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Upper Waitemata Harbour Ecological Monitoring Programme 2005 - 2008

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1 Executive Summary

In November 2005, a long-term monitoring programme was established in the Upper Waitemata Harbour, to monitor the ecological status of benthic macrofauna in habitats that have the potential to be affected by development of the surrounding catchments. Concurrent sampling of sediment characteristics and chemical contaminants was initiated to provide the ability to correlate macrofaunal information with effects of catchment development. This report summarises the data collected so far (November 2005 - February 2008).

Fourteen intertidal sites are monitored in this programme. Nine sites are sampled tri-monthly; four sites are sampled annually; and a final site is sampled as part of the Central Waitemata Harbour monitoring programme. 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.

Few consistent seasonal patterns in abundance across sites were observed. This is similar to results found from the Mahurangi monitoring programme, which has a similar frequency of sampling. A lack of predictable seasonal behaviour may adversely affect the ability of the monitoring programme to detect small changes over short time frames. Fortunately, a relatively small degree of variability in species composition has been observed at most sites, increasing the likelihood of being able to detect changes.

Few continuous changes in species abundances were observed at any of the sites, although species composition at two of the sites is changing slightly. Despite this, similarities between sites, in species composition, observed in the first year continue.

- Upper harbour sites (Brig, Rng, MainU, ParU) show consistently high mud (> 80% mud) and organic content (8-10% organics), and ecological communities dominated by burrowing corophid amphipods, oligochaetes, and polychaetes. HellU differs slightly from these sites as there is more variability in dominant species and there has been a drop in mud content from > 80% mud to approximately 60%.
- The other muddy sites found in the middle and outer harbour (LucU, Luc, Hell, OHbv, MainC) show more variability in mud content (20-80%), lower levels of organic content (2-6%), and ecological communities dominated by deposit feeding polychaetes, particularly three paraonid species.
- The four sandy outer harbour sites (HIW, HIN, HBV, and MainO) have low sediment mud and organic contents, and bivalve-dominated communities. MainO is showing signs of becoming more similar to the muddy sites found in the middle and outer harbour, probably as a result of the extension of a muddy section of the site.

Contaminant levels are generally similar to those observed in 2005.

- Copper levels are elevated at nine sites (Rng, Brig, MainU, ParU, HellU, OHbv, MainO, HIN and Hbv) and continue to exceed ARC ERC Amber values (see page 45 for explanation of values).

- Lead values exceed ARC ERC Amber levels at eleven sites (Rng, MainU, ParU, HellU, MainC, Luc, OHbv, MainO, HIN, HIW and Hbv). The highest lead levels are from HellU which has had replicate values exceed the ARC ERC Red threshold.
- Sediment at the lower Lucas site (Luc) has high levels of iron and associated arsenic, with arsenic reaching ANZECC ISQG- Low level threshold in 2006 (see page 51 for explanation of thresholds).
- However, some changes have been observed. Zinc values have been increasing yearly at nine of the fourteen sites, with Hbv, OHbv and HellU exceeding ARC ERC Amber levels. High molecular weight PAHs have had highest values at three sites in 2007. With only three years of data it is not yet possible to determine whether these are real trends and whether they will affect the ecology. If these trends do persist, investigations into why they are occurring should be undertaken.

A snapshot of land use change between 2003 - 2006/07 shows that the largest degree of change (8.6%) occurred within the Lucas catchment, with an increase in earthworks, building and roading. Changes within the other catchments are still small, although more activity is expected in future years, including increased building, roading and harvesting of pine forest. Despite the recorded landuse changes within the Lucas catchment, no change has been observed in the ecology. This is probably due both to the low level of change and the fact that development in the Lucas catchment has been occurring for a number of years. Changes in the ecology may have already occurred, as sediment concentrations of iron and arsenic are already high at the Lucas sites. Interestingly, despite the small change in landuse recorded in the Hellyers catchment, zinc concentrations in the sediment at the upper site are increasing.

The design of a monitoring programme is an ongoing process and design features should be regularly reviewed. In the 2006 report, we implemented some changes.

- Sampling the upper sites in Paremoremo, Lucas and Hellyers and Waiarohia Inlet was decreased to only once per year (November). Comparing trends in sediment and ecological characteristics demonstrate that these sites appear to be following similar trajectories to nearby sampling locations with similar communities. At this stage we believe that we can use the seasonality observed in the first years sampling to set the limits for natural variability in the sites monitored annually. Thus, we recommend maintaining this once per year frequency for these four sites.
- Processing sediment and ecological samples separately for the MainO sites due to a gradient in mud content across the site. Sediment particle size demonstrates a clear difference in the mud content between the two sections of the site, a slight difference in organic content and no difference in chlorophyll *a* content. There is also not a strong difference in community composition and species abundances across this site (unlike the TK site in Mahurangi). We suggest that while sampling should continue to be stratified to ensure sampling in both sections of the site, that processing separate samples is not necessary. However, the extent of the muddy section should be mapped annually in November.
- We also raised concerns about site damage resulting from frequent sampling at muddy sites. A November 2006 site visit occurred at low tide when each site is fully visible. No site damage was recorded, thus, we do not recommend decreased sample replication or frequency.

Overall, we believe that the design of the monitoring programme is robust and that continued monitoring will provide the ARC with the information they need to determine whether catchment development around the Upper Waitemata Harbour is having significant consequences to its ecological health.

2 Introduction

In November 2005 a long term monitoring programme for the Upper Waitemata Harbour (UWH) was developed, by NIWA, for the Auckland Regional Council (ARC). The primary objective was to determine whether development of the Upper Waitemata Harbour had significant consequences for its ecological health. More specifically, the data would allow model predictions of where increased stormwater associated contaminant inputs would affect ecology to be tested.

The Upper Waitemata Harbour (UWH) catchment encompasses 185 km^2 and drains to a relatively small sub-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 sub-catchments. Catchment land use is primarily pastoral, with some areas of native bush and pine, and established and ongoing urban development in other areas. The Auckland Regional Growth Strategy (ARGS) has identified greenfield development and urban intensification as part of the strategy for the UWH catchment over the next 50 or 100 years.

A multi-agency study of the effects of catchment development on the UWH was undertaken from 2000 to 2004 (see Green et al. 2004 and associated reports). The main focus of that study was to predict effects associated with increasing stormwater-associated contaminant inputs as catchment development progressed. The modelling suggested that contaminant levels, associated with urban discharges after development, would increase and 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 additional negative impacts of sedimentation.

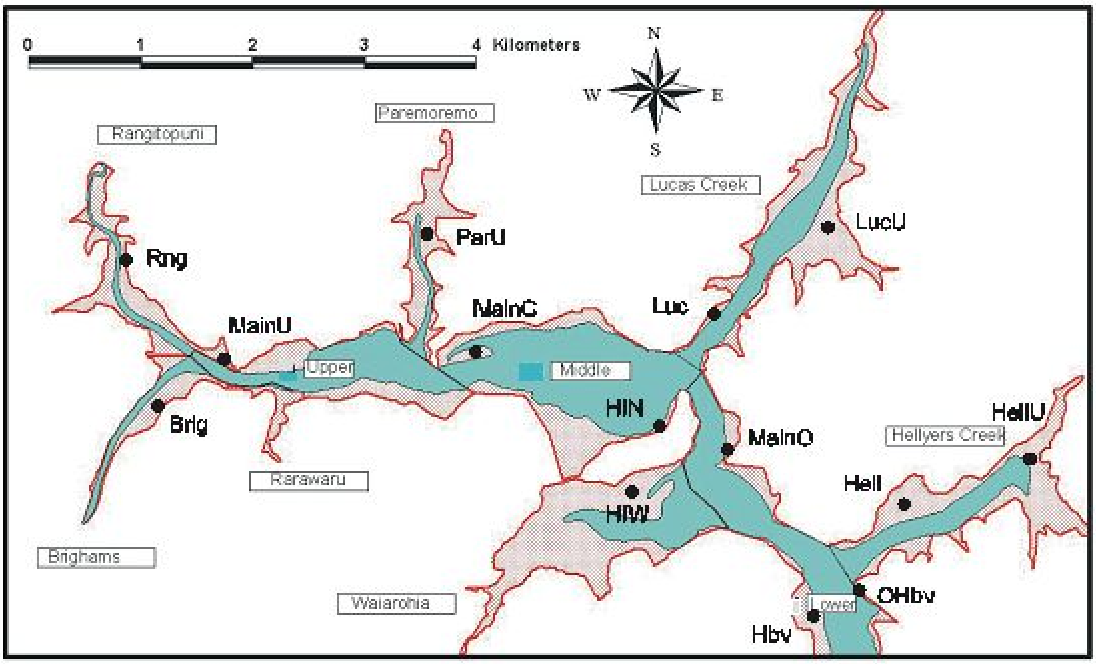
This report summarises the nearly three years of data collected from the Upper Waitemata Harbour monitoring programme so far (November 2005 - February 2008) and assesses if there have been any changes. The report also analyses the strategy of sampling the upper sites in Paremoremo, Lucas and Hellyers and Waiarohia Inlet only once per year (November) provides useful information, and whether there has been any site damage associated with frequent sampling of muddy sites. Finally, the relationship between management changes, likely to result in increased sediment or contaminant loads in the harbour, within the three years prior to 2007, and any changes in the ecology of the harbour.

3 Methods

3.1 Macrofauna

In order to maximise the potential to compare data with the 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, which required sampling by boat to avoid disturbance of the substrate, or sandier sediments that could be sampled on foot at low tide.

Figure 1:
Location of the fourteen sampling sites in the Upper Waitemata Harbour. Sites form three distinct groupsings based on location, sediment characteristics and macrofaunal communities: very muddy upper estuary sites (Rng, Brig, MainU, ParU and HellU); muddy sites dominated by deposit feeding polychaetes (MainC, Luc, LucU, Hell and OHbv); and mid - lower estuary sandy sites (HIW, HIN, HBV, and MainO).



At nine of the sites, samples are collected four times per year (November, February, May and August). After May 2006, sampling at four of the original 13 monitoring sites (Paremoremo, Lucas and Hellyers and Waiarohia Inlet) was decreased to once per year (November) as per recommendations from the 2006 monitoring report and further discussions with ARC (Hewitt et al. 2006). The 14th site (Hbv) is sampled six times a year as part of the Central Waitemata monitoring programme. Note that the November comparisons involving Hbv use data collected in October and the May comparisons involve HBV data collected in April. See Appendix 3 for current sampling protocol.

At the four sandier locations sampled at low tide (HIW, HIN, MainO, Hbv), permanent markers (wooden stakes) were placed at the starting corner of the sampling grid when the sampling programme was initiated. Sampling is 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 ten remaining locations are sampled by boat around high tide. Four positions are randomly selected (within the site area) and located using GPS. Three cores are 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.

In the 2006 report, we recommended a slightly different sampling strategy for the site MainO, as more than half of the site had muddier sediments than the rest. To better analyse differences between the muddier and sandier sections of the site, samples for sediment characteristics were taken and analysed seperately in both areas. Random locations for the macroinvertebrate cores were stratified to ensure that both areas are sampled. .

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, usually to species. For five taxa (Corophidae, Nereidae, Phoxocephalidae, Polydorid polychaetes and Oligochaetes), we used higher taxonomic differentiation on most sampling occasions, with full taxonomic resolution carried out only in November of each year. Note that the Corophidae and Phoxocephalidae amphipods have not been reported as separate taxa for November in this report, as the taxonomy of these families is under investigation at present. For example, it seems likely that the four Phoxocephalidae species previously reported are actually a new species of *Torridoharpinia*.

3.2 Bivalve size class analysis

After identification, the shell length of individual *Paphies australis, Austrovenus stutchburyi* and *Macomona liliana* were 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*) were 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) were collected, one to determine grain size and organic content and the other for chlorophyll *a* analysis. The three cores were pooled, and kept frozen in the dark prior to being analysed as described below.

As per recommendations in the 2006 report, the bottom sediment layer (5-15 cm depth) is only analysed to determine grain size and organic content in November every three years. Chlorophyll *a* is not analysed from bottom sediments. The next bottom sampling is scheduled for November 2008.

Grain size: The samples were homogenised and a subsample of approximately 5 g of sediment was taken and digested in ~ 9% hydrogen peroxide until frothing ceases. The sediment sample was 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 $\leq$3.9 μm. All fractions are then dried at 60°C until a constant weight was achieved (fractions are weighed at ~ 40 h and then again at 48 h). The results of the analysis are presented as percentage weight of gravel/shell hash (>2000 μm), coarse sand (500 – 2000 μm), medium sand (250 – 500 μm), fine sand (63 –250μm), silt (3.9 – 62.9 μm) and clay ($\leq$3.9 μm). Mud content is calculated as the sum of the silt and clay content.

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

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

3.4 Chemical analyses

Once per year (November), at three random locations within the site, at least three replicate cores (5 cm diameter, 0-2 cm deep) were collected to provide adequate material for chemical analyses.

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 recoverable acid digested < 500 μm dry sieved fractions and fine weak acid digested < 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 (PAHs) (mg/kg dry wt); and total recoverable iron, manganese, arsenic, copper, lead and zinc (mg/kg dry wt). As recommended in the 2006 report; chromium, cadmium and nickel do not require ongoing monitoring. However we suggest repeat monitoring of these metals every three years (due to happen November 2008).

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, bhrysene, 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

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 between November 2005 and February 2008 was used to determine whether community composition 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 also defined based on the five most numerically dominant taxa.

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 averaged. The total number of taxa found across all replicates at each site and the Shannon-Weiner index on the totals for each site were also calculated.

At this point in the monitoring programme (3 years), similar to this stage in the Manukau, Mahurangi and Central Waitemata monitoring programmes, no statistical analyses of differences over time, or between have been conducted. Most changes detected after only three years are likely to be part of multi-year cyclic patterns. Instead, graphical analysis was used to determine whether seasonal and multi-year cycles are occurring.

4 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 disused ski jump is located near the site. The site is characterised by soft mud and abundant crab burrows (see Plate 1), with sediment content comprised primarily of mud (averaging 95%), with a small amount of fine sands (Appendix 2).

Chlorophyll *a* content of the sediments ranged between 4.36 and 14.65 µg/g sediment (Appendix 2). Organic content of the sediment is consistently high, and ranged from 6.64 to 9.83% (Appendix 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 (see Plate 2).

Sediment content is primarily comprised of mud (> 81% silt and clay fractions), with a small amount of fine sands (Appendix 2). Chlorophyll *a* content of the sediments ranged between 6.68 and 11.46 µg/g sediment (Appendix 2). Organic content of the sediment ranged from 6.72 to 9.46% (Appendix 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. Very deep (> 1 m) mud and crab burrows are found throughout the site (see plate 3).

Sediment content is primarily comprised of mud (> 84% silt and clay fractions), with a small amount of fine sand (Appendix 2). Chlorophyll *a* content of the sediments ranged between 7.69 and 23.15 µg/g (Appendix 2). Organic content of the sediment ranged from 6.55% and 10.07% (Appendix 2).

Paremoremo Creek (ParU)

Site ParU is located opposite the water 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 (see plate 4). It is difficult to core sample due to much of the site having a matted weedy mass of mangrove seedlings and roots, and sorting of macrofauna is particularly time consuming due to the presence of this weed mass.

Based on recommendations in the 2006 report, sampling was reduced to once per year (November) from May 2006 onwards due to concerns that the intensity of sampling in this small area was too great. Sediment content is primarily comprised of mud (> 93% silt and clay fractions), with a small amount of fine sands (Appendix 2). Chlorophyll *a* content of the sediments ranged between 5.50 and 20.10 µg/g sediment (Appendix 2). Organic content of the sediment ranged from 6.51 to 10.13% (Appendix 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 (see Plate 5).

Sediment content is comprised of fine sand (> 65%) and mud (about 25%), with a small amount of medium and course sand (Appendix 2). Chlorophyll *a* content of the sediments ranged between 8.37 and 14.89 µg/g sediment (Appendix 2). Organic content of the sediment is relatively low, and ranged from 2.38% and 6.16% (Appendix 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 (see Plate 6), with some cockles, and is relatively extensive with approximately 100-150 m between the shore and water's edge at low tide.

Sediment content is comprised of primarily fine sand (average 63%) with other varying contributions of other fractions (6.02 – 28.41% mud; 3.46 – 23.28% medium sand), and a small amount of course sand and gravel (Appendix 2). Chlorophyll *a* content of the sediments generally ranged from 9.98 µg/g to 25.67 µg/g; with an exceptionally high value of 47.91 µg/g in May 2007 that was not accompanied by similar outliers in sediment grainsize or organic content (Appendix 2). Organic content of the sediment is relatively low, and ranged from 1.33 to 2.67% (Appendix 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 (see Plate 7). 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 fine sand (28.56 – 52.95%) and mud (18.24 – 37.75%) and with small amount of course sand and gravel (Appendix 2). Chlorophyll *a* content of the sediments ranged between 7.32 and 14.68 µg/g sediment (Appendix 2). Organic content of the sediment is relatively low, and ranged from 2.81 to 5.22% (Appendix 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 (see Plate 8). From May 06 onwards, sampling was reduced to once per year (November).

Sediment content is comprised of mud (40.48 – 88.01%) and fine sands (10.12 – 53.94%) (Appendix 2). Chlorophyll *a* content of the sediments ranged between 9.48 and 16.97 µg/g sediment (Appendix 2). Organic content of the sediment ranged between 4.37 and 7.80% (Appendix 2).

Outer Main Channel (MainO)

Site MainO is located near Greenhithe within the Lower Harbour basin, and is sampled at low tide on foot. The sampling location is near a ridge of rock at the edge of the beach and two large 6 m timber poles (see Plate 9). There is a strong sand to mud gradient north/northwest within the sampling site, ranging from a sandy substrate to mud depth of up to 50 cm near the starting pegs.

Sediment samples are collected and processed separately from the two distinctly different areas (mud and sand) of site MainO, as per recommendations in the 2006 report (Hewitt et al. 2006).

The sandier component of MainO is comprised of primarily fine sand (48.11 - 72.92%), medium sand (12.82 – 25.16%), and mud (9.91 – 17.49%) (Appendix 2). Chlorophyll *a* content of the sediments ranged between 6.47 and 11.81 µg/g sediment (Appendix 2). Organic content of the sediment ranged between 1.34 and 2.48% (Appendix 2).

Mud content is approximately 10% higher in the muddier half of the transect (19.39 – 30.17%), and fine sand (43.41 – 65.57%) and medium sand contents (10.85 – 20.89%) are lower (Appendix 2). Chlorophyll *a* content varied little between the sand and mud section of the site (Appendix 2). Organic content of the sediment was slightly higher, ranging between 2.56 and 4.47% (Appendix 2).

Waiarohia Inlet (HIW)

Site HIW 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 (see Plate 10), some nearby oyster reefs and is west of the Herald Island RDP site. From May 06 onwards, sampling was reduced to once per year (November).

Sediment content is primarily comprised of fine sands (> 62%), with smaller fractions of mud (7.04 – 22.30%) and medium sands (9.85 – 21.43%), and minor amounts of course sand and gravel (Appendix 2). Chlorophyll *a* content of the sediments ranged between 7.33 and 13.88 µg/g sediment (Appendix 2). Organic content of the sediment is relatively low, and ranged from 0.72 to 2.07% (Appendix 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 fringe is a steep forested slope of bush and scrub, with mangroves along the edge of the cliffside (see Plate 11). 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 variable proportions of mud (31.26 – 89.14%) and fine sand (9.33 – 63.37%) (Appendix 2). Chlorophyll *a* content of the sediments ranged between 7.80 and 25.0 µg/g sediment (Appendix 2). Organic content of the sediment is relatively low, and ranged from 3.15 to 7.04% (Appendix 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 diverge. The site is located near the Hellyers Upper Creek RDP site, and is at the end of Manuka Road (see Plate 12). There are reasonably extensive mangroves located nearby, but not within the sampling site itself. The site is sampled by boat at high tide. From May 06 onwards, sampling was reduced to once per year (November).

Sediment content is comprised of mud (60.12%-94.33%) and fine sands (5 – 29%) (Appendix 2). Chlorophyll *a* content of the sediments ranged between 7.22 and 17.88 µg/g sediment (Appendix 2). Organic content of the sediment ranged from 4.67 to 8.06% (Appendix 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 (see Plate 13), within the lower harbour basin subregion. The site is approximately 30 m wide and 300 m in length, with extensive crab burrows and is sampled by boat. The mud is relatively deep (> 1 m), with very fine fluffy silts on the sediment surface.

Sediment content is primarily mud (49.97 – 87.71%), with a small fraction (11.95 – 46.18%) of fine sand (Appendix 2). Chlorophyll *a* content of the sediments ranged between 5.96 and 18.80 µg/g sediment (Appendix 2). Organic content of the sediment ranged from 3.71 to 8.10% (Appendix 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 (see Plate 14) exhibits many of the characteristics of areas subject to high flow (coarse sediment, hollows in the sediment surface). 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. Field observations have recorded a new channel in the vicinity but this is not yet jeopardizing the site (Townsend et al. 2008).

Sediment at Hbv is predominantly medium and fine sand, with a small amount of coarse sand (Appendix 2, Nicholls et al. 2002, Hewitt et al. 2004, Halliday et al. 2006, Townsend et al. 2008). Chlorophyll *a* content of the sediments ranged between 10.99 and 19.72 µg/g sediment in 2005/2008, while the organic content is low and variable (0.78 to 2.22%).

Table: 1:

Summary of surface sediment characteristics at the 14 UWH sampling locations. Average and standard error of data from Nov 2005 to Feb 08. Chla = chlorophyll *a* in µg.g^{-1}, coarse sand (500 – 2000 µm), medium sand (250 – 500 µm), fine sand (63 – 500 µm), mud (< 62.9 µm).

		%coarse sand	%medium sand	%fine sand	%mud	%organics	chla ug/g
Rng	Ave	0.09	0.15	4.27	95.48	9.03	9.25
	se	0.02	0.04	0.53	0.53	0.29	0.88
Brig	Ave	0.35	1.52	8.21	89.87	7.90	9.12
	se	0.10	0.35	1.48	1.60	0.25	0.51
MainU	Ave	0.19	0.47	8.55	90.77	7.92	12.39
	se	0.09	0.17	1.15	1.23	0.32	1.47
Par	Ave	0.15	0.33	3.21	96.22	8.72	10.85
	se	0.05	0.07	0.53	0.54	0.43	1.83
MainC	Ave	0.68	2.86	71.44	24.82	4.49	11.32
	se	0.08	0.69	1.05	1.33	0.33	0.59
HIN	Ave	3.51	17.69	62.80	11.65	2.13	21.39
	se	0.58	1.66	1.58	1.89	0.14	3.21
Luc	Ave	7.29	19.50	44.43	28.20	3.88	11.07
	se	0.77	2.23	1.86	1.81	0.22	0.69
LucU	Ave	0.89	2.37	33.57	63.13	5.30	13.81
	se	0.27	0.40	4.73	5.22	0.41	0.89
MainO(s)	Ave	5.63	17.81	61.16	13.69	2.04	9.82
	se	0.55	1.21	2.35	0.78	0.09	0.51
MainO(m)	Ave	5.35	14.61	55.74	24.15	3.41	11.06
	se	0.67	1.22	2.76	1.16	0.22	0.72
HIW	Ave	2.41	17.89	66.49	11.42	1.30	9.61
	se	0.29	1.41	0.58	1.59	0.13	0.79
Hell	Ave	0.49	3.35	41.57	54.42	4.47	16.18
	se	0.11	0.69	5.05	5.60	0.47	1.36
HellU	Ave	1.44	4.16	20.11	74.07	5.92	11.60
	se	0.37	0.98	3.26	4.66	0.39	1.18
Ohbv	Ave	0.22	1.27	26.68	71.79	5.50	10.13
	se	0.04	0.32	2.90	3.17	0.34	0.96
Hbv	Ave	7.31	33.23	56.18	3.07	1.53	14.57
	se	0.60	1.18	1.02	0.22	0.12	0.82

5 Have any changes occurred at the sites since monitoring began in 2005?

5.1 Results of the November 2006 investigation

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 were not sure that this will be true at soft mud sites. We therefore conducted a full visual inspection of all sites over three days (14-16th Nov 2006) at low tide.

