Port of Lyttelton ecological monitoring: May 2003

NIWA Client Report: CHC2003-079
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Executive Summary

This report presents the results of a second ecological monitoring survey of the intertidal biota and soft-bottom benthic infauna within the Lyttelton port area. The survey aimed to contribute additional baseline data on the intertidal biota and subtidal benthic infauna, as well as identifying any adverse effects of port operations on the biota in the vicinity of the oil wharf.

All seven intertidal sites were surveyed at high, mid and low shore levels by free searches and photo-quadrats. Subtidal benthic infauna was sampled by taking three replicate anchor-box dredge samples at ten of the original stations, plus at a new station close to the oil wharf. The infauna was extracted by washing bottom sediments on a 0.5 mm sieve.

Analysis of intertidal data revealed few obvious differences between this and the initial survey conducted in February 2000. The prevalence of the green seaweed *Enteromorpha* sp. on upper shore rocks in 2003 compared with *Ulva* sp. in 2000 was probably a seasonal effect. Silt on low shore rocks at two sites appears to have had some effect on the biota, although its presence in 2000 was not recorded. Numerical analyses confirmed the close similarities between surveys, as well as revealing that one site differed appreciably from the others.

The benthic infauna comprised 29 taxa. Mud crabs dominated at all stations, along with a small clam and two polychaete worms. Infaunal abundances varied between 145 and 2250 m^{-2}, with 5-12 taxa present in any one sample. There were no obvious patterns to the distribution of the most abundant taxa, nor of the total fauna.

Numerical analyses of the 2003 data revealed significant differences between the infauna at some stations. Data for both years showed highest similarities among samples from the same year, rather than between samples from the same station between years. The different sampling methods between surveys probably account for these faunal differences.

The low shore intertidal biota near the oil wharf differed significantly from that at other sites, but there were no other differences between biota near the oil wharf and elsewhere in the harbour. Reasons for this difference are uncertain, but include the northerly aspect of this site, softer rock types and possible effects of port operations nearby.

A minimum of five replicate photo-quadrats is recommended for future intertidal monitoring surveys because of the high variability of intertidal biota on Lyttelton shores. Future surveys of the benthic infauna should use the same methods and 0.5 mm sieves that were employed in the 2003 survey. Better controls for both intertidal and infaunal surveys are advised.

1 Introduction

An initial ecological survey of the Port of Lyttelton operational area was undertaken in February 2000 to establish a baseline for future monitoring and management of the harbour by Environment Canterbury (ECan) under its Proposed Regional Coastal Environment Plan. Of particular concern to ECan at that time was the unauthorised discharge of contaminants that may adversely affect the environment and ecological communities inhabiting the harbour.

To this end, the subtidal benthos was sampled at 20 stations in and near the operational area in 2000, and the intertidal biota was surveyed at seven sites. This one-off survey provided an initial assessment of the ecological status of the area. However, biological systems, especially shallow marine benthos, are notoriously variable in both space and time. Consequently, repeat surveys (ideally at much the same time of year) are necessary to understand the nature and extent of such variation in order to identify the effects of discharges of contaminants and other human-induced disturbances.

The Port of Lyttelton lies at the head of Lyttelton Harbour (Te Whaka Raupo), a narrow, deep harbour occupying the collapsed crater of a large, extinct volcano opening to the sea on the northeast side of Banks Peninsula. Despite its length, ocean swells penetrate well into the harbour and wind waves, especially summer sea breezes from the northeast, create significant water movement at shallower depths. The outer portion of the port operational area is partially sheltered from the worst of this by a rock breakwater to seaward, whereas the inner harbour is very sheltered by both its narrow entrance and the breakwater.

Port activities have dominated the area since about 1880. All shores of the port area are now artificial, constructed of either concrete or rock. Several of the shores are also heavily shaded by wharves constructed over them. Subtidal bottom sediments are similarly heavily disturbed; dredging to establish and maintain adequate working depths (>12 m below MLW) for large shipping occurs over the entire operational area, with consequent major effects on the biota.

This report outlines the findings from a repeat survey of the Port of Lyttelton operational area that had two specific objectives:

1. To contribute additional ecological baseline data for the general area to facilitate detection of any future adverse ecological effects from unauthorised discharges.

2. To detect any adverse ecological effects that may have occurred from unauthorised discharges in the vicinity of the oil wharf.

The study was limited to surveying the benthic biota inhabiting intertidal rocky bottoms and subtidal mud bottoms in the Port of Lyttelton operational area. A selection of the original subtidal sampling stations (Figure 1) only was sampled so that statistically adequate replication could be incorporated into the sampling design. Note, all intertidal sites were surveyed, but data were extracted, analysed and reported for a subset of sites only (inner harbour, sites A-C) because of budgetary constraints. The survey did not include fishes.

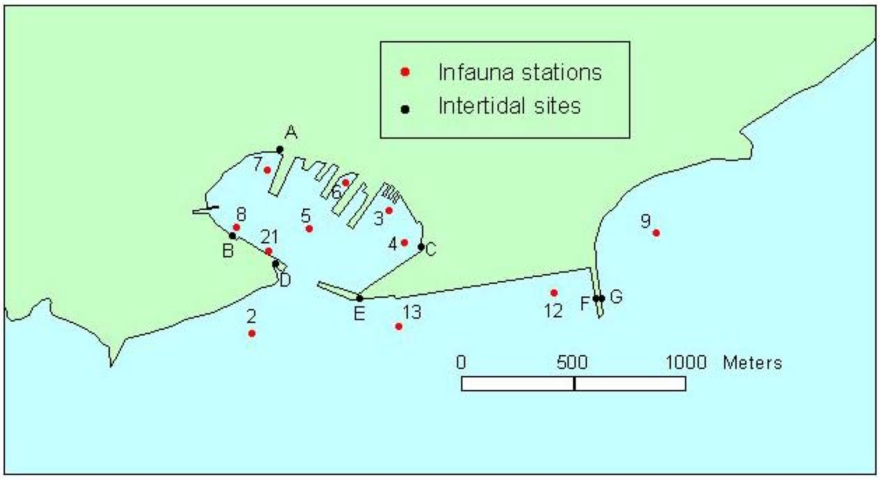


Figure 1: Lyttelton Port area showing subtidal infaunal sampling stations (2-21) and intertidal survey sites (A-G) (intertidal site A-C only reported here).

2 Methods

A reduced set of sampling stations was surveyed for subtidal infauna during this survey because of limited resources and the need for replicate sampling for meaningful analysis. Subtidal sampling station locations and the positions of intertidal sites were checked by DGPS to confirm initial locations and plotted (Figure 1, Appendix 1).

2.1 Intertidal

Intertidal sites were surveyed during low tides on 23 and 29 April 2003. The biota inhabiting intertidal rocky shores was surveyed at low, mid and high tide levels along one transect at each site. Two replicate 0.25 x 0.25 m quadrats were photographed at each level on each transect and other species present at each site recorded. In the laboratory, photographs were analysed to estimate percentage cover using the random dot method (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

Three replicate samples were taken from 11 stations, ten of those sampled during the 2000 survey (2-9, 12-13) and one new station (21, beside the oil wharf) on 2 May 2003. Each faunal sample was washed through a 0.5 mm sieve and the fauna preserved in 5 % formalin for subsequent processing. In the laboratory, animals extracted from each replicate sample were sorted, identified as far as practical and counted. The resulting data were consolidated into a database before analysis to determine patterns of community distributions using the PRIMER statistical software package, as well as other general applications. Taxa occurring in only one sample were excluded from numerical analyses. Cluster analyses were performed on Bray-Curtis similarity values calculated from square-root transformed data and using the group-average algorithm.

All data, including intertidal photographs, are archived within NIWA's data management system. Labelled voucher specimens are retained within the NIWA reference collection as part of NIWA's project management and quality assurance practice.

A separate sediment sample from each station was examined for sediment colour, stratification and any other significant features, and stored frozen for subsequent sediment particle size analysis by ECan.

3 Results

3.1 Intertidal

3.1.1 General descriptions

The shores at each site tended to be very variable in algal cover and the abundance of animals. Especially notable were marked differences between adjacent boulders, in part, probably due to differences in the nature of the rock at different sites on these shores. Most of the rock has been transported to its present site during various phases of construction, so that the rock on any one shore varies from hard, finely textured basalt to smooth concrete to irregular broken concrete surfaces to the friable, coarsely irregular surfaces of some volcanic aggregate.

