Upper Waitemata Harbour Ecological Monitoring Programme: 2005 - 2006

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Upper Waitemata Harbour Ecological Monitoring Programme

Results from the first year of monitoring, 2005 - 2006

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1 Executive Summary

In November 2005, a long-term monitoring programme was established in the Upper Waitemata Harbour. The aim of this programme is to monitor the ecological status and trends in marine macrobenthic species, and to monitor habitats that have the potential to be affected by sedimentation, pollution and other impacts associated with development of the surrounding catchments. Concurrent sampling of sediment characteristics and chemical contaminants will provide the ability to correlate macrofaunal community information with predictions from catchment and hydrodynamic models developed for the Upper Waitemata Harbour.

Following consultation with the ARC, fourteen intertidal sites were selected. A single site is located in each of the Rangitopuni, Brigham, Paremoremo and Waiarohia arms, and the Upper and Outer sections of the main harbour. Two sites are located in each of the Lucas and Hellyers arms, the central part of the main Upper Waitemata harbour and outside the mouth of the Upper Waitemata harbour. Sites vary in sediment type from being predominantly coarse sand to mud. Sandier sites are found in the central and outer part of the main harbour and outside the harbour mouth. Muddy sites are found in all localities.

Data from the first two sampling occasions (November 2005, February 2006) are presented in this report. Comparisons are also made between sites sampled for the ARC in other projects (i.e., sediment accumulation rates in Auckland, survey of the Upper Waitemata Harbour and the regional discharges project). Information gathered by NIWA in public good science programmes and in contracts for the ARC on species sensitivities to sediment and contaminants is also presented.

Chemical concentrations found at the sites were compared with two standards used by the ARC: Threshold Effect Concentrations (TEL); and the Effects Range Low (ERL). No sites showed threshold exceedances for PAHs, Cadmium, Chromium or Nickel; but 12 sites showed TEL exceedances for Arsenic, 6 sites for Copper and 1 site for Zinc. Notably, these site concentrations are markedly below the Probable Effect Level (PEL) guideline, which represents an effect probability of about 50%. Upper Hellyers Creek was the most stressed of the sites.

Ecological communities

Taxa found in the UWH sites are generally found in a number of other Auckland Harbours, with most similarities to the Central Waitemata. Sites were dominated by bivalves, by deposit-feeding polychaetes and crabs, or by burrowing Corophid amphipods and Oligochaetes. Communities did not change largely over time, either between years (2001 when the Upper Waitemata Harbour survey was conducted) or seasonally (November to February).

The sites are generally diverse, although low diversity was found in the Brighams and Paremoremo sites. Similar to findings in other areas, low diversity was not necessarily associated with high mud content. While the ecological community groupings were not coincident to either the sediment or chemical groupings, environmental variables

were important in explaining community composition. Organic content, zinc concentrations in the < 0.5 mm fraction, sediment accumulation rate and % of fine and medium sand explained 69% of the variability between site community composition.

Monitoring recommendations

The design of a monitoring programme is an ongoing process and design features should be regularly reviewed. In this report, we considered whether changes were needed regarding (i) the number of replicates taken at each site; (ii) the number of sites sampled; (iii) whether a subset of taxa and chemicals should be monitored; and (iv) what frequency of sampling is required for the top and bottom layers of the sediment.

- Based on analyses from other monitoring programmes, the ARC has standardised its Ecological Monitoring on 12 replicates. However, while at sites characterised by sand, core holes rapidly infill and long-term effects of sampling do not occur, we are not sure that this will be true at soft mud sites. Therefore, a November 2006 site visit will occur at low tide when each site is fully visible. Site damage will be assessed and, if core holes are visible, decreased sample replication or frequency will be considered.
- We recommend the following changes to sampled sites. (1) Dropping the site situated in the upper reaches of Lucas Creek as this area has already undergone significant development in its catchment. (2) Sampling the site in Paremoremo Creek only once per year, as we are concerned that the intensity of sampling in this small area is too great. (3) Collecting and processing samples from the two distinctly different areas (mud vs sand) of site MainO separately.
- In the ARC ecological monitoring programmes of the Manukau, Mahurangi and Central Waitemata, a subset of key species are monitored. We do not recommend this for the UWH as there is insufficient information available of the response of many taxa to chemical contaminants, a major risk in the UWH. However, for 5 taxa (Corophidae, Nereidae, Phoxocephalidae, Polydorids and Oligochaetes) we suggest using high taxonomic differentiation on most sampling occasions, with full taxonomic resolution carried out in November of each year.
- We recommend ongoing monitoring of iron, manganese, arsenic, PAH, copper, zinc and lead in surficial sediment (0 – 2 cm) yearly. Furthermore, differences observed between the concentrations of lead, zinc and copper in the fine and total fractions confirm the necessity of monitoring both fractions.
- Monitoring of sediment and chemical characteristics of the deeper layer of the sediment (5 – 15 cm) should be done every three years. At the same time chromium, cadmium and nickel concentrations should also be monitored.

2 Introduction

The Upper Waitemata Harbour (UWH) catchment encompasses 185 km^2 and drains to a relatively small estuary with a restricted outlet emptying into the Central Waitemata Harbour (Fig. 1). Most of the catchment is flat to rolling land, though steeper slopes are found in some subcatchments. Catchment landuse is primarily pastoral, with some areas of native bush and pine, and established and ongoing urban development in other areas. However, the Auckland Regional Growth Strategy (ARGS) identified greenfield development and urban intensification in the UWH catchment over the next 50 or 100 years.

A multi-agency study of the effects of catchment development of the UWH was undertaken from 2000 to 2004 (see Green et al. 2004 and associated reports). The main focus of this study was to predict effects associated with increasing stormwater associated contaminant inputs as catchment development progressed. This modelling suggested that contaminant levels, associated with urban discharges after development, will increase and are likely to affect the ecological functioning of the UWH estuarine receiving environments (Cummings et al. 2002). Changes may also be associated with contaminants currently locked in soils entering the harbour during development, as well as further sedimentation impacts.

Over the past few years long-term monitoring programmes have been established in sensitive receiving environments in the Auckland region where catchment land use intensification has been identified as likely to occur in the near future – specifically at Okura and Whitford.

Unlike the Okura and Whitford situation, UWH will require a long-term monitoring approach, as models and development plans suggest the potential for:

- increased sedimentation over long time periods as different areas become developed;
- contaminants currently locked in soils to enter the harbour during development;
- contaminant problems from urban discharges after development.

This report details the design and site selection process of the monitoring programme, describes habitat and ecological characteristics of the sites and places the sites within the context of models developed for the effects of urban contaminants. Species vulnerability, sampling precision and representativeness are used to determine whether changes to the design are required. Furthermore, as the suite of chemicals sampled contains many not previously sampled, a chemical description of the Upper Waitemata Harbour is provided.

2.1 Monitoring programme design

The uniqueness of the UWH and the strong potential for unassociated impacts to occur in the Central Waitemata mean that attempting to select and use control areas is most likely to decrease the potential to detect impacts. Thus the monitoring programme is focused on gradients, pre-impact data and time series analysis, augmented by the Regional Discharges Project (RDP) health index.

Modelling has indicated that in terms of contaminant loading the UWH can be roughly divided into four sectors: Lucas creek and associated main body (high metals); Hellyers Creek (moderate metals); Brighams Creek – Riverlea (horticulture sourced contaminants, including historic sources); Rangitopuni Creek (sediments). The main body can further be divided into three sectors that, while contaminant loading is predicted to be high in all three, may be expected to respond differently, due to different development times in the associated creeks.

Due to the number of sectors, their connectivity and the long development time for the whole of the UWH, a full gradient approach within each sector would be exceedingly costly. However, the sectors themselves (including the Central Waitemata area directly outside the UWH entrance) form a gradient for the whole of the UWH. Thus, a site was located within each sector. To strengthen the design, additional sites were located along anticipated gradients in deposition of sediments and chemicals within some of the sectors (Lucas and Hellyers Creek and the Middle and Outer sections of the main body of the harbour). A further location that was predicted to have little catchment development (Paremoremo sub-estuary) was also included. Together with 2 sites situated in the Central Waitemata on opposite sides of the Upper Waitemata Harbour entrance, 14 sites are in the design (Fig. 1).

The key ecological response variable (benthic macrofauna) is sampled 4 times per year (i.e., a similar frequency to that of the Mahurangi monitoring programme). This data is to be used to develop time-series as per the sentinel sites in the region, but will also be used in conjunction with the RDP health index.

While the focus of the programme is to detect changes in benthic macrofauna, concurrent collection of chemical and sediment data is necessary to fully utilize the information from the gradient design. Chemicals predicted to change associated with development (i.e, polycyclic aromatic hydrocarbons, iron, manganese, arsenic, cadmium, chromium, copper, nickel, lead and zinc) are collected once per year. Sediment characteristics that may change associated with development (sediment grain size, chlorophyll *a* and organic matter concentrations) are collected on each sampling occasion. The difference in the frequency of sampling reflects the latters tight coupling to the benthic community data, as well as their lower cost of analysis and the higher temporal variability. As deposition associated with sedimentation is expected to be key for both sediment and contaminant impacts, chemical and sediment data is collected both from surficial sediment (0 – 2 cm) and from deeper sediment (5 – 15 cm).

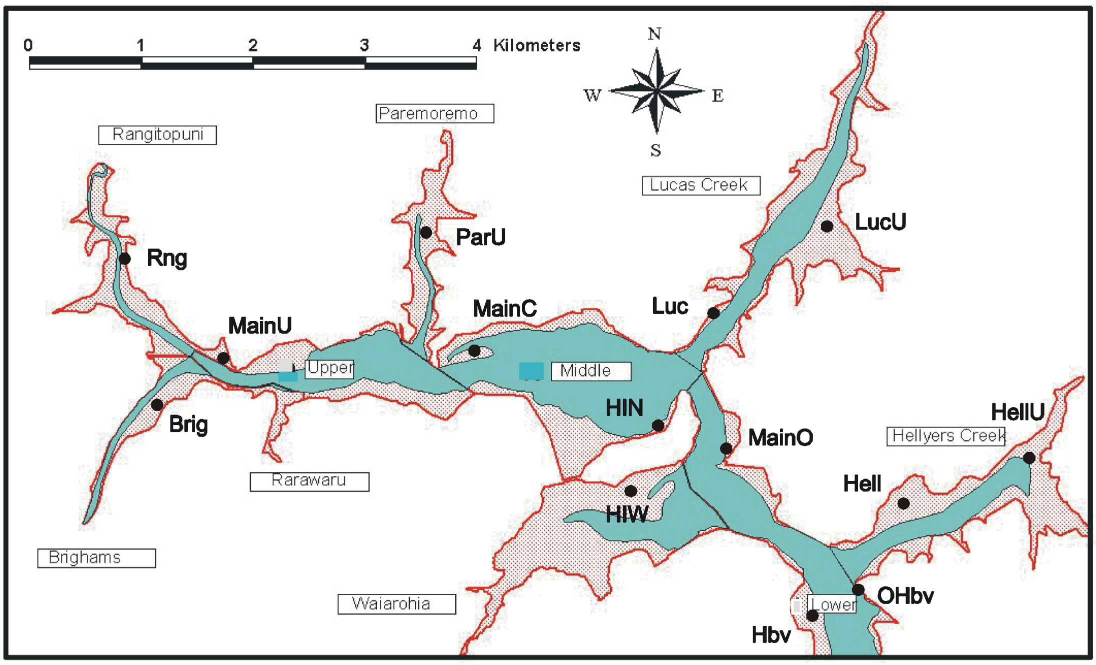
Although measuring sediment deposition and directly assessing contaminant potential of new sediment would be highly useful, there are scientific concerns over the long-term deployment of sediment traps in intertidal areas, due to resuspension and fouling problems. For this reason, and because sedimentation was not a key concern of the ARC in the harbour, this information is not part of the design of the monitoring programme. Sediment accumulation rates used in any analysis will be based on model predictions.

This design will be used to collect baseline information from each location. After development begins, and a sufficient degree of certainty in the temporal signals from locations has been achieved, sampling at individual locations may be switched on or off depending on activity in each sector.

2.2 Site selection

Sites were selected for monitoring in consultation with the ARC, and were largely based on recommendations made in Green et al. (2004), information from a previous benthic habitat mapping of the UWH (Cummings et al. 2002) and field observations by ecologists. The sites were chosen to integrate across the 10 subestuaries (seven 'arms' of tidal creeks that branch off the 'main body' of the UWH estuary: Rangitopuni, Paremoremo, Lucas, Hellyers, Waiarohia, Rarawaru, and Brighams; and three subdivisions of the main body itself: the Upper, Middle and Lower Harbour basins) (Fig. 1, Table 1).

Figure 1:
Subestuaries identified in the Green et al. (2004) report. The location of the Upper Waitemata monitoring programme sites is shown in bold.



The selected sites also included some locations that have been sampled as part of the RDP, though macrofaunal sampling sites were located sufficiently distant to avoid disturbance of RDP sites.

Table 1:
The number of UWH monitoring programme sites within the sub-estuaries identified in the Green et al. (2004) report.

Sub-estuaries	***Number of sites***	***Site name***
Rangitopuni Creek	***1***	***Rng***
Brigham Creek	***1***	***Brig***
Rarawaru Creek	***0***	
Paremoremo Creek	***1***	***ParU***
Lucas Creek	***2***	***Luc, LucU***
Hellyers Creek	***2***	***Hell, HellU***
Waiarohia Inlet	***1***	***HIW***
Upper Harbour basin	***1***	***MainU***
Middle Harbour basin	***2***	***MainC, HIN***
Outer Harbour basin	***1***	***MainO***
Central Waitemata	***2***	***Hbv, OHbv***

3 Methods

3.1 Macrofauna

In order to maximise the potential to compare data between other ARC long-term ecological monitoring programmes, 12 replicate cores for macrofauna were sampled at each site, using a 13 cm diameter, 15 cm deep corer. The dimensions of the sites varied depending on the amount of relatively homogenous intertidal flat present (Appendix 1), with sites varying in size from 1500 to 9000 m^2. Two sampling methods were used, based on whether the location was primarily muddy sediments, requiring sampling by boat to avoid disturbance of the substrate, or sandier sediments that could be sampled on foot at low tide.

At thirteen of the sites, samples are collected 4 times per year (November, February, May and August). The 14^{th} site (Hbv) is sampled 6 times a year as part of the Central Waitemata monitoring programme. All 14 sites are sampled in February and August. Note that November comparisons involving Hbv use data collected in December; this was considered acceptable as the November UWH and December CWH sampling dates were separated by less than one week.

At the four locations sampled at low tide (HIW, HIN, MainO, Hbv), permanent markers (wooden stakes) were placed at the starting corner of the sampling grid. Sampling was conducted as per sampling in the Manukau, Mahurangi and Central Waitemata Ecological Monitoring Programmes. To provide an adequate spread of cores over the site, a site is 'divided' into 12 equal sections and one core sample is taken from a random location within each section. To reduce the influence of previous sampling activity and spatial autocorrelation, samples are not placed within a 5 m radius of each other or of any samples collected in the previous 12 months.

The 10 remaining locations were sampled by boat around high tide. Four positions were randomly selected (within the site area) and located using GPS. Three cores were then taken around each position, using a hand held subtidal corer, approximately 5 m apart. To avoid resampling areas that had been sampled within the previous 24 months, new points for random positions are not selected if they fall within 10 m distance to a previous point.

Core samples were sieved through a 500 µm mesh and the residues stained with rose bengal and preserved in 70 % isopropyl alcohol in seawater. Samples were then sorted and stored in 50 % isopropyl alcohol. Macrofauna were identified to the lowest taxonomic level practicable.

3.2 Bivalve size class analysis

After identification, the shell length of individual *Mactra ovata, Paphies australis*, *Austrovenus stutchburyi* and *Macomona liliana* are measured and placed into size classes (<1 mm, 1 – 5 mm, 5 – 10 mm, then 10 mm increments).

3.3 Sediment characteristics

Sediment characteristics (i.e., grain size, organic content and chlorophyll *a*) are assessed at each site on each sampling occasion. At three random locations within the site, two small sediment cores (2 cm deep, 2 cm diameter) are collected, one to determine grain size and organic content and the other for chlorophyll *a* analysis. The three cores are pooled, and kept frozen in the dark prior to being analysed as described below.

In November, small sediment cores (5-15 cm deep, 2 cm diameter) are collected to determine grain size and organic content of the bottom sediment layer, composited from the three random locations, and analysed as per surface grain size samples. Chlorophyll *a* is not analysed from bottom sediments.

Grain size: The samples are homogenised and a subsample of approximately 5 g of sediment is taken and digested in ~ 9% hydrogen peroxide until frothing ceases. The sediment sample is then wet sieved through 2000 μm, 500 μm, 250 μm and 63 μm mesh sieves. Pipette analysis is used to separate the <63 μm fraction into >3.9 μm and ≤3.9 μm. All fractions are then dried at 60°C until a constant weight is achieved (fractions are weighed at ~ 40 h and then again at 48 h). The results of the analysis are presented as percentage weight of gravel/shell hash (>2000 μm), coarse sand (500 – 2000 μm), medium sand (250 – 500 μm), fine sand (62.5 – 500 μm), silt (3.9 – 62.5 μm) and clay (≤3.9 μm). Mud content is calculated as the sum of the silt and clay content.

Chlorophyll *a*: Within 1 month of sampling, the full sample is freeze dried, weighed, then homogenised and a subsample (~5 g) taken for analysis. Chlorophyll *a* is extracted by boiling the sediment in 90% ethanol, and the extract processed using a spectrophotometer. An acidification step is used to separate degradation products from chlorophyll *a*.

Organic content: Approximately 5 g of sediment is placed in a dry, pre-weighed tray. The sample is then dried at 60°C until a constant weight is achieved (the sample is weighed after ~ 40 h and then again after 48 h). The sample is then ashed for 5.5 h at 400°C (Mook and Hoskin 1982) and then reweighed. Organic content is calculated as the difference in weight.

3.4 Chemical analyses

Once per year (November), at three random locations within the site, one replicate core (15 cm deep, 5 cm diameter) is collected to provide adequate material for chemical analyses. The core is split into a surface layer (0-2 cm) and a bottom layer (below 5 cm) to determine depth-related differences in chemical contaminants (total of three replicates per depth per site).