At all sites there were no visible impacts as a result of the UWH sampling regime or the CWH sampling regime at Hbv. (See Plates 1 -14).

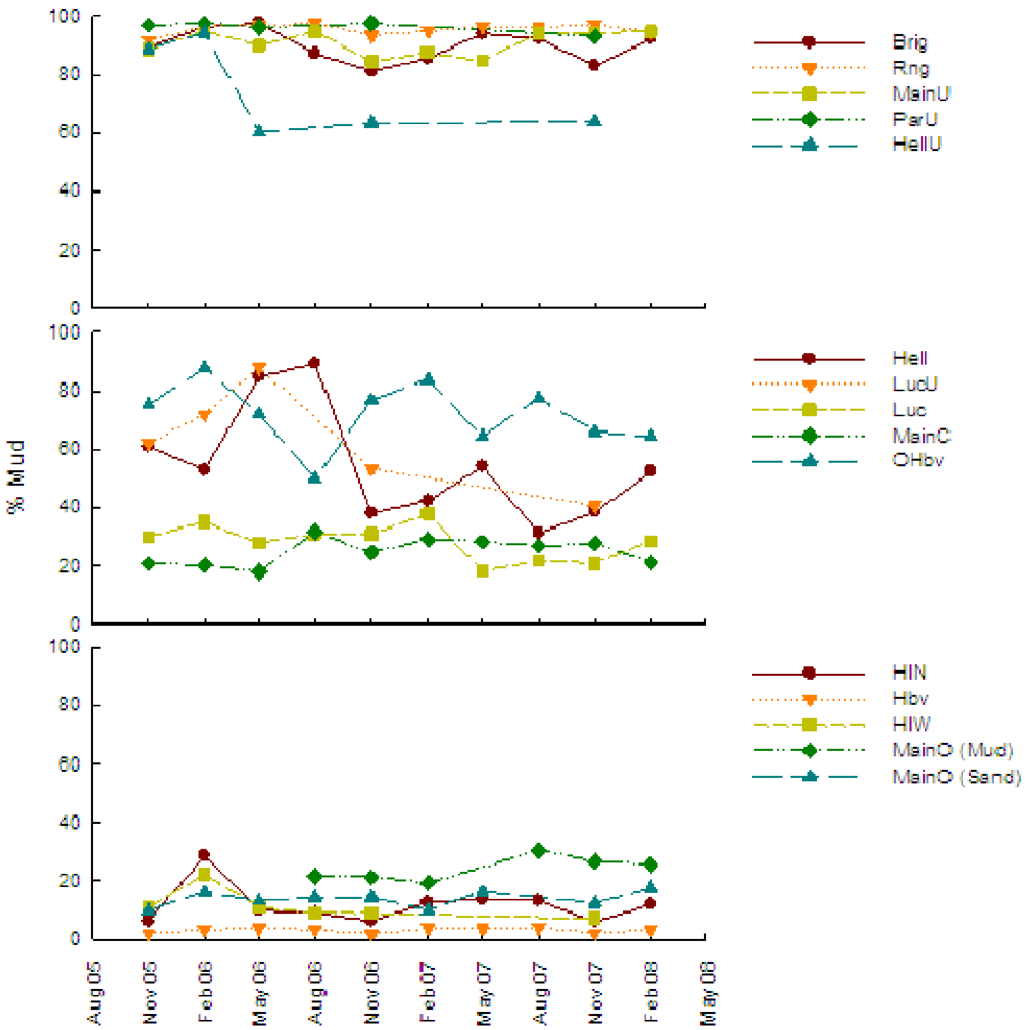
5.2 Sediment Characteristics

Consistent seasonal trends in sediment grainsize, organics, and chlorophyll were not apparent at any of the sites (Figure 2, 3, and 4). This variability between sampling times, but lack of seasonal trend in sediment composition, is not unusual for sediment characteristics from other long-term monitoring projects in the Auckland region. However, longer time series may detect increasing or decreasing trends in sediment composition that correlate with changes in catchment land use or site disturbance.

Sediment grainsize showed slight variations in mud content at most sites (Figure 2), although differences between sites occurred, with highest percent mud (>80%) observed at upper estuary sites (Brig, Rng, MainU, ParU). These sites showed little variability in percent mud (<10% variation across the time series). HellU also had high mud content similar to upper estuary sites in the first two sampling times, but decreasing to approximately 60% mud content in the most recent two years of sampling. The other muddy sites (Hell, Luc, LucU, MainC, OHbv) showed a wide range of mud content from 20 to 80% mud, and higher variability in mud content between sampling times. The lower estuary sites (HIN, HIW, HBV, MainO) had consistently lower mud content (10 to 30%), and low variability between sampling times. Mud content at MainO (sandy) was most similar to the other lower estuary sites. A visual comparison of the breakdown of sediment grainsize is shown for each November in Figure 5.

Figure 2:

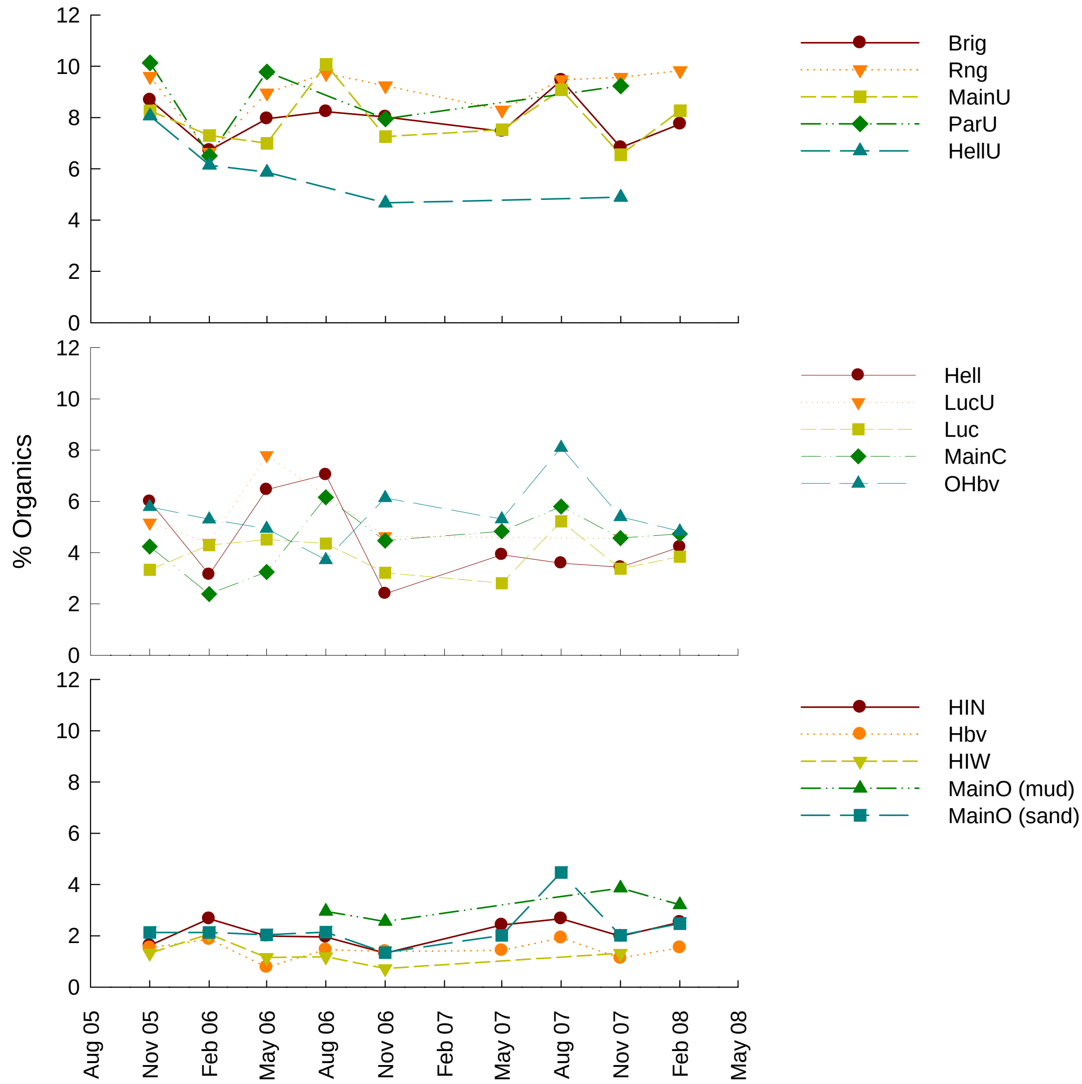
Temporal patterns in mud content for the upper muddy sites, middle sites and sandier lower sites between Nov 2005 and Feb 2008.



Organic content showed no consistent seasonal pattern (Figure 3). Variability between sampling times was high for most sites. Sites showed similar patterns to those of mud content, with highest organic content (8-10%) observed at upper estuary sites (Brig, Rng, MainU, ParU). HellU had similar organic content to the upper estuary sites on the first two sampling times, but a decrease to approximately 6% organic content in the most recent two years of sampling has been observed. The remaining muddy sites (Hell, Luc, LucU, MainC, OHbv) exhibit the highest variability between sampling times, and average organic content between 2 and 8%. Variability between sampling times was lowest at the sandy lower estuary sites (HIN, HIW, HBV, MainO) with average values of 2 to 4% organic content. Some sites did show highest values of organic content in May and/or August of one or both years. Further expansion of this time series should elucidate whether this is a seasonal trend, or if higher values are a result of local storm events.

Figure 3:

Temporal trends in organic content for the upper sites, middle sites and lower sites between Nov 2005 and Feb 2008.



Chlorophyll *a* content showed no consistent seasonal pattern (Figure 4). Variability between sampling times was relatively low for most sites. Chlorophyll content at most sites varied between 8 and 25 mg/g, with no apparent clustering of sites with similar values as was found with mud and organic content. Some sites did show higher values in February, May and/or August of one or both years, though these peaks were not consistent between sites or years. Further data in this time series will determine if any of these peaks will show up as seasonal trends, such as that commonly observed of increased chlorophyll with spring/summer blooms of benthic microphytes.

Figure 4:

Temporal trends in chlorophyll *a* content for the upper muddy sites, middle sites and sandier lower sites between Nov 2005 and Feb 2008.

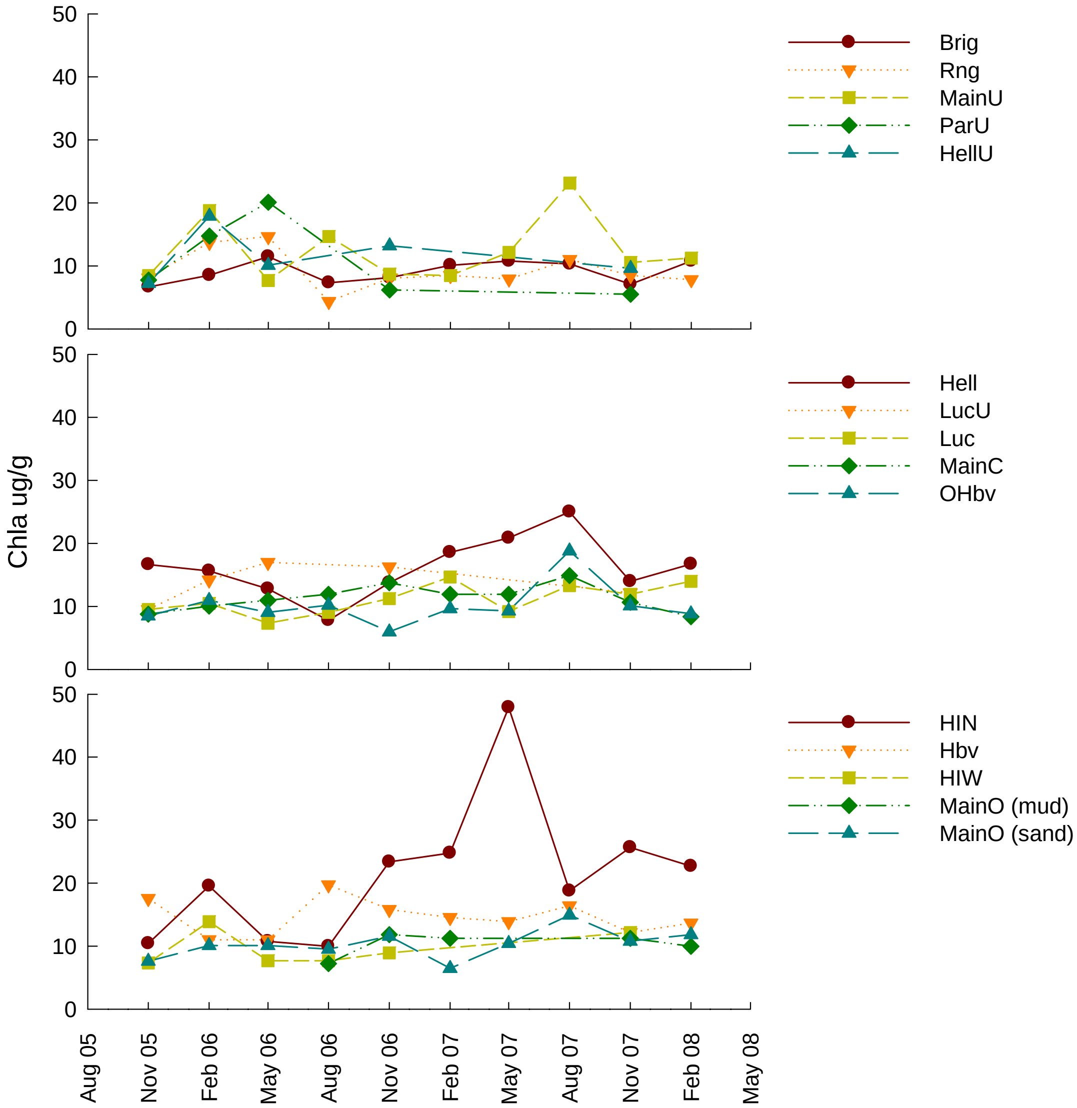
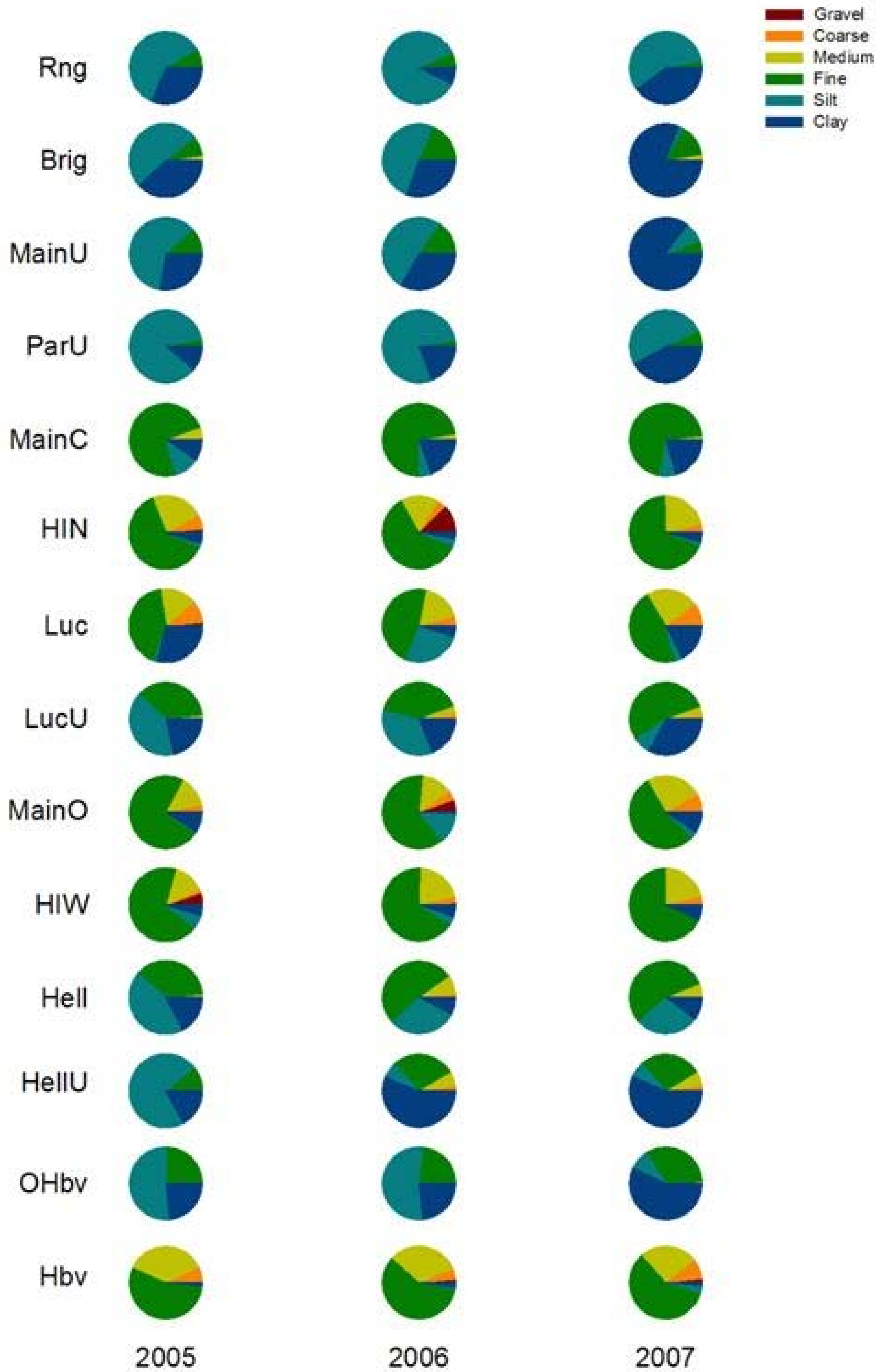


Figure 5:
Sediment composition in November for years 2005, 2006 and 2007 from upper to outer sites.



5.3 Species composition

This section describes seasonal and inter-annual patterns of abundance and variability in the five most dominant taxa at each site.

Clusters of sites with similar dominant taxa, identified in the 2006 report (Hewitt et al. 2006), continue to demonstrate similarity in species composition. The upper estuary sites (Brig, Rng, MainU, ParU) continued to be dominated by burrowing corophid amphipods (*Paracorophium excavatum, Corophium spp.* and ?*Sinocorophium* sp.) and oligochaetes (Table 2, Figure 6). Brig and Rng both had abundant *Arthritica bifurca*, a small mud tolerant bivalve. The mud crab *Helice crassa* and nereid polychaetes (most commonly *Nicon aestuariensis*) were also dominant faunal members at most upper estuary sites in some years. The gastropod, *Amphibola crenata*, was occasionally present at Brig, MainU, and Rng, as juveniles.

HellU was also dominated by corophid amphipods and oligochaetes, though this site showed more variability in dominant species (Table 2). Dominant polychaete species at various sampling times at HellU included polydorid polychaetes (*Polydora cornuta* and *Boccardia syrtis*), and other deposit feeding polychaetes (*Cossura consimilis*, *Heteromastus filiformis*, and *Aricidea* sp). Seasonality was observed for Oligochaetes and *Nicon*, with highest peaks in abundance occurring between May-August and in November respectively (Figure 6). While there was strong within-year variability for other dominant taxa, no consistent patterns between years of sites were observed (e.g., corophidae and *Helice* Figure 6).

The remaining muddy sites (Luc, LucU, Hell, MainC and OHbv) were dominated by deposit-feeding polychaetes (*Cossura consimiis*, *Polydora cornuta, Heteromastus filiformis* and paraonids (*Aricidea* sp., *Paradoneis lyra* and *Levinsenia gracilis*), with species composition varying among sites and among years (Table 2, Figure 7). Two bivalves (*Austrovenus stutchburyi* and *Nucula hartvigiana*) were also dominant species in some years at Luc. Most of these dominant species demonstrate no obvious seasonal patterns, or increasing or decreasing trends in abundance over the 2 ½ years of monitoring, instead showing large fluctuations in abundance, and varying dominance by different species with similar functional roles (Table 2, Figure 7).

All lower estuary sites (Hbv, HIW, MainO and HIN) were dominated by the bivalves *Austrovenus stutchburyi* and *Nucula hartvigiana*, with other bivalves (*Macomona liliana, Paphies australis,* and *Arthritica bifurca*) occasionally dominant (Table 2, Figure 8). The limpet *Notoacmea helmsi* and grazing gastropod *Zeacumantus lutulentus* were also common. While Hbv had polychaetes sensitive to muddy sediments (e.g., *Aonides trifida*); the other 3 sites had less sensitive polychaetes (*Prionospio aucklandica*, *Scoloplos cylindrifer* and *Aricidea* sp.), reflecting the muddier sediments found in part of the sites. No consistent seasonality was observed across years and sites (Figure 8), apart from a small increase in abundance that was noted for *Aonides* at Hbv. Townsend et al. (2008) has analysed trends at Hbv from the Central Waitemata Harbour monitoring program and reports that *Aonides* is increasing and there is an indication *Nucula* has been decreasing since October 2003.

Table 2:

Five most abundant taxa at each site in November of each year.