(a) Site A

The shore consists of large boulders, grading to smaller boulders and pebbles on the low shore. Upper shore boulders (0.5-1 m diameter) were mostly bare, bereft of littorinid snails and limpets. Shaded sides of some boulders were covered with dense mats of the bright green alga *Enteromorpha* sp.

Mid shore boulder tops were mostly bare, but their shaded sides had up to 100 % cover of *Enteromorpha* sp. Some barnacles (*Chamaesipho columna*), occasional tube worms (*Pomatocerus caeruleus*), and sparse *Bostrychia arbuscula* were also present here, especially low down on the shaded sides of boulders. Beneath cobbles and boulders lying between these larger boulders there were abundant false crabs (*Petrolisthes elongatus)*, topshells (*Melagraphia aethiops*) and some snake-skin chitons (*Chiton pelliserpentis*).

The low shore consisted of boulders and cobbles. An almost complete layer of fine silt covered the tops of low shore boulders, but some silt-covered brown and green algae (*Enteromorpha* sp), siphonariid limpets (*Siphonaria australis*) and a few barnacles (*Chamaesipho columna*) lived within this layer. On the sides of larger, low shore boulders and among cobbles and pebbles between them, *Melagraphia aethiops*, *Pomatocerus caeruleus* and the red crustose bryozoan were common. Crabs, however, notably *Petrolisthes elongatus*, were absent. Some small starfish (*Patiriella regularis*) were present under heavily shaded overhangs. Larger algae found in the sublittoral fringe included *Ulva* sp. and *Sargassum sinclairi*.

(b) Site B

The moderately sloping rocky shore at this site consisted of large cobbles to small boulders. Upper shore boulders were mostly bare, except for sparse littorinid snails (*Nodilittorina antipodum* and *N. cincta*) on their crests.

A well-developed barnacle zone, covering 60-100 % of available surfaces characterized mid shore levels at this site. Limpets (*Cellana denticulata* and *C. radians*) were common on the sides of these boulders. False crabs (*Petrolisthes elongatus*) were abundant under cobbles between boulders at this level.

Small boulders making up the low shore at this site were mostly bare. A very thin film of fine silt covered their tops, with sparse barnacle (*Chamaesipho columna*) cover. Small animals (*Pomatocerus caeruleus*, *Chiton pelliserpentis*, *Siphonaria australis*) were sparse on the sides of these rocks. False crabs (*Petrolisthes elongatus*) were present under cobbles and smaller rocks in between larger boulders. A green seaweed (*Ulva* sp.) and an unidentified fine brown alga were common in the sublittoral fringe. Mussels were not present.

(c) Site C

The steeply sloping shore at this westerly-facing site consisted of recently deposited rubble and debris, including local bedrock fragments, polished marble fragments, concrete rubble, bricks and slabs of bitumen, ranging in size from pebbles to boulders. Considerable amounts of flotsam appear to accumulate on this shore and bark material arrives from the log-handling area above.

Upper shore levels were inhabited only by the shore crab (*Cyclograpsus lavauxi*), which was found under rocks and amongst the considerable amounts of wood, plastic and bark debris, and drift brown algae (*Macrocystic pyrifera, Durvillaea antarctica*). Littorinid snails appear to be absent from upper shore levels at this site.

The tops of most mid-shore rocks and boulders were covered with a dense short turf of the green seaweed *Enteromorpha* sp., but animals were absent. Shaded rock surfaces supported luxuriant *Enteromorpha* sp. mats and some patches of the brown-coloured red seaweed *Bostrychia arbuscula*. The large pulmonate limpet *Benhamina obliquata*, topshells (*Melagraphia aethiops*) and the tube worm *Pomatocerus caeruleus*, along with occasional limpets (*Cellana denticulata*), were present in shaded crevices. Barnacles (*Chamaesipho columna*) were found only on the undersides of boulders and cobbles, where *Melagraphia aethiops* and *Petrolisthes elongatus* were also present.

Low shore rocks at this site varied widely in the extent and nature of cover, whilst small cobbles and large pebbles between the small boulders were largely free of algal cover. The tops and sides of some boulders supported dense algae, notably the fine green *Enteromorpha* sp. In patches, the green sea lettuce (*Ulva* sp.) provided partial to almost complete cover. Larger rocks had a layer of fine silt over their upper surfaces with finely filamentous green and red algae growing through this. Large siphonariid limpets were found in these situations, along with sparse green chitons (*Amaurochiton glauca*) and topshells (*Cantharidus* sp.). In crevices and on the tops and sides of other rocks, tubeworms (*Pomatocerus caeruleus* and the small spiral worm, *Spirobis* sp.) were abundant. Topshells (*Melagraphia aethiops*) and siphonariid limpets (*Siphonaria zealandica*) were also common amongst the tube worms in these situations. Other larger seaweeds (*Undaria pinatifida, Codium fragil*e) were apparent.

3.1.2 Percentage cover

(a) High shore

Numbers of species observed and percentage cover estimates were lower than those recorded in general searches at each site, largely because free searches explored more habitats than could be examined by quadrats. High shore levels were dominated by bare rock at all sites (Figure 2), although this was covered by drift seaweeds in one quadrat at Site C. The fine green seaweed, *Enteromorpha* sp., covered 10-30 % of high shore rock surfaces at Sites A and C, but not at Site B, perhaps because the former were more shaded (southerly and westerly aspects, respectively) than Site B (northerly aspect). Littorinid snails were found only at Site B and barnacles (*Chamaesipho columna*) were infrequent at high shore levels at all sites.

Differences between sites over times are few. The most obvious difference, the presence of *Ulva* sp. and the absence of *Enteromorpha* sp. in 2000, and the converse at Sites A and C in 2003, appears due to an autumn-winter increase in the abundance of *Enteromorpha* sp. Thus, the only difference of note was the presence of barnacles at Sites A and C in 2000, and their absence or reduced cover in 2003 (Figure 2).

b. Mid shore

Cover by biota was greater at mid shore levels than on high shore rocks (Figure 2), although there was considerable variation. Bare rock still predominated, except at Site C. Cover by algae (*Enteromorpha* sp.; some apparently misidentified as *Ulva* sp. in 2000) was considerably greater, reaching about 60 % at the more shaded Sites A and C. The calcareous worm, *Pomatocerus caeruleus*, and barnacles (*Chamaesipho columna*) were present at most sites in both years, with the barnacles covering up to half of the rock surfaces, especially at Site B.

There are no obvious differences between surveys, largely due to the variation within each site at each time. The only difference of any note appears to be the absence of barnacles at Site C during 2003, whereas they covered 25 % of rock surfaces in one of two quadrats in 2000 (Figure 2).

