Assessment of the Estuarine Ecological Monitoring Programme to 2012

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Assessment of the Estuarine Ecological Monitoring Programme to 2012

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Executive Summary

Early in the 1990s, the potential threat associated with increased inputs of terrestrial sediment into estuaries and coastal zones as a result of changes in land use (including urbanisation) was recognised by NIWA and the ARC. Since then, the ARC has melded catchment modelling of likely sediment runoff under various development scenarios, with estuarine sediment transport models and results of experimental investigations of ecological effects to inform planning and development. Ecological experimental manipulations can only be conducted at small scales and a number of problems occur in trying to scale up from one-off small scale experiments to potentially large-scale, cumulative impacts. Thus, in 2000 the ARC began monitoring in Okura Estuary (conducted by Uniservices) with the intention of capturing potential changes in the ecology of the estuary associated with periods of pre-development, development and post-development phases. In August 2002, four other estuaries were added to the monitoring programme (Puhoi, Waiwera, Orewa and Mangemangeroa). In August 2004, Turanga and Waikopua estuaries were added to the regional monitoring programme. Finally, in October 2010, sites in Whangateau estuary, previously sampled as part of a habitat survey, were added. This estuarine monitoring programme has been continued by Auckland Council.

The monitoring over time, in spring and autumn, within and between estuaries was designed to detect long-term effects driven by chronic increases in turbidity and in the proportion of fine muddy sediments in the estuary. Similar to other programmes monitoring the health of coastal and estuarine ecosystems, both in New Zealand and internationally, the focus was on the macrofauna living in the intertidal sediments. Environmental variables that may be affected by increased terrestrial sedimentation, such as sediment particle size and height of the seafloor, were also measured. To determine whether individual sediment depositional events resulted in changes to the benthic communities, sites were also monitored after rainfall events and after relatively dry periods in both seasons. In 2007, this sampling was changed to target heavier rainfall events, regardless of when they might occur during the year. Due to the patchiness of heavy rainfall in the Auckland area, this sampling was limited to estuaries that had gauging stations situated in their catchments (namely, Okura, Orewa and Mangemangeroa).

In 2009, NIWA took over the monitoring, and, in line with many of the benthic ecological monitoring programmes run by the ARC, after 5 years of consistent monitoring, a spatially and temporally nested design was introduced. The number of sites continuously monitored in each estuary was reduced to 7 core sites, from 10, with the extra 3 sites being sampled on a rotational basis over 5 years. After 1 year of sampling, the data from all years was analysed and the following changes made to the monitoring programme:

- The event sampling had detected effects of rainfall, despite not sampling within the week immediately after the event, related to the size of the event and the amount of rainfall falling in the 24 hrs prior to sampling. Importantly, sampling over a number of events occurring within a 6 week period revealed cumulative responses by the benthic community. This result provided a valuable function in strengthening the causal link between macrofaunal change and terrestrial sedimentation, and between predictions generated from experimental manipulations of terrestrial sedimentation and from surveys of ambient sediment content. However, now that the link had been demonstrated it was not considered necessary to continue this event sampling.

- Monthly monitoring of environmental variables (volume and grainsize of sediment caught in the sediment traps and height of the bed) comprised a significant portion of the costs of this monitoring programme. However, the data was variable and not particularly useful, so this aspect was removed from the programme.

Incorporation of Whangateau into this monitoring programme has been successful, with the sediment and macrofaunal characteristics of the chosen sites fitting well into the range of the 7 other presently sampled estuaries. Analyses which include the two new years of data found that over 80 % of trends consistent with increased sedimentation reported in 2012 (Hewitt & Gibbs 2012) were still detected, confirming that these trends are most likely a real response to changing conditions within the estuaries. A number of other trends consistent with increased sedimentation were also detected with the increasing length of the time sampled, including, for the first time, increases in the very fine sediment fraction at 5 sites in depositional zones. All the trends detected for number of taxa, community composition, *Macomona*, *Aonides*, *Colurostylis* and *Waitangi* were consistent with increases in sedimentation. 60 trends were detected, although a proportion of these are likely to turn out to be parts of multi-year cycles. More trends over time consistent with increased sedimentation were detected in Okura and fewest in Turanga and Waiwera, suggesting Okura is most likely to be exhibiting long-term changes related to increased terrestrial sedimentation.