Chemical analyses were performed by R J Hill Laboratories Ltd (Hamilton) following sample preparation at NIWA using standard ARC methods and protocols as outlined in Williamson et al. (1998) and Mills et al. (2000). Chemical analysis was performed on both total (< 500 μm dry sieved) and fine (< 63 μm wet sieved) fractions for copper, zinc and lead. All sediments were freeze dried before sub-sampling for chemical analyses. Total sediments were analysed for total organic carbon (g/100g dry wt); polycyclic aromatic hydrocarbons (PAH) (mg/kg dry wt); and total recoverable iron, manganese, arsenic, cadmium, chromium, copper, nickel, lead and zinc (mg/kg dry wt). Fine fractions were analysed for weak acid (2M HCl) extractable copper, lead, and zinc (mg/kg dry weight). PAH analysis separated total PAH into components of: Acenaphthene, Acenaphthylene, Anthracene, Benzo[a]anthracene, Benzo[a]pyrene (BAP), Benzo[b]fluoranthene, Benzo[g,h,i]perylene, Benzo[k]fluoranthene, Chrysene, Dibenzo[a,h]anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-c,d)pyrene, Naphthalene, Phenanthrene, and Pyrene (mg/kg dry wt).

Three sediment samples were selected for quality assurance purposes. These included two replicate samples from within the batch and an archived sample to measure inter-batch variability.

3.5 Statistical analyses

3.5.1 Sediment and chemistry characteristics

Principle component analysis on normalized data was used to investigate similarities between sites in sediment characteristics and chemical content. Comparisons between sites both within this monitoring programme and with data collected by other programmes for sediment characteristics and chemistry were based on analyses of the top 2 cm of sediment.

Differences between particle size of the surface and deeper sediment were defined as significant if the change was greater than 10%. For % organic content, a significant difference was defined as 20% of the mean. For metals, a t-test was performed to determine significance, although the results were then compared to a 10% change to determine how sensitive the analyses were.

Differences between sediment grain size over time were defined as significant if the change was greater than 10%. For % organic content and chlorophyll a, a significant difference was defined as 20% of the mean.

3.5.2 Macrofauna

Community composition: All community analyses were performed on the sum of the 12 cores collected at a site during each sampling period. Multivariate ordination of data collected in November 2005 and February 2006 was used to determine whether community composition at the sites was similar across sites, and if there were temporal variations in community composition over the brief sampling period discussed in this report. Ordination of raw, log transformed and presence/absence data were conducted, using nonmetric multidimensional scaling based on Bray Curtis similarities and correspondence analysis based on chi-square distances. Only the nonmetric multidimensional scaling of the raw data is presented in this report as few differences in interpretation of patterns were apparent with the different techniques/transformations.

Community composition at each site was then defined in two ways: (1) based on the five most numerically dominant taxa and (2) based on a hierarchical system of ecological rules (Hewitt and Funnell 2005). The basis of these rules is threefold: key species, key functions and factors affecting vulnerability to threats (Appendix 2).

Within and between site-similarities were calculated based on Bray-Curtis similarities.

Biodiversity: Univariate measures of biodiversity were also calculated for each site in November: number of species, number of individuals and the Shannon-Weiner index were calculated for each replicate at a site then meaned.

Differences between sampling times: Differences between sampling times at each site were assessed as follows:

(1) Differences in the community composition were tested using a randomised permutation test on Bray-Curtis similarities (ANOSIM; Primer, Clarke 1993).

(2) Differences in dominance structure were assessed by (a) comparing the dominance position of the 5 most dominant taxa at a site and (b) using t-tests (or the non-parametric equivalent) on the abundance of each of the 5 most dominant taxa in November 2005.

(3) Differences in biodiversity (number of species and Shannon-Weiner index) were assessed using t-tests (or the non-parametric equivalent).

Links between ecology and site sediment and chemical characteristics: Spearman's rho correlations with Bray-Curtis similarities, Canonical correlation with chi-square distances and Redundancy analysis based on Hellinger transformations were used to link community composition to site sediment and chemical characteristics. For all techniques, forward selection was conducted to determine the important sediment variables. For the canonical correlations and the redundancy analysis, highly correlated variables were avoided, such that the final model did not contain variance inflation factors >10. Forward selection was repeated a number of times, varying the order of variable selection to ensure that the model selected was stable. For the Spearman's rho correlations (BIOSTEP; Clarke and Gorley 2001), new variables were only added into the model if they increased the correlation coefficient by >0.05. As similar results were obtained irrespective of analysis technique, only the redundancy analysis results are presented here.

4 Site sediment characteristics

4.1 Site descriptions

Rangitopuni Creek (Rng)

Site Rng is located midway up Rangitopuni Creek alongside the main tidal creek channel and is sampled by boat. The site is long and narrow, approximately 5 m wide between the channel and the edge of the mangroves. A ski jump is located near the site. The site is characterised by soft mud and abundant crab burrows, with sediment content comprised primarily of mud (> 90%), with a small amount of fine sands (Table 2). Chlorophyll *a* content of the sediments ranged between 8.09 and 13.73 µg/g sediment (Table 2). Organic content of the sediment ranged from 6.64 to 9.60 % (Table 2).

Brigham Creek (Brig)

Site Brig is located approximately 500 m from the mouth of Brigham Creek and can only be sampled by boat at high tide. There is an extensive strip of intertidal mud in the middle of the tidal creek channel. The site is located near a boat ramp. Mangroves are patchily distributed within the tidal creek, but none are located directly on the sampling site. The site is characterised by soft mud with some mangrove pneumatophores.

Sediment content is primarily comprised of mud (> 89% silt and clay fractions), with a small amount of fine sands (Table 2). Chlorophyll *a* content of the sediments ranged between 6.68 and 8.52 µg/g sediment (Table 2). Organic content of the sediment ranged from 6.72 to 8.68 % (Table 2).

Upper Main Channel (MainU)

Site MainU is located opposite the entrance to Brigham Creek within the Upper Harbour basin and is sampled by boat. The site consists of a steep mud bank inshore of the main channel, with large drainage channels and mangroves located on the shoreward edge of the site. The site consists of very deep (> 1 m) mud with crab burrows.

Sediment content is primarily comprised of mud (> 88% silt and clay fractions), with a small amount of fine sands (Table 2). Chlorophyll *a* content of the sediments was 18.77 µg/g sediment at the February 2006 sampling occasion (Table 2). Organic content of the sediment ranged from 7.30 to 8.26 % (Table 2).

Table 2:

Summary of surface sediment characteristics at the 14 UWH sampling locations, from Nov 2005 and Feb 2006. Chla = chlorophyll *a* in $\mu g.g^{-1}$, coarse sand (500 – 2000 µm), medium sand (250 – 500 µm), fine sand (62.5 – 500 µm), mud (< 62.5 µm).

Site	Date	%mud	%fine sand	%medium sand	%coarse sand	%organics	chla
Rng	Nov-05	91.59	8.41	0.00	0.00	9.60	8.09
	Feb-06	96.43	3.36	0.20	0.00	6.64	13.73
Brig	Nov-05	89.25	8.53	1.99	0.23	8.68	6.68
	Feb-06	96.30	3.52	0.19	0.00	6.72	8.52
MainU	Nov-05	88.43	11.54	0.04	0.00	8.26	8.46
	Feb-06	94.88	4.95	0.17	0.00	7.30	18.77
ParU	Nov-05	96.84	2.46	0.70	0.00	10.13	7.75
	Feb-06	97.65	2.22	0.13	0.00	6.51	14.73
MainC	Nov-05	20.58	73.80	4.85	0.77	4.24	8.78
	Feb-06	20.17	71.07	7.56	1.20	2.38	10.05
HIN	Nov-05	6.15	62.77	23.28	6.20	1.62	10.42
	Feb-06	28.41	67.43	3.46	0.70	2.67	19.53
Luc	Nov-05	30.08	42.46	16.08	9.69	3.33	9.52
	Feb-06	34.97	49.69	11.08	4.13	4.29	10.48
LucU	Nov-05	62.05	36.38	1.53	0.04	5.17	9.48
	Feb-06	71.86	26.53	1.61	0.00	4.37	14.19
MainO	Nov-05	9.91	72.92	13.80	3.25	2.13	7.61
	Feb-06	16.10	58.89	16.10	6.80	2.13	10.10
HIW	Nov-05	10.54	68.66	13.74	1.53	1.32	7.33
	Feb-06	22.30	66.73	9.85	1.12	2.07	13.88
Hell	Nov-05	61.08	37.30	1.50	0.12	6.00	16.65
	Feb-06	52.80	44.00	2.86	0.33	3.15	15.63
HellU	Nov-05	88.78	10.49	0.73	0.00	8.06	7.22
	Feb-06	94.33	5.34	0.21	0.12	6.14	17.88
OHbv	Nov-05	75.19	24.59	0.19	0.04	5.79	8.48
	Feb-06	87.71	11.95	0.10	0.24	5.30	10.96
Hbv	Dec-05	0.98	44.21	42.33	10.71	1.75	10.68
	Feb-06	1.90	55.46	31.37	6.54	2.01	11.00

Paremoremo Creek (ParU)

Site ParU is located opposite the ski club in Paremoremo Creek on the only mangrove free area of intertidal flat in the sub-estuary and is sampled by boat. There is a solid belt of mud across the tidal creek north of the site. The sampling site consists of very deep (> 1 m) mud in a thin strip between the tidal creek channel and an extensive mangrove forest on the shore. Mangrove seedlings and pneumatophores are located throughout the site. It is difficult to core sample due to much of the site being dominated by a matted weedy mass of mangrove seedlings and roots, and sorting of macrofauna is particularly time-extensive due to the presence of this weed mass.

Sediment content is primarily comprised of mud (> 96% silt and clay fractions), with a small amount of fine sands (Table 2). Chlorophyll *a* content of the sediments ranged between 7.75 and 14.73 µg/g sediment (Table 2). Organic content of the sediment ranged from 6.51 to 10.13 % (Table 2).

Central Main Channel (MainC)

Site MainC is located on an extensive intertidal flat of waist deep soft-sediment within the Middle Harbour basin and is sampled by boat. The sampling location is east of the nearby RDP sampling site (Paremoremo), across from a small inshore tidal creek channel.

Sediment content is comprised of fine sands (> 70 %) and mud (about 20 %), with a small amount of medium and course sands (Table 2). Chlorophyll *a* content of the sediments ranged between 8.78 and 10.05 µg/g sediment (Table 2). Organic content of the sediment is relatively low, and ranged from 2.38 to 4.24 % (Table 2).

Herald Island (HIN)

Site HIN is sampled from shore and is located on the north side of Herald Island on Christmas Beach in front of a playground. The site is sandy, with some cockles, and is relatively extensive with approximately 100-150 m between the shore and water's edge at low tide (Plate 1).

Sediment content is comprised of fine sands (> 60 %), with other fractions varying within the site (6.15 – 28.41 % mud; 3.46 – 23.28 % medium sand), and a small amount of course sand and gravel (Table 2). Chlorophyll *a* content of the sediments ranged between 10.42 and 19.53 µg/g sediment (Table 2). Organic content of the sediment is relatively low, and ranged from 1.62 to 2.67 % (Table 2).

Lucas Creek outer (Luc)

Site Luc is located just north of the mouth of Lucas Creek directly across from the slipway near an industrial boatyard and is sampled by boat. The site is approximately 300 m inshore of the main channel on a clay bank. There are no mangroves at the site. The sampling site is extremely long and narrow (approximately 15 m wide at low tide), and consists of firm clay with rocks, shell hash and large chunks of hard clay.

Sediment content is comprised of mud (30 – 35 %) and fine sands (42 – 50 %), with small amount of course sand and gravel (Table 2). Chlorophyll *a* content of the sediments ranged between 9.52 and 10.48 µg/g sediment (Table 2). Organic content of the sediment is relatively low, and ranged from 3.33 to 4.29 % (Table 2).

Lucas Creek upper (LucU)

Site LucU is located at the entrance to Te Wharau Creek within the Lucas Creek tidal creek sub-estuary and is sampled by boat at high tide. The site is located just offshore of Schnapper Rock and a cemetery on shore. The sampling site is a narrow mud strip between the tidal creek channel and the front edge of a strip of mangroves located just a few meters from the shoreward edge of the tidal creek.

Sediment content is comprised of mud (62 – 72 %) and fine sands (26 – 37 %) (Table 2). Chlorophyll *a* content of the sediments ranged between 9.48 and 14.19 µg/g sediment (Table 2). Organic content of the sediment ranged from 4.37 to 5.17 % (Table 2).

Outer Main Channel (MainO)

Site MainO is located offshore of Greenhithe within the Lower Harbour basin, and is sampled at low tide on foot. The sampling location is just offshore of a ridge of rock at the edge of the beach, with two large 6 m timber poles nearby. There is a strong sand to mud gradient as you travel north/northwest within the sampling site, ranging from a sandy substrate to mud depth of up to 50 cm near the starting pegs.

Sediment content is comprised of fine sands (58 – 73 %), with smaller fractions of mud (9 – 17 %) and medium sands (13 – 17 %) (Table 2). Chlorophyll *a* content of the sediments ranged between 7.61 and 10.10 µg/g sediment (Table 2). Organic content of the sediment was 2.13 % at both sampling occasions (Table 2).

Waiarohia Inlet (HIW)

Site HIW (Plate 2) is sampled from shore and is located on an extensive sand/mudflat off Kowhai Beach on the south side of Herald Island near the mouth of the Waiarohia Inlet. The site is a large intertidal flat with fine muddy sands and is west of the Herald Island RDP site.

Sediment content is primarily comprised of fine sands (> 65 %), with smaller fractions of mud (10.54 – 22.30 %) and medium sands (9.85 – 13.74 %), and minor amounts of course sand and gravel (Table 2). Chlorophyll *a* content of the sediments ranged between 7.33 and 13.88 µg/g sediment (Table 2). Organic content of the sediment is relatively low, and ranged from 1.32 to 2.07 % (Table 2).

Hellyers Creek outer (Hell)

Site Hell is located near the mouth of Hellyers Creek within the first bay on the northern side of the entrance to the tidal creek and is sampled by boat. The catchment appears to be native bush, with a steep forested slope of bush and scrub, with mangroves along the edge of the cliffside. The site is sampled from a boat, accessed at mid tide, and consists of 10-15 cm deep soft sediment.

Sediment content is comprised of mud (52 – 62 %) and fine sands (37 – 44 %) (Table 2). Chlorophyll *a* content of the sediments ranged between 15.63 and 16.65 µg/g sediment (Table 2). Organic content of the sediment is relatively low, and ranged from 3.15 to 6.00 % (Table 2).

Hellyers Creek upper (HellU)

Site HellU is located southeast of the boat ramp at the northern edge of Hellyers Creek where Hellyers and Kaipatiki Creek split into two smaller tidal creeks. The site is located near the Hellyers Upper Creek RDP site, and is at the end of Manuka Road. There are reasonably extensive mangroves located nearby, but not within the sampling site itself. The site is sampled by boat at high tide, and is extremely muddy.

Sediment content is primarily comprised of mud (> 88 %) (Table 2). Chlorophyll *a* content of the sediments ranged between 7.22 and 17.88 µg/g sediment (Table 2). Organic content of the sediment ranged from 6.14 to 8.06 % (Table 2).

Central Waitemata East (OHbv)

Site OHbv is located at the southeast end of Beachhaven Road near the outlet of the Upper Waitemata Harbour into the Central Waitemata Harbour, within the Lower Harbour basin subregion. The site is located southeast of the mouth of Hellyers Creek and is sampled by boat. The site is approximately 30 m wide and 300-400 m in length, with extensive crab burrows. The mud is relatively deep (> 1 m), with very fine fluffy silts on the sediment surface.

Sediment content is primarily comprised of mud (75 – 88 %), with a small fraction (11 – 25 %) of fine sands (Table 2). Chlorophyll *a* content of the sediments ranged between 8.48 and 10.96 µg/g sediment (Table 2). Organic content of the sediment ranged from 5.30 to 5.79 % (Table 2).

Central Waitemata West (Hbv)

Site Hbv is located on the sandflats near the Hobsonville Air Base, close to the deep channel entering the Upper Waitemata Harbour. The sandflat is sampled bimonthly for macrofauna and sediment characteristics in the Central Waitemata Harbour long-term monitoring programme.

The sandflat at Hbv exhibits many of the characteristics of areas subject to high flow (coarse sediment, hollows in the sediment surface) (Plate 3). Large fragments of old logs are often found buried below the sediment surface, and there is a thick shell layer approximately 15 cm below the surface.