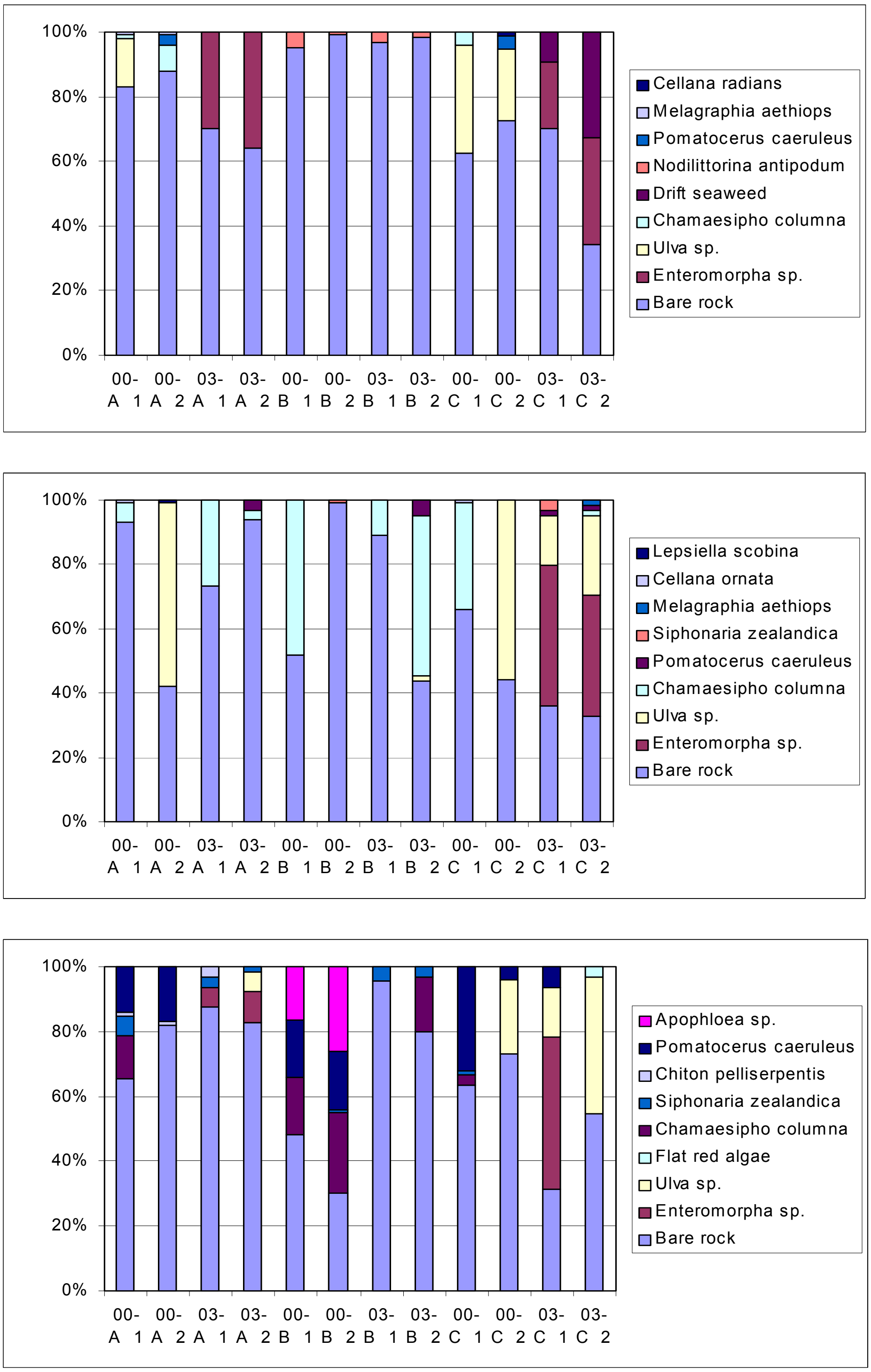


Figure 2: **Percent cover estimates of both replicates in each year (00, 2000; 03, 2003) for sites A-C high (top), mid (middle) and low (bottom) shore levels (1, 2 represent replicate quadrats).**

(c) Low shore

Survey results from both years indicate markedly lower cover of biota at Site A than at the other two sites (Figure 2). There are also marked differences in the composition of biota at each site, probably due to the considerable spatial heterogeneity of low shore biota on rocky shores.

3.1.3 Differences between 2000 and 2003

Some differences apparent between surveys merit comment, although they may result from the high variability of biota at these levels and the low replication of sampling. Firstly, a sediment layer covered much of the rock surface at all three sites during 2003, but was not recorded in 2000. Secondly, *Pomatocerus caeruleus* comprised about 15-18 % of cover at Site A during 2000, but its recorded cover was considerably lower during 2003 (Figure 2). However, free searches recorded this tubeworm at Site A during 2003 and they were abundant in one of the three low shore photos. Thirdly, barnacles, siphonariid limpets and a red alga (*Apophloea* sp.) comprised 15-20 % of the cover at Site B during 2000, but were absent or reduced in the most recent survey, when a film of sediment was found over much of the rock surface. Fourthly, algae were more prevalent at Site C in 2003 than during 2000 (Figure 2). Fifthly, mussels (*Mytilus galloprovincialis* and *Aulacomya ater*), present on low shore rocks at Site B in 2000, were absent in 2003.

3.1.4 Numerical analysis

Cluster analysis revealed that all sites and all levels were quite similar (>45 % similarity) (Figure 3). Although many replicates are closely grouped at high similarities, others are widely spaced, with low similarities. However, several tendencies are apparent.

- The high shore biota at Site B was remarkably similar within and between surveys (c. 75 % similarity), but very different (<5 % similarity) from the biota at all other sites and levels in both surveys.

- Biota inhabiting high shore rocks was quite homogeneous at Sites A and C (within sites, c. 75 % similarity; between sites, 60 % similarity) in 2003, but very different (<5 % similarity) from the homogeneous biota at the same level at Site B. In contrast, the high shore biota at Site A in 2000 was very variable (c. 10 % similarity), but less variable (c. 65 % similarity) at Site C.

- There was considerable variation (10 % similarlity) in the mid shore biota at Site A in 2000, but greater similarity (c. 50 %) in 2003. Biota at mid shore levels at Sites B and C showed much the same pattern.

- The low shore biota at Site A was relatively homogeneous (60 % similarity) in both surveys, but very different (c. 10 % similarity) between surveys. At Site B, the biota appears relatively homogeneous in 2000, but quite heterogeneous (10 % similarity) in the 2003 survey. The biota was very heterogeneous within and between surveys at Site C.

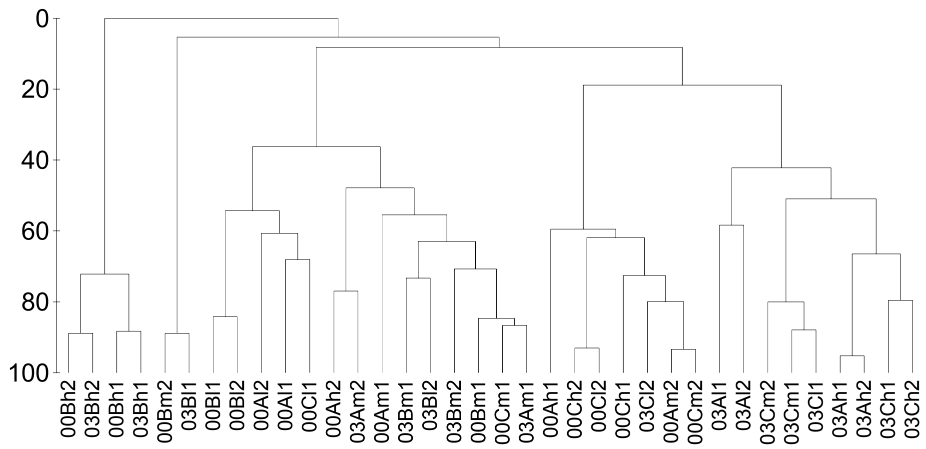


Figure 3: **Cluster analysis dendrogram showing levels of similarity (%, y-axis) of intertidal biota between years (00, 2000; 03, 2003), different sites (A-C), levels (h, high; m, mid shore; l, low shore) and replicates (1, 2) at Lyttelton Harbour.**

The multidimensional scaling (MDS) representation of the similarities between replicates, levels, sites and years (Figure 4) shows two very tight clusters: one for Site B high shore biota in both years and the other for all other biota. Thus, the MDS plot confirms the patterns seen in the cluster analysis.