These results suggest that ongoing monitoring of the 7 cores sites is worthwhile. The rotational sampling of the other 3 sites in each estuary also seems to be effective as data from these sites monitored during 2010 – 2012 did not indicate that anything different had occurred at these sites. However, we recommend that in another 2 years, when the time series approaches 10 years, the data should be analysed to determine:

1. whether the number of core sites could be further scaled back
2. whether sampling in both spring and autumn is required or whether sampling once per year would be sufficient.

This monitoring programme provides a vital feedback to planning and policy conducted in the region, allowing assessment of urban development impacts, and thus the relative risks of differing management policies, on the estuaries that so many Aucklanders wish to utilise.

1.0 Introduction

Planning for growth of the Auckland region has for some time suggested that the estuaries on the fringes of the metropolitan area are prime candidates for residential expansion. Early in the 1990's, the significant threat of increased terrestrial sediment runoff into estuaries and coastal zones as a result of this development was recognised by NIWA and the ARC. Initially it was thought that muddy areas (e.g., tidal creeks and upper estuary areas) would be less affected than sandy areas, but a number of small-scale experimental studies, co-funded by FRST and ARC , found that all areas were potentially at risk (Norkko et al. 2002). Around the east coast of the Auckland Region, ecological responses were observed as a result of quite small experimental applications of terrestrial sediment onto the seafloor and into the water column. These responses ranged from changes in the feeding behaviour and health of individual species to complete eradication of whole macrofaunal communities (Ellis et al. 2002, Hewitt & Pilditch 2004, Lohrer et al. 2004, Norkko et al. 2006, Hewitt & Norkko 2007). To better manage the risks associated with this major contaminant, the ARC melded catchment modelling of likely sediment runoff under various development scenarios, with estuarine sediment transport models and results of experimental manipulations on ecology to inform planning and decision making.

Ecological experimental manipulations can only be conducted at small scales and a number of problems arise in trying to scale up from a one-off small-scale experiment to potentially large-scale and cumulative impacts (Thrush et al. 1999, Hewitt et al. 2007). A weight of evidence approach has been used to infer broader-scale effects by comparing the taxa shown to be sensitive in the experiments with those demonstrating relationships with sediment mud content or sediment accumulation rates from large-scale surveys (Lundquist et al. 2003, Gibbs & Hewitt 2004, Thrush et al. 2004, Anderson et al. 2007). However, stronger evidence is often required in a court of law. Monitoring is also required to determine the validity of scaling up predictions from small scale experiments to catchment scale planning and to monitor the long term effectiveness of those planning decisions. Thus, in 2000 the ARC began monitoring in Okura Estuary (conducted by Uniservices) with the intention of capturing potential changes in the ecology of the estuary associated with periods of pre-development, development and post-development phases.

In August 2002, four other estuaries were added to the monitoring programme (Puhoi, Waiwera, Orewa and Mangemangeroa). Mangemangeroa was added as the urbanisation beginning to occur around its catchment was planned to intensify over time. Orewa was included as an example of an estuary with an already developed catchment. Puhoi and Waiwera were included in order to place any potential changes through time in the other estuaries within a broader regional context. However, Mangemangeroa is spatially separated from the others (lying to the south of Auckland City and discharging into the Whitford Embayment). To enable useful comparisons to be made and to extend the number of reference estuaries, in August 2004, Turanga and Waikopua (also from the Whitford Embayment) were added to the regional monitoring programme.

The design of the monitoring centered around three phases of development that differed spatially between estuaries and, for some estuaries, varied over time. Ten sites were located along the length of each estuary. Sites further up the estuary were assumed to be most likely to be impacted by terrestrial sedimentation. The monitoring over time within and between estuaries was designed to detect long-term effects driven by chronic increases in turbidity and in the proportion of fine muddy sediments in the estuary.