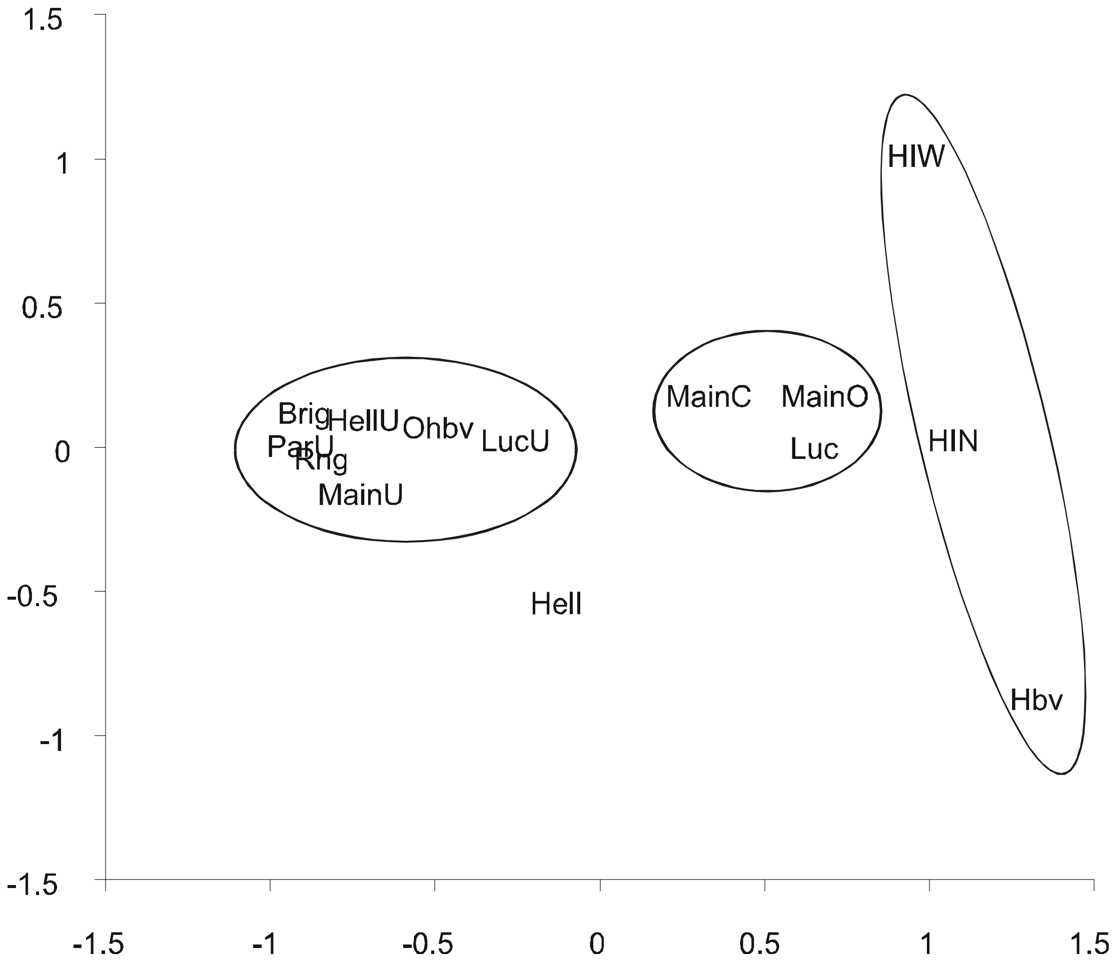
Sediment at Hbv is predominantly medium and fine sand, with a small amount of coarse sand (Table 2, Nicholls et al. 2002, Hewitt et al. 2004, Halliday et al. 2006). Chlorophyll *a* content of the sediments ranged between 10 and 18 µg/g sediment in 2005/2006, while the organic content is low and variable.

4.2 Site comparisons

A principle component analysis of the sediment characteristics from the 14 sites reveals a very strong first axis, explaining 61% of the variability. The second axis adds a further 18%. A number of clusters are visible (Fig 2).

Figure 2:

Principle component analysis of site sediment properties (top 2 cm) in November 2005, plotted in two dimensional space. The closer two sites are together on the plot the more similar their sediment properties are.



- a diffuse cluster containing sites Hbv, HIW and HIN. These sites all have higher proportions of fine – coarse sand and are low in silt, clay and organics. They vary in their chlorophyll *a* concentrations and the % of sediment sized > 2mm, with Hbv having the highest chlorophyll *a* concentrations and HIW having the highest % of sediment sized > 2 mm.
- a tight cluster containing sites MainO, MainC and Luc. These sites have % mud contents between 10 –30% and fine-medium sand contents between 59 – 87%. Organic content varies from 2 – 5% and chlorophyll *a* concentrations range from 7 – 10 $\mu g.g^{-1}$ sediment.
- a cluster containing LucU, OHbv, MainU, HellU, ParU, Brig and Rng. These sites all have mud contents > 60% and chlorophyll *a* concentrations < 10 $\mu g.g^{-1}$. They form a gradient of mud and organic content with ParU and Rng being most similar with

high mud and organic contents. Brig, HellU and MainU have the next highest mud and organic contents and OHbv, LucU and HellU have the least.

- Site Hell. This site is most like site LucU having a mud content of ~60% and an organic content of ~6%, but it has a high chlorophyll *a* concentration, similar to site Hbv.

Green et al. (2004) gives a table of sediment accumulation rates under the existing land uses for sub-estuaries of the Upper Waitemata. These values were obtained from model predictions, but were generally similar to the existing field data, with the exception of Hellyers (0.13 mm per year predicted, 8.6 mm per year measured in the only field data available). Highest sediment accumulation occurs for Rangitopunui (21.7), followed by Brighams and the Upper section of the main harbour (10.7 and 12.5 respectively). Lucas Creeks had reasonably high values (7.9), while Paremoremo and the Middle and outer areas of the main harbour have lower values (3 – 5). Lowest values were quoted for the Waiarohia estuary.

4.3 Differences between surficial and deep sediment layers

Few significant differences between sediment layers were observed (Table 3). The only particle size difference occurred at Luc for %clay and %silt. However, the two complemented each other and no difference was found for %mud (sum of silt and clay particle sizes). More differences were found for %organic content, with higher levels in surface sediment found at sites Hell, HellU and MainC.

4.4 Differences over time

Similar to other monitoring programmes differences between times were observed for all sites (Table 2). All sites, except Hell, exhibited increases in chlorophyll *a* content, although these were small for Luc and MainC. Nine sites exhibited decreases in % organic content, although these were only large for Rng, ParU, MainC, Brig, Hell and HellU. Changes in particle size were also observed. Brig, Luc and MainU all exhibited changes in %clay and %silt, however these did not change the %mud concentrations. HIW and HIN both exhibited increases in %mud content; at HIN this was accompanied by a decrease in %medium sand. LucU, OHbv and MainO all exhibited decreases in the % of fine sand; at OHbv this was accompanied by an increase in % mud. At no sites did the observed changes in particle size change the designation of the sites with respect to sediment type.

Table 3:

Differences in sediment properties between top 2 cm and deeper (5 - 15 cm) sediments in November 2005. Particle size measured as gravimetric %, %organics calculated from loss on ignition, and chlorophyll a (chla) µg/g sediment.

Site	*Depth*	*%clay*	*%silt*	*%mud*	*%fine sand*	*%medium sand*	*%coarse sand*	*% organic*	*Chla*
Rng	*bottom*	*38.63*	*54.72*	*93.35*	*6.52*	*0.14*	*0.00*	*8.76*	*NA*
	top	*31.53*	*60.06*	*91.59*	*8.41*	*0.00*	*0.00*	*9.60*	*8.09*
Brig	*bottom*	*32.84*	*54.73*	*87.58*	*8.98*	*2.20*	*0.39*	*8.00*	*NA*
	top	*37.76*	*51.49*	*89.25*	*8.53*	*1.99*	*0.23*	*8.68*	*6.68*
MainU	*bottom*	*31.23*	*55.25*	*86.47*	*13.21*	*0.32*	*0.00*	*8.70*	*NA*
	top	*27.54*	*60.88*	*88.43*	*11.54*	*0.04*	*0.00*	*8.26*	*8.6*
ParU	*bottom*	*14.04*	*82.46*	*96.49*	*2.97*	*0.54*	*0.00*	*9.04*	*NA*
	top	*11.11*	*85.73*	*96.84*	*2.46*	*0.70*	*0.00*	*10.13*	*7.75*
MainC	*bottom*	*7.36*	*14.72*	*22.08*	*70.90*	*5.86*	*1.16*	*2.98*	*NA*
	top	*9.43*	*11.15*	*20.58*	*73.80*	*4.85*	*0.77*	*4.24*	*8.78*
HIN	*bottom*	*7.36*	*14.72*	*8.52*	*55.07*	*21.14*	*6.65*	*1.87*	*NA*
	top	*9.43*	*11.15*	*6.15*	*62.77*	*23.28*	*6.20*	*1.62*	*10.42*
Luc	*bottom*	*8.87*	*22.67*	*31.54*	*43.31*	*18.60*	*5.67*	*3.84*	*NA*
	top	*28.80*	*1.28*	*30.08*	*42.46*	*16.08*	*9.69*	*3.33*	*9.52*
LucU	*bottom*	*20.29*	*43.97*	*64.27*	*34.01*	*1.21*	*0.51*	*4.94*	*NA*
	top	*21.51*	*40.54*	*62.05*	*36.38*	*1.53*	*0.04*	*5.17*	*9.48*
MainO	*bottom*	*5.07*	*5.64*	*10.71*	*63.89*	*12.46*	*4.08*	*1.74*	*NA*
	top	*9.25*	*0.66*	*9.91*	*72.92*	*13.80*	*3.25*	*2.13*	*7.61*
HIW	*bottom*	*1.61*	*9.15*	*10.76*	*66.01*	*16.14*	*1.80*	*1.48*	*NA*
	top	*4.58*	*5.96*	*10.54*	*68.66*	*13.74*	*1.53*	*1.32*	*7.33*
Hell	*bottom*	*25.28*	*40.45*	*65.73*	*32.68*	*1.46*	*0.13*	*4.51*	*NA*
	top	*17.29*	*43.79*	*61.08*	*37.30*	*1.50*	*0.12*	*6.00*	*16.65*
HellU	*bottom*	*3.57*	*78.63*	*82.20*	*13.15*	*3.61*	*1.04*	*5.98*	*NA*
	top	*16.91*	*71.87*	*88.78*	*10.49*	*0.73*	*0.00*	*8.06*	*7.22*
Ohbv	*bottom*	*23.75*	*53.97*	*77.72*	*22.03*	*0.25*	*0.00*	*6.68*	*NA*
	top	*23.33*	*51.85*	*75.19*	*24.59*	*0.19*	*0.04*	*5.79*	*8.48*
Hbv	*bottom*	*0.00*	*0.00*	*1.00*	*48.0*	*44.3*	*6.70*	*1.00*	*NA*
	top	*0.98*	*0.00*	*0.98*	*44.21*	*42.33*	*10.71*	*1.75*	*10.68*

5 Site chemistry characteristics

5.1 Site comparisons

For most of the discussion on site chemistry, total PAH will be used. However, an initial comparison of the separate PAH components was carried out. Sites were not strongly clustered, exhibiting a range of dissimilarity in the dominant PAH. The few similarities observed were: (1) OHbv and Hell exhibited the highest levels of Acenaphthenel, Anthracene, Fluorene and Pyrene and had the highest total PAH values, (2) ParU and MainC exhibited high values of Naphthalene and low Phenanthrene.

Table 4:

Mean concentration (mg/kg dry wt) of PAHs (adjusted to 1 % total carbon (TOC)) and metals in the top sediment collected from the 14 monitoring sites in November 2005, with exceedances of the Threshold Effect Concentration (TEL) (shaded) and Effect Range Low (ERL) (bold red) shown. Cu = copper, Pb = lead, Zn = zinc, Fe = iron, As = arsenic, Cd = cadmium, Cr = chromium, Ni = nickel.

				<63 µm metals			Total recoverable metals								
Site	**Depth**	**TOC**	**Total PAH**	**Cu**	**Pb**	**Zn**	**Fe**	**Mn**	**As**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Rng	*top*	2.6	0.1	20	24	92	20500	85	9	0.1	19	23	8.4	23	86
Brig	*top*	2.4	0.2	21	28	99	19900	75	**10.1**	0.1	21	23	8.5	25	95
MainU	*top*	2.2	0.2	18	27	91	20767	138	**10.1**	0.1	18	20	7.8	24	83
ParU	*top*	2.5	0.1	20	32	102	24700	286	**12.8**	0	22	22	8.6	26	94
MainC	*top*	1.3	0.2	17	28	96	18067	129	**14.9**	0.1	13	13	5.7	25	94
HIN	*top*	0.5	0.2	22	34	105	9870	70	**10**	0.1	8	11	3.1	17	53
Luc	*top*	0.9	0.3	21	33	118	25633	125	**16**	0.1	17	13	10.5	24	87
LucU	*top*	1.4	0.3	19	29	97	16333	86	**8.7**	0.1	17	18	6.8	22	83
MainO	*top*	0.4	0.3	21	27	94	10637	41	**10.3**	0	7	11	2.6	18	45
HIW	*top*	0.4	0.2	19	31	98	4143	28	3.3	0	5	6	1.8	7	25
Hell	*top*	1.5	0.3	16	30	85	16067	105	**9**	0.1	16	16	6.8	24	84
HellU	*top*	2.1	0.2	21	38	121	21233	101	**10.6**	0.1	22	22	9.1	34	122
Ohbv	*top*	1.7	0.4	17	30	95	18100	194	**11.9**	0.1	21	22	7.8	30	101
Hbv	*top*	0.4	0.2	23	34	123	4033	37	3.5	0	4	4	1.6	7	26
TEL			1.68	18.7	30.2	124			7.24	0.68	52.3	18.70	15.9	30.2	124
ERL			4	34	46.7	150			**8.2**	1.2	81	34	20.9	46.7	150

Values of copper, lead and zinc found in the weak acid extracted <63µm fraction of sediment were not well correlated with total values (Pearsons R < 0.25). Frequently the concentration per gm of sediment was higher in the < 63 µm fraction (Table 4), however, copper was significantly higher in the < 0.5 mm fraction at sites OHbv and ParU, and lead was higher at site MainC.

The chemical parameters monitored included a suite of metal and metalloid (arsenic) determinands, in order to determine the range and concentration of contaminants that may be associated with volcanic soils. Soil monitoring studies have identified elevated concentrations and wide variability of a range of metals associated with volcanic soils (chromium, cobalt, copper, nickel, vanadium and zinc, ARC 2002), and receiving waters may be expected to reflect these spatial differences. Iron and manganese were analysed, since these elements may markedly affect the binding and hence bioavailability of contaminants of concern for potential toxicological effects.

The surficial sediment contaminant concentrations are compared with published sediment quality guidelines in Table 4, following that used by ARC (Williamson and Kelly 2003) to establish the 'traffic light' system for levels of concern; specifically, values exceeding the Threshold Effect Concentration (TEL) signify an 'amber' condition for 'elevated' levels and those exceeding the Effects Range Low (ERL) concentrations signify 'red' or 'high contaminant concentrations'. No exceedances of the TEL were observed for PAHs, cadmium, chromium, lead and nickel; but 12 of the 14 sites had exceedances for arsenic, 6 sites for copper and 1 site for zinc. All of the sites with arsenic values above the TEL also exceeded the ERL, indicating that these sites would be classified as having 'high contaminant concentrations'. Notably, site concentrations of all chemicals are markedly below the Probable Effect Level (PEL) guideline of 41.6 mg/kg, which represents an effect probability of about 50%.

It is interesting to compare these results with the results of contaminant monitoring in shellfish conducted by the ARC (Kelly and McMurtry 2004). The UWH site did not show higher levels of arsenic in oysters compared to sites in other harbours, but show markedly higher chromium levels in 2001 and 2002 (possibly a result of geothermal soil contaminants). This suggests that by using an extended range of trace element analysis, this technique may be useful for detecting harbour areas affected by geothermal soil contaminants.

Threshold Toxicity Units (TTUs = sediment concentration/guideline value (TEL)) were calculated to provide an indication of the relative level of guideline exceedance (Table 5). The TTU values were generally higher for arsenic than for copper or lead, and indicate that arsenic might be expected to provide the largest contribution to any observed toxicity. The sum of the TTU values (using only those with values above 1) assumes an additively of potential contaminant effects and can be used to rank the sites for potential adverse effects. Based on this ranking, HellU is the most stressed site, although even this is not highly contaminated, only exceeding the ERL threshold for arsenic.

Different results were observed if the weak acid extracted fine fraction metal concentrations were used (note that this techniques is usually only used for total metals). Based on the metal concentrations in the fine fraction, the most stressed sites were Luc, ParU, HellU, and HIN.

Table 5:

Mean sediment Threshold Toxic Units (TTU) for contaminants in surficial sediment (from Table 4). TTU = sediment concentration/TEL guideline. ΣTTU is calculated as the sum of guidelines which exceed 1 TTU (highlighted), Fe and Mn are not included as no guidelines exist for these metals.

		Total recoverable metals									Total fraction	
											Sum of hits	ΣTTUs
Site	Total PAH	Fe	Mn	As	Cd	Cr	Cu	Ni	Pb	Zn		
Rng	0.1			1.2	0.1	0.4	1.2	0.5	0.8	0.7	2	2.5
Brig	0.1			1.4	0.1	0.4	1.2	0.5	0.8	0.8	2	2.6
MainU	0.1			1.4	0.1	0.3	1.1	0.5	0.8	0.7	2	2.5
ParU	0.1			1.8	0.0	0.4	1.2	0.5	0.9	0.8	2	2.9
MainC	0.1			2.1	0.1	0.2	0.7	0.4	0.8	0.8	1	2.1
HIN	0.1			1.4	0.1	0.2	0.6	0.2	0.6	0.4	1	1.4
Luc	0.2			2.2	0.1	0.3	0.7	0.7	0.8	0.7	1	2.2
LucU	0.2			1.2	0.1	0.3	1.0	0.4	0.7	0.7	1	1.2
MainO	0.2			1.4	0.0	0.1	0.6	0.2	0.6	0.4	1	1.4
HIW	0.1			0.5	0.0	0.1	0.3	0.1	0.2	0.2	0	0
Hell	0.2			1.2	0.1	0.3	0.9	0.4	0.8	0.7	1	1.2
HellU	0.1			1.5	0.1	0.4	1.2	0.6	1.1	1.0	3	3.8
Ohbv	0.2			1.6	0.1	0.4	1.2	0.5	1.0	0.8	2	2.8
Hbv	0.1			0.5	0.0	0.1	0.2	0.1	0.2	0.2	0	0

Exploratory data analysis for key contaminants was undertaken to investigate chemical relationships (Appendix 3). Three important points were highlighted by this analysis. (1) The iron measurements show strong relationships with total copper and zinc for the majority of sites and depths. This indicates that processes affecting iron chemistry and transport will markedly affect the fate, transport and bioavailability of the other trace metal contaminants. (2) The arsenic level was highest in the Lucas sites and showed a moderately strong relationship with Fe concentrations. Both Lucas sites were outliers in the relationships observed across sites between iron, copper, zinc. (3) Correlations between chemicals were poor for the weak acid fine fraction metals, which also showed a tendency to differentiate top and bottom sediments. This probably reflects the variable organic and debris content of the fine fraction.