Cluster analysis (Figure 5) and MDS (Figure 6) using mean cover values for levels at sites in each year confirm the close similarity between surveys for two levels for Site B, and the distinctiveness of the biota at this site. It also shows that the high shore

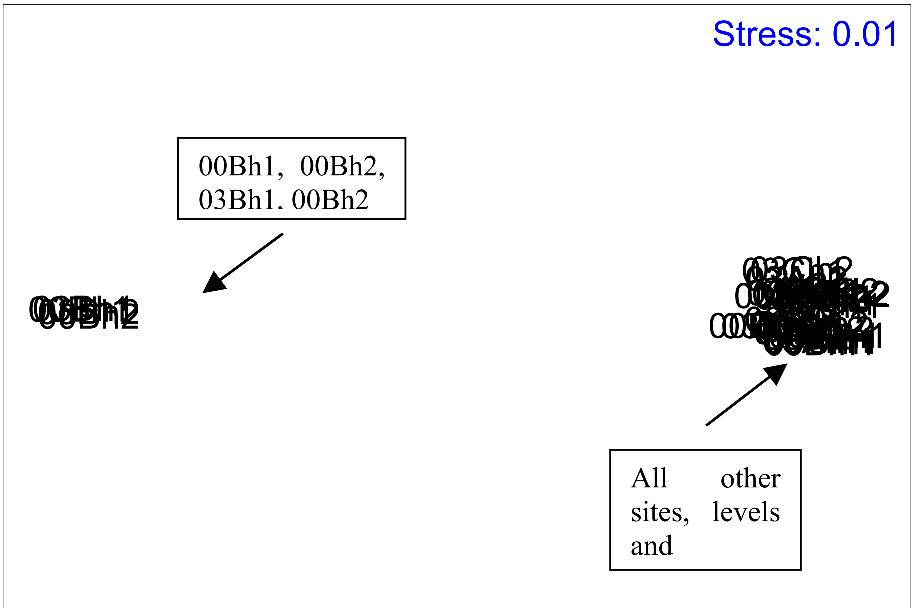


Figure 4.: **Multidimensional scaling representation of relationships between intertidal biota at Lyttelton Harbour between years (00, 2000; 03, 2003), different sites (A-C), levels (h, high; m, mid shore; l, low shore) and replicates (1, 2).**

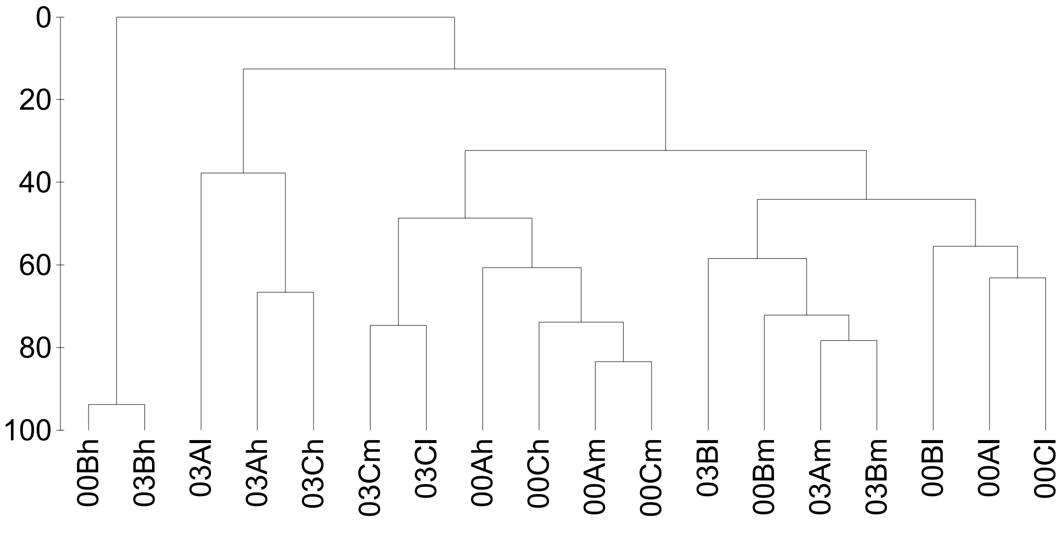


Figure 5: **Cluster analysis dendrogram showing levels of similarity (%, y-axis) of intertidal biota between years (00, 2000; 03, 2003), different sites (A-C), levels (h, high; m, mid shore; l, low shore) and replicates (1,2) at Lyttelton Harbour using mean estimates (n = 2) of cover.**

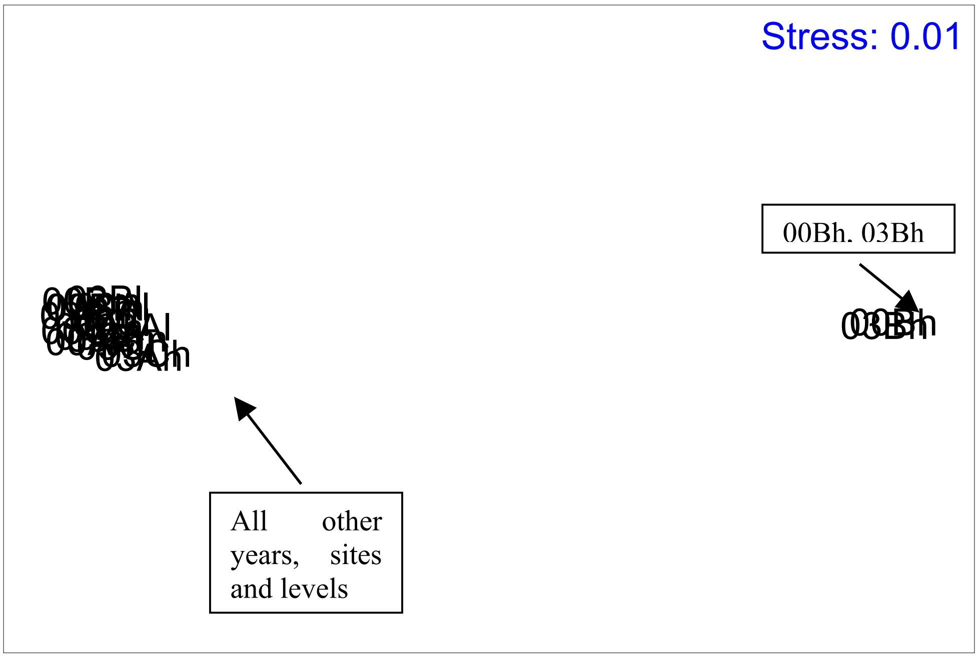


Figure 6: **Multidimensional scaling plot of similarities of intertidal biota in 2000 (00) and 2003 (03), Sites A-C, and shore levels (h, high; m, mid shore; l, low shore) at Lyttelton Harbour based on mean estimates (n = 2) of cover.**

biota at Sites A and C was very similar (60-70 % similarity) in each survey, but that there was considerable difference (c. 15 % similarity) between surveys. Mid shore biota at Site B also appears similar between years (c. 70 %) (Figure 5). Mid shore biota was only moderately similar (50 %) between years at Site C, and even less similar (c. 35 %) between years at Site A. The pattern for low shore biota further reflects the patterns for high shore biotas at each site: the biota at Site B was more similar between years (50 % similarity) than that observed at Sites A and C (c. 15 % similarity) (Figure 5).

There are several possible explanations for this pattern. The decreased similarity between years at lower shore levels found at Site B is probably attributable to the increased diversity, increased variability and increased susceptibility to disturbance events at lower levels on the shore. This pattern is likely to occur across all sites, although other factors have probably intervened to alter the biota between years. One of these factors is the probable confusion of some algal taxa. Some environmental perturbation is another possible factor accounting for these differences between years. Although this cannot be determined from these data, the thin (c. 1 mm) layer of fine sediment covering mid to low shore rocks at Site A may have induced changes in the biota at this site since the original survey.

Statistical analyses of the differences in intertidal biota between years (two-way analysis of similarities) for each shore level indicated no significant differences between years (Global R = 0.22-0.60, p = 0.1-1.0). Differences between sites were significant, however, for low shore biota (Global R = 0.58, p = 0.13), but not for high or mid shore levels (Global R = 0.11-0.89, p = 0.36-.090).

3.2 Subtidal

A total of 29 taxa (Appendix 3) was identified within the benthos at the 11 stations sampled in 2003. Most of these taxa were present in just one or two replicate samples (Figure 7), with just 14 taxa occurring in three or more replicates. Four taxa were present in most samples: the mud crab *Macrophthalamus hirtipes*, the small bivalve *Theora lubrica*, and the polychaetes Sigalionidae and *Aglaophamus* sp. Other widely occurring taxa were the polychaete worms Lumbrineridae, Cossuridae and Trichobranchidae (Appendix 3).