Date	Site	Most abundant				Least abundant
Nov-05	**Rng**	Oligochaeta	*Arthritica bifurca*	Corophiidae	Phoxocephalidae	Nereididae
Nov-06		Corophiidae	Oligochaeta	Nereididae	*Helice crassa*	Phoxocephalidae
Nov-07		Oligochaeta	Nereididae	*Helice crassa*	Barnacle	*Arthritica bifurca*
Nov-05	**Brig**	Oligochaeta	*Arthritica bifurca*	Phoxocephalidae	Nereididae	*Exosphaeroma* sp.
Nov-06		Oligochaeta	Corophiidae	Phoxocephalidae	Nereididae	Polydorid
Nov-07		Oligochaeta	Corophiidae	Nereididae	Phoxocephalidae	*Arthritica bifurca*
Nov-05	**MainU**	Corophiidae	Oligochaeta	Polydorid	Nereididae	*Helice crassa*
Nov-06		Corophiidae	Oligochaeta	*Helice crassa*	Nereididae	*Paradoneis lyra*
Nov-07		Corophiidae	Oligochaeta	*Helice crassa*	Nereididae	Polydorid *Pseudopolydora*
Nov-05	**ParU**	Corophiidae	Oligochaeta	*Helice crassa*	Polydorid	Barnacle
Nov-06		Oligochaeta	Corophiidae	*Helice crassa*	Barnacle	Capatellid
Nov-07		Oligochaeta	Phoxocephalidae	Corophiidae	Nereididae	Capatellid
Nov-05	**HellU**	Corophiidae	Oligochaeta	Polydorid	*Helice crassa*	*Aricidea* sp.
Nov-06		Corophiidae	Polydorid	*Aricidea* sp.	*Cossura consimilis*	*Heteromastus filiformis*
Nov-07		*Cossura consimilis*	Oligochaeta	*Heteromastus filiformis*	*Aricidea* sp.	Nereididae
Nov-05	**MainC**	*Aricidea* sp.	*Paradoneis lyra*	*Cossura consimilis*	*Heteromastus filiformis*	Phoxocephalidae
Nov-06		*Aricidea* sp.	*Paradoneis lyra*	*Cossura consimilis*	*Heteromastus filiformis*	Oligochaeta
Nov-07		*Aricidea* sp.	*Paradoneis lyra*	*Cossura consimilis*	*Heteromastus filiformis*	Phoxocephalidae
Nov-05	**Luc**	*Aricidea* sp.	Chaetozone sp.	*Nucula hartvigiana*	*Austrovenus stutchburyi*	*Paradoneis lyra*
Nov-06		*Aricidea* sp.	*Paradoneis lyra*	*Heteromastus filiformis*	Nereididae	Cirratulidae (*Chaetozone* sp.)
Nov-07		*Aricidea* sp.	Chaetozone sp.	Nereididae	*Heteromastus filiformis*	*Austrovenus stutchburyi*

Date	Site	Most abundant				Least abundant
Nov-05	**LucU**	*Cossura consimilis*	*Aricidea* sp.	*Levinsenia gracilis*	Nereididae	*Heteromastus filiformis*
Nov-06		*Cossura consimilis*	*Aricidea* sp.	*Levinsenia gracilis*	*Heteromastus filiformis*	Nereididae
Nov-07		*Aricidea* sp.	*Cossura consimilis*	*Levinsenia gracilis*	*Heteromastus filiformis*	*Paradoneis lyra*
Nov-05	**Ohbv**	*Aricidea* sp.	*Levinsenia gracilis*	*Paradoneis lyra*	*Cossura consimilis*	*Heteromastus filiformis*
Nov-06		*Aricidea* sp.	*Cossura consimilis*	*Heteromastus filiformis*	Phoxocephalidae	*Levinsenia gracilis*
Nov-07		*Aricidea* sp.	*Cossura consimilis*	*Paradoneis lyra*	*Levinsenia gracilis*	*Heteromastus filiformis*
Nov-05	**Hell**	*Cossura consimilis*	*Levinsenia gracilis*	*Aricidea* sp.	*Heteromastus filiformis*	Nereididae
Nov-06		*Aricidea* sp.	*Cossura consimilis*	Nereididae	*Heteromastus filiformis*	Phoxocephalidae
Nov-07		*Cossura consimilis*	*Levinsenia gracilis*	*Aricidea* sp.	*Heteromastus filiformis*	Nereididae
Nov-05	**MainO**	*Austrovenus stutchburyi*	Nereididae	*Nucula hartvigiana*	*Aricidea* sp.	*Macomona liliana*
Nov-06		*Austrovenus stutchburyi*	*Aricidea* sp.	Cirratulidae	*Arthritica bifurca*	Nereididae
Nov-07		*Austrovenus stutchburyi*	*Aricidea* sp.	Cirratulidae	*Heteromastus filiformis*	*Nucula hartvigiana*
Nov-05	**HIN**	*Nucula hartvigiana*	*Austrovenus stutchburyi*	*Notoacmea helmsi*	*Aricidea* sp.	*Prionospio aucklandica*
Nov-06		*Nucula hartvigiana*	*Austrovenus stutchburyi*	Chiton Monoplacophora	Nereididae	*Zeacumantus lutulentus*
Nov-07		*Nucula hartvigiana*	*Austrovenus stutchburyi*	*Notoacmea helmsi*	*Zeacumantis lutulentus*	Nereididae
Nov-05	**HIW**	*Austrovenus stutchburyi*	*Nucula hartvigiana*	*Prionospio aucklandica*	*Scoloplos cylindrifer*	*Macomona liliana*
Nov-06		*Austrovenus stutchburyi*	*Nucula hartvigiana*	*Macomona liliana*	*Orbinia papillosa*	*Zeacumantus lutulentus*
Nov-07		*Nucula hartvigiana*	*Austrovenus stutchburyi*	*Notoacmea helmsi*	*Prionospio aucklandica*	*Macomona liliana*
Nov-05	**Hbv**	*Nucula hartvigiana*	*Aonides trifida*	*Austrovenus stutchburyi*	Exogoninae	*Notoacmea helmsi*
Nov-06		*Nucula hartvigiana*	*Aonides trifida*	*Austrovenus stutchburyi*	*Notoacmea helmsi*	*Paphies australis*
Nov-07		*Nucula hartvigiana*	*Aonides trifida*	*Austrovenus stutchburyi*	*Notoacmea helmsi*	*Paracalliope* sp.

Figure 6:

Temporal trends in dominant species at upper estuary sites, up to February 2008. Note that since May 2006, sites ParU, and HellU have only been sampled in November each year.

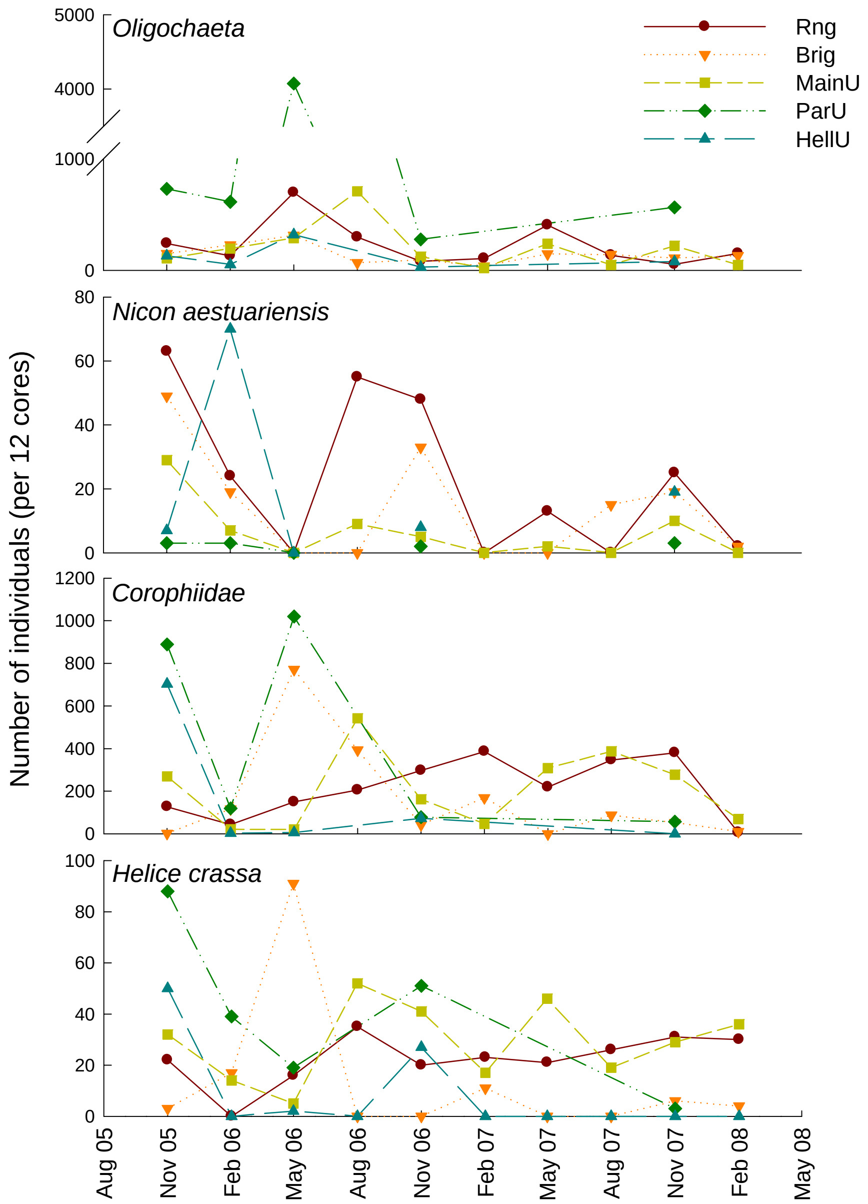


Figure 7:

Temporal trends in dominant species at mid-estuary sites. Note that since May 2006, sites HellU, and LucU have only been sampled in November each year.

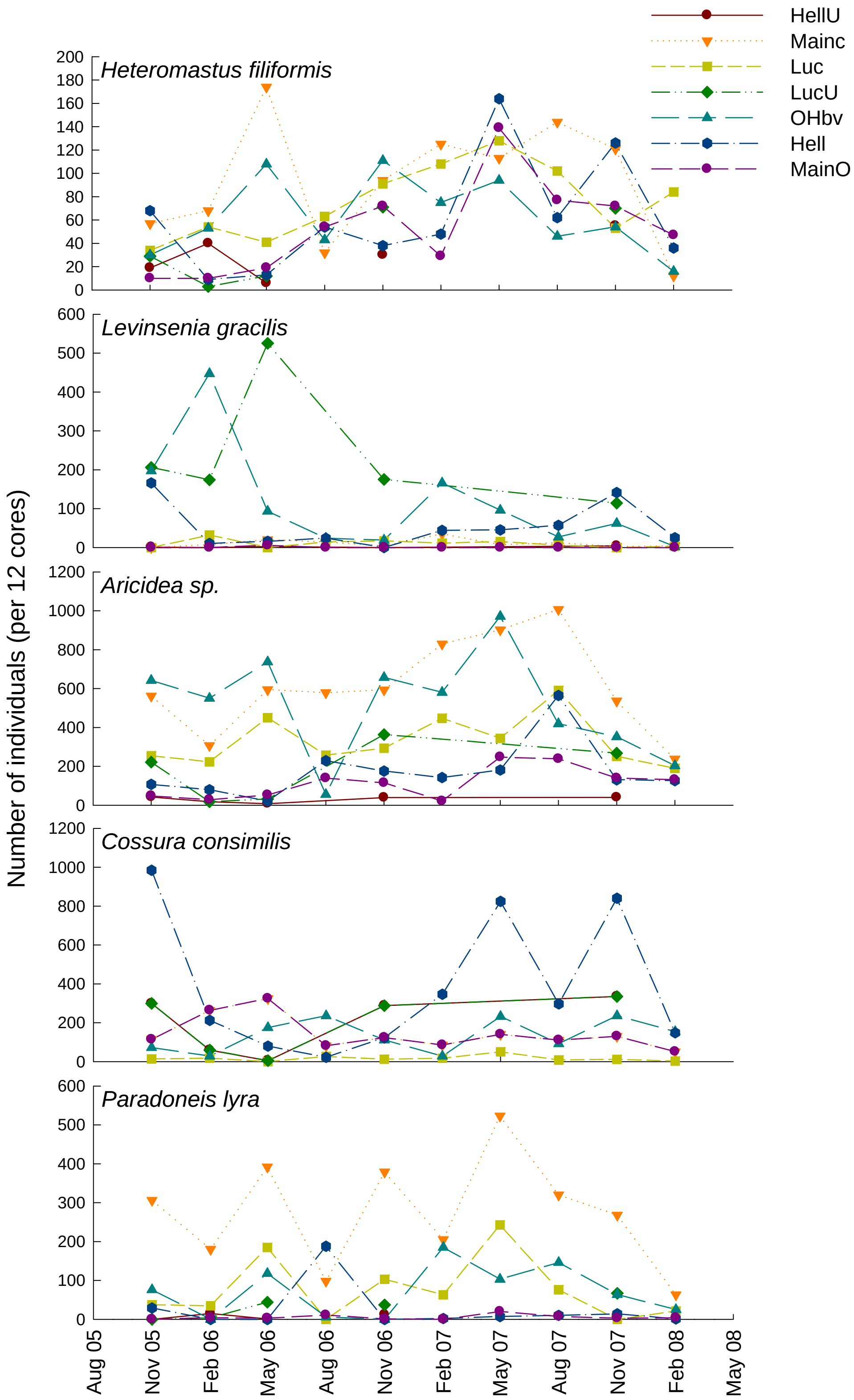
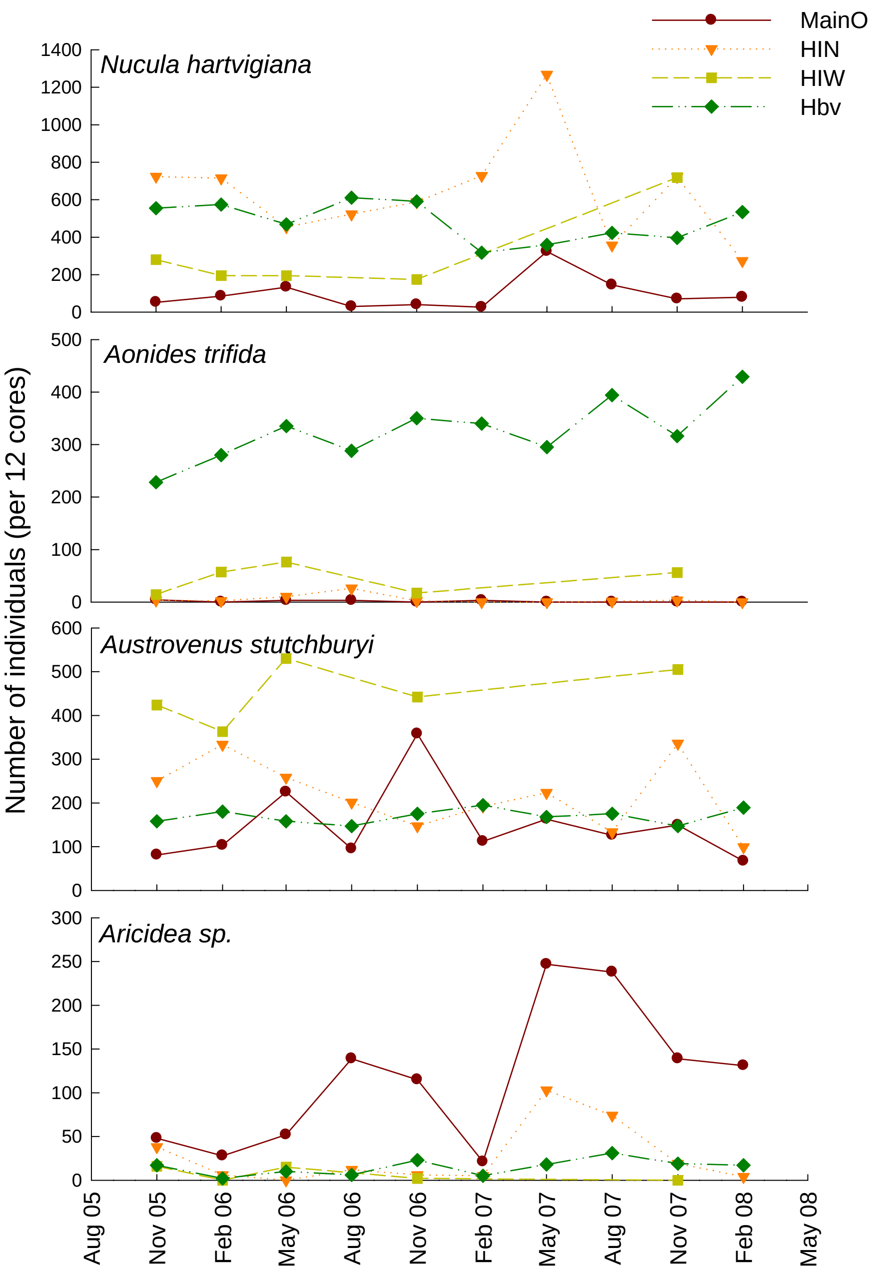


Figure 8:

Temporal trends in dominant species at lower estuary sites. Note that since May 2006, site HIW has only been sampled in November each year.



5.4 Bivalve size frequency distributions

Bivalves were primarily found at the outer harbour sites (HIN, HIW, MainO and HBV), with sites differing in their proportion of adults to juveniles (Figure 9). MainO had consistently juveniles and few adults of either *Austrovenus* or *Macomona* (Figure 10). HIW had fewer adult *Austrovenus* but large populations of adult *Macomona* (Figure 11). Juvenile and intermediate size classes of *Austrovenus* were present in large numbers at HIW; juveniles of *Macomona* have decreased in abundance since monitoring began (Figure 11). HIN displays high numbers of all size classes of *Austrovenus*, but lower, variable numbers throughout the years of *Macomona.* (Figure 12). *The Paphies* temporal plot at site HIN (Figure 12) shows interesting large peaks in intermediates over time not associated with juveniles. This is potentially because, while *Paphies*, like *Macomona*, disperse as post settlement juveniles, they remain highly mobile throughout their life cycle. Moreover, there is a strong difference in the habitat preferred by juveniles versus adults (although we do not know at what precise size they move into the new habitat). Intermediate sizes of *Austrovenus* were most common at Hbv, though an increasing trend in the number of adult sizes was also observed in the past year (Figure 13). *Macomona liliana* at HBV consisted of all three size categories: adults, intermediate and juveniles (Figure 13).

Figure 9:

Bivalve size frequency distributions averaged over all the November sampling times.

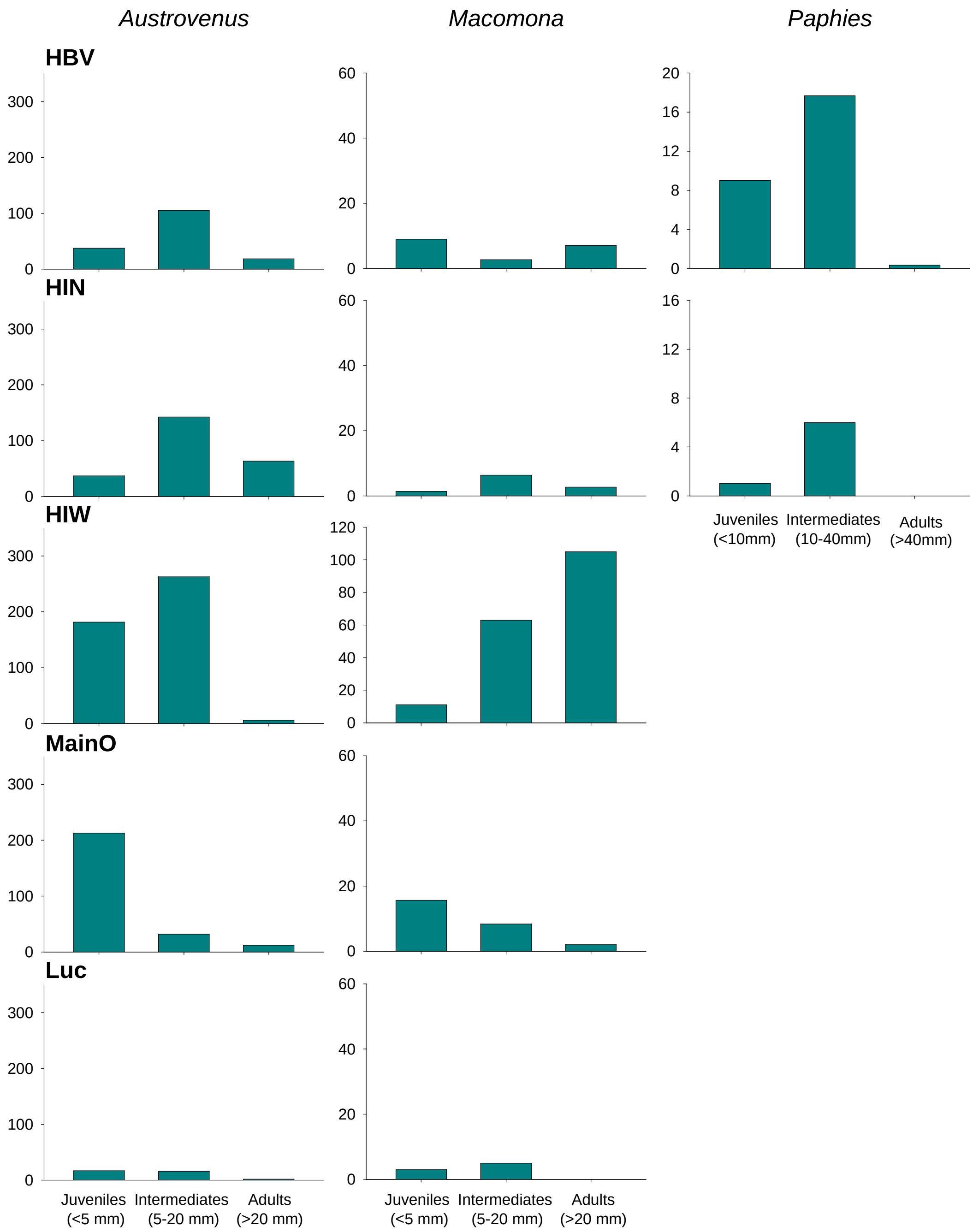


Figure 10:

Temporal plots of bivalve size frequencies at site MainO (muddy and sandy cores combined).

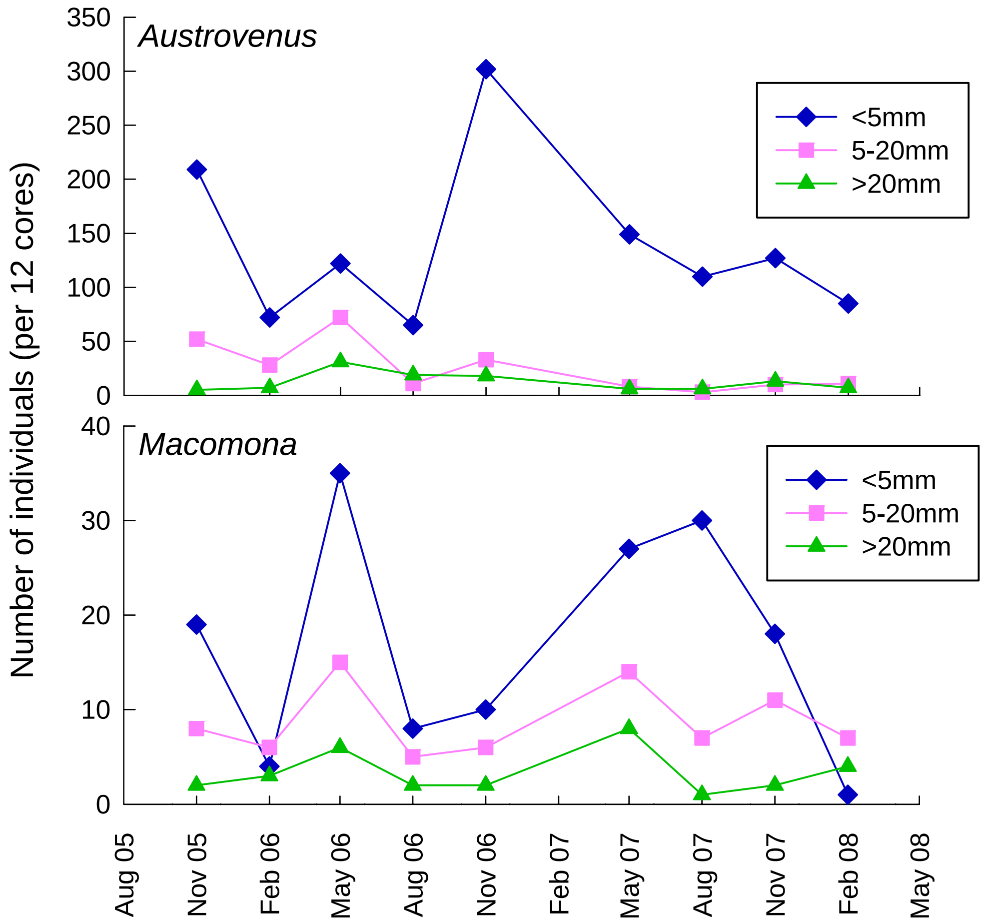


Figure 11:

Temporal plots of bivalve size frequencies at site HIW.