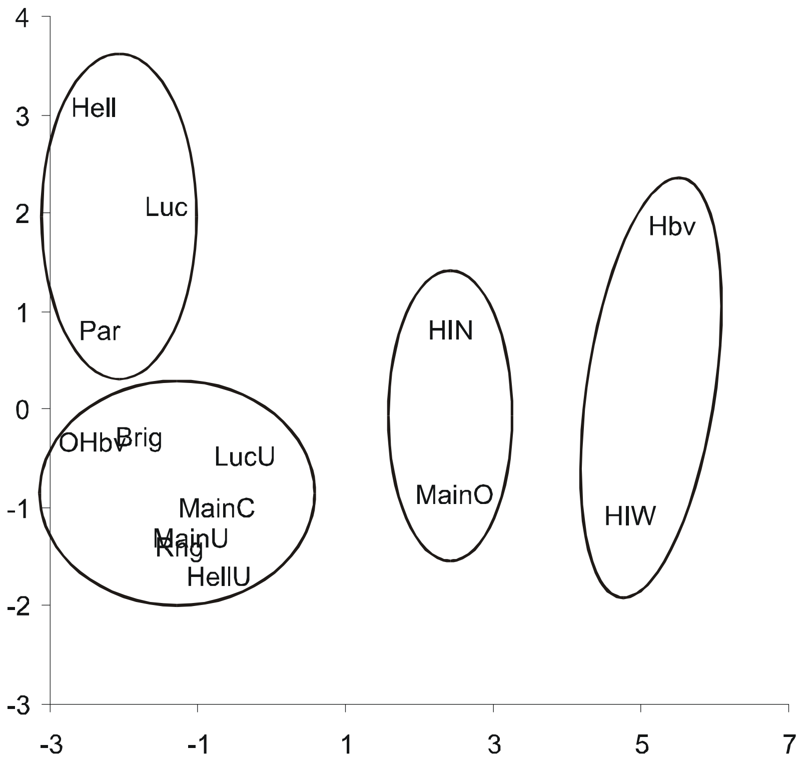
A principle component analysis of the metal concentrations from the 14 sites, revealed a very strong first axis, explaining 51 % of the variability. The second axis added a further 18%. A number of clusters are visible (Fig 3):

- a cluster that is tight along the first axis but diffuse along the second containing sites Hbv and HIW. These sites have low concentrations of most metals.
- a tighter cluster containing sites MainO and HIN, with low TOC and very similar concentrations of iron, arsenic, copper and zinc.

- Luc, Hell and ParU have the highest concentrations of manganese, and copper and medium concentrations of lead and zinc.
- Ohbv, Rng, Brig, MainU, MainC, LucU and HellU have high TOC, medium to high concentrations of chromium, nickel, lead and zinc and medium concentrations of iron and manganese.

These clusters bear some similarity to the clusters based on sediment characteristics but have important differences, (e.g., the split of HIN from Hbv and HIW) which mean that metal concentrations do not strongly reflect sediment characteristics.

Figure 3:
Principal components analysis of site sediment metal concentrations (top 2 cm) in November 2005, plotted in two dimensional space. The closer two sites are together on the plot the more similar their sediment chemistry is.



5.2 Differences between surficial and deep sediment layers

Generally there were few significant differences in the chemical concentrations found in the surface and deep sediment layers (Table 6), suggesting that if changes occur they will be able to be attributed to changes in chemical inputs to the harbour. However, for some sites (Hell, HIN, OHbv, ParU and Rng), a number of differences were observed. Frequently these differences involved arsenic and manganese, and levels were not always highest in the sediment surface.

Manganese tended to be higher in surface sediments for some sites (Table 6: MainU, Par, MainC, HIN), with similar elevations (~2-fold) in zinc for MainC and HIN, and copper for HIN. The manganese differences probably reflect redox changes with depth and are not reflected in the iron concentrations, which could be expected to be less sensitive to redox changes. Notably, the sites with different top and bottom manganese levels do not all have high TOC, which might be expected to be a driver for redox processes. The absence of strong depth gradients in the sediment for copper, iron, lead, zinc and PAH's means that sampling of surficial sediments will provide a good indication of site chemistry.

Table 6:

Differences between surface (top 2 cm) and deeper (5 - 15 cm) sediment properties; total Polycyclic Aromatic Hydrocarbons (PAH) were measured in mg/kg dry wt; Total Organic Carbon (TOC) in g/100g dry wt; <63 µm extractable metals and total recoverable metal were measured in mg/kg dry wt. Cu = copper, Pb = lead, Zn = zinc, Fe = iron, As = arsenic, Cd = cadmium, Cr = chromium, Ni = nickel.

				<63 µm metals			**Total recoverable metals**								
Site	**Depth**	**Total PAH**	**TOC**	**Cu**	**Pb**	**Zn**	**Fe**	**Mn**	**As**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Rng	***bottom***	0.1	2.6	20	26	93	20467	76	10.3	0.1	20	21	8.9	22	84
	top	0.1	2.6	20	24	92	20500	85	9.0	0.1	19	23	8.4	23	86
Brig	***bottom***	0.2	2.3	20	28	97	19667	67	11.4	0.1	19	21	8.4	24	90
	top	0.2	2.4	21	28	99	19900	75	10.1	0.1	21	23	8.5	25	95
MainU	***bottom***	0.2	2.2	19	28	93	18900	70	8.1	0.1	20	20	8.5	25	84
	top	0.2	2.2	18	27	91	20767	138	10.1	0.1	18	20	7.8	24	83
ParU	***bottom***	0.2	2.5	19	31	101	21400	115	9.2	0.1	23	22	8.7	27	92
	top	0.1	2.5	20	32	102	24700	286	12.8	0.0	22	22	8.6	26	94
MainC	***bottom***	0.3	1.3	12	20	64	17100	75	12.5	0.1	13	13	5.5	25	93
	top	0.2	1.3	17	28	96	18067	129	14.9	0.1	13	13	5.7	25	94
HIN	***bottom***	0.7	0.4	14	28	77	10020	36	8.2	0.1	8	7	3.0	14	38
	top	0.2	0.5	22	34	105	9870	70	10.0	0.1	8	11	3.1	17	53
Luc	***bottom***	0.3	0.8	20	33	109	24267	117	16.7	0.1	19	15	11.7	24	90
	top	0.3	0.9	21	33	118	25633	125	16.0	0.1	17	13	10.5	24	87
LucU	***bottom***	0.3	1.4	13	23	81	17600	104	12.3	0.1	17	17	7.4	21	74
	top	0.3	1.4	19	29	97	16333	86	8.7	0.1	17	18	6.8	22	83
MainO	***bottom***	0.5	0.3	25	30	86	10120	30	9.0	0.1	8	12	3.1	16	43
	top	0.3	0.4	21	27	94	10637	41	10.3	0.0	7	11	2.6	18	45
HIW	***bottom***	0.3	0.3	16	32	86	4293	23	3.7	0.0	5	5	2.0	9	26
	top	0.2	0.4	19	31	98	4143	28	3.3	0.0	5	6	1.8	7	25
Hell	***bottom***	0.4	1.0	16	32	82	12633	59	7.5	0.1	14	13	6.3	22	79
	top	0.3	1.5	16	30	85	16067	105	9.0	0.1	16	16	6.8	24	84
HellU	***bottom***	0.3	1.9	21	43	118	20200	82	10.2	0.1	21	21	8.9	37	113
	top	0.2	2.1	21	38	121	21233	101	10.6	0.1	22	22	9.1	34	122
Ohbv	***bottom***	0.5	1.4	20	36	106	16733	105	9.4	0.1	22	23	8.1	33	106
	top	0.4	1.7	17	30	95	18100	194	11.9	0.1	21	22	7.8	30	101
Hbv	***bottom***	0.5	0.7	12	36	103	4473	17	4.5	0.0	4	5	1.8	9	28
	top	0.2	0.4	23	34	130	4033	37	3.5	0.0	4	4	1.6	7	26

6 Site ecology

6.1 Site summaries and comparisons

Taxa found at the UWH sites are generally found in a number of other Auckland Harbours, with strongest concordance in species occurrence being with the Central Waitemata (see Appendix 4 for a list of taxa). Based on taxa abundances, 4 clusters of sites were apparent (Fig. 4) that were more than 50% dissimilar.

- Sites from the outer part of the harbour: Hbv, HIW, MainO and HIN. These sites were dominated by bivalves (Table 7), *Austrovenus stutchburyi*, *Nucula hartvigiana* and *Macomona liliana*). Adult *Nucula* were found at all sites, but sites differed in their proportion of adults to juveniles for other species (Fig. 5). HIN had high numbers of all size classes of *Austrovenus*, but mainly juvenile *Macomona*. HIW had fewer adult *Austrovenus* but large populations of adult *Macomona*. MainO had mainly juveniles and few adults of either *Austrovenus* or *Macomona*. Adult *Austrovenus* were also relatively rare at Hbv, but the population of *Macomona liliana* consisted largely of adults. The limpet *Notoacmea helmsi* was also common. While Hbv had polychaetes sensitive to muddy sediments (e.g., *Aonides oxycephala*); other sites had less sensitive polychaetes (*Prionospio aucklandica*, *Scoloplos cylindrifer* and *Aricidea* sp.), reflecting the muddier sediments found in part of the sites. The hierarchical ecological rules developed for the Kaipara (Hewitt and Funnell 2005, Appendix 2), defines this cluster as *Austrovenus*-*Macomona* communities.
- LucU, Hell, MainC and OHbv. These sites were dominated by deposit-feeding polychaetes (*Cossura consimiis*, *Polydora cornuta* and Paraonids (*Aricidea* and *Levinsenia gracilis*)), although crabs were abundant at all but MainC.
- Luc, sited between these first two clusters, had a mix of bivalves and polychaetes. Since few adult bivalves were found, this site was classified as a deposit-feeder community.
- The remaining sites (Brig, ParU, Rng, MainU and HellU) are all from the upper part of the harbour with the exception of HellU. These sites were dominated by burrowing Corophid amphipods (*Paracorophium excavatum* and ?*Sinocorophium* sp.) and Oligochaetes, with some polychaetes. Brig and Rng both had abundant *Arthritica bifurca*, a small mud tolerant bivalve.

The only similarity between these clusters and the ones based on sediment characteristics was that Hbv, HIW and HIN were close together.

Figure 4:
Nonmetric multidimensional scaling ordination plot of the community structure during November 2005. The stress of the plot is 0.08. Sites that are closest together are most similar.

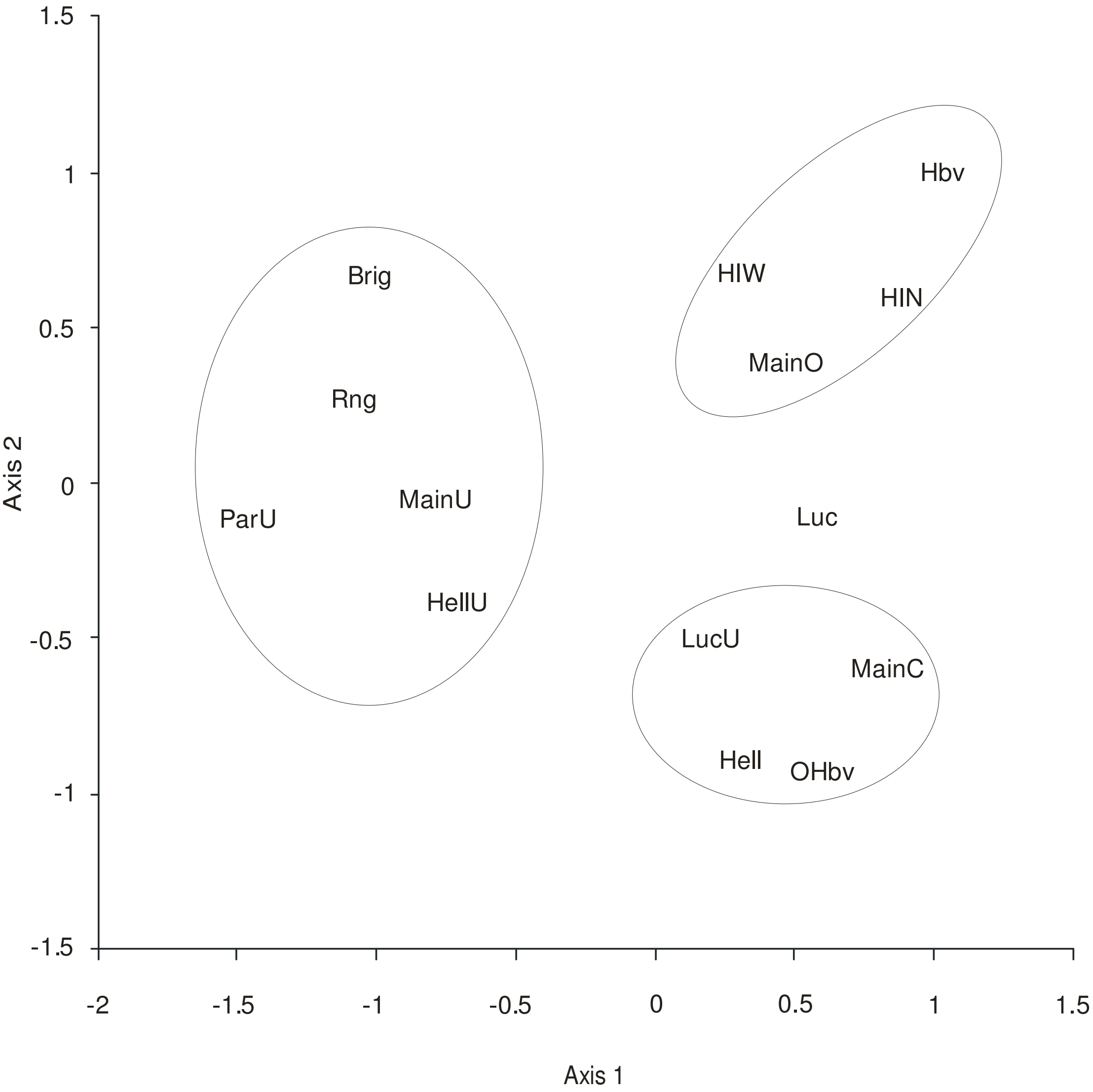


Figure 5:
Size class distributions of cockles (*Austrovenus stutchburyi*), wedge shells (*Macomona liliana*), pipis (*Paphies australis*) and *Mactra ovata* in three distinctive size categories, measured as maximum shell length, at each site in November 2005.

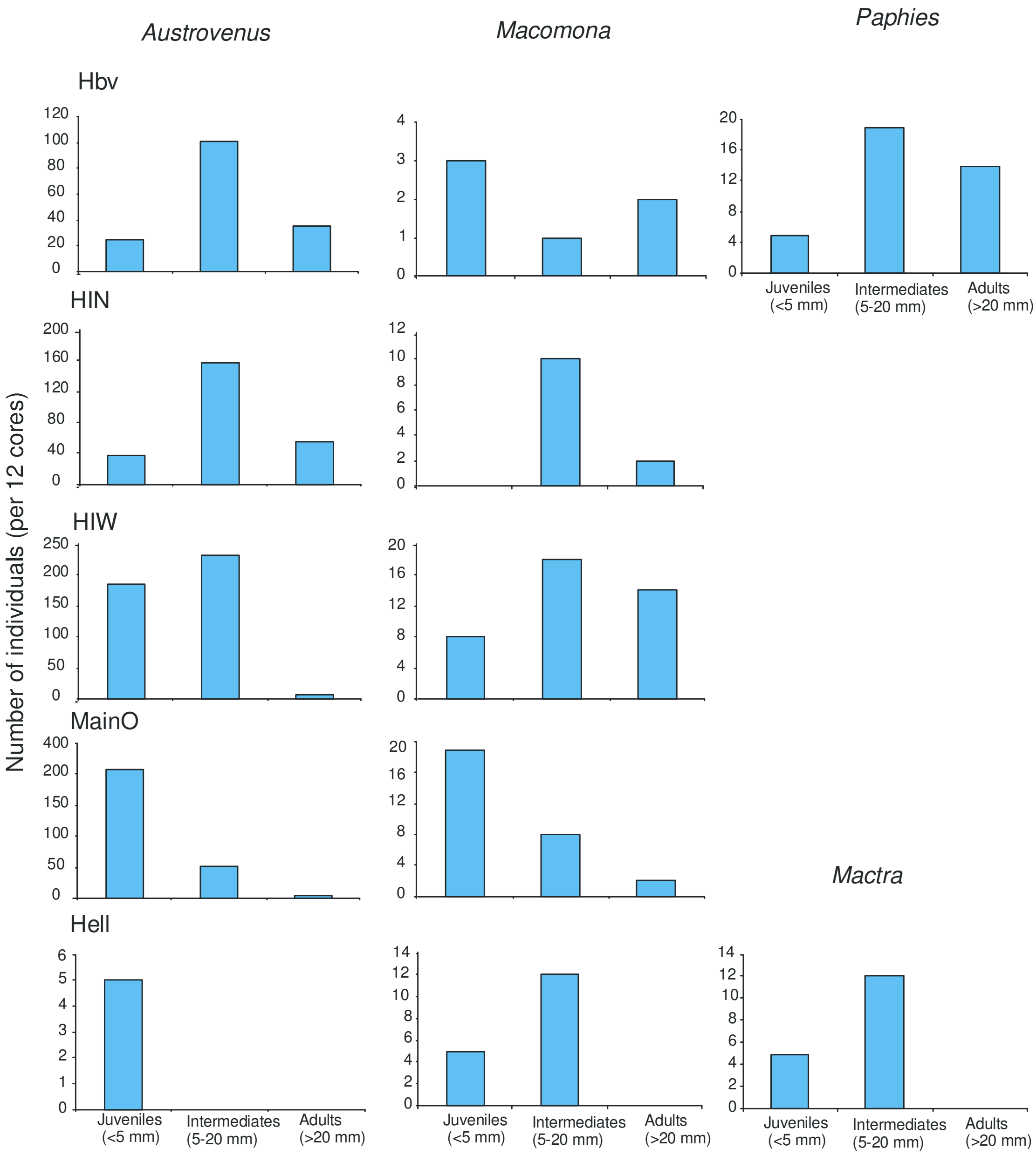


Table 7:

The five most abundant taxa found at each site during November 2005.