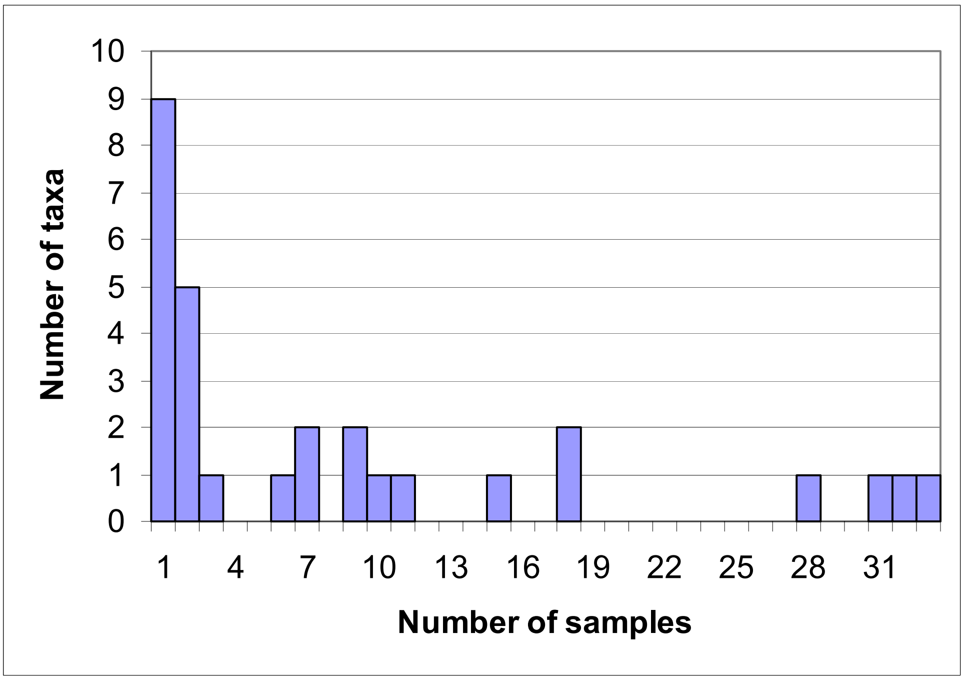
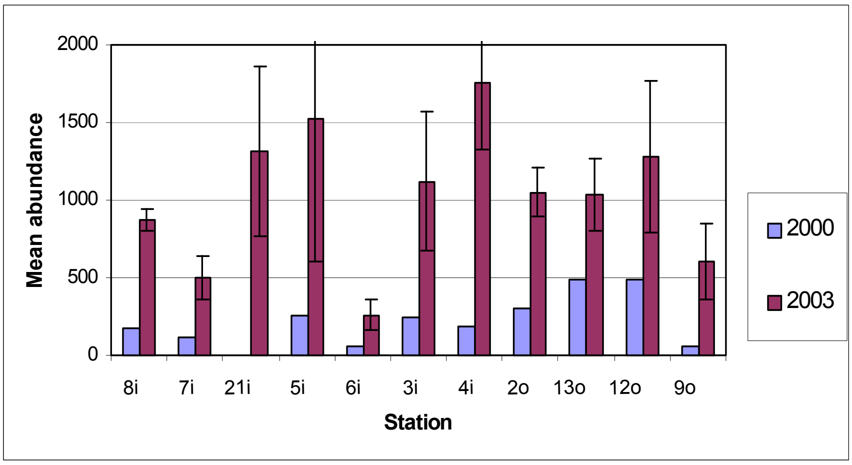


Figure 7: Numbers of taxa present in different numbers of replicate samples from Lyttelton Harbour in May, 2003 .

Abundances of infauna varied between 145 and 2255 m^{-2} in individual samples, but mean densities ranged between 260 and 1760 animals m^{-2} (Stations 6 and 4, respectively) (Figure 8), although variation within stations was often wide. There was no obvious pattern in the abundances of infauna between stations, except that densities were more variable among inner harbour stations compared with those in the outer port area during 2003. Comparison with abundances reported from the 2000 survey are difficult due to the different sampling methods used (different sampling devices and mesh sizes) and the lack of replication during 2000. Although the 2000 survey sampled a larger volume of sediment, reported densities were higher in 2003, probably due to the smaller mesh size used for extracting the biota (0.5 mm cf. 2.0 mm in 2000).

The diversity of infauna within individual samples ranged from 5 to 12 taxa in 2003, and the mean number of taxa per station was between 6.3 and 9.3 (Figure 8). Again, there was no obvious pattern to this variation in diversity in 2003. Diversity was lower in the single sample collected from most stations in 2003 (Figure 8).



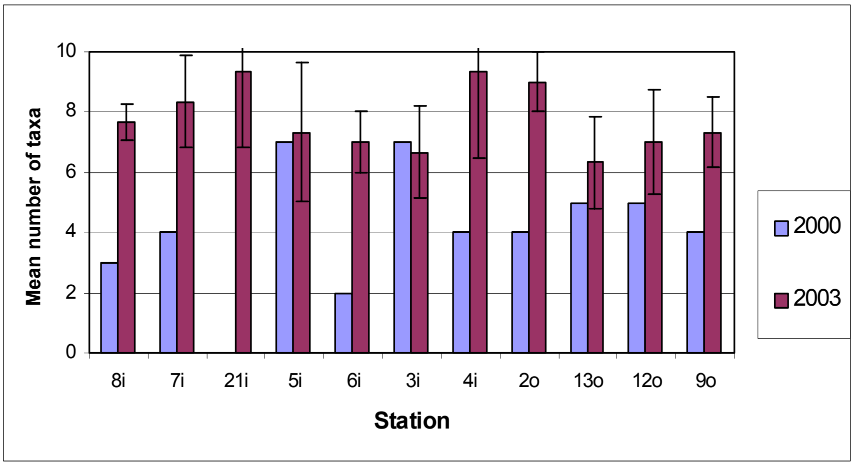
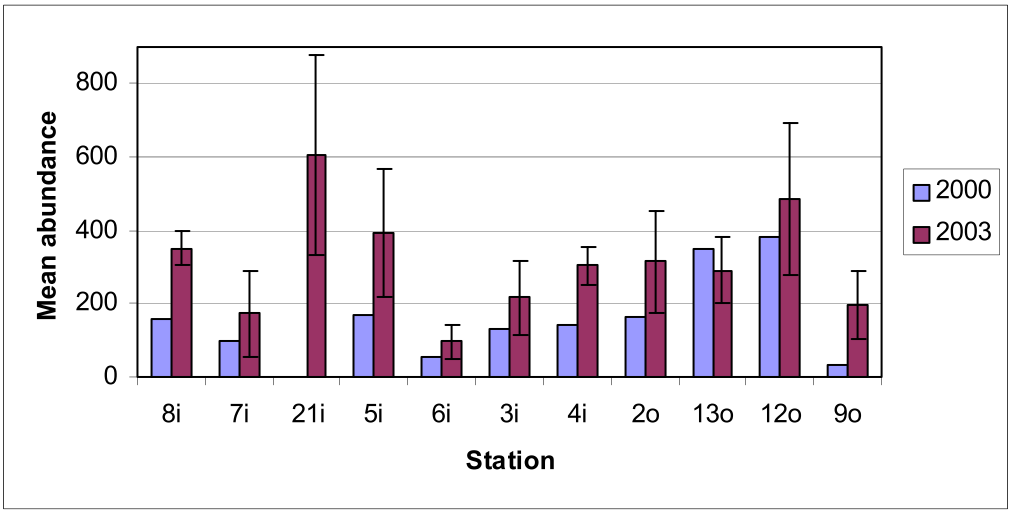


Figure 8: **Mean abundance (top) and diversity (bottom) of infauna at each station in Lyttelton Harbour (2000: numbers per dredge sample, n = 1; 2003: numbers m^{-2}, ±1 SD, n = 3), stations arranged west to east for inner harbour (i) and outer port area (o).**

Abundances of the two commonest and widespread taxa, *Macrophthalamus hirtipes* and *Theora lubrica* show no obvious pattern amongst the stations (Figure 9). Both species appear much more abundant in 2003 than in 2000, but differences in sampling methods probably explain much of this.