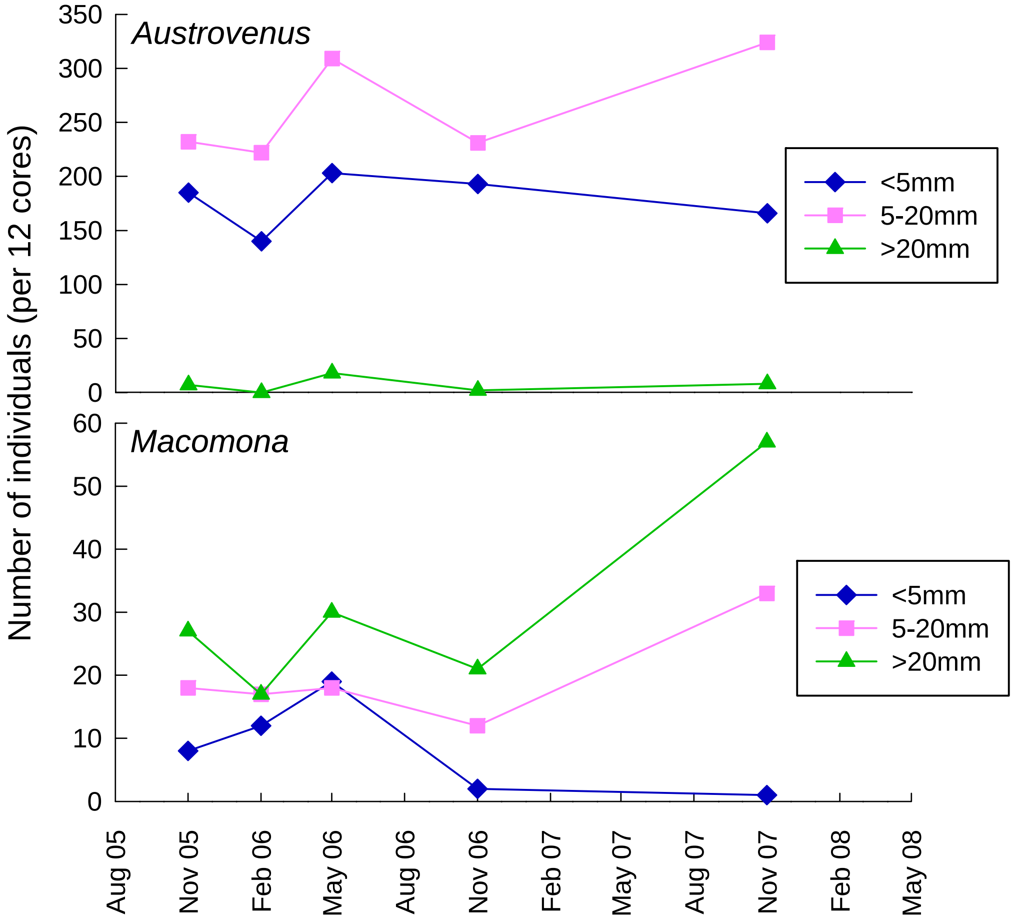


Figure 12:
Temporal plots of bivalve size frequencies at site HIN.

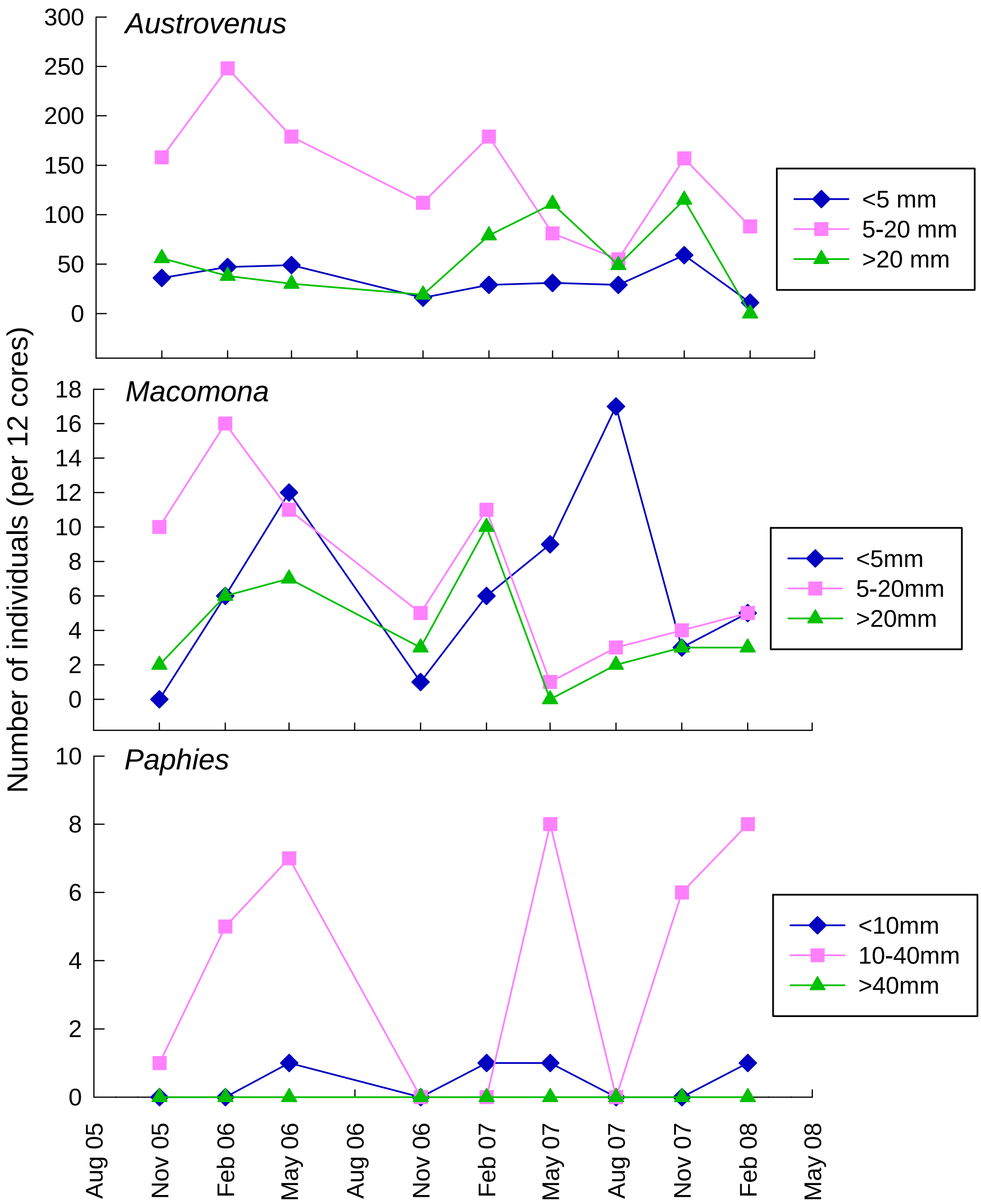
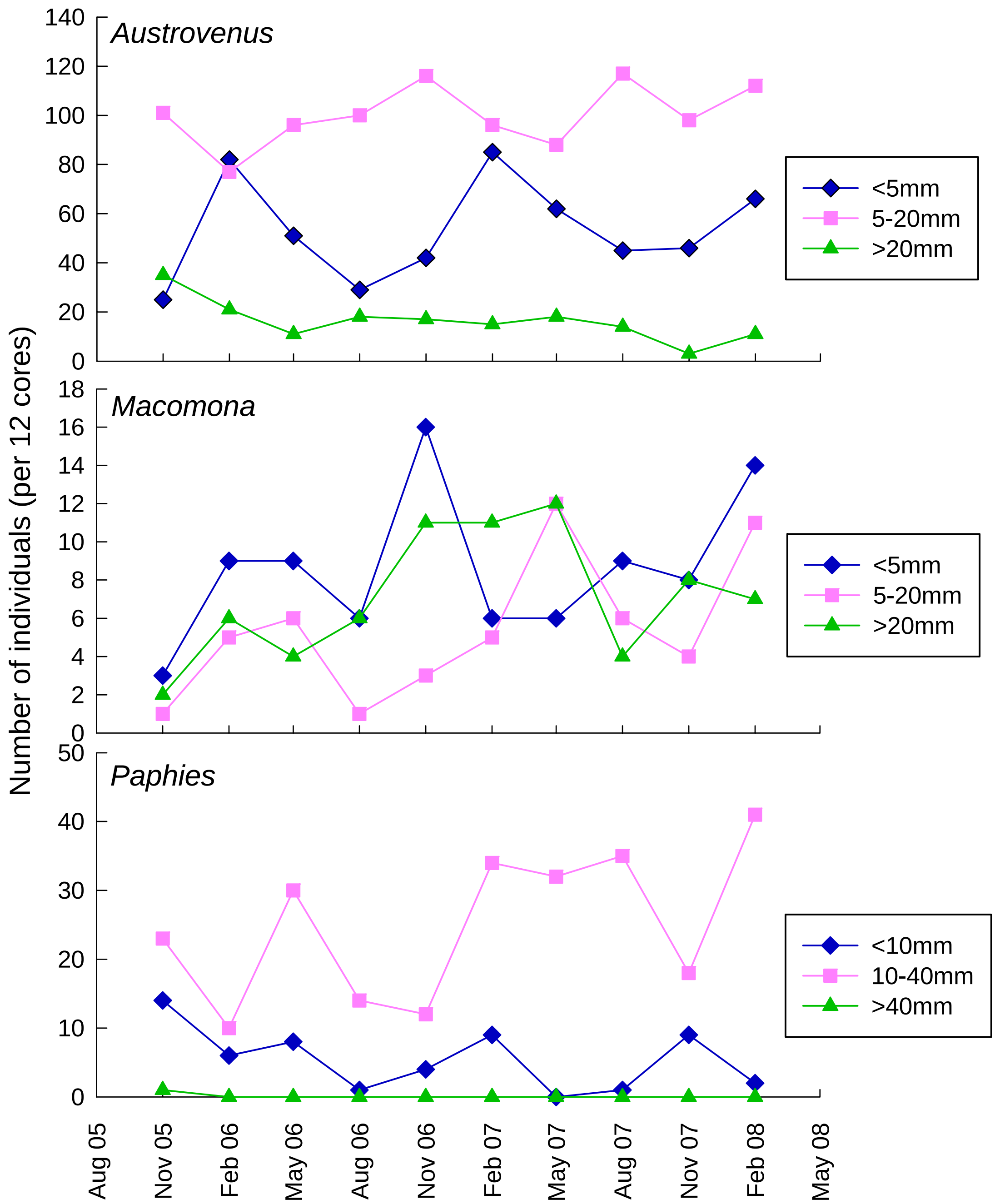


Figure 13:
Temporal plots of bivalve size frequencies at site HBV.



5.5 Species diversity

Shannon Weiner diversity index values at each site demonstrated broadly similar patterns over time (Figure 14). Upper estuary sites generally had the lowest species diversity values, with increasing diversity toward the sandy outer harbour sites (Figure 15). The highest site values were for MainO and Luc, as both sites included both deposit-feeding polychaetes typical of mid-estuary sites and bivalves. Some sites demonstrated peaks in diversity in August (Ohbv, MainO, Hell). There were no increasing or decreasing trends in species diversity apparent in this short time series.

Patterns in the number of species found at each site were similar to those observed for species diversity (Figure 16). Lower numbers of species were sampled at upper estuary sites compared to lower estuary sites (Figure 17), with on average 15 species present at sandy outer harbour sites, where over 30 species were found. Many sites showed a seasonal peak in number of species in August of both years of sampling (Figure 16).

Figure 14:
Temporal patterns in taxa diversity (Shannon-Weiner index) at all sites.

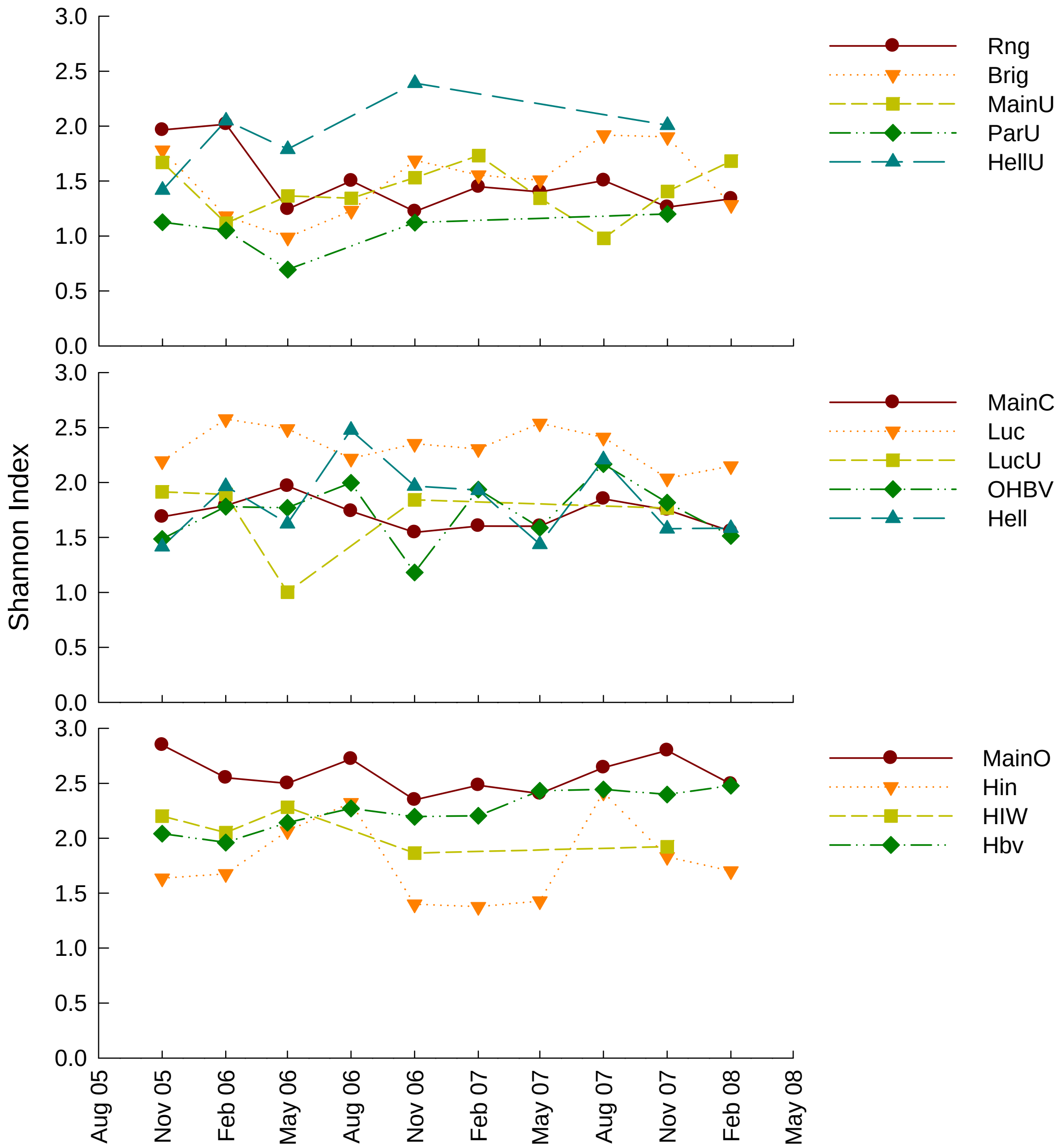


Figure 15:

Temporal patterns in taxa diversity (Shannon-Weiner index calculated on replicate cores) for all sites in November presented in rank order with +/- standard error bars.

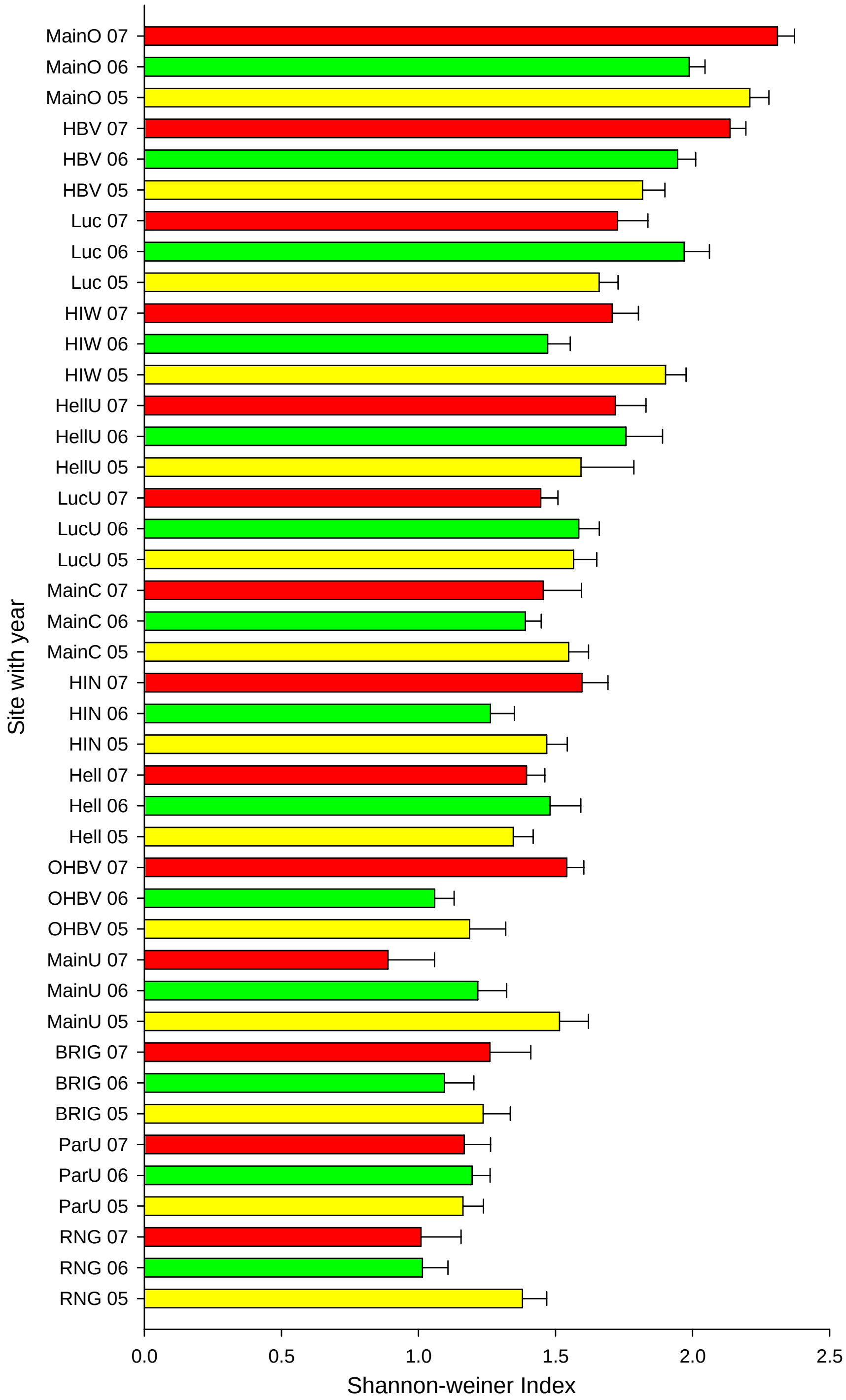


Figure 16:

Temporal Patterns in taxa richness (total number of species found on each sampling occasion) at all sites.

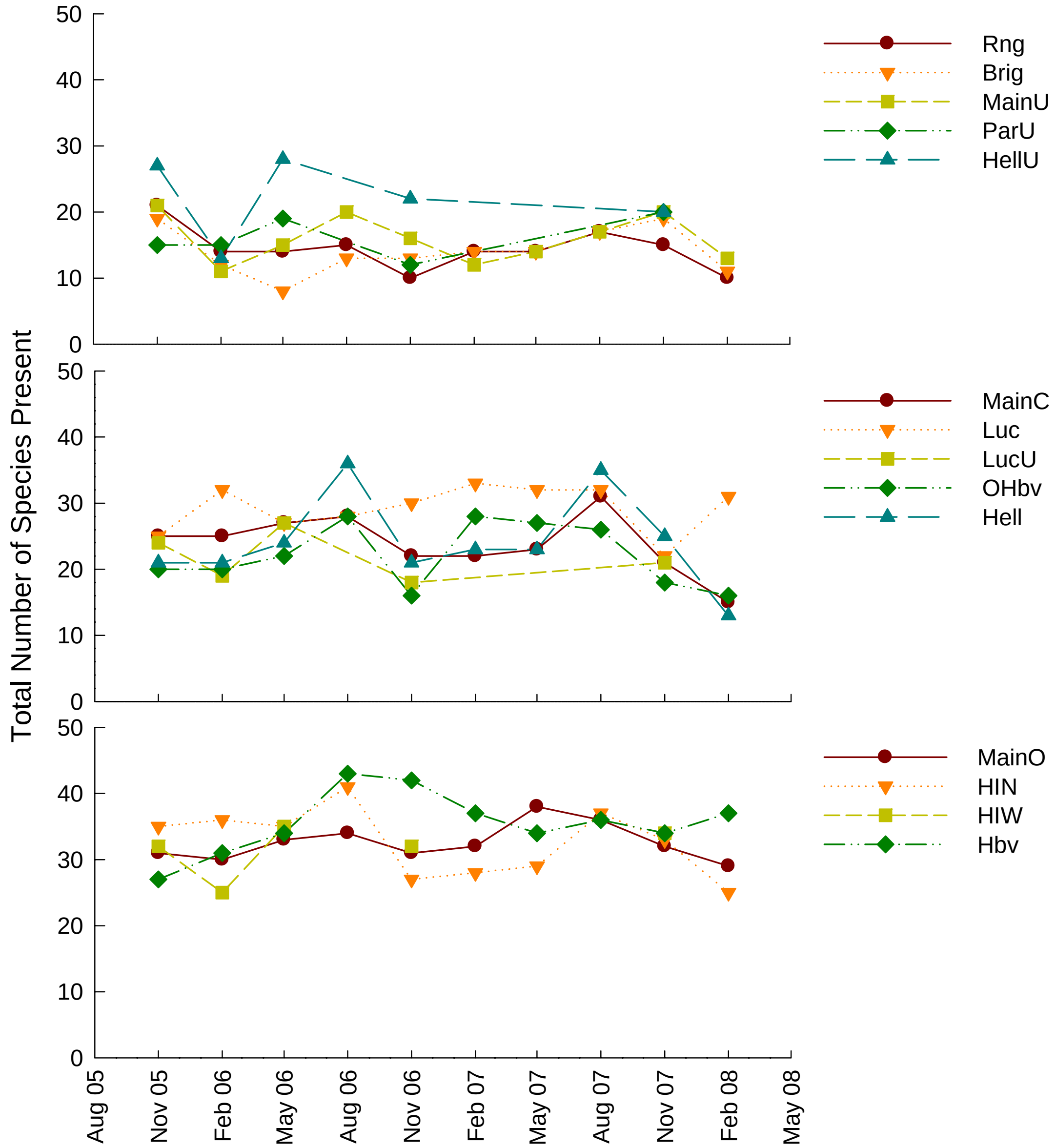
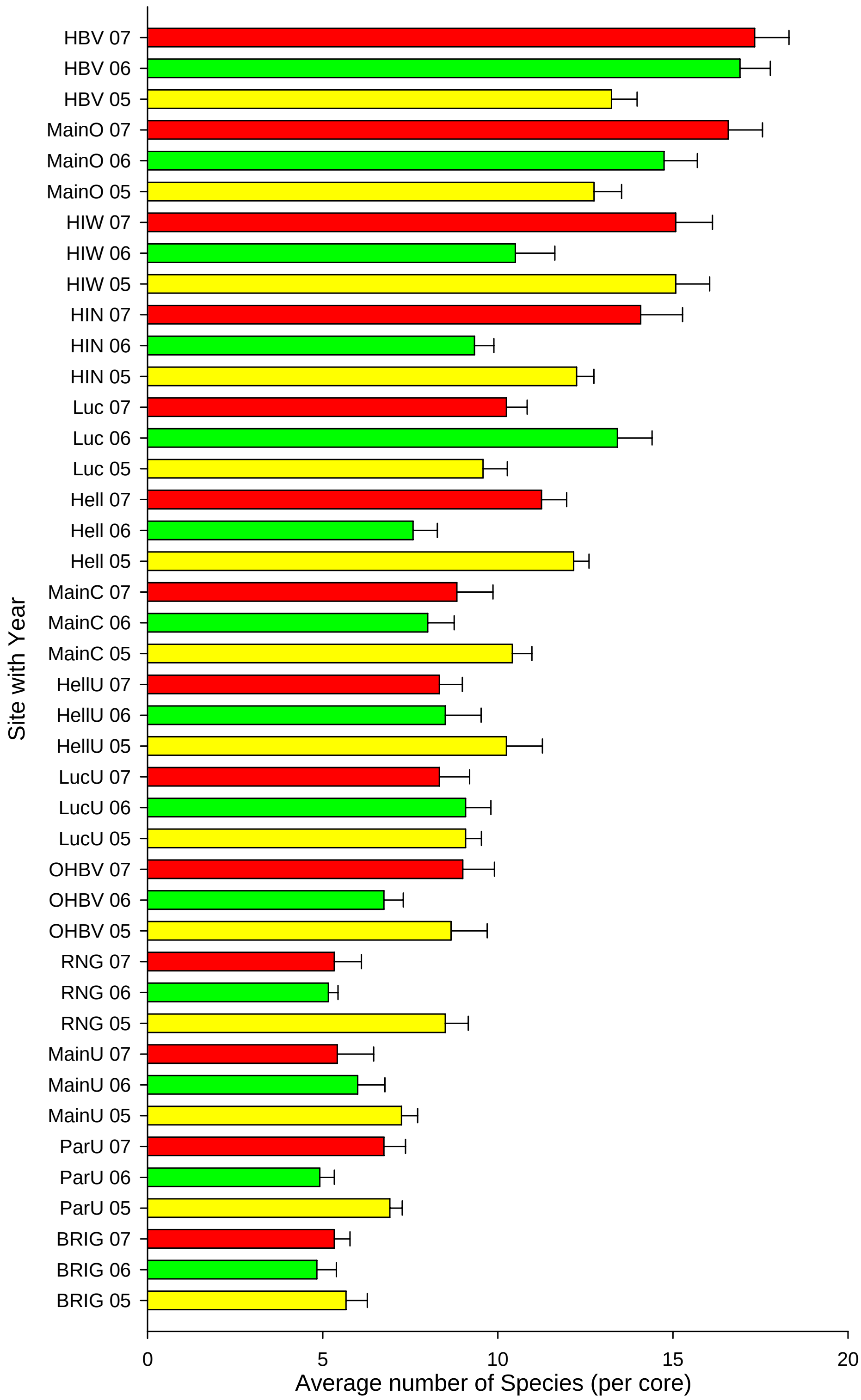