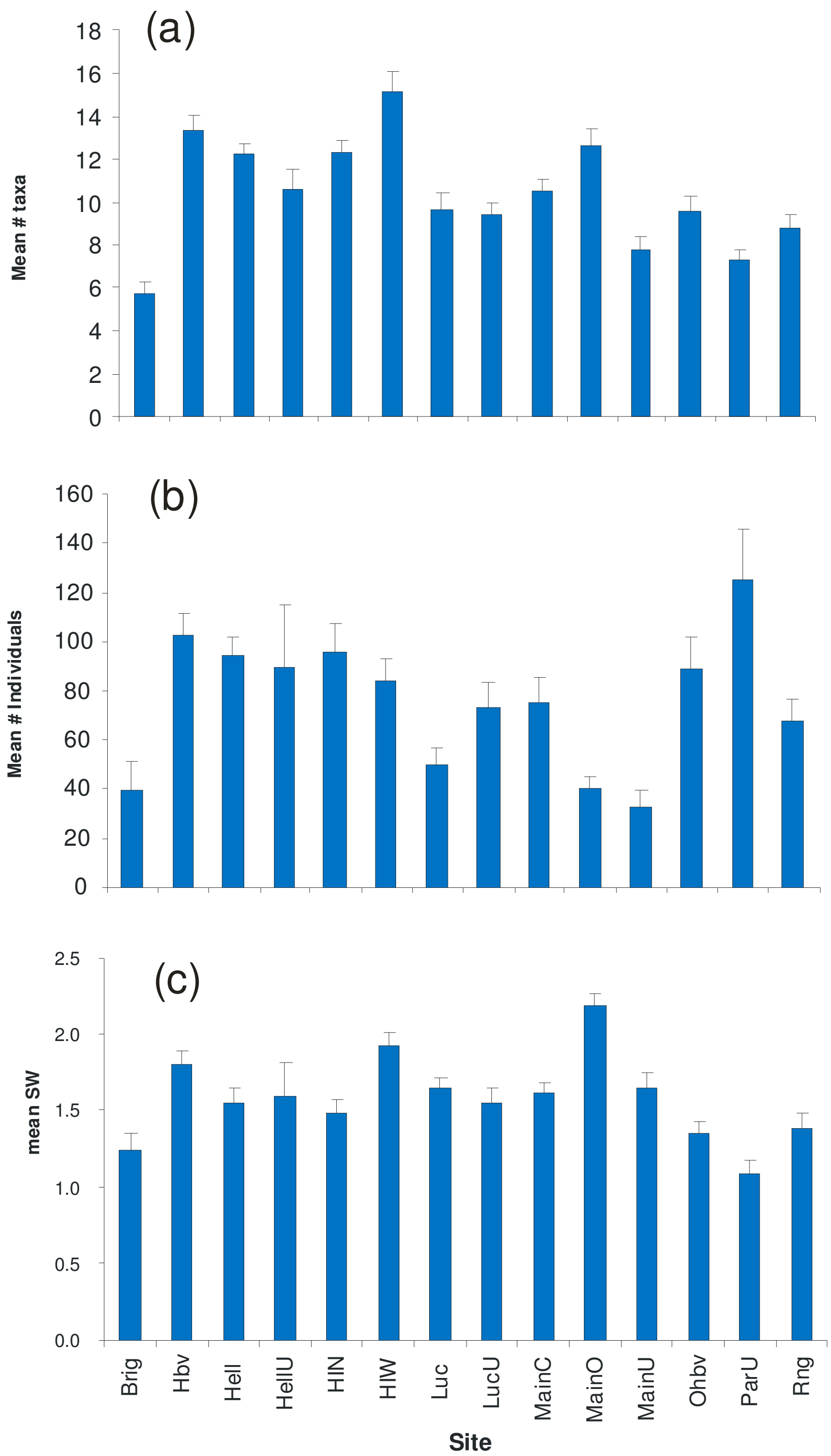
Site	1	2	3	4	5
Hbv	Nucula hartvigiana	Aonidies oxycephala	Austrovenus stutchburyi	Exogoninae	Notoacmea helmsi
HIW	Austrovenus stutchburyi	Nucula hartvigiana	Scoloplos cylindrifer	Prionospio aucklandica	Macomona liliana
MainO	Austrovenus stutchburyi	Nucula hartvigiana	Aricidea sp.	Scoloplos cylindrifer	Chaetozone sp.
HIN	Nucula hartvigiana	Austrovenus stutchburyi	Notoacmea helmsi	Aricidea sp.	Prionospio aucklandica
Luc	Aricidea sp.	Chaetozone sp.	Nucula hartvigiana	Austrovenus stutchburyi	Paradoneis lyra
LucU	Cossura consimiis	Aricidea sp.	Levinsenia gracilis	Helice crassa	Polydora cornuta
Hell	Cossura consimiis	Levinsenia gracilis	Aricidea sp.	Heteromastus filiformis	Prionospio aucklandica
MainC	Aricidea sp.	Paradoneis lyra	Cossura consimiis	Heteromastus filiformis	Phoxocephalid sp A
OHbv	Aricidea sp.	Levinsenia gracilis	Paradoneis lyra	Cossura consimiis	Helice crassa
Brig	Oligochaete sp.1	Arthritica bifurca	Proharpinia sp.	Nicon aestuariensis	Exosphaeroma ?chilensis
ParU	Paracorophium excavatum	Oligochaete sp.2	Oligochaete sp.1	Helice crassa	Boccardia syrtis
Rng	Oligochaete sp.1	Arthritica bifurca	Paracorophium excavatum	Proharpinia sp.	Nicon aestuariensis
MainU	Paracorophium excavatum	?Sinocorophium sp.	Oligochaete sp.1	Polydora cornuta	Oligochaete sp.2
HellU	Paracorophium excavatum	Oligochaete sp.2	Polydora cornuta	Helice crassa	Aricidea sp.

Sites varied widely in how self-similar the communities were. The most internally consistent sites were Hell, HIN, Hbv, MainC, Ohbv and ParU; all with > 50% self similarity. Sites HellU and MainU had the lowest self similarity (< 30%).

Species richness (number of taxa) was highest at HIW, Hbv, HIN, MainO and Hell, and lowest at Brig (Fig. 6a). Total number of individuals was lowest at sites Brig, MainO, Luc and MainU (Fig. 6b). Highest Shannon-Weiner diversity values were observed at sites MainO, Hbv and HIW, and the lowest at ParU (Fig. 6c). Similar to Lundquist et al. (2003), low diversity was not necessarily associated with high % mud content and low diversity sites were not confined to the upper portions of the harbour or sub-estuaries.

Figure 6:

Mean number of (a) taxa, (b) individuals and (c) Shannon-Weiner diversity index (SW) found in 12 cores at each site in November 2005. Error bar represents one standard error.

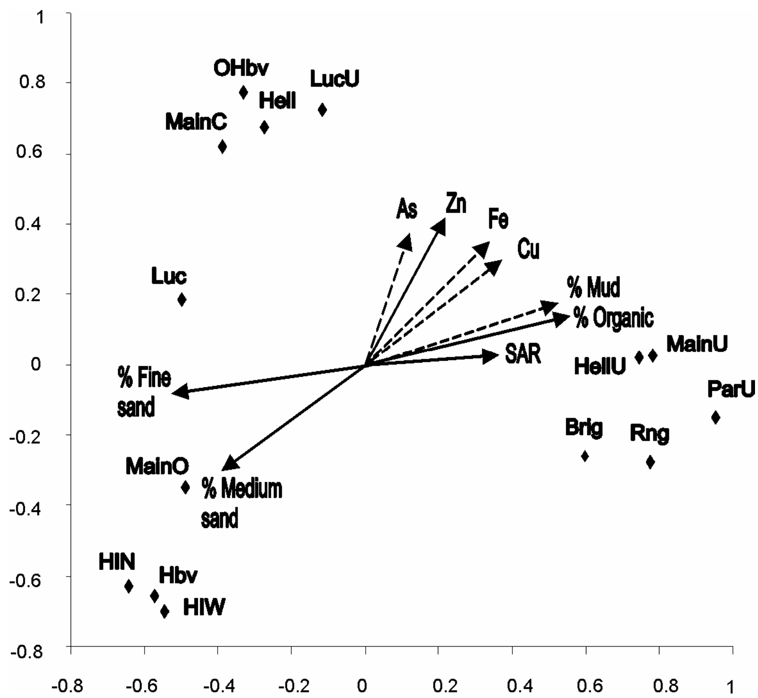


6.2 Links between ecology and habitat characteristics

Regardless of which type of ordination was used, similar environmental variables emerged as influential. Fig. 7 presents the relationship between community composition in site groupings and environmental variables. Percentage organic content, total zinc concentrations, sediment accumulation rate and % of fine and medium sand were the most important ($p = 0.002$), explaining 69% of the variability between site community composition. Closely correlated with these were % mud content, total copper, total arsenic and total iron. Nickel, chromium and lead were so closely correlated with iron that their effects could not be separated and the other metals, total PAH's and chlorophyll *a* were not important.

Section 5.1 indicates that the most chemically stressed site in the UWH is HellU, although even this does not have high levels of the measured chemicals. This site is dominated by Corophid amphipods (*Paracorophium excavatum* and ?*Sinocorophium*), Oligochaetes, polychaetes (*Aricidea* sp., *Polydora cornuta* and *Boccarida syrtis*), and the crab *Helice crassa*, all emphemeral and disturbance-tolerant species A number of other polychaetes are also common (*Heteromastus filiformis*, *Cossura consimilis*, Nereidae and Exogoninae). Most of these taxa should be relatively insensitive to low levels of chemical contamination. Few species expected to be sensitive to chemical contamination are observed, although the sensitivities of many species are unknown (see section 8.4)

Figure 7:
Redundancy analysis of the relationship between community composition and environmental variables. The solid lines represent the most important variables, dashed lines represent highly correlated variables. The closer a site is located to the direction the arrow points the higher the % content or concentration of that variable it has.



6.3 Community changes over time

Some changes in community composition were observed between the two sample dates (early and late summer), but communities did not become distinctly different ($p > 0.05$). No sites exhibited a complete change, between November and February, in the taxa comprising the 5 most dominant, however, only MainC exhibited no changes (Table 8), despite a significant decrease in *Aricidea* observed at that site.

Five sites exhibited only one change in the taxa comprising the 5 most abundant (HIW, MainO, HIN, ParU and MainU). At HIW and MainO, increased abundances of *Aricidea* and *Chaetozone* respectively were detected. At HIN a decrease in the abundance of *Aricidea* and *Notoacmea* and an increase in *Nicon* were detected. At ParU, despite the small change in dominance structure, decreases in numbers of *Paracorophium*, Oligochaetes and *Helice* were detected. At MainU increases in the abundance of Oligochaetes were detected.

One site exhibited two changes in the taxa comprising the 5 most abundant (Rng). At this site, decreases in abundance were observed for all of the five most dominant taxa in November 2005 and increases in abundance were detected for Oligochaete sp.2 and barnacles.

Table 8:

The five most abundant taxa found at each site during November 2005 and February 2006. Statistically significant changes in the abundance of the dominant taxa are noted.

Site	*Nov05*	*Feb06*	*Changes*
MainC	***Aricidea*** ***Paradoneis*** ***Cossura*** ***Heteromastus*** ***Phoxocephalid***	***Aricidea*** ***Cossura*** ***Paradoneis*** ***Heteromastus*** ***Phoxocephalid***	***Decrease in Aricidea***
HIW	***Austrovenus*** ***Nucula*** ***Prionospio*** ***Scoloplos*** ***Macomona***	***Austrovenus*** ***Nucula*** ***Aonides*** ***Prionospio*** ***Scoloplos***	***Increase in Aonides***
MainO	***Austrovenus*** ***Nucula*** ***Aricidea*** ***Ceratonereis*** ***Macomona***	***Austrovenus*** ***Nucula*** ***Chaetozone*** ***Ceratonereis*** ***Aricidea***	***Increase in Chaetozone***
HIN	***Nucula*** ***Austrovenus*** ***Notoacmea*** ***Aricidea*** ***Prionospio***	***Nucula*** ***Austrovenus*** ***Notoacmea*** ***Nicon*** ***Prionospio***	***Decrease in Aricidea and Notoacmea, increase in Nicon.***
ParU	***Paracorophium*** ***Oligochaete sp.2*** ***Oligochaete sp.1*** ***Helice*** ***Boccardia***	***Oligochaete sp.1*** ***Oligochaete sp.2*** ***Paracorophium*** ***Helice*** ***Barnacle***	***Decrease in Paracorophium, Oligochaetes and Helice***
MainU	***Paracorophium*** ***?Sinocorophium*** ***Oligochaete sp.1*** ***Polydora*** ***Oligochaete sp.2***	***Oligochaete sp.2*** ***Oligochaete sp.1*** ***Polydora*** ***Paracorophium*** ***Helice***	***Increase in Oligochaetes***
Rng	***Oligochaete sp.1*** ***Arthritica*** ***Paracorophium*** ***Proharpinia*** ***Nicon***	***Oligochaete sp.1*** ***Arthritica*** ***Paracorophium*** ***Oligochaete sp.2*** ***Barnacle***	***Increases in Oligochaete2 and barnacles, decreases in Oligochaete1, Arthritica, Paracorophium, Prohaprinia and Nicon***

Site	Nov05	Feb06	Changes
Luc	***Aricidea***	***Aricidea***	***Increase in Muscilitis and Nicon***
	Chaetozone	***Nicon***	
	Nucula	***Chaetozone***	
	Austrovenus	***Muscilitis***	
	Paradoneis	***Heteromastus***	
LucU	***Cossura***	***Levinsenia***	***Decrease in Cossura, Aricidea, Helice and Polydora, increase in Levinsenia***
	Aricidea	***Nicon***	
	Levinsenia	***Cossura***	
	Helice	***Polydora***	
	Polydora	***Oligochaete sp.1***	
Hell	***Cossura***	***Cossura***	***Decrease in Cossura, Levinsenia , Aricidea, Heteromastus and Prionospio, increase in Nicon, Paracorophium and Torridoharpinia.***
	Levinsenia	***Aricidea***	
	Aricidea	***Nicon***	
	Heteromastus	***Paracorophium***	
	Prionospio	***Torridoharpinia***	
OHbv	***Aricidea***	***Aricidea***	***Increase in Levinsenia, Paracorophium and Polydora, decrease in Cossura***
	Levinsenia	***Levinsenia***	
	Paradoneis	***Oligochaete sp.1***	
	Cossura	***Paracorophium***	
	Heteromastus	***Polydora***	
Brig	***Oligochaete sp.1***	***Oligochaete sp.1***	***Increases in Oligochaete2, Paracorophium and Helice, decreases in Arthritica, Prohapinia and Exosphaeroma***
	Arthritica	***Paracorophium***	
	Proharpinia	***Oligochaete sp.2***	
	Nicon	***Nicon***	
	Exosphaeroma	***Helice***	
HellU	***Paracorophium***	***Nicon***	***Decreases in Paracorophium, Oligochaete2, Polydora, Helice, Aricidea, increases in Nicon and Cossura***
	Oligochaete sp.2	***Oligochaete sp.1***	
	Polydora	***Heteromastus***	
	Helice	***Polydora***	
	Aricidea	***Cossura***	

Five sites exhibited three changes in the taxa comprising the 5 most abundant (Luc, LucU, Hell, Ohbv and Brig). At Luc, densities of the 5 most abundant taxa remained the same, yet increases in the abundances of *Musculista* and *Nicon* shifted the dominance hierarchy. Decreased numbers of *Austrovenus* juveniles were also observed. Conversely at LucU 4 of the 5 most dominant taxa from November had decreased in abundance by February. At Hell there were decreases in abundance of all of the 5 most dominant taxa from November, with the greatest decrease occurring for *Levinsenia*. Increases in abundance were also observed (*Nicon* and amphipods). At

Ohbv increases in the abundance of *Levinsenia*, *Paracorophium* and *Polydora*, and a decrease in the abundance of *Cossura* were detected. At Brig, increases in the abundance of Oligochaete sp2, *Paracorophium* and *Helice*, and decreases in *Arthritica*, *Proharpinia* and *Exosphaeroma* were detected.

Faunal turnover was most pronounced at HellU. Decreases in the abundance of all 5 dominant taxa occurred between November and February. Only *Polydora* (3rd most dominant in November) was among the 5 most dominant in February. Increases in abundance for *Nicon* and *Cossura* were detected.

7 Comparison with 2001 survey of the Upper Waitemata Harbour

Selection of the sites for this monitoring programme was guided by the 2001 survey of the Upper Waitemata Harbour (Cummings et 2002), with some of the sites located where sampling had previously occurred (HIN, Hell, HellU, Brig, MainO, HIW and Luc). Because the original survey had also been conducted in November it was considered worthwhile to compare their present communities with those observed in 2001. Other sites were sampled in the same general area as the 2001 survey (ParU, LucU, Rng, OHbv, Hbv and MainU), although not always on the same tidal flat or on the same side of the channel. For these sites, some characteristics were different, e.g., the presence of mangroves, oysters or mud banks (Table 9).

7.1 Sediment characteristics

Generally, chlorophyll *a* concentrations varied between the survey and the monitoring done in November 2005. This variation did not show consistent patterns, however, and did not occur at all sites. Organic content of the sediment was the most consistent, showing little variation between the survey and monitored sites from the same location. Even sediment particle size was generally consistent for the sites located in the same position, with the exception of MainO, where the monitored site spans both mud and sand.