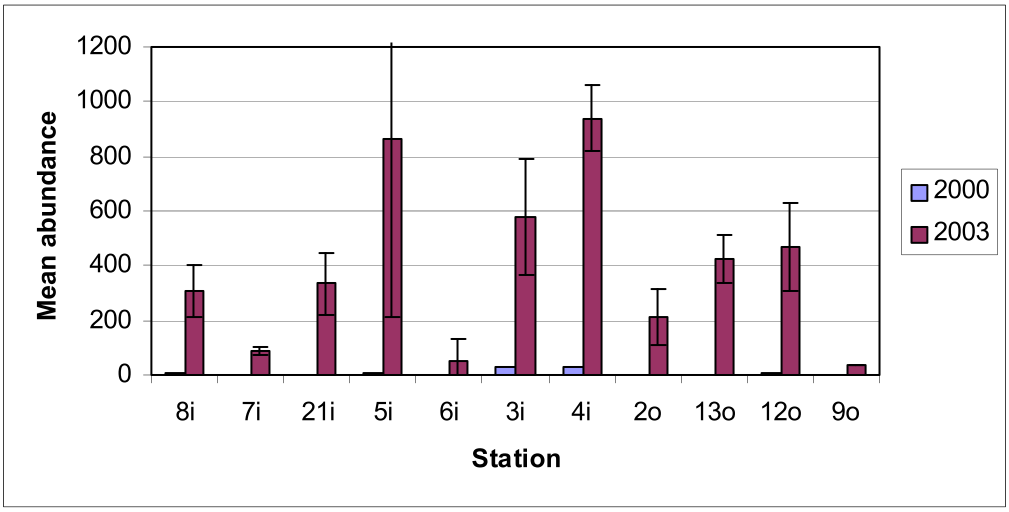


Figure 9: **Mean abundances of the mud crab, *Macrophthalamus hirtipes*, (top) and the small bivalve *Theora lubrica* (bottom), at inner harbour (i) and outer (o) each station during each sampling in the Lyttelton Port area (2000: numbers per dredge sample, n = 1; 2003: numbers m^{-2}, ±1 SD, n = 3).**

Clustering of samples and replicates from 2003 based on similarities calculated from density data showed that replicates from some stations differed appreciably from each other (e.g., Station 6, 40 % similarity), whereas replicates from some other stations were grouped at high similarities (e.g., Station 8, >75 % similarity) (Figure 10). Replicates from most other stations were grouped at >65 % similarity. High similarities between replicates from different stations and the wide spacing of replicates the same station in the dendrogram reveal that the fauna at most stations was very similar (i.e., similarities between samples from other stations are mostly higher than similarities between replicate samples from the same station). Thus, this dendrogram tells us that the infauna at Station 6 was most different from that at all others, but is also very heterogeneous. Similarly, the fauna at Station 9 is quite different from that at Station 6 and most other stations. Two other clusters are apparent: one includes Stations 3, 4 and 8, and another comprises Stations 5, 12 and 21. However, both of these clusters are linked at >65 % similarity. The remaining stations (2, 5, 7, 13) appear to overlap with the other clusters (Figure 10), indicating no meaningful differences between the faunas at these stations.

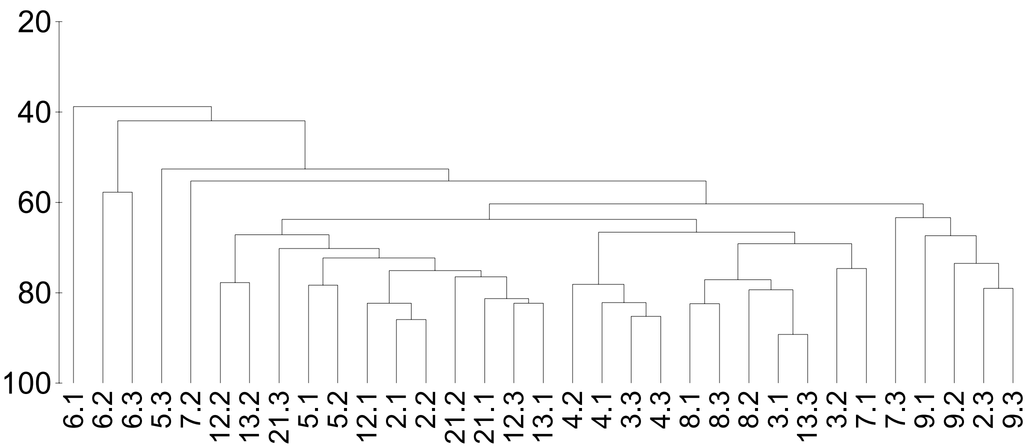


Figure 10: Cluster analysis dendrogram showing levels of similarity (%, y-axis) between infauna in replicate samples from all Lyttelton Harbour monitoring stations sampled during 2003.

A multidimensional scaling plot of these samples based on their faunal similarities (Figure 11) confirms the similarity of most samples and the distinctiveness of Station 6 infauna seen in the dendrogram. Analysis of similarities for these data indicated statistically significant differences between stations (Global R = 0.45, p = .001), but that differences between stations within and outside the inner harbour were not significant (Global R = 0.067, p = 0.156).

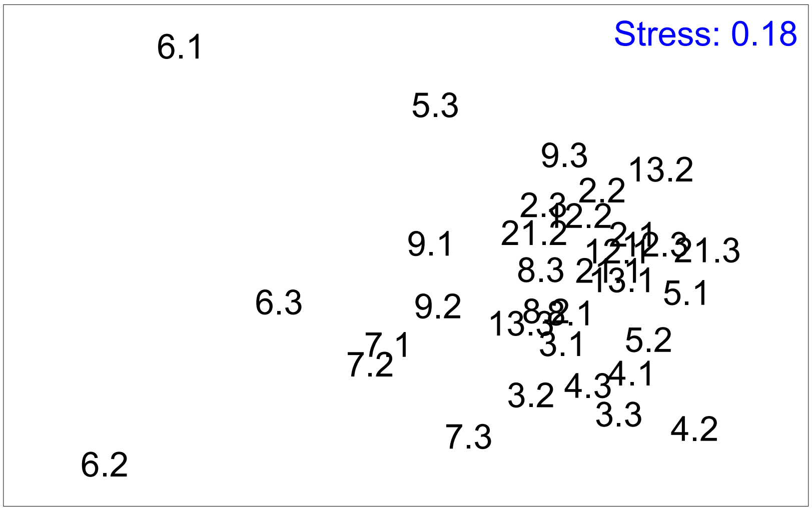


Figure 11: **Multidimensional scaling representation of relationships between infauna in replicate samples from Lyttelton Harbour, 2003.**

Data for both years were combined, replicates pooled and converted to presence-absences to minimise differences in the efficiencies of sampling protocols in each of the two surveys. Cluster analysis of stations in both years using similarities calculated from these faunal presence-absence data (Figure 12) arrayed station-years in six groups at about 60-65 % similarity:

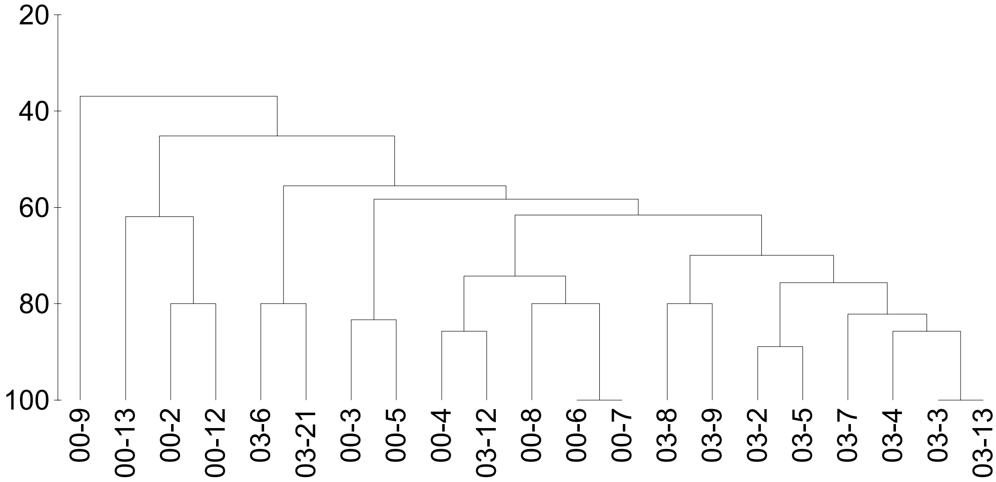


Figure 12: **Cluster analysis dendrogram showing patterns of similarity (%, y-axis) between infauna at all Lyttelton Harbour monitoring stations during the 2000 (00, n = 1) and 2003 (03, n = 3) using presence-absence data. Note, station 21 not sampled in 2000.**

- Station 9 (2000) located in its own group having about 35 % similarity with other stations, and with itself in 2003.

- Stations 2, 12 and 13 (2000), all stations within the dredged area outside the inner harbour, were located in a second group sharing 60-80 % similarity with each other, but just 45 % similarity with themselves in the second survey.