Figure 17:

Temporal patterns in taxon richness (number of taxa calculated on replicate cores) for all sites in November presented in rank order with +/- standard error bars.



5.6 Community composition

Multivariate analysis of total community composition demonstrates that the patterns initially observed have been maintained over time (Figure 18a). The main groupings are the upper estuary sites including Brig, Rng, ParU and MainU (Figure 18b); the other muddy sites Hell, Luc, LucU, MainC, OHbv (Figure 18c); and the sandier outer harbour sites HIN, HIW, HBV (Figure 18d), with HellU and MainO separated from these 3 main groupings. Most of the sites show small changes both seasonally and between years. However, both HellU and MainO demonstrate increasing similarity with time to the Hell-Luc-LucU-MainC-OHbv grouping. Hell, LucU and ParU show the most seasonal variability.

Figure 18a:

Nonmetric multidimensional scaling ordination plot of the community structure between November 2005 and February 2008. The stress of the plot is 0.14, indicating a good fit. There are clusters of three main groups; upper estuary sites – Group A (Rng, Brig, ParU, MainU), deposit feeding polychaete dominated sites – Group B (Hell, Luc, LucU, MainC, OHbv) and outer sandy sites – Group C (Hbv, HIW, HIN). HellU and MainO are separate from three main groupings.

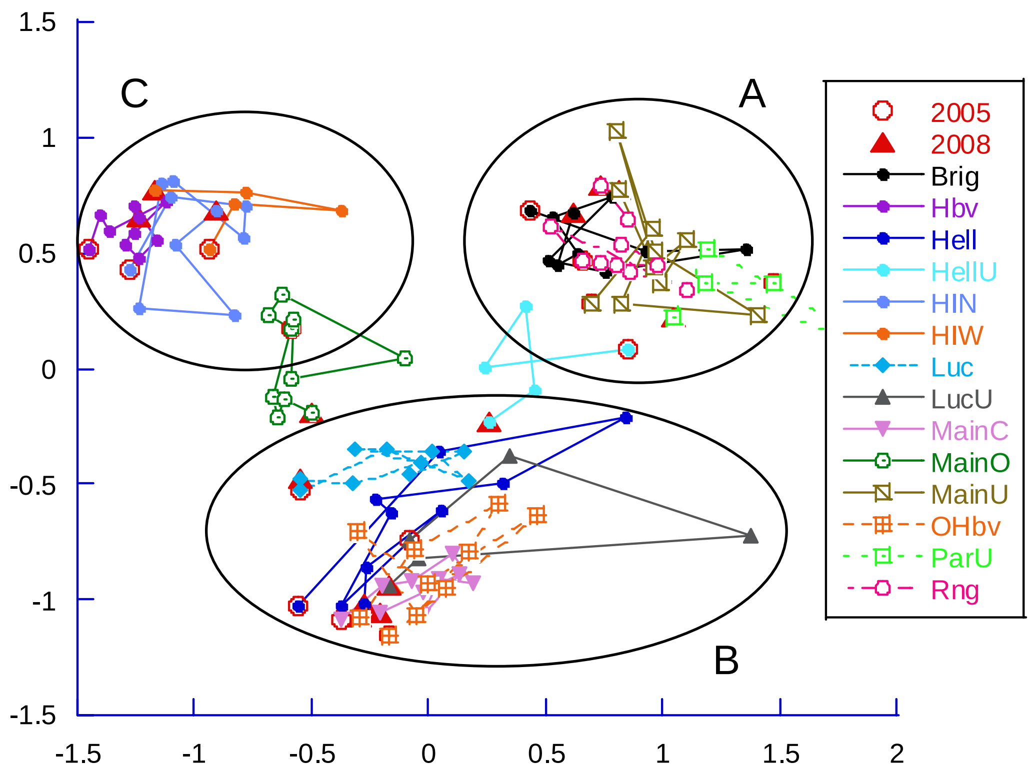


Figure 18b:

Detail of upper estuary sites (Group A). These sites are characterised by very muddy sediment with low diversity and high abundance of individuals. HellU site is separate from the main cluster because it shares attributes of both Group A and Group B i.e., it is a muddy site but with deposit feeding polychaetes.

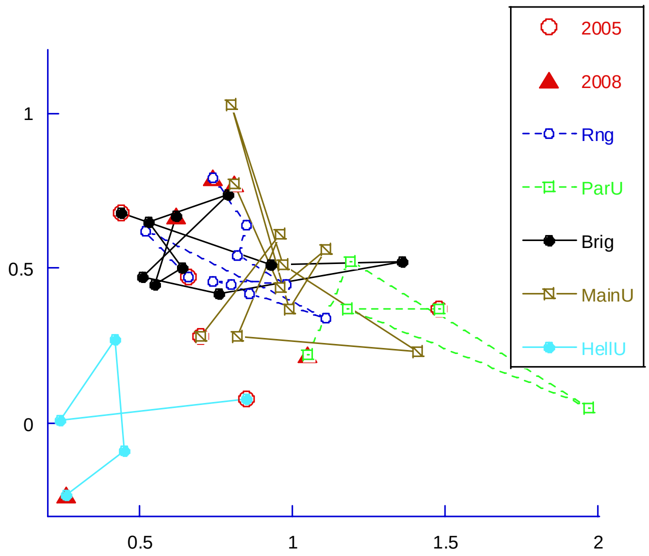


Figure 18c:

Detail of deposit feeding polychaete dominated Sites (Group B)

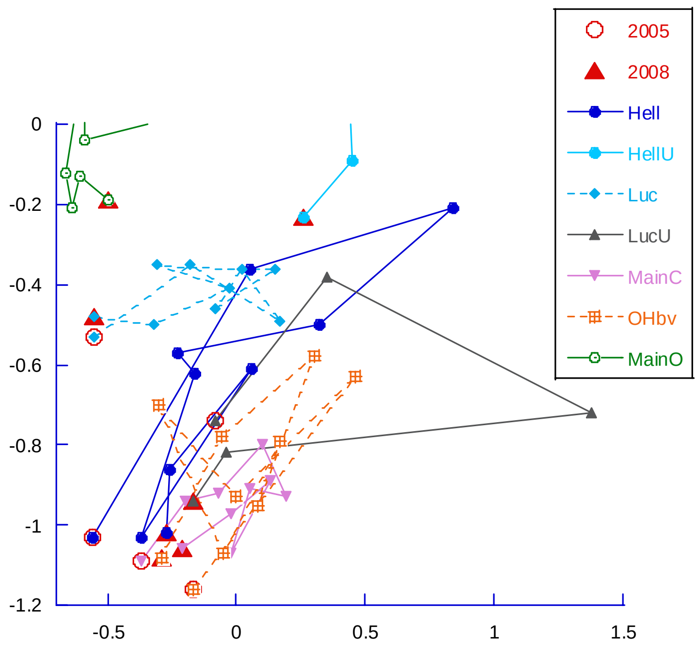
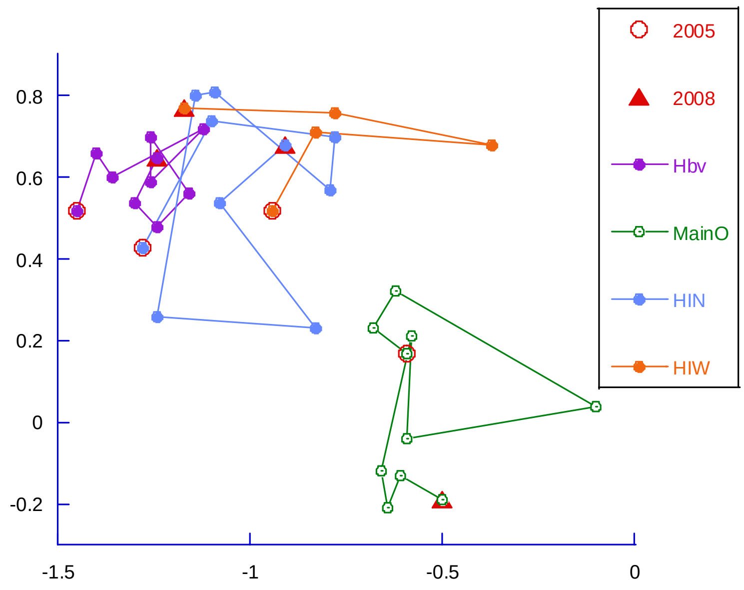


Figure 18d:
Detail of outer sandy sites (Group C) Site MainO is a complex site as it has a muddy and sandy portion to it. This is reflected in the MDS plot which shows MainO separated from the main cluster.



5.7 Chemistry characteristics

In the following discussions the measured concentrations of contaminants have been compared against the Auckland Regional Council Environmental Response Criteria (ARC ERC) for estuarine environments (ARC 2004) and three environmental sediment quality guidelines: the interim sediment quality guidelines (ISQG) of ANZECC (2000); the sediment quality guideline values as per MacDonald et al. (1996), Threshold Effects Level and Probable Effects level (TEL/PEL); and Long and Morgan's (1990) Effects Range Low and Effects Range Median (ERL/ERM) (see Table 3). These guidelines are set for single contaminants based largely on analysis of contaminated sediments, they may not take into consideration the effect of several contaminants present in the site-specific sediments and their potential synergistic effects on ecological communities.

Table 3:

Sediment quality guidelines. Copper, lead, zinc, arsenic, high molecular weight Polycyclic Aromatic Hydrocarbons (HMW-PAH) and Total PAH units are mg/kg on a dry weight basis (<500µm fraction). The PAH values have been normalised to 1% total organic carbon (TOC), as recommended in the ANZECC (2000) guidelines.

Source	ARC (2004)			MacDonald et al. (1996)		Long and Morgan (1990)		ANZECC (2000)	
Guideline	Green	Amber	Red	TEL	PEL	ERL	ERM	ISQG-Low	ISQG-High
Copper	<19	19-34	>34	18.7	108.2	34	270	65	270
Lead	<30	30-50	>50	30.2	112.2	47	218	50	220
Zinc	<124	124-150	>150	124	271	150	410	200	410
Arsenic				7.24	41.6	8.2	70	20	70
HMW-PAH	<0.66	>0.66<1.7	>1.7	0.66	6.7	1.7	9.6	1.7	9.6
Total PAH				1.7	17.8	4	44.8	4	45

Auckland Regional Council grades the level of impact to sediment and water quality with green, amber and red environmental response criteria (ERC) (ARC 2004).

- Green sites are low impact sites. Additional investigations are not required unless significant changes in catchment land use occur. Green sites should be reassessed every 5 years.
- Amber sites are showing signs of degradation. Management actions taken as early as possible are likely to be most effective at limiting further degradation. These sites present the best opportunity to make a difference to the future quality of the receiving environment.
- Red sites are higher impact sites where significant degradation has already occurred, and remedial opportunities are often more limited. Restoration of the site may not be feasible in the short term, but actions should be taken to slow the rate of decline and limit the spread of contaminants.

In this analysis we concentrate on monitored contaminants that are of primary concern to the ARC which have ERC thresholds. These are the heavy metals (copper, lead and zinc) and high molecular weight polyaromatic hydrocarbons (HMW-PAHs). Two other metals (iron and manganese) and a metalloid (arsenic) are also included in our analysis which do not have ERC thresholds but are relevant to monitoring the health of the UWH.

5.7.1 Polycyclic aromatic hydrocarbons (PAHs)

To aid better comparison of PAH levels between sites with different total organic carbon (TOC) levels (see Figure 21), it is standard practice to normalise the results to 1% TOC. This allows direct comparison to management threshold levels which are based on concentrations normalised to 1% TOC.

The ARC has adopted the use of MacDonald et al (1996) and ANZECC (2000) guideline values for high molecular weight PAH to establish the ERC values (Table 3). This subset of PAH compounds; benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene are more reliably analysed and are more relevant to evaluating combustion derived stormwater contamination. Values for total PAH were included in the analysis as there are other management thresholds we can compare them to.

There were no exceedances of any management thresholds in relation to HMW-PAHs (see Figure 19 and Table 4). The ARC-ERC Amber value for HMW PAHs (0.66 mg/kg dry weight) is more than double the highest value from the time series so far. The range of values for all sites over three sampling events was 0.05 – 0.26 mg/kg dry wt. Consistently higher values have come from OHbv (0.20 - 0.25 mg/kg dry wt) and Hell (0.19 - 0.26 mg/kg dry wt).

Figure 19:

High molecular weight PAH (HMW-PAH) values normalised to 1% TOC. Values are the mean of three replicates with +/- standard error bars. The ARC ERC Amber threshold which equates to MacDonald et al. (1996) TEL (0.66mg/kg dry wt) is shown.

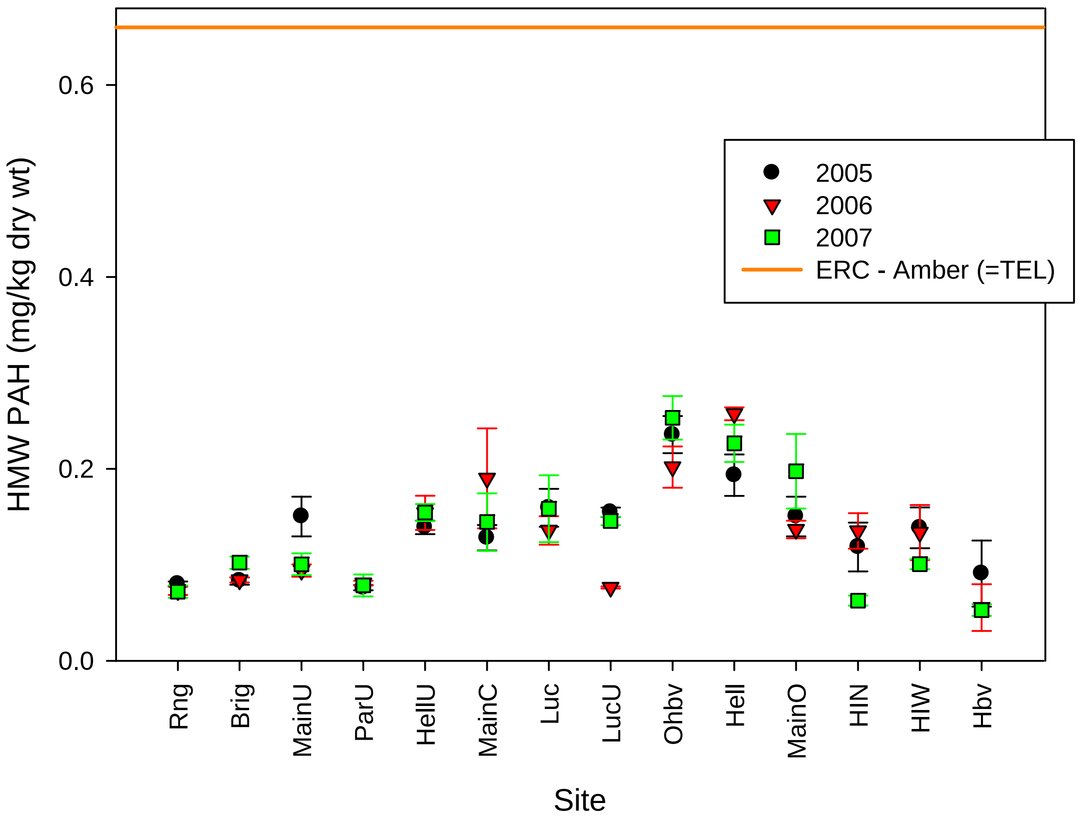
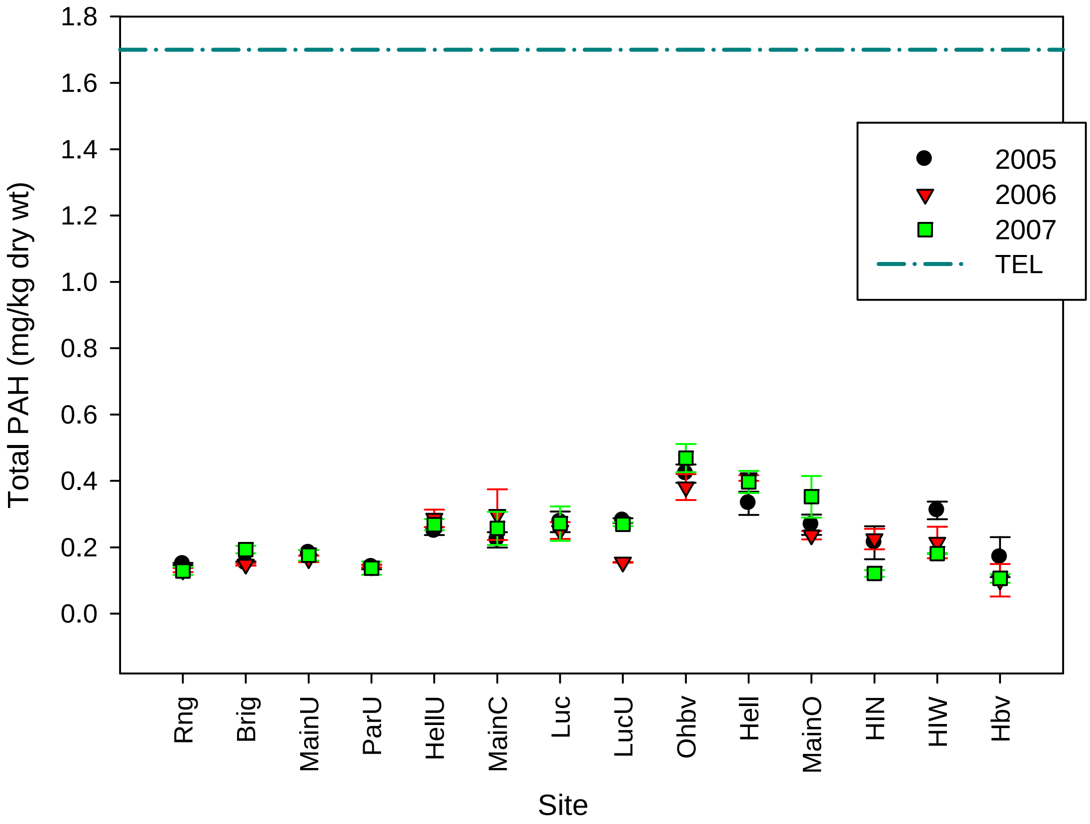


Figure 20:

Total PAHs normalised to 1%TOC. Values are the mean of three replicates with +/- standard error bars. The MacDonald et al. (1996) TEL for total PAHs (1.68mg/kg dry wt) is shown.



Total PAHs have not markedly increased over consecutive years (see Figure 20 and Table 4). However values for 2007 were the highest over the three years at OHbv, MainO and Brig. The highest overall level was at site OHbv, adjacent to the suburb of Beachhaven with 0.47 mg/kg dry weight in 2007. This is still well below the TEL (MacDonald et al. 1996) of 1.68mg/kg dry wt.

Figure 21:

Total organic carbon (TOC). Values are the mean of three replicates with +/- standard error bars.