7.2 Ecological comparisons

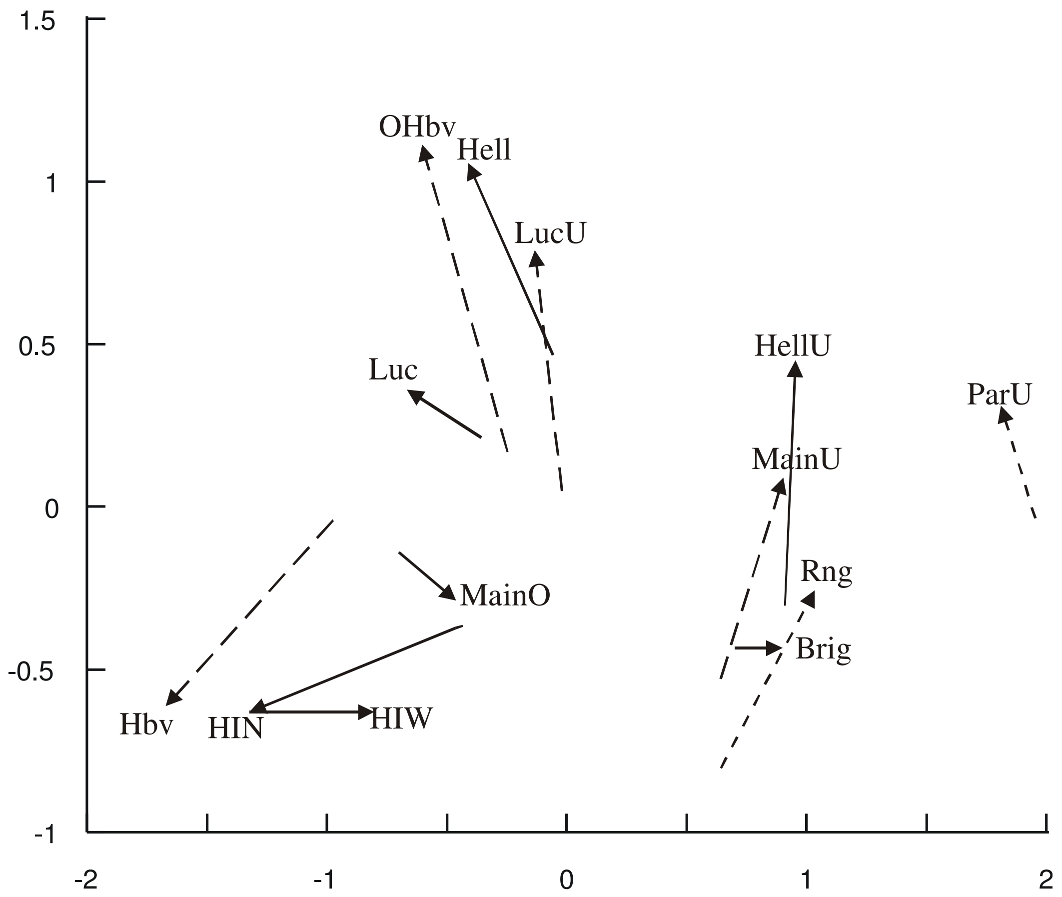
Although the community composition of sites does seem to have shifted between 2001 and 2005, the shifts have preserved the relative groupings (Fig. 8). However, the cluster of outermost sandy sites (Hbv, HIN, HIW and MainO) exhibit greater dispersal in 2005 than 2001. These sites may be differentiating themselves from the muddier sites.

Table 9:

Comparison between the sediment properties measured in the top 2 cm of sediment in November 2005 and those measured in the same position or a nearby locality (50 –500 m away) during the 2001 Upper Waitemata survey (Cummings et al. 2002).

Site		% Mud	% Fine-medium sand	% Coarse sand-shell hash	% Organic	Chl *a*	Location of survey site compared to mp	Differences in habitats
HellU	2001	63.49	36.13	0.42	4.58	12.8	same	N/A
	2005	61.08	38.80	0.12	6.00	16.65		
Hell	2001	96.36	3.74	0.06	7.44	8.45	same	N/A
	2005	88.78	11.22	0.00	8.06	7.22		
Luc	2001	27.03	59.99	12.98	4.47	5.18	same	N/A
	2005	30.08	58.54	11.38	3.33	9.52		
Ohbv	2001	41.01	50.99	7.99	3.24	11.75	same	N/A
	2005	75.19	24.78	0.04	5.79	8.48		
MainO	2001	33.35	64.84	1.81	4.14	7.29	same	N/A
	2005	9.91	86.72	3.37	2.13	7.61		
LucU	2001	49.02	48.95	2.08	5.89	8.69	near	N/A
	2005	62.05	37.91	0.04	5.17	9.48		
Hbv	2001	10.62	87.25	2.12	2.19	19.39	near	mudbank
	2005	2.12	90.83	7.05	1.50	17.60		
HIW	2001	51.83	46.25	1.92	3.23	11.14	near	oyster bed
	2005	10.54	82.40	7.06	1.32	7.33		
ParU	2001	90.01	9.69	0.29	8.69	10.24	near	mangroves
	2005	96.84	3.16	0.00	10.13	7.75		
Rng	2001	42.05	40.81	17.14	6.29	9.35	near	mangroves
	2005	91.59	8.41	0.00	9.60	8.09		
MainU	2001	89.97	9.21	0.82	9.07	12.06	near	across channel
	2005	88.43	11.57	0.00	8.26	7.6		
HIN	2001	14.58	74.08	11.34	2.28	10.96	same	N/A
	2005	6.15	86.05	7.80	1.62	10.42		
Brig	2001	91.72	7.34	0.95	9.08	7.51	same	N/A
	2005	89.25	10.52	0.23	8.68	6.68		

Figure 8:
Non-metric multidimentional ordination of the community structure of each site in November 2001 and November 2005. Site label shows November 2005 position and line shows direction of change from the November 2001 position. Solid lines show sites located in the same position, dashed lines show sites in a similar location. No relevant site was sampled for MainC.



8 Comparison with RDP sampling of Upper Waitemata Harbour

8.1 Sediment characteristics

Six of the monitoring sites are located near to sites the ARC monitors for the RDP, which measures sediment characteristics, copper, zinc and lead concentrations and macroinvertebrate communities. For HbV, HellU and Rng sites, the sediment characteristics of the RDP and monitoring sites are similar (Table 10). However, for LucU (RDP Te Wharau), HIW (RDP Herald Island) and MainC (RDP Paremoremo), the RDP sites have higher %mud content. A deliberate decision was taken when placing the monitoring sites to locate them in sandy places where possible, as animals living in sandy sediments are frequently more sensitive to sediment and chemical contamination.

8.2 Metal concentrations

Some differences in metal concentrations were observed between the RDP sites and the similarly located sites in this monitoring programme (Table 11). Generally these were increases in the concentration of weak acid extracted zinc, and were not reflected in the total zinc concentrations (HIW, Rng, MainC and HbV). However, the Herald Island site had distinctly lower total zinc and lead concentrations. These suggests that metal concentrations are spatially variable even on the 100 m scale and can not easily be extrapolated to contamination of larger areas.

Table 10:

Sediment properties of the surface sediments (top 2 cm) compared with nearby RDP sites in 2005.

Site		% coarse	% medium	% fine	% mud
Hbv		*7.05*	*36.31*	*54.51*	*2.12*
Hobsonville	*RDP*	*7.10*	*36.30*	*54.50*	*2.12*
HellU		*0.00*	*0.73*	*10.49*	*88.78*
Kaitapaki	*RDP*	*2.02*	*0.74*	*11.90*	*85.33*
LucU		*0.04*	*1.53*	*36.38*	*62.05*
Te Wharau	*RDP*	*0.20*	*1.09*	*19.94*	*78.78*
MainC		*0.77*	*4.85*	*73.80*	*20.58*
Paremoremo	*RDP*	*0.06*	*0.30*	*5.56*	*94.07*
Rng		*0.00*	*0.00*	*8.41*	*91.59*
Rangitopuni	*RDP*	*0.23*	*2.41*	*5.23*	*92.13*
HIW		*7.06*	*13.74*	*68.66*	*10.54*
Herald Island	*RDP*	*0.61*	*55.12*	*19.00*	*25.27*

Table 11:

Sediment metal concentrations of the surface sediments (top 2 cm) compared with the nearby RDP sites in 2005 (although Hobsonville 2002 values have been included to give an indication of temporal variability). <63 µm extractable metals and total recoverable metals were measured in mg/kg dry wt.

		<63 µm fraction			*Total recoverable*		
Site		***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
Hbv		***22.5***	***34.1***	***123.0***	***4.4***	***7.1***	***25.5***
Hobsonville 2002	***RDP***	***18.3***	***24.1***	***95.0***	***2.6***	***5.9***	***21.8***
Hobsonville 2005	***RDP***	***17.0***	***28.0***	***76.0***	***3.8***	***9.0***	***26.0***
HellU		***21.0***	***37.6***	***121.0***	***22.3***	***34.3***	***122.3***
Kaitapaki	***RDP***	***21.0***	***35.2***	***124.7***	***24.2***	***34.1***	***137.7***
LucU		***19.3***	***28.6***	***97.0***	***18.5***	***22.2***	***83.0***
Te Wharau	***RDP***	***23.7***	***30.1***	***117.***	***20.3***	***22.7***	***98.8***
MainC		***17.3***	***27.6***	***95.6***	***13.1***	***25.5***	***93.6***
Paremoremo	***RDP***	***18.5***	***23.8***	***78.9***	***20.7***	***23.5***	***86.6***
Rng		***20.0***	***24.4***	***92.3***	***22.6***	***22.6***	***85.9***
Rangitopuni	***RDP***	***17.0***	***22.0***	***77.0***	***22***	***23.9***	***90.0***
HIW		***18.6***	***30.5***	***98.3***	***5.5***	***7.5***	***24.9***
Herald Island	***RDP***	***16.3***	***26.7***	***84.6***	***7.7***	***15.1***	***75.3***

8.3 Ecological comparisons

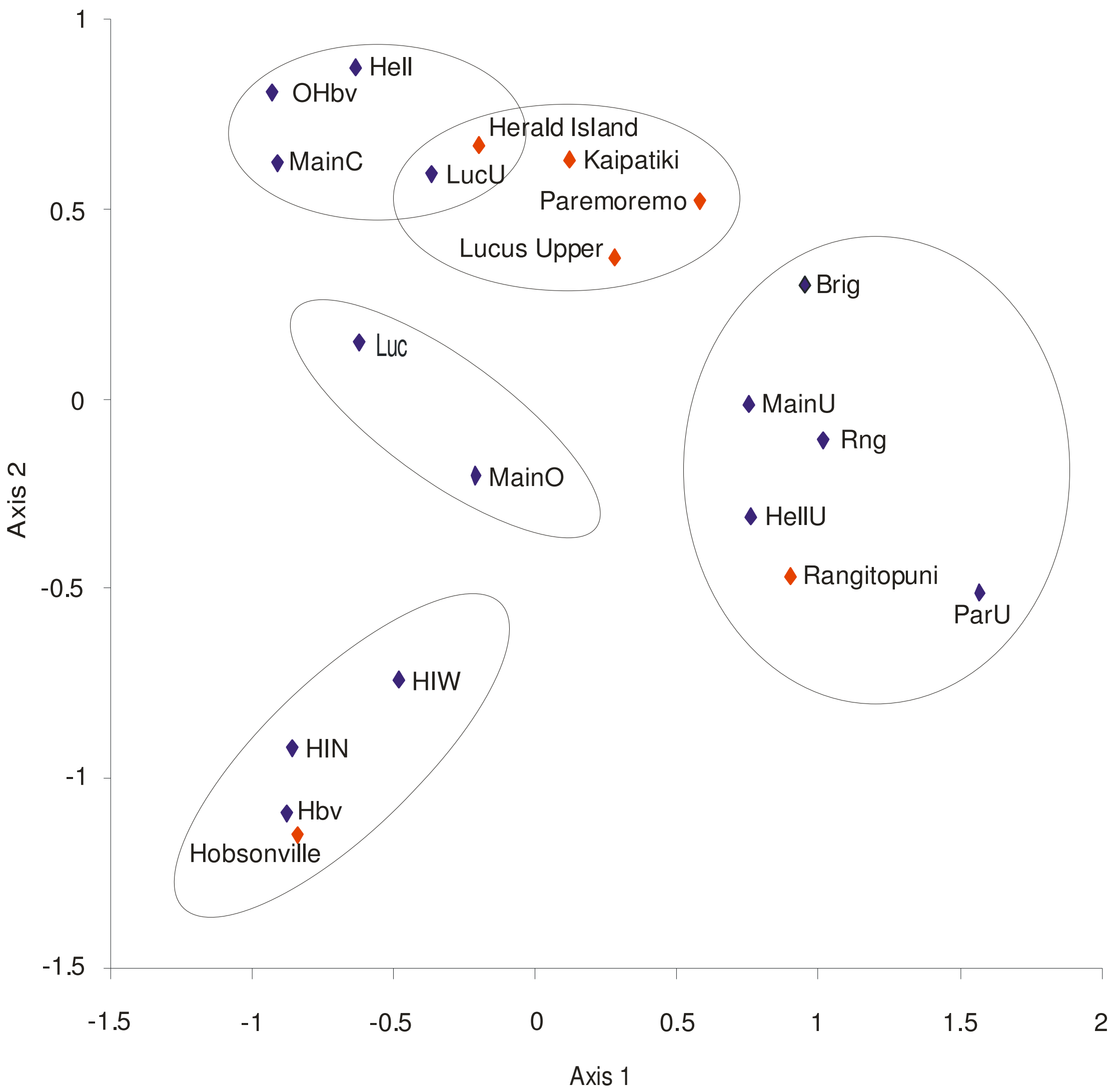
Five clusters of sites were observed (Fig 9). These largely group the monitoring sites similarly to the descriptions in section 6.1:

- Monitoring sites Hbv, HIN and HIW; note that the RDP site Hobsonville is actually the same site as Hbv.
- Monitoring sites Luc and MainO.
- Monitoring sites Ohbv, Hell and MainC.
- Monitoring sites LucU and RDP sites Lucas Upper, Paremoremo, Kaipatiki and Herald Island.
- Monitoring sites ParU, Brig, MainU, HellU and Rng and RDP site Rangitopuni.

The differences in communities between the RDP sites and the monitoring sites located nearby corroborate the differences in metal concentrations and sediment characteristics detailed in the previous sections.

Figure 9:

Nonmetric multidimensional ordination plot comparing the community structure of UWH monitoring sites during November 2005 and the nearby RDP sites in the same year. monitoring sites in blue, RDP sites in red.



8.4 Species and known vulnerability

Little information is presently available on the sensitivity of the UWH taxa to most contaminants. However, in two FRST funded programmes, species abundance and chemical data collected by both NIWA and the ARC are being analysed. In one case this is to assess the degree to which species in coastal and estuarine waters are responding to multiple, rather than single, stressors. In the other, the focus is on determining methods to measure health, including indicator species. In both these projects, the relationships between the abundance of a number of species (including many of the monitored taxa) and concentrations of copper, zinc and lead in the < 63 μm sediment fraction are being assessed using quantile regressions (Table 12). Quantile regressions investigate all responses to a stressor, rather than concentrating on a mean response. They are, therefore, very effective for situations where a number of factors operate within a constraining factor. A common phenomenon in ecology is for data points in scatter plots of species-environment data to be widely scattered beneath an upper (or above a lower) limit – a "factor ceiling". Quantile regressions based on 90th percentiles enable us to estimate the factor ceiling.

Table 12:

The form of response observed for the common UWH taxa to sediment concentrations of copper (Cu), zinc (Zn) and lead (Pb). NR = no response, L = linear, T = threshold, B = bell shaped, unimodal response, low abundance increasing to a maximum then decreasing again, NA = not available. Max density range shows the concentrations for which maximum densities are within 10 % of the maximum observed.

Order	***Taxa***	***Cu Sensitivity***		***Zn Sensitivity***		***Pb Sensitivity***	
		Response shape and max density range (PPM)					
Amphipoda	***Paracorphium excavatum***	***L***	***<5***	***L***	***<50***	***L***	***<5***
	Melita awa	***L***	***<5***	***L***	***<50***	***L***	***<5***
Bivalvia	***Arthritica bifurca***	***B***	***10-35***	***B***	***70-220***	***B***	***20-80***
	Austrovenus stutchburyi	***B***	***10-30***	***B***	***70-160***	***B***	***20-50***
	Macomona liliana	***B***	***5-10***	***B***	***20-70***	***B***	***10-20***
	Nucula hartvigiana	***B***	***15-25***	***B***	***70-170***	***B***	***25-50***
Cnidaria	***Anthopleura aureoradiata***	***NA***		***NA***		***NA***	
Cumacea	***Colurostylis lemurum***	***NA***		***NA***		***NA***	
Gastropoda	***Diloma subrostrata***	***NA***		***NA***		***NA***	
	Notoacmea helmsi	***NA***		***NA***		***NA***	
	Zeacumantus lutulentus	***NA***		***NA***		***NA***	
Isopoda	***Exosphaeroma* spp.**	***NA***		***NA***		***NA***	
Polychaeta	***Aonides oxycephala***	***B***	***15-25***	***B***	***70-120***	***B***	***20-40***
	Prionospio aucklandica	***L***	***<5***	***L***	***<50***	***L***	***<5***
	***Aricidea* sp.**	***L***	***<10***	***L***	***<20***	***L***	***<10***
	Boccardia syrtis	***L***	***<5***	***L***	***<50***	***L***	***<10***
	Cossura consimiis	***B***	***10-25***	***B***	***75-150***	***B***	***25-50***
	***Euchone* sp.**	***NA***		***NA***		***NA***	

Glycera spp.	*NA*		*NA*		*NA*	
Heteromastus filiformis	*NA*		*NA*		*NA*	
Macroclymenella stewartensis	*L*	*<10*	*L*	*<50*	*L*	*<10*

9 Sensitivity to sediments

Information on the effects of increased sedimentation and suspended sediment concentrations on species abundances is available through NIWA (FRST-funded) and ARC data. This body of work has been summarised in Gibbs and Hewitt (2004). The results for the common upper Waitemata Harbour taxa are listed in a summary table (Table 13).

Table 13:

Summary of common upper Waitemata Harbour taxa's sensitivity to increases in fine sediment, both as sedimentation and suspended sediment (SS). The information in this table was collated from Norkko et al. (2001), Berkenbusch et al. (2001), Nicholls et al. (2003) and Gibbs & Hewitt (2004).