- Stations 6 and 21 (2003) were paired, having 55 % similarity with the fauna at other stations.

- A fourth group comprising Stations 3 and 5 (2000) sharing >70 % similarity with each other and c. 60 % with most other stations.

- Four 2000 (4, 6, 7, 8) and one 2003 (12) stations clustered at >75 % similarity.

- A set of eight 2003 stations (2, 3, 4, 5, 7, 8, 13) sharing >70 % similarity with each other.

This arrangement is replicated by the MDS plot (Figure 13). Within both the cluster analysis and the MDS, faunal samples are clustered more by year than by location, with only one pair (00-4 and 03-12) having greatest similarity with a sample from a different year. Thus, samples from the 2000 survey are allocated amongst four clusters, whilst those from 2003 fell into two groups (one also includes sample 03-12). Thus, differences between years were significant (ANOSIM, Global R = 0.205, p = 0.013), but differences between inner and outer harbour locations were not (Global R = 0.105, p = 0.203).

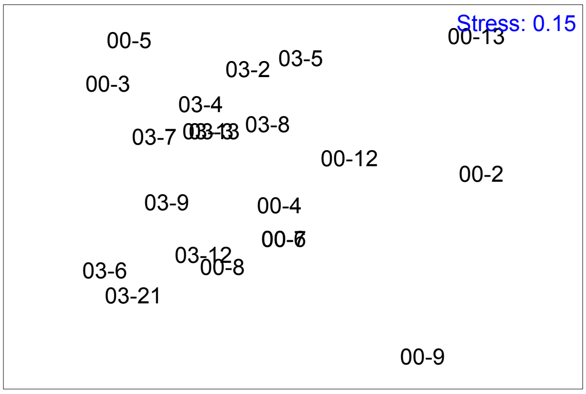


Figure 13: Multidimensional scaling representation of relationships between infauna at all Lyttelton Harbour monitoring stations during the 2000 (00, n = 1) and 2003 (03, n = 3) using presence-absence data. Note, station 21 not sampled in 2000.

4 Conclusions

Few differences were found between the biota at the three intertidal sites between years. The apparent replacement of *Ulva* sp. at mid and upper shore levels by *Enteromorpha* sp. in 2003 seems most likely due to seasonal differences in the occurrence of these two algae, rather than attributable to some environmental effect. Mis-identification of *Enteromorpha* sp. as *Ulva* sp. is possible, but seems unlikely because of their quite different habits. There was some evidence of reduced barnacle cover at Sites A and C in 2003 compared with 2000, but more intensive sampling at both times would be necessary to confirm this observation. However, the layer of silt covering intertidal rocks at Site A could well affect the settlement and survival of barnacles and other organisms on these shores. Mussels were absent from low shore rocks at Site B in 2003, but present in 2000. However, mussel cover was very low in 2000, suggesting that this site may be marginally suitable habitat with infrequent recruitment. Alternatively, their scarcity may mean that they were simply not found during 2003.

Numerical analyses of intertidal biota cover on these shores revealed a generally high variability within each level at each site, so that differences between levels, sites and years could not be resolved adequately. Given the high within-level variability observed here and characteristic of rocky shore biota universally (Underwood 1992, 1995), considerably greater replication is required, especially if this monitoring programme seeks to identify change attributable to port activities. A minimum of five replicate quadrats to estimate community composition at each level at each site seems essential, and as many as ten may be desirable. In addition, equivalent data from one or more control sites beyond the immediate reach of port operations is essential if any observed changes are to be attributed to port-related activities (Underwood 1992). The original survey included one control site on the seaward side of the Cashin Quay breakwater that normally should be included in the survey and analysis. Therefore, future monitoring surveys should be of sufficient scale to include both control sites and greater replication in order to be effective.

The benthic infaunal biodiversity within the port area was low compared with that elsewhere in Lyttelton Harbour (Knight, 1974) and within similar situations elsewhere around Banks Peninsula (e.g., Fenwick and Cole 2001; Fenwick and Ross 2002). Only 29 taxa were found in the present survey of Lyttelton port area, whereas 114 taxa are reported from Lyttelton Harbour, as a whole. The benthic infauna comprised 35-47 taxa within three areas in adjacent Port Levy. Infaunal diversity in Pigeon Bay varied widely from 17 and 20 taxa at more sheltered sites further into that harbour, to 58 taxa at more seaward locations (Fenwick and Cole 2001; Fenwick and Ross 2002).

Infaunal densities (260-1760 m^{-2}) were slightly lower in the port area compared with Pigeon Bay (400-2800 m^{-2}) (Fenwick and Cole 2001), although densities at most port stations during 2003 were within 900-1500 individiuals m^{-2}. Further, the composition of the infauna within the Lyttelton port area is generally similar to that found in these other harbours. The two dominant species within the port area (*Macrophthalamus hirtipes* and *Theora lubrica*) are consistent members of infaunal communities at adjacent harbours, often numerically dominating the benthos (Fenwick and Cole 2001).

The same number of taxa was reported from the 2000 survey (Handley et al. 2000) as was distinguished in 2003, although some species were found in only one of the two surveys. Dominant taxa were similar in both surveys (*Macrophthalamus hirtipes*, *Theora lubrica*, Sigalionidae, *Aglaophamus* sp./Nephtyidae), but numbers are not strictly comparable because of different sampling methods and sieve sizes.

Statistical analyses showed that there was considerable variation within stations (between replicates), and that this variation[1] was often as great as that between stations. However, it was clear that the infauna at Station 6 in 2003 differed appreciably from that at other stations, and that the infauna at all other stations shared considerable similarity with each other.

Comparisons between years showed a statistically significant grouping of the infauna by years rather than station locations, indicating that differences in sampling and sample processing had a marked effect on the results or that the fauna had changed substantially over the entire port area. The former explanation seems more likely because of the substantial effect that dredge types and sieve sizes (e.g., Holme and McIntyre 1971; Gage et al. 2002) have on estimates of benthic community compositions and abundances. Thus, subsequent surveys using the methods established here should provide a statistically sound basis for monitoring future changes in the infauna within the Lyttelton port area.

The most recent sampling produced no evidence of any differences in the infauna in the vicinity of the oil wharf compared with that at other stations. However, low shore intertidal biota at this site (Site B) differed significantly from that at other sites. Reasons for this difference are unclear. This site faced north, so that its rocks probably dry out more often compared with the other two sites. Also, much of the rock at this

[1] It is important to note that the similarity scale used in cluster analysis is relative to the similarity of the most different items being clustered and has no absolute meaning. Thus, similarity scales appearing in different cluster analyses are comparable in a relative sense only.

site was soft and friable, making it less suitable for attached organisms. Minor spill events from the oil wharf and other port-related activities (e.g., proximity to the graving dock) may contribute to the differences observed, but the relative importance of pollution-related and other factors in these ecological differences are unknown.

5 Acknowledgments

I am grateful to and wish to thank the several people whose willing assistance in various ways enabled completion of this project on time. Lyttelton Port Company staff, notably Neil Garnett and Michael Barnett, assisted with safe access to the harbour area, and Hal Upton kindly provided facilities for processing samples. Oli Floerl made himself available to help with the fieldwork, but was prevented from enjoying the mud by mechanical failure. Amanda Byrne (ECan) and Steve Fox willingly assisted with fieldwork, working efficiently and cheerfully, despite the mud. Anna Tovey sorted the infaunal samples from the mud, identified the molluscs and analysed the photo-quadrats. Stephen Brown identified the polychaetes. Katie Image prepared the map of sampling stations. Paul Sagar reviewed the draft report and offered several helpful suggestions. Malcolm Main (ECan) provided several useful comments and observations that improved the final report. As always, Carol Whaitiri contributed substantially by formatting the document.

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Appendix 1: Locations of intertidal survey sites and subtidal benthos sampling stations for the 2003 Lyttelton Port area monitoring survey.