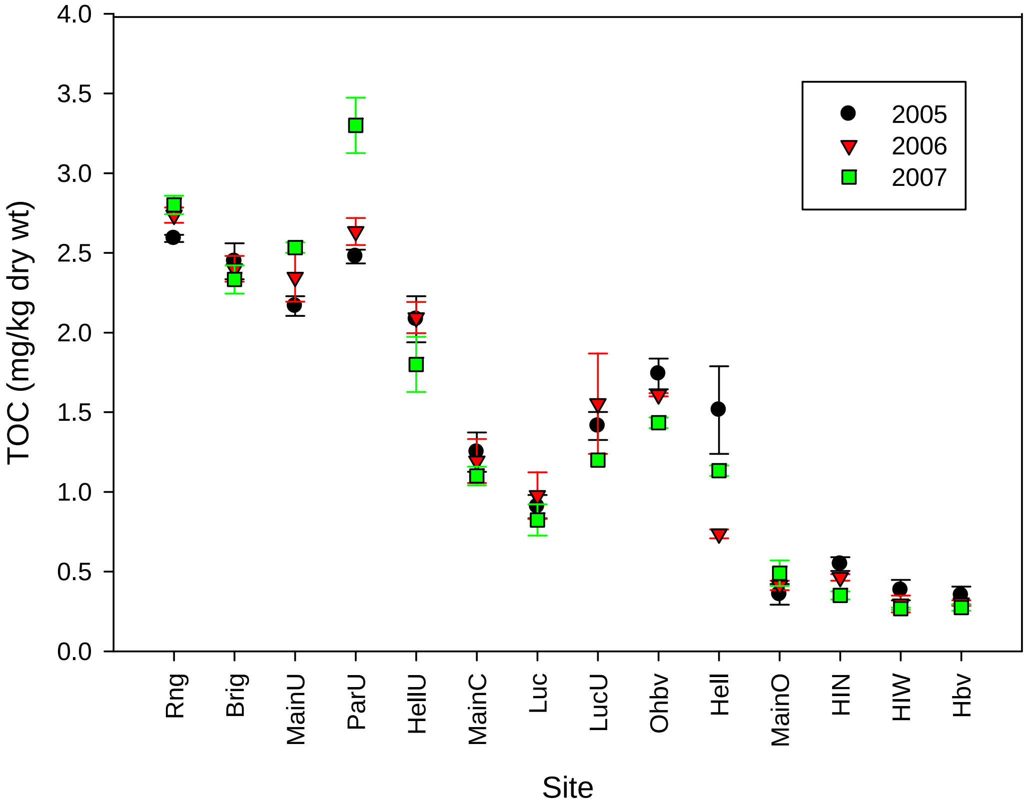


Table 4:

High molecular weight Polyaromatic Hydrocarbons (HMW-PAHs) and Total PAH values for all sites. All PAH values have been normalised to 1% total organic carbon (TOC). The threshold value (0.66 mg/kg dry wt) for High Molecular Weight PAHs used by the ARC (ERC Amber value) and McDonald et al. (1996) (TEL) has not been exceeded at any site during the time series so far.

	Polyaromatic Hydrocarbons (PAH) mg/kg dry wt normalised to 1% TOC					
	2005		2006		2007	
Site	HMW PAH	Total PAH	HMW PAH	Total PAH	HMW PAH	Total PAH
Rng	0.08	0.15	0.07	0.13	0.07	0.13
Brig	0.08	0.15	0.08	0.15	0.10	0.19
MainU	0.15	0.18	0.09	0.17	0.10	0.18
ParU	0.08	0.14	0.08	0.14	0.08	0.14
HellU	0.14	0.25	0.15	0.29	0.15	0.27
MainC	0.13	0.22	0.19	0.30	0.14	0.26
Luc	0.16	0.28	0.14	0.25	0.16	0.27
LucU	0.15	0.28	0.08	0.15	0.15	0.27
Ohbv	0.24	0.42	0.20	0.38	0.25	0.47
Hell	0.19	0.33	0.26	0.41	0.23	0.40
MainO	0.15	0.27	0.14	0.24	0.20	0.35
HIN	0.12	0.21	0.14	0.23	0.06	0.12
HIW	0.14	0.31	0.13	0.21	0.10	0.18
Hbv	0.09	0.17	0.06	0.10	0.05	0.11
HMW PAH ERC Amber		0.66				
HMW PAH TEL		0.66				
Total PAH TEL		1.68				

5.7.2 Copper, Lead and Zinc

The environmental response criteria (ERC) thresholds for copper, lead and zinc are applied slightly differently depending on site characteristics (ARC 2004). The Regional Discharges Project (RDP) have divided Auckland's urban marine area into two types of receiving environments for the purposes of monitoring the impact of stormwater and wastewater discharges. These are Settling Zones and Outer Zones. The rationale for this subdivison is explained in Auckland Regional Council (2002b) "Environmental Targets for the Urban Coastal Marine Area". Maps for the urban coastal marine area are reproduced in the report "Regional maps of settling zones and outer zones" (ARC 2002c). The settling zones are areas where the settling out of contaminants is expected whereas the outer zones are located in higher energy environments where contaminants are less likely to settle permanently. In settling zones, the ARC environmental response criteria (ERC) for copper lead and zinc are applied to the < 500μm sediment fraction (which is often referred to as the total sediment fraction). In outer zones, a more protective approach is adopted and the ERC for copper lead and zinc are compared against the higher of the weak acid digestion of the mud fraction (<63 μm) or the strong acid digestion of the total sediment fraction (<500μm). Definitions for UWH monitored sites (M. Green pers. comm.) for the purposes of comparing heavy metal ERCs are outlined in Table 5.

Table 5:

Two types of receiving environments outlined by the Regional Discharges Project (RDP) applied to the UWH monitored sites

Settling Zones	Outer Zones
Rng	MainU
Brig	MainC
ParU	Ohbv
HellU	MainO
Luc	HIN
LucU	HIW
Hell	Hbv

5.7.2.1 Copper

Concentrations of copper for the majority of sites have not changed markedly over this time series (Figures 22 and Table 6). However there has been a noticeable temporal increase over this time period at MainU (23%) and MainC (20%). Nine of the sites (Rng, Brig, MainU, ParU, HellU, OHbv, MainO, HIN and Hbv) that were over the ARC ERC Amber value in 2005 were still exceeding this value (19 mg/kg dry wt) in 2007. There was a very high anomalous replicate value for fine fraction of copper at site Hbv in November 2005 (135 mg/kg dry wt). This was a repeat analysis, the initial analysis was even higher (143 mg/kg dry wt). The reason for this outlier is undetermined. The sample may have come from a localised hot spot of contamination. This outlier has not been included in Figure 22 or Table 6. There is also a smaller outlier replicate at HIN in 2006 (i.e., 48 mg/kg dry wt) which has been included.

Comparisons between the separate methodologies (total recoverable acid digested (< 500μm) sediment fraction and weak acid digestion of the mud fraction (<63 μm)) and other sediment quality guidelines can be found in Appendix 4).

Copper is associated with both stormwater discharge and volcanic soils and receiving waters may be expected to reflect these spatial differences (ARC 2002a).

Figure 22:

Copper values at U WH sites compared to ARC environmental response criteria (ERC). Values are from total recoverable acid digested (< 500µm) sediment fraction or weak acid digestion of the mud fraction (<63 µm), depending if site is in a settling zone or outer zone. Values are the mean of three replicates with +/- standard error bars.

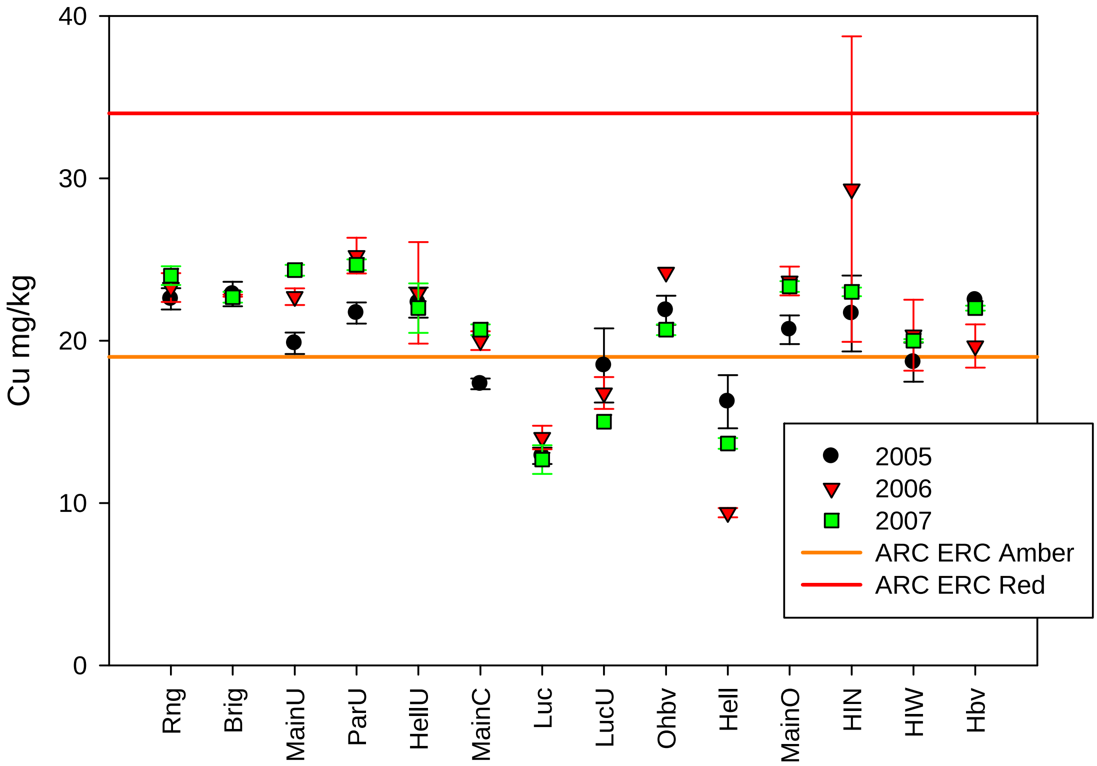


Table 6:

Copper results from both extraction techniques; total recoverable acid digested (<500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm). The ARC ERC value compares the <500µm fraction for settling zones and uses the highest value between the <500µm fraction and the <63 µm for the outer zones. RDP zone classification from ARC (2002b).

		Copper (mg/kg dry wt)					
		2005		2006		2007	
Site	RDP Zone	(<63µm)	(<500µm)	(<63µm)	(<500µm)	(<63µm)	(<500µm)
Rng	Settling Zone	20.0	22.6	20.0	23.3	22.0	24.0
Brig	Settling Zone	21.0	22.9	19.7	22.8	20.3	22.7
MainU	Outer Zone	18.0	19.8	19.7	22.7	21.0	24.3
ParU	Settling Zone	20.0	21.7	19.7	25.2	20.3	24.7
HellU	Settling Zone	21.0	22.3	20.3	22.9	23.7	22.0
MainC	Outer Zone	17.3	13.1	20.0	13.4	20.7	12.3
Luc	Settling Zone	20.7	12.9	19.7	14.0	21.7	12.7
LucU	Settling Zone	19.3	18.5	19.7	16.8	20.0	15.0
Ohbv	Outer Zone	16.7	21.9	22.0	24.2	21.0	20.7
Hell	Settling Zone	16.0	16.2	15.7	9.4	18.3	13.7
MainO	Outer Zone	20.7	10.9	23.7	15.9	23.3	14.6
HIN	Outer Zone	21.7	10.5	29.3	8.0	23.0	6.0
HIW	Outer Zone	18.7	5.5	20.3	3.9	20.0	2.7
Hbv	Outer Zone	22.5	4.4	19.7	5.4	22.0	2.8
ERC Amber	>19<34						
ERC Red	>34						
TEL	18.7						

5.7.2.2 Lead

Six sites exceeded ARC ERC for lead in 2005 and eleven sites exceeded this level (30 mg/kg dry wt) from years 2006 and 2007 (Table 7 and Figure 23). Only three of the sites had slight temporal increases (MainU, MainO and Hbv). High values were observed in 2006 (greater than 37 mg/kg dry wt) at ParU, HellU and OHbv. OHbv had the highest averaged value from three replicates (43 mg/kg dry wt) in 2006. HellU had the highest replicate value in 2006 (58.5 mg/kg dry wt) exceeding the ARC ERC red value of 50 mg/kg dry weight. Results from the separate methodologies (total recoverable acid digested (< 500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm)) can be found in Appendix 5 compared with other sediment quality guidelines.

Figure 23:

Lead values at U WH sites compared to ARC environmental response criteria (ERC). Values are from total recoverable acid digested (< 500µm) sediment fraction or weak acid digestion of the mud fraction (<63 µm), depending if site is in a settling zone or outer zone. Values are the mean of three replicates with +/- standard error bars.

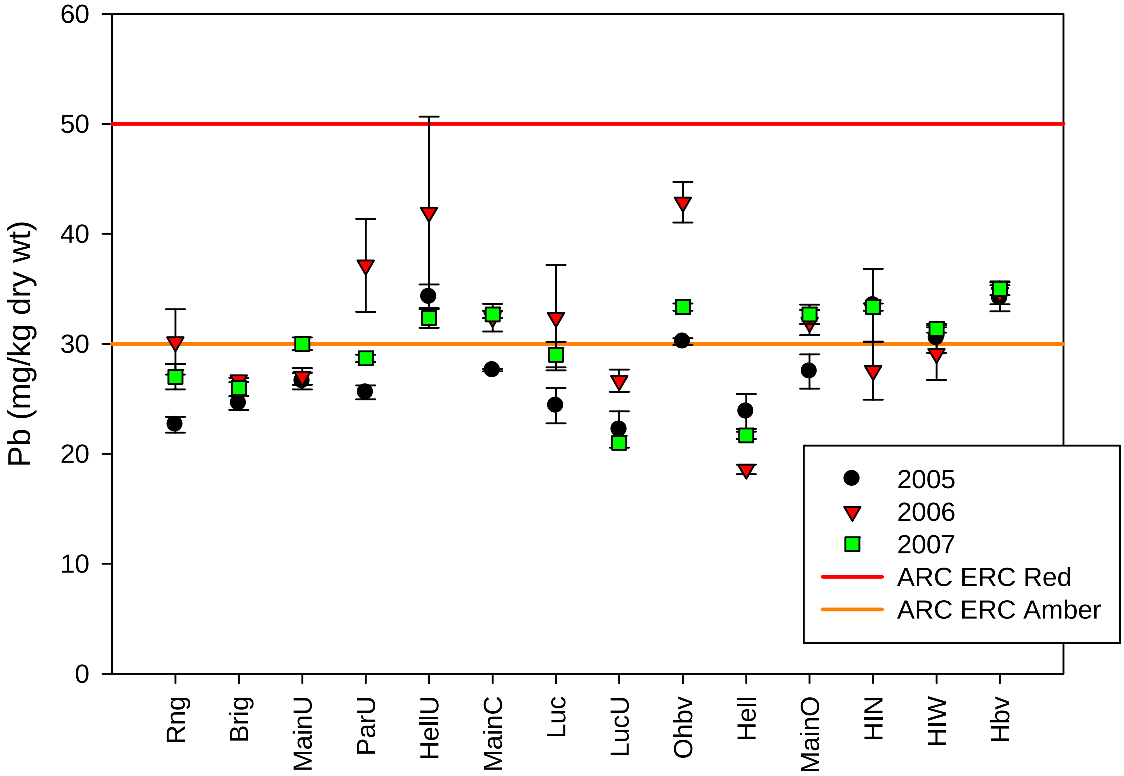


Table 7:

Lead results from both extraction techniques; total recoverable acid digested (<500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm). The ARC ERC value compares the <500µm fraction for settling zones and uses the highest value between the <500µm fraction and the <63 µm for the outer zones. RDP zone classification from ARC (2002b).

		Lead (mg/kg dry wt)					
		2005		2006		2007	
Site	RDP Zone	(<63µm)	(<500µm)	(<63µm)	(<500µm)	(<63µm)	(<500µm)
Rng	Settling Zone	24.4	22.6	27.4	30.2	29.7	27.0
Brig	Settling Zone	27.6	24.6	26.6	26.7	28.3	26.0
MainU	Outer Zone	26.6	23.5	27.0	27.0	30.0	28.3
ParU	Settling Zone	32.0	25.6	29.2	37.1	31.0	28.7
HellU	Settling Zone	37.7	34.3	33.7	41.9	38.7	32.3
MainC	Outer Zone	27.6	25.5	32.4	27.2	32.7	27.0
Luc	Settling Zone	32.6	24.4	30.3	32.4	33.3	29.0
LucU	Settling Zone	28.6	22.2	29.0	26.6	29.3	21.0
Ohbv	Outer Zone	30.3	30.2	36.9	42.9	36.0	33.3
Hell	Settling Zone	29.6	23.8	28.3	18.6	32.0	21.7
MainO	Outer Zone	27.5	17.5	31.9	18.0	32.7	18.7
HIN	Outer Zone	33.5	16.6	27.5	13.4	33.3	13.3
HIW	Outer Zone	30.5	7.5	29.1	7.1	31.3	5.4
Hbv	Outer Zone	34.1	7.1	34.6	9.6	35.0	6.9
ERC Amber	>30<50						
ERC Red	>50						
TEL	30.2						

5.7.2.3 Zinc

Zinc values were progressively increasing at nine sites (Rng, Brig, MainU, ParU, MainC, LucU, MainO, HIN and HIW) averaging an increase of 18% (Figures 24 and Table 8).

The ARC ERC amber threshold (124 mg/kg dry wt) was exceeded four times at three different sites over the three years. These were at Hbv in 2005 and 2007, OHbv in 2006 and HellU in 2007. The highest value was at HellU with a value of 137.0 mg/kg dry wt. This is consistent with Green et al. (2007) who have predicted that the Hell site will exceed ARC ERC Red Threshold (>150mg/kg dry wt) by 2013.

Zinc values (<500µm fraction) are generally consistent with most of the iron values (Figure 25 and Appendix 6). This is because iron (and manganese) may markedly affect the binding of zinc to the sediment (ARC 2004). It is important to note that zinc is associated with both stormwater and volcanic soils (Hickey 2000, ARC 2002a).

Results from the separate methodologies (total recoverable acid digested (< 500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm)) can be found in the Appendix compared with other sediment quality guidelines (Appendix 6).

Figures 24:

Zinc values at U WH sites compared to ARC environmental response criteria (ERC). Values are from total recoverable acid digested (< 500µm) sediment fraction or weak acid digestion of the mud fraction (<63 µm), depending if site is in a settling zone or outer zone. Values are the mean of three replicates with +/- standard error bars.

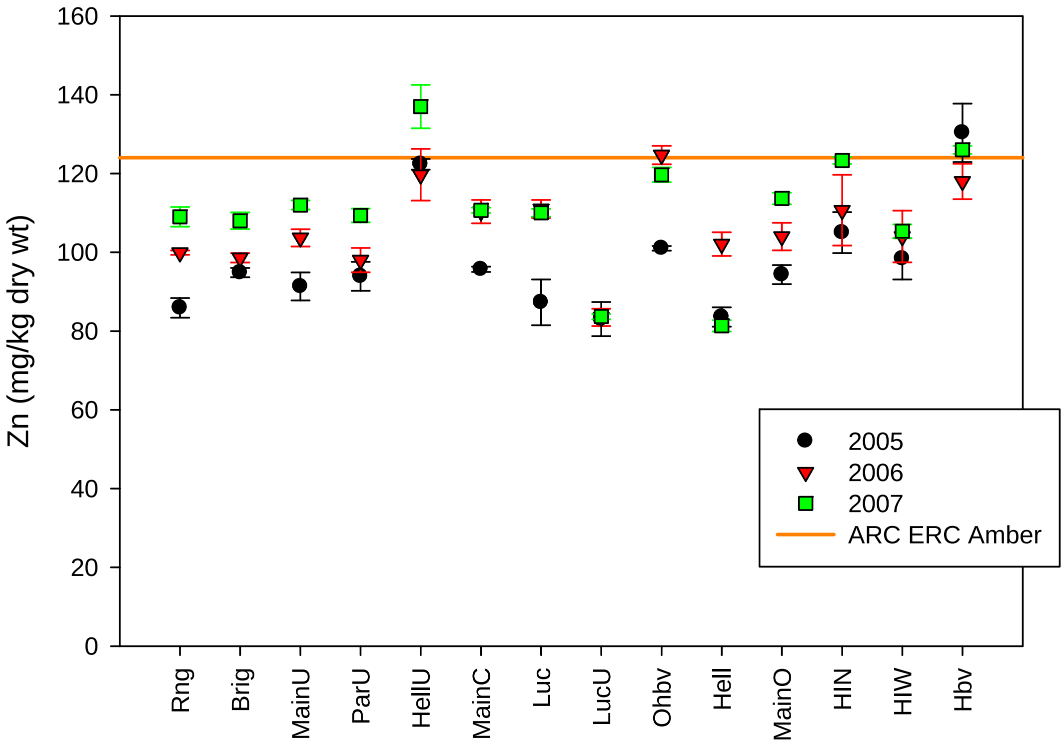


Table 8:

Zinc results from both extraction techniques; total recoverable acid digested (<500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm). The ARC ERC value compares the <500µm fraction for settling zones and uses the highest value between the <500µm fraction and the <63 µm for the outer zones. RDP zone classification from ARC (2002b).

		Zinc mg/kg dry wt					
		2005		2006		2007	
Site	RDP Zone	(<63µm)	(<500µm)	(<63µm)	(<500µm)	(<63µm)	(<500µm)
Rng	Settling Zone	92.3	85.9	98.7	99.9	108.3	109.0
Brig	Settling Zone	99.3	94.8	100.7	98.6	102.0	108.0
MainU	Outer Zone	91.3	83.2	103.7	98.2	112.0	111.0
ParU	Settling Zone	102.0	93.9	99.3	98.0	106.0	109.3
HellU	Settling Zone	121.0	122.3	118.7	119.7	134.3	137.0
MainC	Outer Zone	95.7	93.6	110.3	100.9	110.7	106.0
Luc	Settling Zone	117.7	87.3	110.0	111.0	122.7	110.0
LucU	Settling Zone	97.0	83.0	97.7	83.4	101.7	83.7
Ohbv	Outer Zone	95.3	101.0	124.7	118.3	115.3	119.7
Hell	Settling Zone	84.7	83.6	87.7	102.1	96.7	81.3
MainO	Outer Zone	94.3	45.0	104.0	58.0	113.7	65.7
HIN	Outer Zone	105.0	53.3	110.7	40.5	123.3	53.3
HIW	Outer Zone	98.3	24.9	104.0	19.6	105.3	17.3
Hbv	Outer Zone	130.3	25.5	118.0	28.7	126.0	25.7
ERC Amber	>124<150						
ERC Red	>150						
TEL	124						

5.7.3 Iron, Arsenic and Manganese

For the metals, iron and manganese and the metalloid arsenic, there are no ARC ERC values. Thereby, only the total recoverable metal/metalloid from the acid digested (<500µm) sediment fraction was compared with other environmental sediment quality guidelines.

The site with the most iron is Luc which recorded a high of 29000 mg/kg dry wt most recently in 2007. This may be associated with settlement of leachate from soils from the Lucas catchment. Interestingly, higher iron concentrations are recorded at the downstream site in the subcatchment (Luc) and not upstream at LucU. This may have to do with physical dynamics of suspended soils within the channels. From field observations the Luc site is located on a broad flat mud flat whereas LucU is relatively close to a deeper channel. Iron concentrations covary with manganese and arsenic (see Figures 25, 26 and 27, and Tables 9 and 10).

The metalloid arsenic reaches twice the value of most of the other sites at the lower Lucas site (Luc). The ANZECC ISQG –Low threshold for arsenic (20 mg/kg dry wt) was slightly exceeded at this site in 2006 with a value of 21.4 mg/kg dry wt. The ERL and TEL for arsenic (8.2 and 7.24 mg/kg dry wt respectively) are considerably lower than the

ANZECC threshold. Twelve of the fourteen sites have exceeded these values over the time series.

Manganese does not have environmental thresholds but like iron it does play an important role in binding contaminants. There is a trend at the upper catchment site of ParU where manganese has decreased dramatically by 72% whilst Total Organic Carbon is increasing. This may indicate that the upper portion of this subcatchment is experiencing periodic low dissolved oxygen, which would cause the manganese to release from the sediments (C. Hickey, personal communication).