Order	*Taxa*	*Info on sensitivity to fine sediment*	*Sensitivity ranking*
Amphipoda	*Paracorophium excavatum*	*In field surveys, this species was found to occur at all sediment types, but preferred sites with a mud content > 95%*	*strong mud preference*
Bivalvia	*Arthritica bifurca*	*In field surveys, this species was found to prefer sites with a medium proportion of silt/clay, although this data was based on low abundances*	*low*
	Austrovenus stutchburyi	*Sensitive in field surveys and medium levels of SS. Found in sediment with 0-60% silt clay, prefers 5-10% silt/clay. Sensitive to burial by thin layers (0.5-1.5 cm) of terrestrial clay.*	*medium*
	Macomona liliana	*Sensitive to high levels of SS. Macomona survival was decreased in high SS (750 mgL-1 lab trials. In field surveys, this species was found to prefer sites with a low silt/clay proportion (<5%).*	*sensitive*
	Nucula hartvigiana	*Partially sensitive to burial by thin layers (0.5-1.5 cm) of terrestrial clay. In field surveys, this species was found to prefer sites with a low silt/clay proportion (<5%), but occurs at a wide range of sediment types (0-60%).*	*medium*
	Paphies australis	*Sensitive to burial by thin layers (0.5-1.5 cm) of terrestrial clay. Species prefers sites with a low proportion of silt/clay. Only occurs in sites with les than 5% fines*	*highly sensitive*
Cnidaria	*Anthopleura aureoradiata*	*In field surveys, this species was found to prefer sites with a low silt/clay proportion (5-10%), but occurs at a slightly wide range of sediment types (0-15%).*	*highly sensitive*

Cumacea	*Colurostylis lemurum*	*In field surveys, this species was found to prefer sites with a low silt/clay proportion (<5%), but occurs at a wide range of sediment types (0-60%).*	*sensitive*
Decopoda	*Helice crassa*	*In field surveys, this species was found to prefer sites with a high silt/clay percentage (<80%), but occur at sites with a wide range of sediment types/*	*strong mud preference*
Gastropoda	*Diloma subrostrata*	*In field surveys, this species was found to prefer sites with a low silt/clay proportion (5-10%), but occurs at a slightly wide range of sediment types (0-15%).*	*highly sensitive*
	Haminoea zelandiae	*No info*	
	Notoacmea helmsi	*In field surveys, this species was found to prefer sites with a low silt/clay proportion (<5%), but occurs at a slightly wide range of sediment types (<10%).*	*highly sensitive*
	Zeacumantus lutulentus	*Not sensitive in lab trials of SS*	*low*
Isopoda	*Exosphaeroma* spp.	*No info*	
Oligochaeta	*Oligochaeta* spp.	*In field surveys, this species was found to occur in all sediment types, but preferred sites with a mud content > 95%*	*strong mud preference*
Polychaeta	*Aonides oxycephala*	*V. sensitive in field surveys Prefers sediment with 0-5% silt/clay. Sensitive to burial by thin layers (0.5-1.5 cm) of terrestrial clay.*	*highly sensitive*
	Prionospio aucklandica	*Sensitive to burial by thin layers (0.5-1.5 cm) of terrestrial clay. In field surveys this species showed no preference for sites with a particular proportion of silt/clay.*	*sensitive*
	Aricidea sp.	*In field surveys, this species was found to occur in all sediment types, but preferred sites with a mud content less than 70%.*	*low*
	Boccardia syrtis	*Sensitive to high levels of SS (750 mg/l) in lab experiments Boccardia stopped feeding under high SS concentrations. Not sensitive to burial by thin (0.5-1.5 cm) layers of terrestrial clay, but sensitive to thick layers (3-9 cm). In field surveys, this species was found to prefer sites with less than 10-15% fines.*	*medium*
	Cossura sp.	*In field surveys, this species was found to occur at sites with a wide range of sediment types (5-65%), but preferred sites with moderate mud content (20-25%)*	*low*
	Euchone sp.	*No info*	
	Glycera sp.	*Not sensitive to burial by thick layers (3-9 cm) of terrestrial clay. In field surveys, this species was found to occur at sites with a wide range of sediment types.*	*low*
	Heteromastus filiformis	*In field surveys, this species was found to occur at sites with a wide range of sediment types.*	*low*
	Macroclymenella stewartensis	*In field surveys, this species was found to occur at sites with a wide range of sediment types (0-60%), although its density was highest at sites with a low proportion of silt/clay (10-15%).*	*medium*

Nereidae	***In field surveys, this species was found to occur in all sediment types, although its density was highest at sites with a medium proportion of silt/clay (55-60%).***	***Mud preference***
***Scolecolepides* sp.**	***In field surveys, this species was found to occur in all sediment types, although its density was highest at sites with a medium proportion of silt/clay (25-30%).***	***Mud preference***
Scoloplos cylindrifer	***In field surveys, this species was found to occur in most sediment types (0-60%), although its density was highest at sites with a low proportion of silt/clay (<5%)***	***sensitive***

10 Sampling design and recommendations

The design of a monitoring programme is an ongoing process and design features should be regularly reviewed. Hewitt (2000) suggests that, after the first year, consideration should be given to whether changes are needed to the number of replicates taken at each site and the number of sites sampled. This section considers such changes, as well as whether a subset of taxa and chemicals should be monitored and what frequency of sampling is required for the top and bottom layers of the sediment.

10.1 Macrofauna

Number of replicates

Consideration of the number of replicates to collect at a site generally revolves around cost/benefit analyses. A technique for assessing the point at which additional replicates do not confer additional benefit for single, patchily-distributed species was developed by Hewitt et al. (1993) and applied to benthic invertebrate monitoring data in the Manukau, Mahurangi and Central Waitemata. A technique for similarly assessing the effect of replication on multivariate analyses was developed by Anderson et al. (2003) and used to assess benthic invertebrate communities in the Auckland region. These techniques found that between 10 and 12 replicates are optimal. As a result, the ARC has standardized its Ecological Monitoring on 12 replicates and its RDP community-based sampling on 10 replicates. Variability (as standard deviation) of dominant taxa in this report observed on the first sampling occasion is similar to those observed in the CWH and did not decrease with sample size. For these reasons, we recommend continuing the monitoring at 12 replicates per site.

However, while at sites characterised by sand, core holes rapidly infill and long-term effects of sampling do not occur, we are not sure that this will be true at soft mud sites. Therefore, a November 2006 site visit will occur at low tide when each site is fully visible. Site damage will be assessed and, if core holes are visible, decreased sample replication or frequency will be considered.

Number of sites

Initially 9 sites were recommended for sampling, one in each of the areas predicted, by Green et al. (2004), to have different rates of contamination under urban development. An extra 5 sites were added in consultation with ARC (HellU, LucU, OHbv, MainC and ParU). These sites increase the number of sites in Hellyers, Lucas, Main harbour central and outside the UWH from one to two in each area. For Hellyers, Lucas and the central main harbour, the additional sites are similar in community composition to sites further up the harbour. In the case of Hellyers, as increased urban development is not anticipated, this site will provide a level of control for the upper harbour sites. Lucas Creek, however, has already undergone significant development in its catchment. The site situated in the upper reaches (LucU) does not add significantly to the robustness of the monitoring programme.

The 2 sites in both the central main harbour and outside the UWH are located on opposite sides of the channel, one in a sandy area and one in a muddy area. As such, both contribute to the robustness of the monitoring programme and should be retained if possible.

Sampling at two other sites needs to be considered:

- ParU is situated on a very small intertidal area. This was the only unvegetated area of sufficient size and homogeneity in Paremoremo Creek. We are concerned that the intensity of sampling in this small area is too great. Given the temporal consistency noted at this site between 2003 and 2005, we recommend that this site is only sampled once per year. The implications of this change are (1) between-year temporal changes associated with natural variability in seasonal cycles could affect the programmes ability to detect change, and (2) there would be fewer degrees of freedom and thus less ability to detect trends. However, both these problems could be addressed using multi-site comparisons of the behaviour of taxa observed at the site.
- Site MainO has a distinct change in sediment characteristics across the site, changing from sand covered rock to soft mud. We recommend that this site is monitored in a similar way to TK in Mahurangi. That is, sediment characteristics and macrofauna are collected and analysed separately for the two areas. Estimates of the change in area of the two components are made yearly. This only results in a single additional sediment sample to be processed on each sampling occasion.

Monitoring a subset of taxa.

In the ARC ecological monitoring programmes of the Manukau, Mahurangi and Central Waitemata, a subset of key species are monitored. We do not recommend this for the UWH for two reasons. (1) The lack of information available of the response of many taxa to chemical contaminants. (2) The RDP definition of health is based on community composition and thus requires all taxa to be monitored.

We have, however, explored the effect of different taxonomic resolutions for some taxa, where the time taken to differentiate to species is considerable, e.g., differentiating between *Polydora cornuta* and *Boccardia srytis*, or differentiating juveniles of Nereidae, Corophidae or Phoxocephalidae. These taxa are not differentiated further than this in the RDP health model. The RDP health model also does not differentiate between Oligochaetes/Capitella (a polychaete), or within Polydorids or Orbinidae. Also, apart from Corophidae, Phoxocephalidae and Paracalliopidae, the RDP model uses a general Amphipoda category. At this stage, differentiation between sites for the 2 Oligochaete species, the 2 Orbindae species and the 2 polydorid species are consistent over time, so we do not recommend clumping these taxa. However, amphipods as a group often exhibit variability in species composition over time; we recommend identifying these to family level for most sampling occasions, with full taxonomic resolution carried out in November of each year.

10.2 Sediment and Chemical sampling

Monitoring a subset of chemical variables.

The chemicals chosen for analysis in the first year comprised both those likely to be important during the development and ongoing use of the catchments (PAH, copper, zinc and lead) and other metals (iron, arsenic, manganese, chromium, cadmium and nickel) that may affect ecological communities. Obviously the first four chemicals require ongoing monitoring. Furthermore, differences observed between the concentrations of lead, zinc and copper in the weak acid extraction and the total extracted confirm the necessity of monitoring both fractions. For the other six metals, the strong correlations between iron, manganese and the other metals (including zinc, copper and lead) suggest that the availability of the other metals is closely linked to iron and manganese. For this reason it is important to continue to monitor both of these. Similarly, the relatively high values found for arsenic indicate that ongoing monitoring would be useful. However, chromium, cadmium and nickel do not require ongoing monitoring. We suggest repeat monitoring of these metals every three years.

Sampling of top and bottom layers.

The lack of significant differences between top and bottom layers of the sediment for most variables at most sites suggests:

(1) that if changes do develop between the layers they may be attributable to changes in inputs to the UWH, and may affect local communities;

(2) that bottom layers may not need to be sampled every year in order to define a baseline of differences.

We, therefore, recommend that three yearly sampling of bottom sediment should be sufficient to track changes between the top and bottom layers of sediment. This sampling time frame should be adapted in accordance with development schedules.

11 Summary

11.1 Context

In November 2005, a long-term monitoring programme was established in the Upper Waitemata Harbour. The aim of this programme is to monitor the ecological status and trends in marine macrobenthic species representative of the region, and to monitor habitats that have the potential to be affected by sedimentation, pollution and other impacts associated with development of the surrounding catchments. Concurrent sampling of sediment characteristics and chemical contaminants will provide the ability to correlate macrofaunal community information with predictions from catchment and hydrodynamic models developed for the Upper Waitemata Harbour.

Following consultation with the ARC, fourteen intertidal sites were selected. A single site is located in each of the Rangitopuni, Brigham, Paremoremo and Waiarohia arms, and the Upper and Outer sections of the main harbour. Two sites are located in each of the Lucas and Hellyers arms, the central part of the main Upper Waitemata harbour and outside the mouth of the Upper Waitemata Harbour. Methods and techniques used for sampling and sample processing were consistent with established monitoring programmes in the Central Waitemata, Manukau and Mahurangi Harbours, with slight variations to minimise disturbance in soft mud habitats. Sites were sampled every third month beginning in November 2005. This design will be used to collect base line data from each location. After development begins, and a sufficient degree of certainty in the temporal signals from locations has been achieved, sampling at individual locations may be switched on or off depending on activity in each sector.

Data from the first two sampling occasions (November 2005, February 2006) are presented in this report. Comparisons are also made between sites sampled for the ARC in other projects (i.e., survey of the Upper Waitemata Harbour and the Regional Discharges Project). Information gathered by NIWA in public good science programmes and in contracts for the ARC on species sensitivities to sediment and contaminants is also presented, as is information from this programme useful for the present Middle Waitemata Modelling project.

11.2 Sediment and chemical characteristics

Four groups of sites with different sediment characteristics were found. (1) Three sites on the outer and west of the harbour with high proportions of fine to coarse sand and low amounts of silt, clay and organics. (2) Three sites in the main outer and central section and the outer Lucas Creek with high proportions of fine-medium sand. (3) The site in the outer area of Hellyers Creek with a high mud content and a high chlorophyll *a* concentration. (4) The remaining seven sites had high mud contents and low chlorophyll *a* concentrations. These groupings did not change over time.

Few differences between the sediment characteristics in the surface (0 – 2 cm) and deeper (5 – 15 cm) sediments were found. Higher levels of organic content were found in surface sediment at the Hellyers Creek sites and the central main harbour site.

The suite of chemicals measured included not only contaminants likely to increase as a result of development, but also contaminants that may be associated with volcanic soils. Iron and manganese were analysed, since these elements may markedly affect the binding and hence bioavailability of contaminants of concern for potential toxicological effects. Concentrations were compared with the Threshold Effect Concentrations (TEL); and the Effects Range Low (ERL) standards presently used by the ARC. TEL exceedances were only observed for Arsenic (12 sites), Copper (6 sites) and Zinc (1). Notably, these site concentrations are markedly below the Probable Effect Level guidelines, used internationally. Summing across threshold exceedances indicated that the upper Hellyers Creek site was the most stressed site, although even this was not highly contaminated, with only arsenic exceeding the ARL threshold.

Generally there were few significant differences in the chemical concentrations found in the surface and deep sediment layers, suggesting that if changes occur they will be able to be attributed to changes in chemical inputs to the harbour. Differences observed involved arsenic and manganese and levels were not always highest in the sediment surface.

11.3 Ecological communities

Based on the ecology, again four groups of sites were found, however, these were not consistent with either the sediment or chemical groupings. (1) Sites from the outer part of the harbour (Hbv, HIW, MainO and HIN) were dominated by the bivalves *Austrovenus*, *Nucula* and *Macomona*. (2) A site from each of Hellyers, Lucas, the central Waitemata and the central main section of the UWH was dominated by deposit-feeding polychaetes and crabs. (3) The outer Lucas site was dominated by a mix of bivalves and polychaetes. (4) Sites from the upper part of the UWH (Brig, ParU, Rng, MainU) and the upper Hellyers site were dominated by burrowing Corophid amphipods and Oligochaetes, with some polychaetes. Similar to findings in other areas, low diversity was not necessarily associated with high mud content.

Communities did not change largely over time, either between years (2001 when the Upper Waitemata Harbour survey was conducted) or seasonally (November to February).

Some environmental variables emerged as influencing community composition. Organic content, total zinc concentrations, sediment accumulation rate and % of fine and medium sand explained 69% of the variability between site community composition.

11.4 Monitoring recommendations

The design of a monitoring programme is an ongoing process and design features should be regularly reviewed. We considered whether changes were needed: to the number of replicates taken at each site; the number of sites sampled; whether a subset of taxa and chemicals should be monitored; and what frequency of sampling is required for the top and bottom layers of the sediment:

- Based on analyses in a number of places, the ARC has standardised its Ecological Monitoring on 12 replicates. However, while at sites characterised by sand, core holes rapidly infill and long-term effects of sampling do not occur, we are not sure that this will be true at soft mud sites. Therefore, a November 2006 site visit will occur at low tide when each site is fully visible. Site damage will be assessed and, if core holes are visible, decreased sample replication or frequency will be recommended.
- We recommend the following changes to sampled sites. (1) Eliminating the site situated in the upper reaches of Lucas Creek as this area has already undergone significant development in its catchment. (2) Sampling the site in Paremoremo Creek only once per year, as we are concerned that the intensity of sampling in this small area is too great. (3) One site (MainO) has a distinct change in sediment characteristics across the site, changing from sand covered rock to soft mud. Collecting and processing samples from the two distinctly different areas (mud vs sand) of site MainO separately is suggested. Estimates of the change in area of the two components should be made yearly.
- The 2 sites in both the central main harbour and outside the UWH are located on opposite sides of the channel, one in a sandy area and one in a muddy area. As such, both contribute to the robustness of the monitoring programme and should be retained.
- In the ARC ecological monitoring programmes of the Manukau, Mahurangi and Central Waitemata, a subset of key species are monitored. We do not recommend this for the UWH for two reasons. (1) The lack of information available of the response of many taxa to chemical contaminants. (2) The RDP definition of health is based on community composition and thus requires all taxa to be monitored. However, for some taxa we suggest using high taxonomic differentiation (Corophidae, Nereidae, Phoxocephalidae, Polydorid and Oligochaete) to save time for most sampling occasions, with full taxonomic resolution carried out in November of each year.
- We recommend ongoing monitoring of PAH, copper, zinc and lead. Furthermore, differences observed between the concentrations of lead, zinc and copper in the fine and total fractions confirm the necessity of monitoring both fractions. Our results suggest that the availability of the other metals is closely linked to iron and manganese. For this reason it is important to continue to monitor both of these. Similarly, the relatively high values found for arsenic indicate that ongoing monitoring of this variable would be useful. However, chromium, cadmium and nickel do not require ongoing monitoring. Monitoring of poly aromatic

hydrocarbons, copper, zinc, lead, iron, manganese and arsenic in surficial sediment should be done yearly in November.

- Monitoring of deeper layers of the sediment should be done every three years. Coincident with that chromium, cadmium and nickel should also be monitored.

12 References

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13 Appendices

Appendix 1. Sites, locations, sampling methodology, and co-ordinates (NZMG) for the 13 monitored sites in the Upper Waitemata Harbour. Details are also included for the Central Waitemata Harbour site (Hobsonville) sampled only for chemical contaminants as part of this project.