I	NZ Grid reference					Sediment layers			
	Easting	Northing	Latitude ° South	Longitude ° East	Depth (m)	Surface colour	Surface depth (cm)	Subsurface colour	H_2S
Intertidal									
A	2487068	5733687	43.60559	172.7157					
B	2486861	5733302	43.60904	172.7131					
C	2487700	5733254	43.6095	172.7235					
D	2487053	5733178	43.61017	172.7155					
E	2487423	5733026	43.61155	172.7201					
F	2488476	5733023	43.6116	172.7331					
G	2488497	5733027	43.61157	172.7334					
Subtidal									
2	2486948	5732870	43.61293	172.7142	6.1	brown	2.5	light grey	No
3	2487553	5733418	43.60802	172.7217	10.1	brown	3	dark grey	Yes
4	2487622	5733274	43.60932	172.7225	10.7	brown	3	grey	Yes
5	2487198	5733338	43.60873	172.7173	11.3	brown	3	grey	No
6	2487364	5733540	43.60692	172.7194	10.5	brown	3	grey	No
7	2487015	5733596	43.6064	172.715	8.5	brown	2	dark grey	Yes
8	2486880	5733340	43.6087	172.7134	10.7	brown	3	grey	Yes
9	2488740	5733317	43.60897	172.7364	8.2	brown	1.5	grey	No
12	2488286	5733049	43.61137	172.7308	12.2	brown	2	dark grey	Yes
13	2487597	5732900	43.61268	172.7222	12.5	brown	2	dark grey	Yes
21	2487019	5733239	43.60962	172.7151	12	brown	2	dark grey	Yes

Appendix 2.1: Percent cover of each taxon at each shore level at intertidal Site A, Lyttelton por t area, April 2003.

	A hi 1	A hi 2	A low 1	A low 2	A mid 1	A mid 2
Bare rock	70	64	0	53	73	94
*Enteromorph*a sp.	30	36	6	9	0	0
Ulva sp.	0	0	0	6	0	0
Red alga	0	0	0	0	0	0
Chamaesipho columna	0	0	0	0	27	3
Hormosira banksii (drift)	0	0	0	0	0	0
Macrocystis pyrifera (drift)	0	0	0	0	0	0
Siphonaria zealandica	0	0	3	2	0	0
Chiton pelliserpentis	0	0	3	0	0	0
Nodilittorna antipodum	0	0	0	0	0	0
Melagraphia aethiops	0	0	0	0	0	0
Pomatocerus caeruleus	0	0	0	0	0	3
sediment film on rock	0	0	66	6	0	0

Appendix 2.2: Percent cover of each taxon at each shore level at intertidal Site B, Lyttelton port area, April 2003.

	B hi 1	B hi 2	B low 1	B low 2	B mid 1	B mid 2
Bare rock	97	98	33	75	89	44
Enteromorpha sp.	0	0	0	0	0	0
Ulva sp.	0	0	0	0	0	2
Red alga	0	0	0	0	0	0
Chamaesipho columna	0	0	0	16	11	50
Hormosira banksii (drift)	0	0	0	0	0	0
Macrocystis pyrifera (drift)	0	0	0	0	0	0
Siphonaria zealandica	0	0	2	3	0	0
Chiton pelliserpentis	0	0	0	0	0	0
Nodilittorna antipodum	3	2	0	0	0	0
Melagraphia aethiops	0	0	0	0	0	0
Pomatocerus caeruleus	0	0	0	0	0	5
sediment film on rock	0	0	66	6	0	0

Appendix 2.3: Percent cover of each taxon at each shore level at intertidal Site C, Lyttelton port area, April 2003.

	C hi 1	C hi 2	C low 1	C low 2	C mid 1	C mid 2
Bare rock	70	34	27	16	36	33
Enteromorpha sp.	20	33	47	0	44	38
Ulva sp.	0	0	16	42	16	25
Red alga	0	0	0	3	0	0
Chamaesipho columna	0	0	0	0	0	2
Hormosira banksii (drift)	6	0	0	0	0	0
Macrocystis pyrifera (drift)	3	33	0	0	0	0
Siphonaria zealandica	0	0	0	0	3	0
Chiton pelliserpentis	0	0	0	0	0	0
Nodilittorna antipodum	0	0	0	0	0	0
Melagraphia aethiops	0	0	0	0	0	2
Pomatocerus caeruleus	0	0	6	0	2	2
sediment film on rock	0	0	5	39	0	0

Appendix 3: Abundance of each species/taxon within each replicate infaunal sample at each station in Lyttelton Harbour, May 2003.

		2.1	**2.2**	**2.3**	**3.1**	**3.2**	**3.3**	**4.1**	**4.2**	**4.3**	**5.1**	**5.2**	**5.3**	**6.1**	**6.2**	**6.3**	**7.1**	**7.2**	**7.3**
Macrophthalmus hirtipes	Decapoda	345	436	164	218	114	318	273	364	273	561	400	212	91	55	145	145	303	73
Nectocarcinus antarcticus	Decapoda																		
Pontophilus australis	Decapoda												30						
Diastylidae	Cumacea	55	18									36							
Bodotriidae	Cumacea												30						
Torridoharpinia hurleyi	Amphipoda															18			
Oedicerotidae	Amphipoda							18											
Lembos sp.	Amphipoda																		
Theora lubrica	Bivalvia	327	145	164	636	341	750	818	1055	945	1337	1127	121	145		18	73	101	91
Kellia cycladiformis	Bivalvia																		
Xymene plebeius	Gastropoda			18		45		18	18			18							18
Micrelenchus tenebrosus	Gastropoda																		
Heterothyone alba	Holothuroidea			18															
unid bryozoan	Bryozoa													18	18	18	18	25	
Aglaophamus sp.	Polychaeta	73	91	145	36	45	45	73	73	36	107	73	30			18	36		36
Capitellidae	Polychaeta								18					18					
Cirratulidae	Polychaeta					45	91	73	436	91							36	25	
Cossuridae	Polychaeta	91	73	18				36					61		18			25	
Glyceridae	Polychaeta															18			
Goniadidae	Polychaeta	18	18						18		27								36
Lumbrineridae	Polychaeta	18		18	36	68	182	18	18	55		18			18		36	76	36
Maldanidae	Polychaeta																		
Ophellidae	Polychaeta													18				51	
Orbinidae	Polychaeta													18					36
Sabellidae	Polychaeta	18					45	55	91			18		18					
Sigalionidae	Polychaeta	182	127	145	73	91	114	109	91	109	107	127			18	36	36	51	109
Spionidae	Polychaeta						68	18	73			18			18	36			18
Sternaspidae	Polychaeta																		
Trichobranchidae	Polychaeta	91	109	218							80	18							18

Appendix 3 ctd: Abundance of each species/taxon within each replicate infaunal sample at each station in Lyttelton Harbour, May 2003.

		8.1	8.2	8.3	9.1	9.2	9.3	12.1	12.2	12.3	13.1	13.2	13.3	21.1	21.2	21.3
Macrophthalmus hirtipes	Decapoda	309	400	345	164	127	303	436	309	710	382	200	291	527	382	909
Nectocarcinus antarcticus	Decapoda												18			
Pontophilus australis	Decapoda		18													
Diastylidae	Cumacea															
Bodotriidae	Cumacea															
Torridoharpinia hurleyi	Amphipoda	18		36	18					28				18		107
Oedicerotidae	Amphipoda															27
Lembos sp.	Amphipoda															27
Theora lubrica	Bivalvia	418	255	255	36	36	38	473	309	625	527	364	382	400	200	401
Kellia cycladiformis	Bivalvia							18								
Xymene plebeius	Gastropoda		18		18							18				
Micrelenchus tenebrosus	Gastropoda									28						
Heterothyone alba	Holothuroidea															
unid bryozoan	Bryozoa														18	27
Aglaophamus sp.	Polychaeta	91	55	18	55	55	152	36		142	127		36	18	145	80
Capitellidae	Polychaeta															
Cirratulidae	Polychaeta				18									18		
Cossuridae	Polychaeta						114	127	18	28	18			18	18	27
Glyceridae	Polychaeta															
Goniadidae	Polychaeta							18								
Lumbrineridae	Polychaeta	18	18	18		36							36			
Maldanidae	Polychaeta			18												
Ophellidae	Polychaeta															
Orbinidae	Polychaeta															
Sabellidae	Polychaeta										36			18	18	27
Sigalionidae	Polychaeta	36	91	55	55	91	152	91	164	85	73	182	18	91	91	241
Spionidae	Polychaeta	36				18					18					27
Sternaspidae	Polychaeta					18										
Trichobranchidae	Polychaeta	18		73	36	164	114	36	18	142	55	327		36		27