Figures 25:

Total recoverable acid digest for iron (<500µm fraction) at all sites. Values are the mean of three replicates with +/- standard error bars.

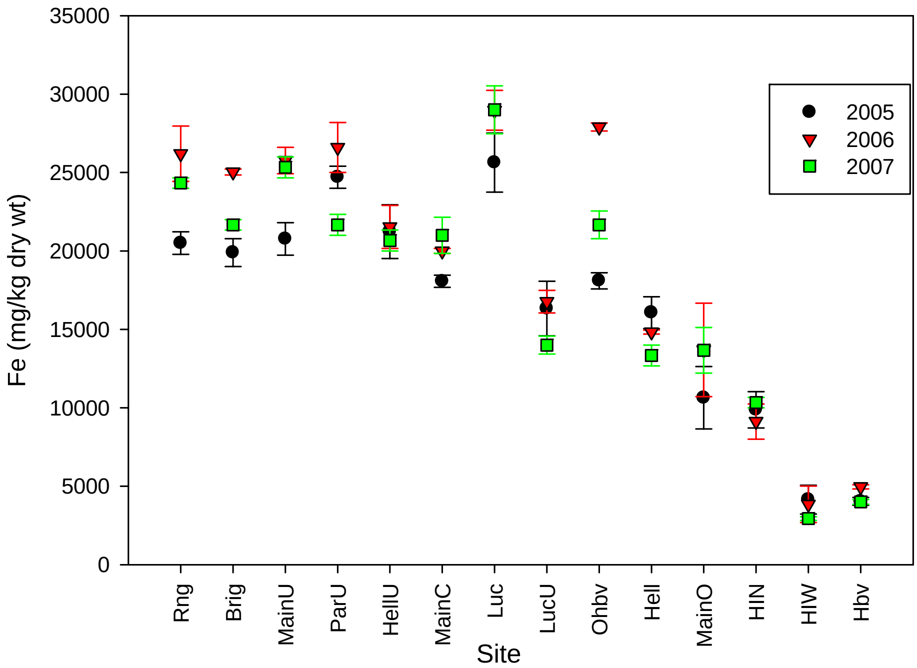


Figure 26:

Total recoverable acid digest for arsenic (<500µm fraction) at all sites. Values are the mean of three replicates with +/- standard error bars.

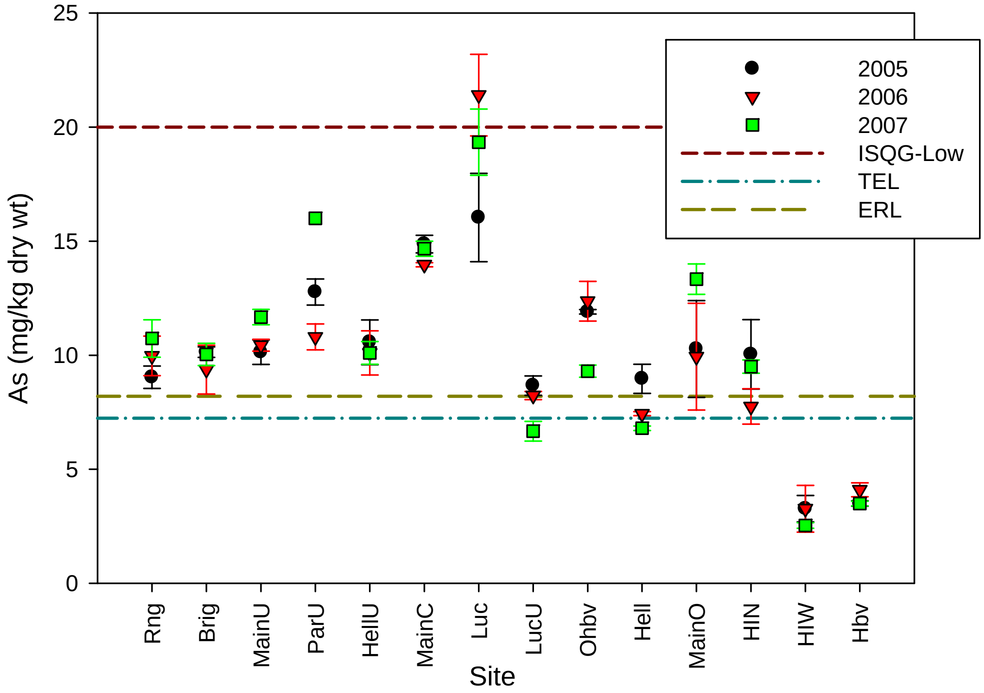


Figure 27:

Total recoverable acid digest for manganese (<500µm fraction) at all sites. Values are the mean of three replicates with +/- standard error bars.

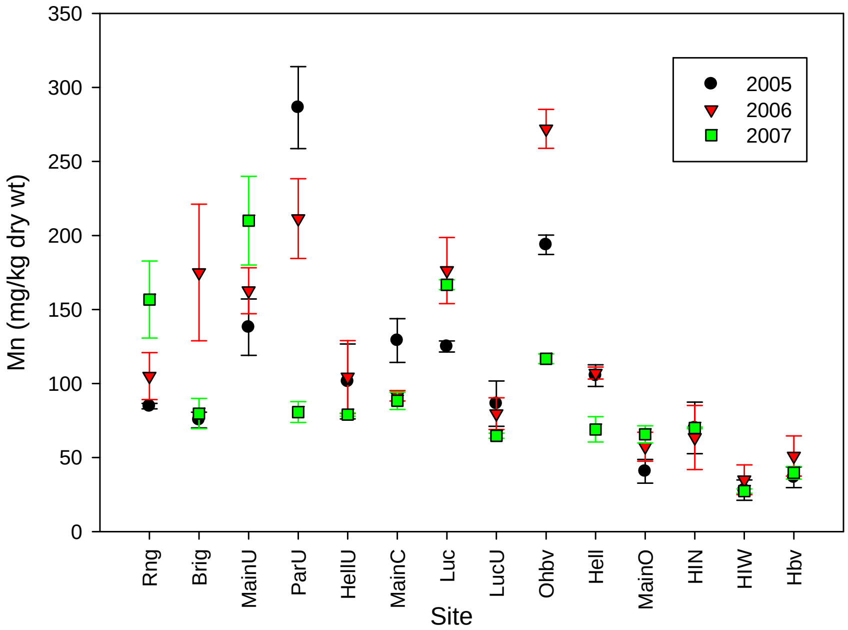


Table 9:

Total Organic Carbon and Manganese (total recoverable digest <500µm).

	TOC & manganese (mg/kg dry wt)					
	2005		2006		2007	
Site	TOC	Mn	TOC	Mn	TOC	Mn
Rng	2.59	84.67	2.74	105.00	2.80	156.67
Brig	2.45	75.33	2.40	175.00	2.33	79.67
MainU	2.17	138.00	2.35	162.67	2.53	210.00
ParU	2.48	286.33	2.63	211.33	3.30	80.67
MainC	1.25	129.00	1.19	91.67	1.10	88.33
HIN	0.55	70.00	0.46	63.50	0.35	70.00
Luc	0.91	125.00	0.98	176.33	0.82	166.67
LucU	1.41	86.33	1.55	79.67	1.20	64.67
MainO	0.36	40.67	0.41	57.33	0.49	65.67
HIW	0.38	28.00	0.30	35.00	0.27	27.33
Hell	1.51	105.33	0.74	107.00	1.13	69.00
HellU	2.08	101.33	2.09	104.33	1.80	79.00
Ohbv	1.74	193.67	1.61	272.00	1.43	116.67
Hbv	0.35	36.67	0.30	51.00	0.27	39.67

Table 10:

Iron and manganese (both total recoverable digest <500µm).

	Iron (Fe) & Arsenic (As) mg/kg dry wt					
	2005		2006		2007	
Site	Fe	As	Fe	As	Fe	As
Rng	20500	9.0	26200	10.0	24333	10.7
Brig	19900	10.1	25033	9.4	21667	10.0
MainU	20767	10.1	25767	10.4	25333	11.7
ParU	24700	12.8	26600	10.8	21667	16.0
MainC	18067	14.9	20000	14.0	21000	14.7
HIN	9870	10.0	9125	7.8	10333	9.5
Luc	25633	16.0	28967	21.4	29000	19.3
LucU	16333	8.7	16767	8.2	14000	6.7
MainO	10637	10.3	13690	9.9	13667	13.3
HIW	4143	3.3	3847	3.3	2933	2.5
Hell	16067	9.0	14833	7.4	13333	6.8
HellU	21233	10.6	21533	10.1	20667	10.1
Ohbv	18100	11.9	27900	12.4	21667	9.3
Hbv	4033	3.5	4957	4.1	4000	3.5
Arsenic Thresholds	ISQG-Low 20					
	TEL 7.24					
	ERL **8.2**					

To summarise:

- No exceedances of any management thresholds in relation to High Molecular Weight PAHs or Total PAHs (normalised to 1% TOC). Consistently higher values have come from OHbv and Hell.
- Copper levels exceed ARC ERC Amber levels at nine of the sites (Rng, Brig, MainU, ParU, HellU, OHbv, MainO, HIN and Hbv). There has been a 23% increase at MainU and a 20% increase at MainC.
- Lead values exceed ARC ERC Amber levels at eleven sites (Rng, MainU, ParU, HellU, MainC, Luc, OHbv, MainO, HIN, HIW and Hbv). The highest levels are from HellU which has had a replicate value exceed the ARC ERC Red threshold.
- Zinc values have been progressively increasing yearly at nine of the fourteen sites. ARC ERC Amber levels was exceeded four times at three different sites (Hbv, OHbv and HellU). The highest value was at HellU with a value of 137.0 mg/kg dry wt. Green et al. (2004) predicts the Hell site will exceed ARC ERC Red threshold by 2013.
- Sediment at the lower Lucas site (Luc) shows high levels of iron and associated arsenic. Arsenic reachs ANZECC ISQG- Low level threshold in 2006.

6 Assessment of changes to the original sampling design

After April 2006, some changes to the sampling design were initiated to increase the cost-effectiveness of the monitoring programme. The upper sites in Paremoremo (ParU), Lucas (LucU) and Hellyers (HellU) were difficult to sample and time consuming to sort (due largely to the amount of mangrove debris at the sites). The Waiarohia Inlet (HIW) site was not considered to be essential to detecting ecological changes associated with predicted changes in contaminant levels due to increased development. Monitoring at these sites was therefore scaled down to annually in November. It was thought that the initial three sampling periods would give some information on the degree of temporal variability, and that this, combined with the ongoing seasonal sampling at the other sites would be sufficient to provide guidance on the natural levels of variability.

In order for this change to be cost-effective, the ecology at these sites needs to behave similarly to other similar sites. In particular, similarities (and dissimilarities) in communities discussed in the first report need to be maintained.

Seasonal changes in species composition occur at all sites, but for HellU and HIW they are relatively small (i.e., the site does not move far within the MDS ordination space) (Figure 18). ParU and LucU both show higher seasonal variability; although LucU still remains similar to the nearby sites. ParU shows distinct seasonally that make it less similar to other sites. This will need to be taken into account when determining whether a change of concern has occurred in species composition at the ParU site.

However, we do not believe that this seasonality in species composition will prevent the sampling at ParU providing effective information, as seasonal changes in dominant species generally track those of other sites or are relatively small (Figure 6). This statement is true for the other sites as well, although HellU shows some what more variability in dominant species than the other upper/muddy sites (Figure 6).

Comparison of sediment characteristics (Figures 2 – 4) shows that the ParU, LucU and HellU track each other and at least one of the other sites in the upper group (Brig, Rng or MainU) well for %mud and chlorophyll a concentrations. HIW closely follows seasonal and multi-year cycles at the outer sites of HIN, HBV and MainO in chlorophyll *a* , % mud and organics. Seasonal variation in organics at Hell U is similar to that of Hell, ParU to that of Rng; although LucU is more variable than Luc.

Thus, at this stage we believe that we can use the seasonality observed in the first years sampling to set the limits for natural variability in the sites monitored annually.

7 Landuse changes within the UWH catchment

A snapshot of land use change between the years 2003/4 to 2006/7 shows that the largest degree of landuse change has occurred within the Lucas catchment (Table 11, Figure 28). Since 2003/4 there has been a 8.55% increase in land use within the Lucas catchment comprising of 119.32 ha of Earthworks, 165.62 ha of Building and 15.98 ha of Roading. Changes within the other catchments are still small, although more activity is expected in future years, including increased building, roading and harvesting of pine forest.

Table 11:

Land use changes recorded in the UWH catchments between 2003/4 to 2006/7.

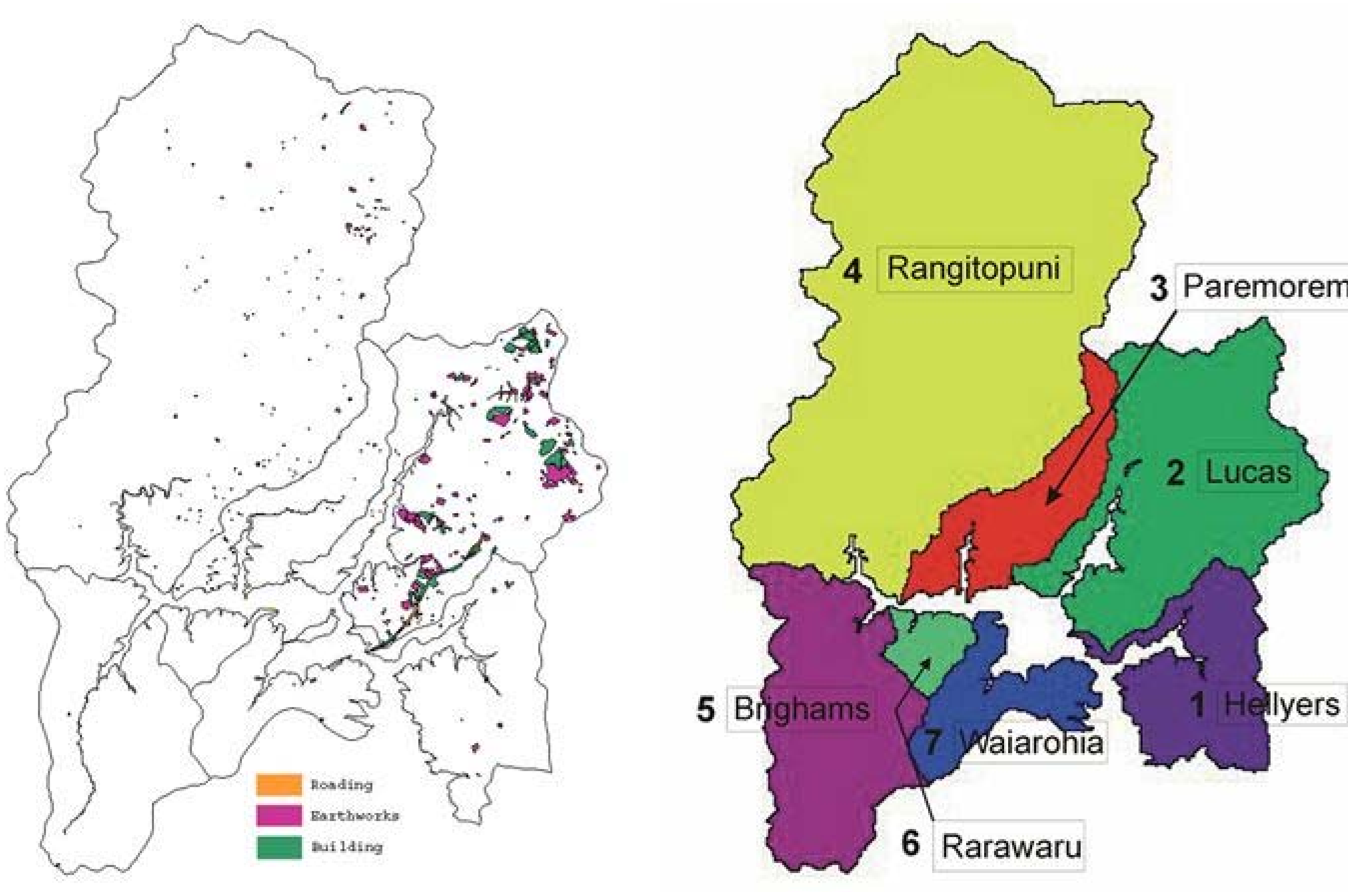
	UWH sub Catchments (ha)							Totals
	Brighams	Waiarohia	Rarawaru	Hellyers	Lucas	Paremoremo	Rangitopuni	
Catchment Area	2456.48	982.50	364.85	1731.01	3517.98	1298.53	9920.22	20271.56
2006 Earthwork	0.00	0.00	1.00	4.13	119.32	0.97	7.88	133.29
2006 Building	0.41	0.00	0.43	6.09	165.62	2.41	18.10	193.05
2006 Roading	0.00	0.00	0.00	2.08	15.98	0.00	0.00	18.06
Total land use change	0.41	0.00	1.42	12.30	300.92	3.37	25.98	344.40
% Land use change	0.02	0.00	0.39	0.71	8.55	0.26	0.26	1.70

Despite the recorded land use changes within the Lucas catchment, no change has been observed in the ecology. This is probably due to two main factors. Firstly, development in the Lucas catchment has been occurring for a number of years and it is likely that changes in the ecology have already occurred. Sediment concentrations of iron and arsenic are already high at the Lucas sites (especially Luc). Secondly, the changes recorded are not large (< 9%).

Interestingly, despite the small change in landuse recorded in the Hellyers catchment' zinc concentrations in the sediment at HellU are increasing. PAHs (corrected to 1% TOC) have increased slightly at OHbv, Main O and Brig and copper concentrations have increased at MainU. With only three years of data it is not yet possible to determine whether these are real trends and whether they will affect the ecology. If these trends do persist, investigations into why they are occurring should be undertaken.

Figure 28:

Land use changes recorded in the UWH catchments between 2003/4 to 2006/7.



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9 Acknowledgements

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10 Appendices

Appendix 1:

Sites, catchments, 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	Catchment	Methodology	Dimensions of site (m)	Easting	Northing
Rangitopuni Creek	Rng	Rangitopuni	Boat	100 x 30	E2653449	N6491807
Brigham Creek	Brig	Brighams	Boat	100 x 30	E2653704	N6490358
Upper Main Channel	MainU	Rangitopuni	Boat	100 x 30	E2654360	N6491000
Paremoremo Creek	ParU	Paremorero	Boat	100 x 30	E2656207	N6492093
Central Main Channel	MainC	Various	Boat	100 x 30	E2657029	N6491049
Herald Island	HIN	Various	Walk	90 x 70	E2658445	N6490345
Lucas Creek	Luc	Lucas	Boat	100 x 30	E2658788	N6491194
Lucas Te Wharau Creek	LucU	Lucas	Boat	100 x 30	E2659829	N6492163
Outer Main Channel	MainO	Various	Walk	100 x 30	E2659043	N6490098
Waiarohia Inlet	HIW	Waiarohia	Walk	90 x 70	E2658350	N6489550
Hellyers Creek	Hell	Hellyers	Boat	100 x 30	E2660692	N6489573
Upper Hellyers Creek	HellU	Hellyers	Boat	100 x 30	E2661895	N6489996
Opposite Hobsonville	OHbv	Various	Boat	100 x 30	E2660255	N6488769
Hobsonville (also CWH site)	Hbv	Various	Walk	100 x 90	E2660106	N6487972

Appendix 2:

Surface sediment characteristics at the 14 UWH sampling locations, from Nov 2005 to Feb 08. Chla = chlorophyll *a* in $\mu g.g^{-1}$; percent of coarse sand (500 – 2000 µm), medium sand (250 – 500 µm), fine sand (63 – 500 µm), mud (< 63 µm), and organic content. *Organic content values in Feb 2007 were not included due to spurious values.

	Date	Series	%coarse sand	%medium sand	%fine sand	%mud	%organics	chla ug/g
	Nov-05	1	0.00	0.00	8.41	91.59	9.60	8.09
	Feb-06	2	0.00	0.20	3.36	96.43	6.64	13.73
	May-06	3	0.12	0.20	2.87	96.80	8.95	14.65
	Aug-06	4	0.10	0.10	2.31	97.50	9.72	4.36
	Nov-06	5	0.20	0.41	5.94	93.44	9.24	8.03
	Feb-07	6	0.09	0.21	4.81	94.89	*	8.48
	May-07	7	0.03	0.03	3.52	96.41	8.29	7.91
	Aug-07	8	0.05	0.07	3.74	96.14	9.48	11.00
	Nov-07	9	0.07	0.07	2.88	96.97	9.56	8.48
Rng	Feb-08	10	0.22	0.22	4.88	94.63	9.83	7.80
	Nov-05	1	0.23	1.99	8.53	89.25	8.68	6.68
	Feb-06	2	0.00	0.19	3.52	96.30	6.72	8.52
	May-06	3	0.11	0.50	1.84	97.55	7.96	11.46
	Aug-06	4	0.55	2.84	9.06	87.22	8.23	7.33
	Nov-06	5	0.00	0.00	18.76	81.24	8.02	8.14
	Feb-07	6	1.15	3.81	9.44	85.51	*	10.09
	May-07	7	0.30	0.86	4.89	93.96	7.46	10.77
	Aug-07	8	0.29	1.70	5.71	92.30	9.46	10.31
	Nov-07	9	0.56	1.99	14.34	83.11	6.83	7.11
Brig	Feb-08	10	0.33	1.37	5.98	92.22	7.75	10.78
	Nov-05	1	0.00	0.04	11.54	88.43	8.26	8.46
	Feb-06	2	0.00	0.17	4.95	94.88	7.30	18.77
	May-06	3	0.27	0.85	8.73	89.91	6.99	7.69
	Aug-06	4	0.00	0.12	5.21	94.68	10.07	14.67
	Nov-06	5	0.00	0.00	15.48	84.52	7.26	8.71
	Feb-07	6	0.97	0.44	11.13	87.46	*	8.48
	May-07	7	0.32	1.98	12.97	84.74	7.52	12.16
	Aug-07	8	0.13	0.25	5.42	94.20	9.08	23.15
	Nov-07	9	0.08	0.12	5.59	94.21	6.55	10.54
MainU	Feb-08	10	0.10	0.73	4.45	94.72	8.26	11.23
	Nov-05	1	0.00	0.70	2.46	96.84	10.13	7.75
	Feb-06	2	0.00	0.13	2.22	97.65	6.51	14.73
	May-06	3	0.38	0.44	2.67	96.13	9.78	20.10
	Nov-06	5	0.19	0.13	2.22	97.47	7.95	6.19
Par	Nov-07	9	0.18	0.26	6.49	93.03	9.23	5.50
MainC	Nov-05	1	0.77	4.85	73.80	20.58	4.24	8.78
	Feb-06	2	1.20	7.56	71.07	20.17	2.38	10.05
	May-06	3	0.63	5.60	75.75	18.02	3.25	10.96
	Aug-06	4	0.27	0.49	67.57	31.67	6.16	11.92
	Nov-06	5	0.72	1.88	72.78	24.62	4.47	13.75
	Feb-07	6	0.66	3.29	65.28	29.11	*	11.92
	May-07	7	0.96	1.44	68.99	28.43	4.83	11.92
	Aug-07	8	0.44	1.22	71.42	26.86	5.80	14.89
	Nov-07	9	0.56	1.21	70.58	27.65	4.57	10.66

