annelida	Polychaeta		Hesionidae	*Ophiodromus?* sp.
Annelida	Polychaeta		Hesionidae	*Podarke* sp.
Annelida	Polychaeta		Lumbrineridae	*Abyssoninoe galatheae*
Annelida	Polychaeta		Lumbrineridae	*Lumbricalus aotearoae*
Annelida	Polychaeta		Lumbrineridae	Lumbrineris sp.1
Annelida	Polychaeta		Lumbrineridae	*Ninoe ninetta*
Annelida	Polychaeta		Magelonidae	*Magelona* sp.
Annelida	Polychaeta		Maldanidae	*Asychis* sp. A
Annelida	Polychaeta		Maldanidae	*Maldane* sp.
Annelida	Polychaeta		Maldanidae	*Nicomache* sp.
Annelida	Polychaeta		Maldanidae	*Praxillella* ? sp.
Annelida	Polychaeta		Nephtyidae	*Aglaophamus* sp.
Annelida	Polychaeta		Nephtyidae	*Aglaophamus verrilli*
Annelida	Polychaeta		Nereidae	*Ceratonereis* sp.
Annelida	Polychaeta		Onuphiidae	*Onuphis aucklandensis*
Annelida	Polychaeta		Opheliidae	*Travisia* sp.
Annelida	Polychaeta		Orbiniidae	*Phylo novaezelandiae*
Annelida	Polychaeta		Orbiniidae	*Scoloplos (Leodamas)* sp.
Annelida	Polychaeta		Orbiniidae	*Scoloplos (Scoloplos)* sp.
Annelida	Polychaeta		Oweniidae	*Owenia fusiformis*
Annelida	Polychaeta		Paraonidae	*Aricidea (Aedicira) sp.*
Annelida	Polychaeta		Paraonidae	*Levinsenia?* sp.
Annelida	Polychaeta		Phyllodocidae	Phyllodocid sp. A
Annelida	Polychaeta		Phyllodocidae	Phyllodocid sp. B
Annelida	Polychaeta		Phyllodocidae	Phyllodocid sp. C
Annelida	Polychaeta		Pilargidae	Pilargid sp.
Annelida	Polychaeta		Polynoidae	*Lepidonotus* sp.
Annelida	Polychaeta		Sabellariidae	*Sabellaria* sp.
Annelida	Polychaeta		Sabellidae	Sabellid sp.
Annelida	Polychaeta		Sigalionidae	*Sthenelais* sp. A
Annelida	Polychaeta		Sigalionidae	*Sthenelais* sp. B
Annelida	Polychaeta		Sigalionidae	*Sthenolepis?* sp.

Annelida	Polychaeta		Spionidae	*Boccardia (Paraboccardia) syrtis*
Annelida	Polychaeta		Spionidae	*Paraprionospio* sp.
Annelida	Polychaeta		Spionidae	*Prionospio* sp. A
Annelida	Polychaeta		Spionidae	*Prionospio* sp. B
Annelida	Polychaeta		Spionidae	*Prionospio yuriel*
Annelida	Polychaeta		Spionidae	*Spiophanes* sp.
Annelida	Polychaeta		Sternaspidae	*Sternaspis scutata*
Annelida	Polychaeta		Syllidae	Exogoninae sp.
Annelida	Polychaeta		Terebellidae	Amphritinae
Annelida	Polychaeta		Terebellidae	*Artacama* sp.
Annelida	Polychaeta		Terebellidae	*Lysilla* sp.
Annelida	Polychaeta		Terebellidae	*Paralanice* ? sp.
Annelida	Polychaeta		Trichobranchidae	*Terebellides stroemii*
Cnidaria	Hydrozoa			*Obelia* sp.
Cnidaria	Hydrozoa			*Virgularia gracillima*
Crustacea	Amphipoda	Gammaridea	Ampeliscidae	*Ampelisca chiltoni*
Crustacea	Amphipoda	Gammaridea	Amphilochidae	Amphilochidae
Crustacea	Amphipoda	Gammaridea	Amphilochidae	*Peltopes peninsulae*
Crustacea	Amphipoda	Gammaridea	Aoridae	Aoridae indet gen. et sp.
Crustacea	Amphipoda	Gammaridea	Caprellidae	*Caprellina longicollis*
Crustacea	Amphipoda	Gammaridea	Isaeidae	*Gammaropsis* sp.
Crustacea	Amphipoda	Gammaridea	Isaeidae	*Haplocheira barbimana*
Crustacea	Amphipoda	Gammaridea	Ischyroceridae	Ischyroceridae
Crustacea	Amphipoda	Gammaridea	Liljeborgiidae	*Liljeborgia akaroica*
Crustacea	Amphipoda	Gammaridea	Lysianassidae	*Hippomedon* sp.
Crustacea	Amphipoda	Gammaridea	Melitidae	*Melita festiva*
Crustacea	Amphipoda	Gammaridea	Oedicerotidae	?*Sinoediceros* sp.
Crustacea	Amphipoda	Gammaridea	Paracalliopiidae	*Paracalliope novizealandiae*
Crustacea	Amphipoda	Gammaridea	Photidae	*Photis nigrocula*
Crustacea	Amphipoda	Gammaridea	Photidae	*Photis phaeocula*
Crustacea	Amphipoda	Gammaridea	Phoxocephalidae	*Proharpinia* sp. A
Crustacea	Amphipoda	Gammaridea	Phoxocephalidae	*Proharpinia* sp. B
Crustacea	Amphipoda	Gammaridea	Phoxocephalidae	*Torridoharpinia hurleyi*
Crustacea	Amphipoda	Gammaridea	Urothoidae	*Urothoe* sp.
Crustacea	Cumacea	Cumacea	Bodotriidae	?*Pomacuma* sp.
Crustacea	Cumacea	Cumacea	Bodotriidae	Pseudocumidae
Crustacea	Cumacea	Cumacea	Diastylidae	*Diastylis insularum*
Crustacea	Cumacea	Cumacea	Diastylidae	*Diastylopsis elongata*
Crustacea	Cumacea	Cumacea	Diastylidae	*Diastylopsis thilenuisi*
Crustacea	Cumacea	Cumacea	Leuconidae	Leuconidae indet.
Crustacea	Decapoda	Brachyura	Gonioplacidae	*Neommatocarcinus huttoni*
Crustacea	Decapoda	Brachyura	Hymenosomatidae	*Hymenosoma depressum*
Crustacea	Decapoda	Brachyura	Ocypodidae	*Macrophthalamus hirtipes*
Crustacea	Decapoda	Brachyura	Portunidae	*Liocarcinus corrugatus*
Crustacea	Decapoda	Brachyura	Portunidae	*Nectocarcinus antarcticus*
Crustacea	Decapoda	Reptantia	Axiidae	Axiidae
Crustacea	Decapoda	Reptantia	Crangonidae	*Pontophilis pilosoides*
Crustacea	Isopoda	Asellota	?Desmosomatidae	?Desmosomatidae sp.
Crustacea	Isopoda	Asellota	Munnidae	?*Pleurosignum* sp.
Crustacea	Isopoda	Isopoda	Cirolanidae	?*Cirolana* sp.
Crustacea	Isopoda	Sphaeromatidea	Sphaeromatidae	Sphaeromatidae
Crustacea	Isopoda	Valvifera	Arcturidae	Arcturidae sp. 2
Crustacea	Isopoda	Valvifera	Arcturidae	Arcturidae sp. A
Crustacea	Mysidacea			Mysidacea