Site	Code	Methodology	Dimensions of site (m)	Easting	Northing
Rangitopuni Creek	Rng	Boat	100 x 30	E2653449	N6491807
Brigham Creek	Brig	Boat	100 x 30	3E2653704	N6490358
Upper Main Channel	MainU	Boat	100 x 30	E2654360	N6491000
Paremoremo Creek	ParU	Boat	100 x 30	E2656207	N6492093
Central Main Channel	MainC	Boat	100 x 30	E2657029	N6491049
Herald Island	HIN	Walk	90 x 70	E2658478	N6490325
Lucas Creek	Luc	Boat	100 x 30	E2658788	N6491194
Lucas Te Wharau Creek	LucU	Boat	100 x 30	E2659839	N6490317
Outer Main Channel	MainO	Boat	100 x 30	E2659043	N64900098
Waiarohia Inlet	HIW	Walk	90 x 70	E2658041	N6489650
Hellyers Creek	Hell	Boat	100 x 30	E2660692	N6489573
Upper Hellyers Creek	HellU	Boat	100 x 30	E2661895	N6489996
Opposite Hobsonville	OHbv	Boat	100 x 30	E2660255	N6488769
Hobsonville (also CWH site)	Hbv	Walk	100 x 90	E2660106	N6487972

Appendix 2: Ecological community decision rules (from Hewitt and Funnell 2005).

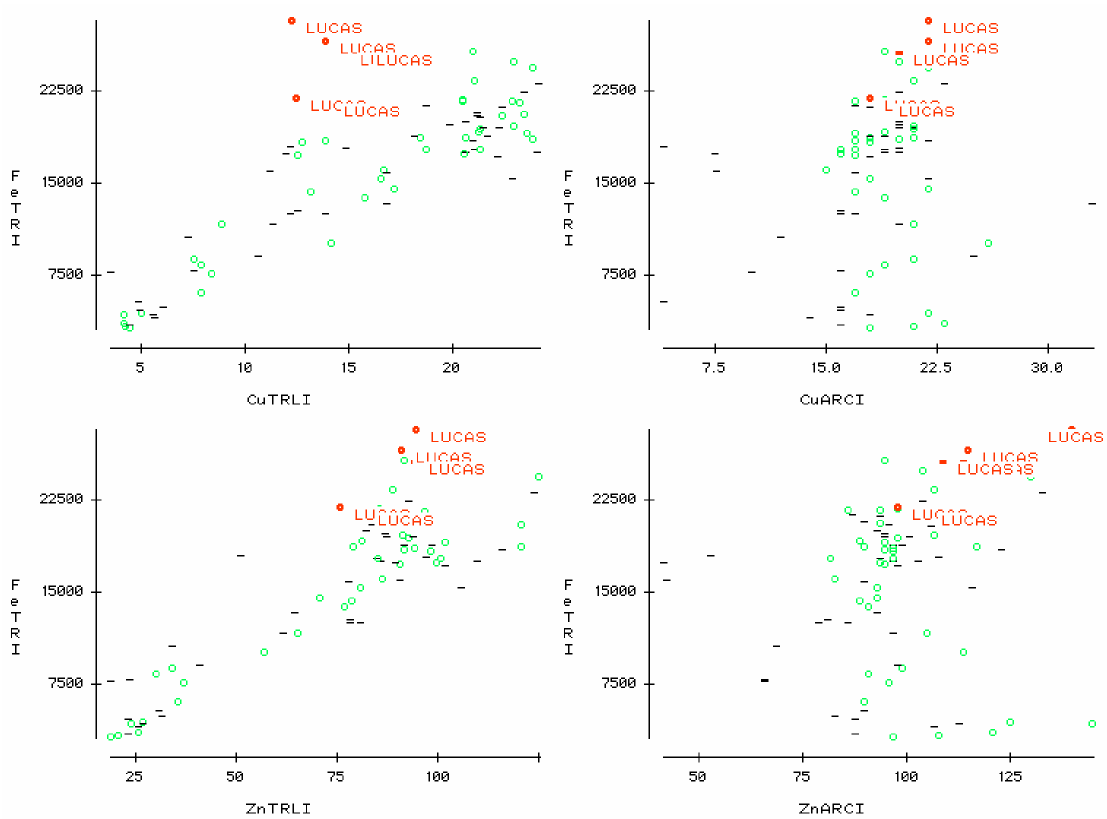
There are a number of species of demonstrated importance in New Zealand's estuaries and harbours, either recreationally (e.g., cockles, pipis, scallops), or by their effect on the surrounding community (e.g., *Zostera* and *Macomona*). There are also particular groups of species that are functionally important, both to the benthic communities surrounding them and to the rest of the ecosystem. For example, tube-building animals can stabilise sediment and reduce sediment resuspension (Thrush et al. 1996b). Burrowing animals can increase sediment oxygenation and exchange of nutrients between the seafloor and the overlying water (Lohrer et al. 2004). Mobile surface dwellers increase sediment resuspension (Davis 1993, Orvain et al. 2003) and suspension feeders can remove sediment from the water column increasing nutrient fluxes to the seafloor (Dame 1993, Wildish and Kristmanson 1997, Norkko et al. 2001a). While individual species will show different responses to stress, more generally different types of animals will also be differentially vulnerable to specific impacts and their loss will have specific implications to ecological function and values. For example, deposit feeders are less likely than most suspension feeders to be vulnerable to increased suspended sediment loads. Suspension feeders may also be more vulnerable to changes in flow characteristics and phytoplankton depletion (Jorgensen 1996, Wildish and Kristmanson 1997) that may result from certain types of aquaculture.

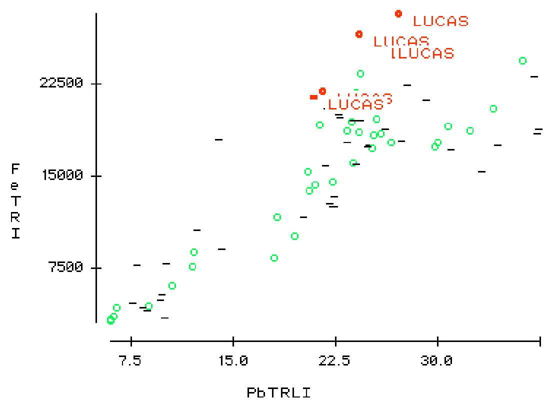
Ecological community description decision rules:

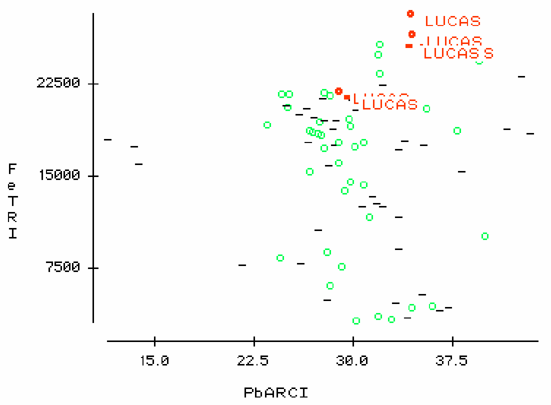
1. Did the sites have densities of adult *Macomona*, *Austrovenus*, or *Paphies* (or some combination of these) greater than or equal to 226 individuals per m^2 (3 individuals per core)?
2. Did the sites have high diversity at a high taxonomic (order) level (e.g., amphipods, polychaetes, bivalves)? And if so, were there high numbers of large organisms, burrowing organisms, surface mobile bioturbators, tube builders or suspension feeders?
3. Were the sites dominated by polychaetes? And if so, were they tube-builders, deposit feeders or large predators/scavengers?
4. Were the sites dominated by bivalves? And if so, were they invasive, deposit feeders or suspension feeders?
5. If the sites were not dominated by either polychaetes or bivalves, were they dominated by large animals or surface bioturbators?

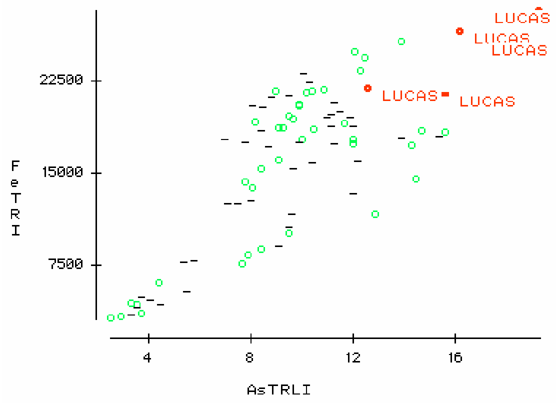
Appendix 3: Chemistry regressions – exploratory data analysis

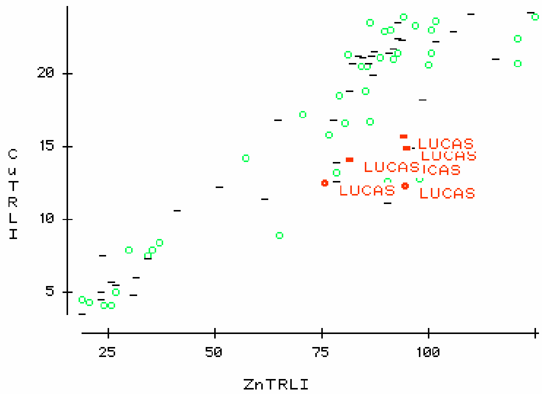
Plots shown for total metals ('TRI') and weak acid extracted metals for <63μm fraction ('ARC') with symbols designating top (o) and bottom (-) samples. Lucas sites identified.

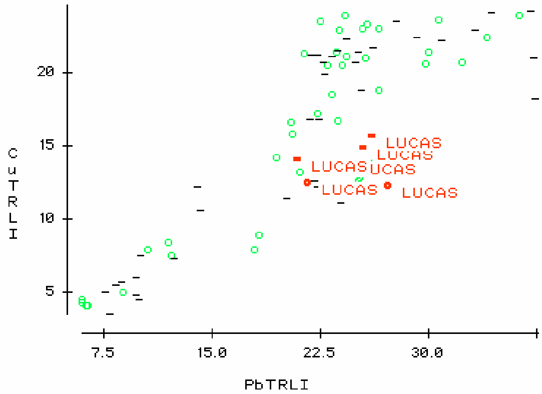



LUCAS
FeTRI
22500
15000
7500
7.5
15.0
22.5
30.0
PbTRLI


LUCAS
FeTRI
22500
15000
7500
15.0
22.5
30.0
37.5
PbARCI


LUCAS
FeTRI
22500
15000
7500
4
8
12
16
AsTRLI


LUCAS
CuTRLI
20
15
10
5
25
50
75
100
ZnTRLI


LUCAS
CuTRLI
20
15
10
5
7.5
15.0
22.5
30.0
PbTRLI

Appendix 4: Taxa found in UWH

Phyllum	Class	Order	Family	Genus	Species
Annelida	Oligochaeta		Tubificidae		sp. 1
Annelida	Oligochaeta		Tubificidae		sp. 2
Annelida	Polychaeta	Capitellida	Capitellidae	*Capitella*	sp.
Annelida	Polychaeta	Capitellida	Capitellidae	*Heteromastus*	*filiformis*
Annelida	Polychaeta	Capitellida	Maldanidae	*Macroclymenella*	*stewartensis*
Annelida	Polychaeta	Capitellida	Capitellidae	*Notomastus*	sp.
Annelida	Polychaeta	Capitellida	Capitellidae	unidentified species	
Annelida	Polychaeta	Cossurida	Cossuridae	*Cossura*	*consimilis*
Annelida	Polychaeta	Eunicida	Lumbrineridae	unidentified species	
Annelida	Polychaeta	Phyllodocida	Nereididae	*Ceratonereis*	sp.
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycera*	*lamelliformis*
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Glycinde*	*trifida*
Annelida	Polychaeta	Phyllodocida	Nereididae	*Nicon*	*aestuariensis*
Annelida	Polychaeta	Phyllodocida	Polynoidae	*Paralepidonotus*	*ampulliferus*
Annelida	Polychaeta	Phyllodocida	Nereididae	*Perinereis*	*vallata*
Annelida	Polychaeta	Phyllodocida	Syllidae		Syllinae-indent
Annelida	Polychaeta	Phyllodocida	Syllidae		Exogoninae-indet
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Aglaophamus*	*macroura*
Annelida	Polychaeta	Sabellida	Sabellidae	*Euchone*	sp.
Annelida	Polychaeta	Sabellida	Sabellidae	*Pseudopotamilla*	indet juvenile
Annelida	Polychaeta	Scolecida	Paraonidae	*Aricidea*	sp. B (subgenus Acmira)
Annelida	Polychaeta	Scolecida	Paraonidae	*Levinsenia*	*gracilis*
Annelida	Polychaeta	Scolecida	Orbiniidae	*Orbinia*	*papillosa*
Annelida	Polychaeta	Scolecida	Paraonidae	*Paradoneis*	*lyra*
Annelida	Polychaeta	Scolecida	Orbiniidae	*Scoloplos*	*cylindrifer*
Annelida	Polychaeta	Scolecida	Orbiniidae	*Scoloplos*	sp. A
Annelida	Polychaeta	Spionida	Spionidae	*Aonides*	*oxycephala (trifida)*
Annelida	Polychaeta	Spionida	Spionidae	*Aquilaspio (Prionospio)*	*aucklandica*
Annelida	Polychaeta	Spionida	Spionidae	*Boccardia*	*syrtis*
Annelida	Polychaeta	Spionida	Spionidae	*Polydora*	*cornuta*
Annelida	Polychaeta	Spionida	Spionidae	*Pseudopolydora*	*paucibranchiata*
Annelida	Polychaeta	Spionida	Spionidae	*Scolecolepides*	*benhami*
Annelida	Polychaeta	Terebellida	Cirratulidae	*Chaetozone*	*sp.*
Annelida	Polychaeta	Terebellida	Pectinariidae	*Pectinaria*	*australis*
Cnidaria	Anthozoa	Actinaria	Actiniidae	*Anthopleura*	*aureoradiata*
Crustacea	Cirripedia			unidentified species	
Crustacea	Malacostraca	Amphipoda	Corophiidae	*?Americorophium*	sp.
Crustacea	Malacostraca	Amphipoda	Phoxocephalidae	*Proharpinia*	sp A
Crustacea	Malacostraca	Amphipoda	Corophiidae	*?Sinocorophium*	sp.
Crustacea	Malacostraca	Amphipoda	Corophiidae	*Corophium*	*insidiosum*
Crustacea	Malacostraca	Amphipoda	Gammaridae	*Melita*	*awa*
Crustacea	Malacostraca	Amphipoda	Paracalliopidae	*Paracalliope*	*novizealandiae*
Crustacea	Malacostraca	Amphipoda	Corophiidae	*Paracorophium*	*excavatum*
Crustacea	Malacostraca	Amphipoda	Phoxocephalidae	*Torridoharpinia*	*hurleyi*
Crustacea	Malacostraca	Amphipoda	Phoxocephalidae	unidentified species	
Crustacea	Malacostraca	Amphipoda	Lysianassidae	*Parawalkdeckia*	sp.
Crustacea	Malacostraca	Amphipoda	Eusiridae	*Paramoera*	*chevreuxi*

Phyllum	**Class**	**Order**	**Family**	**Genus**	**Species**
Crustacea	Malacostraca	Cumacea	Diastlidae	*Colurostylis*	*lemurum*
Crustacea	Malacostraca	Decapoda	Alpheidae	*Alpheus*	*?socialis*
Crustacea	Malacostraca	Decapoda	Hymenosomatidae	*Halicarcinus*	*whitei*
Crustacea	Malacostraca	Decapoda	Grapsidae	*Helice*	*crassa*
Crustacea	Malacostraca	Decapoda	Grapsidae	*Hemigrapsus*	*crenulatus*
Crustacea	Malacostraca	Decapoda	Grapsidae	*Macropthalmus*	*hirtipes*
Crustacea	Malacostraca	Decapoda			unidentified crab megalopae
Crustacea	Malacostraca	Isopoda	Sphaeromatidae	*?Exosphaeroma*	sp.
Crustacea	Malacostraca	Isopoda	Sphaeromatidae	*Exosphaeroma*	*chilensis*
Crustacea	Malacostraca	Isopoda	Sphaeromatidae	*Exosphaeroma*	*?falcatum*
Crustacea	Malacostraca	Tanaidacea			unidentified species
Echinodermata	Holothuroidea	Apodida		unidentified species	
Mollusca	Bivalvia	Mytiloida	Mytilidae	*Musculista*	*senhousia*
Mollusca	Bivalvia	Nuculoida	Nuculidae	*Nucula*	*hartvigiana*
Mollusca	Bivalvia	Ostreoida	Ostreidae	*Crassostrea*	*gigas*
Mollusca	Bivalvia	Veneroida	Erycinidae	*Arthritica*	*bifurca*
Mollusca	Bivalvia	Veneroida	Veneridae	*Austrovenus*	*stutchburyi*
Mollusca	Bivalvia	Veneroida	Psammobiidae	*Hiatula*	*sp.*
Mollusca	Bivalvia	Veneroida	Tellinidae	*Macomona*	*liliana*
Mollusca	Bivalvia	Veneroida	Mactridae	*Mactra (Cyclomactra)*	*ovata*
Mollusca	Bivalvia	Veneroida	Mesodesmatidae	*Paphies*	*australis*
Mollusca	Bivalvia	Veneroida	Semelidae	*Theora*	*lubrica*
Mollusca	Gastropoda	Archaeogastropoda	Trochidae	*Diloma*	*subrostrata*
Mollusca	Gastropoda	Archaeogastropoda	Trochidae	*Micrelenchus*	*?huttoni*
Mollusca	Gastropoda	Bassomatophora	Amphibolidae	*Amphibola*	*crenata*
Mollusca	Gastropoda	Cephalspidea	Haminoeida	*Haminoea*	*?zelandiae*
Mollusca	Gastropoda	Neogastropoda	Buccinidae	*Cominella*	*glandiformis*
Mollusca	Gastropoda	Neogastropoda	Muricidae	*Xymene*	*plebius*
Mollusca	Gastropoda	Neogastropoda	Terebridae	*Duplicaria*	sp.
Mollusca	Gastropoda	Neotaenioglossa	Rissoidae	*Estea*	
Mollusca	Gastropoda	Neotaenioglossa	Potamididae	*Zeacumantus*	*lutulentus*
Mollusca	Gastropoda	Patellogastropoda	Acmaeidae	*Notoacmea*	*helmsi*
Mollusca	Gastropoda			unidentified turret shell	
Mollusca	Polyplacophora	Neoloricata	Chitonidae	unidentified species	
Nemertea					spp.
Phoronida				unidentified species	