	Feb-08	10	0.61	1.09	77.17	21.10	4.73	8.37
	Nov-05	1	6.20	23.28	62.77	6.15	1.62	10.42
	Feb-06	2	0.70	3.46	67.43	28.41	2.67	19.53
	May-06	3	4.77	19.87	60.44	9.87	2.00	10.76
	Aug-06	4	6.68	21.41	51.75	8.93	1.96	9.98
	Nov-06	5	3.96	16.71	60.55	6.32	1.33	23.38
	Feb-07	6	3.41	20.19	63.42	12.46	*	24.76
	May-07	7	2.96	19.32	57.75	13.50	2.43	47.91
	Aug-07	8	1.33	13.23	69.89	13.00	2.66	18.79
	Nov-07	9	3.66	21.79	68.53	6.02	1.99	25.67
HIN	Feb-08	10	1.43	17.62	65.45	11.81	2.53	22.70
	Nov-05	1	9.69	16.08	42.46	30.08	3.33	9.52
	Feb-06	2	4.13	11.08	49.69	34.97	4.29	10.48
	May-06	3	7.98	34.36	28.56	27.97	4.52	7.32
	Aug-06	4	4.37	11.75	52.95	30.94	4.35	9.06
	Nov-06	5	4.24	17.62	47.30	30.84	3.21	11.24
	Feb-07	6	6.46	11.12	43.03	37.75	*	14.68
	May-07	7	8.64	27.78	45.12	18.24	2.81	9.17
	Aug-07	8	11.30	23.52	43.03	21.57	5.22	13.30
	Nov-07	9	10.36	23.19	45.63	20.82	3.38	11.92
Luc	Feb-08	10	5.75	18.52	46.56	28.79	3.84	13.99
	Nov-05	1	0.04	1.53	36.38	62.05	5.17	9.48
	Feb-06	2	0.00	1.61	26.53	71.86	4.37	14.19
	May-06	3	0.67	0.98	10.12	88.01	7.80	16.97
	Nov-06	5	2.05	3.85	40.88	53.22	4.64	16.27
LucU	Nov-07	9	1.70	3.88	53.94	40.48	4.55	12.15
	Nov-05	1	3.25	13.80	72.92	9.91	2.13	7.61
	Feb-06	2	6.80	16.10	58.89	16.10	2.13	10.10
	May-06	3	5.09	19.28	62.35	12.93	2.04	10.09
	Aug-06	4	4.80	16.47	64.08	14.20	2.14	9.51
	Nov-06	5	3.91	14.01	62.45	14.18	1.34	11.57
	Feb-07	6	3.68	12.82	72.20	9.88	*	6.47
	May-07	7	6.81	20.81	55.03	16.29	2.02	10.43
	Nov-07	9	8.21	25.16	54.41	12.22	2.02	10.77
MainO(s)	Feb-08	10	8.12	21.82	48.11	17.49	2.48	11.81
	Aug-06	4	4.56	12.08	61.62	21.73	2.95	7.22
	Nov-06	5	4.22	12.76	61.29	21.37	2.56	11.82
	Feb-07	6	2.88	12.07	65.57	19.39	*	11.23
	Aug-07	8	7.40	19.01	43.41	30.17	4.47	14.91
	Nov-07	9	4.04	10.85	58.48	26.63	3.86	11.23
MainO(m)	Feb-08	10	8.99	20.89	44.04	25.63	3.21	9.98
	Nov-05	1.0	1.53	13.74	68.66	10.54	1.32	7.33
	Feb-06	2.0	1.12	9.85	66.73	22.30	2.07	13.88
	May-06	3.0	2.34	20.58	62.85	10.81	1.16	7.67
	Aug-06	4.0	2.60	21.43	66.03	8.90	1.18	7.68
	Nov-06	5.0	2.85	20.77	66.67	8.93	0.72	8.94
HIW	Nov-07	9.0	4.00	20.98	67.98	7.04	1.32	12.15
Hell	Nov-05	1	0.12	1.50	37.30	61.08	6.00	16.65
	Feb-06	2	0.33	2.86	44.00	52.80	3.15	15.63
	May-06	3	0.28	1.48	13.40	84.84	6.45	12.79
	Aug-06	4	0.43	1.10	9.33	89.14	7.04	7.80
	Nov-06	5	1.50	8.19	51.98	38.11	2.40	13.75

	Feb-07	6	0.62	5.68	51.43	42.27	*	18.57
	May-07	7	0.18	1.99	43.82	54.02	3.92	20.86
	Aug-07	8	0.40	3.52	63.37	31.26	3.58	25.00
	Nov-07	9	0.49	5.69	55.43	38.39	3.43	13.98
	Feb-08	10	0.53	1.52	45.68	52.27	4.22	16.73
	Nov-05	1	0.00	0.73	10.49	88.78	8.06	7.22
	Feb-06	2	0.12	0.21	5.34	94.33	6.14	17.88
	May-06	3	2.52	7.28	29.00	60.12	5.87	10.09
	Nov-06	5	2.22	6.42	28.08	63.28	4.67	13.18
HellU	Nov-07	9	2.36	6.19	27.62	63.83	4.89	9.62
	Nov-05	1	0.04	0.19	24.59	75.19	5.79	8.48
	Feb-06	2	0.24	0.10	11.95	87.71	5.30	10.96
	May-06	3	0.24	1.33	26.42	72.02	4.94	9.06
	Aug-06	4	0.41	3.07	46.18	49.97	3.71	10.20
	Nov-06	5	0.13	0.37	22.64	76.86	6.13	5.96
	Feb-07	6	0.18	0.38	15.60	83.85	*	9.63
	May-07	7	0.10	2.90	32.68	64.32	5.30	9.29
	Aug-07	8	0.49	2.04	19.98	77.49	8.10	18.80
	Nov-07	9	0.08	0.80	33.00	66.11	5.40	10.09
Ohbv	Feb-08	10	0.33	1.56	33.74	64.34	4.83	8.83
	Oct-05	1	6.86	36.31	54.51	2.12	1.53	17.55
	Feb-06	2	6.78	36.18	63.63	3.22	1.87	11.00
	Apr-06	3	6.47	30.86	57.92	3.68	0.78	10.99
	Aug-06	4	5.10	32.09	56.96	3.21	1.46	19.72
	Oct-06	5	7.92	36.62	52.08	1.80	1.39	15.81
	Feb-07	6	4.95	34.87	55.41	3.72	2.22	14.55
	Apr-07	7	7.76	36.13	50.80	3.63	1.43	13.87
	Aug-07	8	12.43	23.11	58.35	3.87	1.92	16.39
	Oct-07	9	7.67	33.52	55.62	2.13	1.13	12.15
Hbv	Feb-08	10	7.19	32.59	56.54	3.28	1.54	13.64

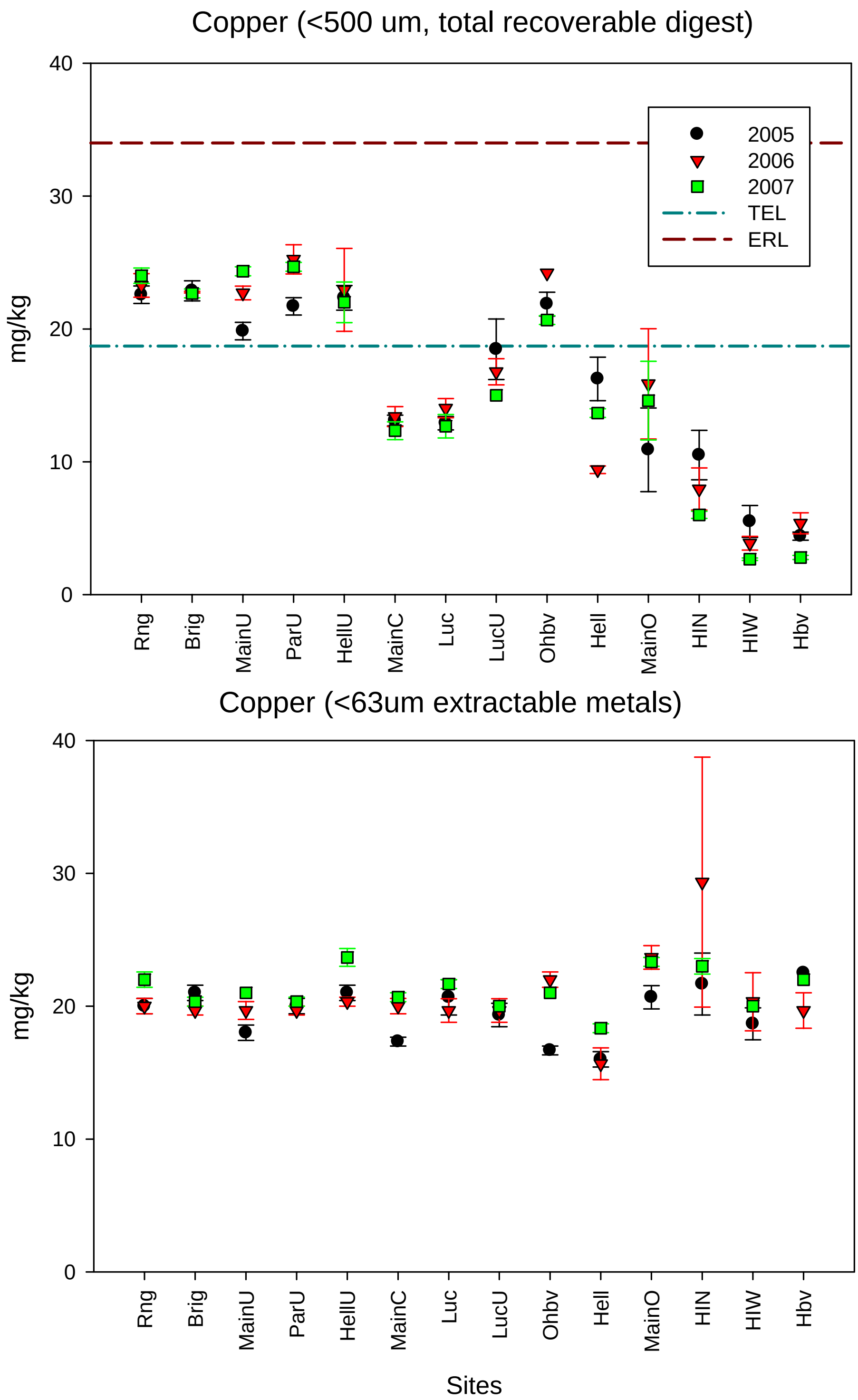
Appendix 3:

Sampling protocol for the UWH Monitoring Program.

Year	Month	Macrofauna, GS/Organics and Chla for 9 sites: Rng, Brig, MainU, MainC, HIN, Luc, MainO, Hell and OHbv	Macrofauna GS/Organics and Chla for 4 sites: Par, LucU, HellU and HIW	Hbv Macrofauna with CWH monitoring program	Chemistry 15 sites top layer (0-2cm) on iron, manganese, arsenic, PAH, copper, zinc and lead	Chemistry 15 sites bottom layer (5 – 15 cm) on iron, manganese, arsenic, PAH, copper, zinc,lead, chromium, cadmium and nickel
2005	Nov	Yes	Yes		Yes	Yes
2006	Feb	Yes	Yes	Yes		
	May	Yes	Yes			
	April			Yes		
	Aug	Yes				
	Oct			Yes		
	Nov	Yes	Yes		Yes	
2007	Feb	Yes		Yes		
	May	Yes				
	April			Yes		
	Aug	Yes				
	Oct			Yes		
	Nov	Yes	Yes		Yes	
2008	Feb	Yes		Yes		
	May	Yes				
	April			Yes		
	Aug	Yes				
	Oct			Yes		
	Nov	Yes	Yes		Yes	Yes
2009	Feb	Yes		Yes		
	May	Yes				
	April			Yes		
	Aug	Yes				
	Oct			Yes		
	Nov	Yes	Yes		Yes	
2010	Feb	Yes		Yes		
	May	Yes				
	April			Yes		
	Aug	Yes				
	Oct			Yes		
	Nov	Yes	Yes		Yes	
2011	Feb	Yes		Yes		
	May	Yes				
	April			Yes		
	Aug	Yes				
	Oct			Yes		
	Nov	Yes	Yes		Yes	Yes

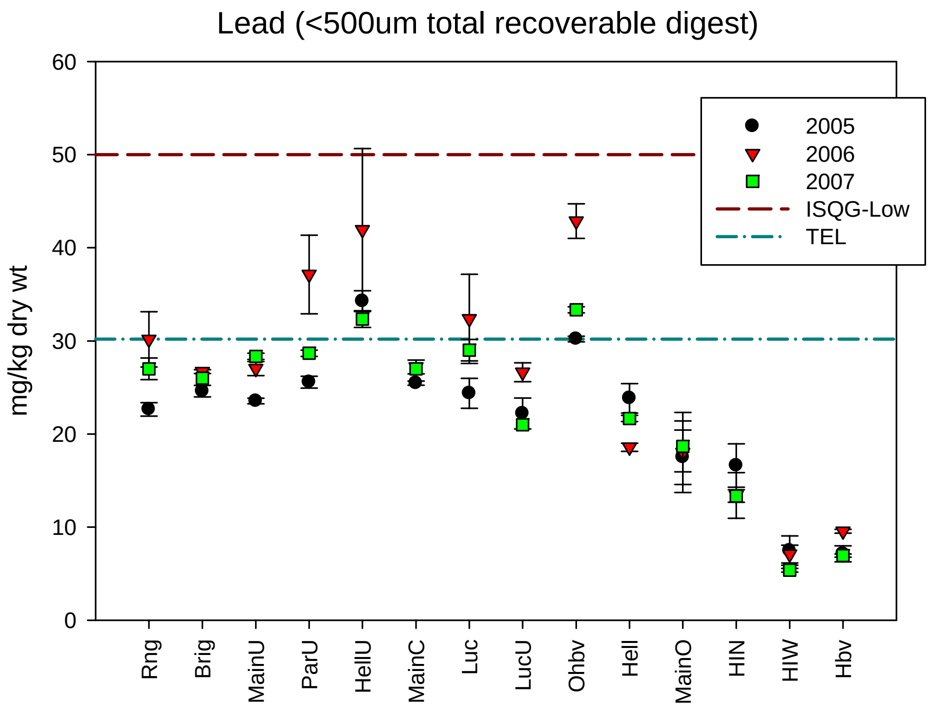
Appendix 4:

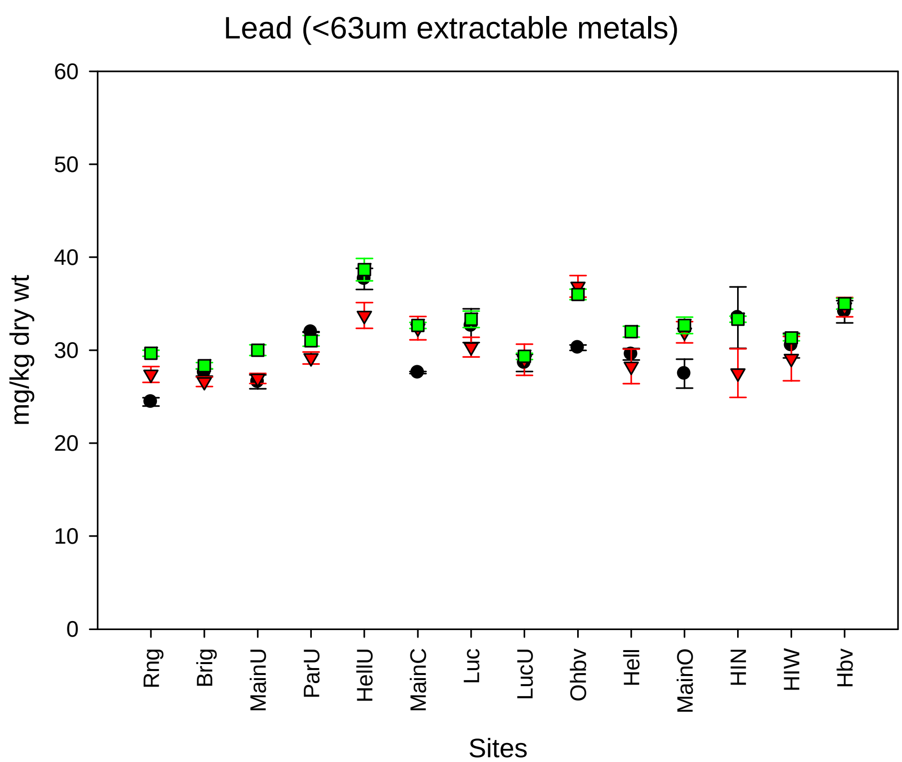
Copper results from total recoverable acid digested (< 500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm). Note that the sediment quality guidelines are used to compare total sediment (< 500µm) only.



Appendix 5:

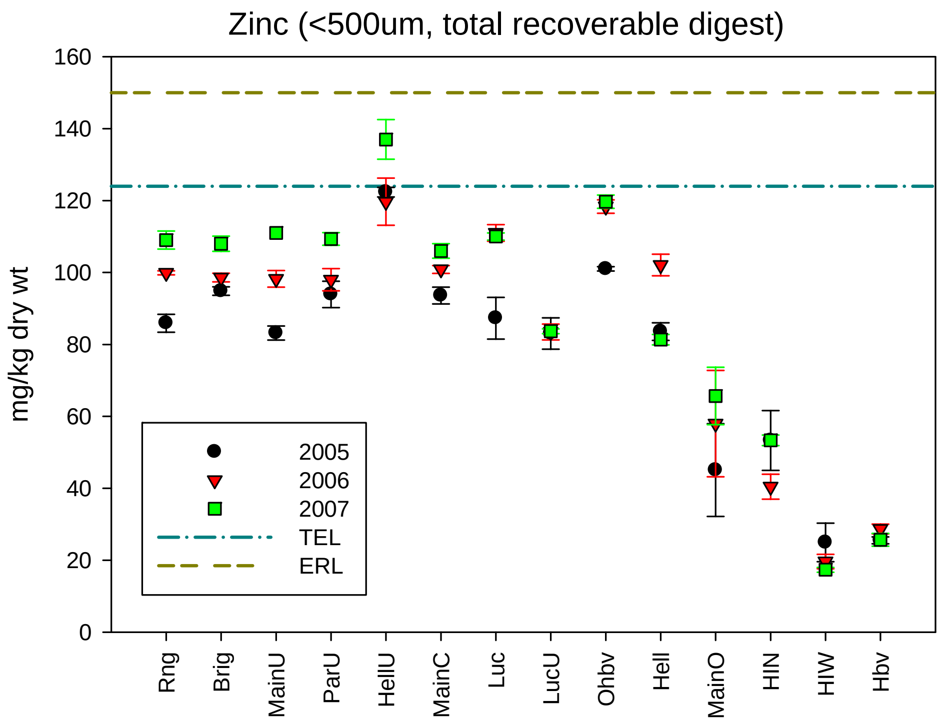
Lead results from total recoverable acid digested (< 500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm). Note that the sediment quality guidelines are used to compare total sediment (< 500µm) only.

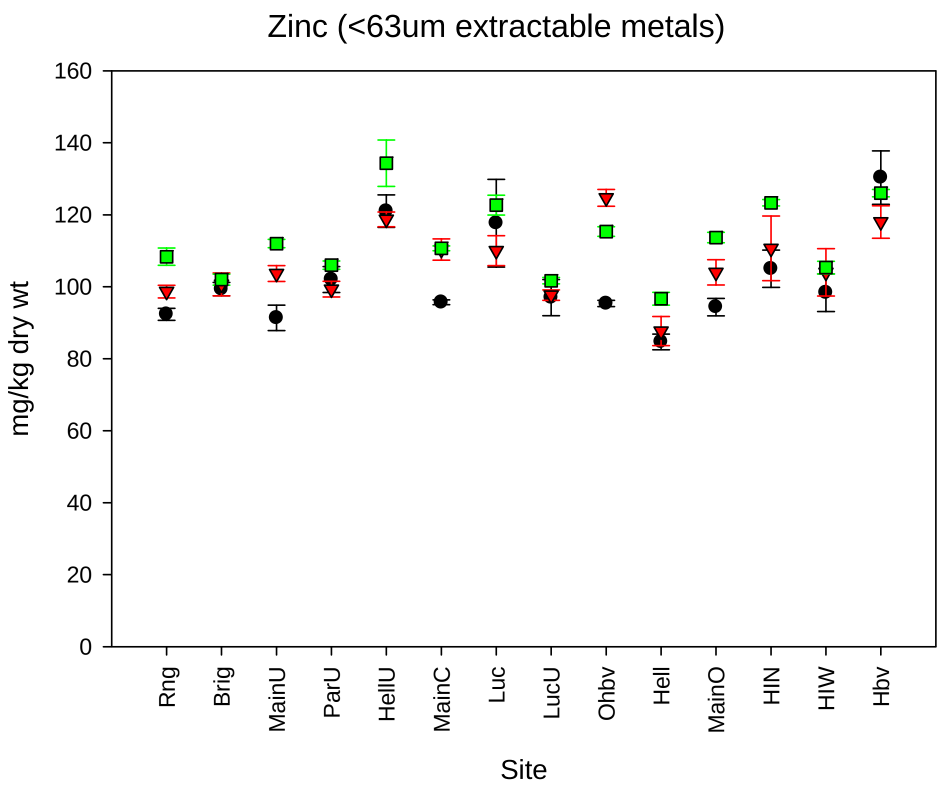




Appendix 6:

Zinc results from total recoverable acid digested (< 500µm) sediment fraction and weak acid digestion of the mud fraction (<63 µm). Note that the sediment quality guidelines are used to compare total sediment (< 500µm) only.





11 Plates

Plates 1 – 14 are photographs and field observations taken during the November 2006 site investigation. There were no visible impacts of prior sampling at any of the fourteen sites

Plate 1:
Site Rng (Rangitopuni catchment). Muddy sediment with mangrove pneumatophores and crab burrows, some channels down through site.

Plate 2:

Site Brig (Brighams Creek): Deep fine mud with a fluffy layer on top. Crab burrows present.

Plate 3:

Site MainU (Main channel upper). Deep fine mud with crab burrows. Some deeper channels at eastern end of site.

Plate 4:
Site ParU (Paremorero Creek). Soft fine mud with crab burrows and mangrove pneumatophores present. Some channels traverse the site.

Plate 5:
Site MainC (Main central channel). Waist deep fine sediment. Burrows present.

Plate 6:

Site HIN (North facing Herald Island): Sandy with mud patches and areas of cockle shells (small banks). Small ripples and an anoxic layer ~2cm deep. Small channels (~25-30cm wide and 2-5cm deep) from stormwater drains meander across site.

Plate 7:

Site Luc (Lucas Creek): Soft fine mud over clay layer. Some oyster shells present.

Plate 8:

Site LucU (Upper Lucas Creek): Soft fine mud, crab burrows and mangrove pneumatophores present.

Plate 9:

Site MainO (Outer Main Channel): Sand flat with a muddy component to the site. Crab burrows present in muddier section.

Plate 10:

Site HIW (Herald Island on the Waiarohia catchment side): Sandflat surrounded by muddier sediment. Some ripples and crab burrows on site.

Plate 11:

Site Hell (Hellyers Creek): Soft fine mud with crab burrows and ray pits. There is a shell layer ~150-200mm below surface.

Plate 12:

Site HellU (Upper Hellyers Creek): Soft fine mud and crab burrows.

Plate 13:

Site OHbv (Central Waitemata East): Deep fine mud and crab burrows. Some ray pits and channels across the site.

Plate 14:

Site Hbv (Central Waitemata West). Sandflat on Hobsonville side of the estuary. Cockle shells, sand ripples and some ray pits present.