To determine whether individual sediment depositional events resulted in changes to the benthic communities, the sites were monitored in spring and autumn in each year, once after a rainfall event and once after a relatively dry period. A report of the results from 2000 to 2007 found no effect of individual events and this lack of effect was suggested to be a result of the size of rainfall events that were being monitored (Anderson et al. 2007). At this time the definition of an event was > 15 mm in a 24-hour period. Unfortunately this size of event could be expected to occur at least twice in each of the seasons and therefore was unlikely to have a detectable effect in a system as physically dynamic as an estuary. Most of the studies investigating one-off events relate to sediment deposition events associated with much more severe storms (e.g., Norkko et al. 2002; Hewitt et al. 2003). After consultation with the ARC, Uniservices altered the design of the monitoring programme to target heavier rainfall events, regardless of when they might occur during the year. Due to the patchiness of heavy rainfall in the Auckland area, such monitoring was to be limited to estuaries that had gauging stations situated in their catchments (namely, Okura, Orewa and Mangemangeroa). This new event sampling detected effects of rainfall, despite not sampling within the week immediately after the event, related to the size of the event and the amount of rainfall falling in the 24 hrs prior to sampling (Hewitt & Gibbs 2010). Importantly, sampling over a number of events occurring within a 6 week period revealed cumulative responses by the benthic community. This result provided a valuable function in strengthening the causal link between macrofaunal change and terrestrial sedimentation, and between predictions generated from experimental manipulations of terrestrial sedimentation and from surveys of ambient sediment content. However, now that the link had been demonstrated it was not considered necessary to continue this event sampling.

Unfortunately, since monitoring began, a number of the reference estuaries have either had urbanisation increase around their catchments or been subject to extensive road works within the catchments associated with the extension of the northern motorways. The present lack of real reference estuaries has necessitated a shift in the design and analysis of the monitoring programme.

Two further changes occurred in the monitoring programme in 2009. Firstly, in line with many of the benthic ecological monitoring programmes run by the ARC, after five years of consistent monitoring the number of sites monitored in each harbour has been reduced. Secondly, the collection and analysis of data shifted from Uniservices to NIWA. In 2010, a report (Hewitt & Gibbs, 2010) investigated two important design questions, including the event sampling discussed above.

1. Have the 2009 changes in design or operation had any impact on the ability of the monitoring programme to detect changes over time?
    a. Are there any differences caused by the change in provider?
    b. Has the reduction in sites had a deleterious effect on our ability to detect change?
2. Are there any other cost-effective improvements that can be made to the monitoring programme now that over six years of data have been collected from all estuaries? This question is divided into two further questions:
    a. Considerable effort is placed in this programme in the monitoring of traps that collect sediment passing over the sites, with the idea that this information can provide a causal link to terrestrial sedimentation. How

useful is this information? Is there other, more cheaply collected information that is better?

b. Is the temporal variability caused by sampling within a three month window sufficient to confound detection of changes?

As a result, the reduction in continuously monitored sites in each estuary to seven, with the extra three sites being sampled on a rotational basis over five years, was confirmed. Monthly monitoring of environmental variables (volume and grainsize of sediment caught in the sediment traps and height of the bed) was discontinued in November 2010 as it comprised a significant portion of the costs without proportionate usefulness.

Finally, in 2010, a further estuary was added to the monitoring programme. In 2009, a habitat survey of Whangateau was conducted (Townsend et al. 2010), and a number of intertidal sites sampled in a similar fashion to the sites in this programme. Seven of these sites were then chosen to add to the monitoring programme.

This report will, therefore, investigate the following questions:

1. How do the sites in Whangateau compare with the sites presently monitored? Are the sediment and benthic macrofaunal community characteristics sufficiently similar to allow the multivariate model that is used to analyse for community responses to mud to continue to be used.
2. Are there ecological changes over time in any of the estuaries that are associated with increased terrestrial sedimentation?
3. Are there any indications that any changes have occurred at the sites not continuously monitored in Okura, Waiwera and Mangemangeroa, that is not apparent in the time signal of sites that are continuously monitored?
4. What are the contaminant characteristics of the estuaries?

2.0 Sampling methods

2.1 Estuaries and sites

Eight small east coast estuaries are monitored: Puhoi, Waiwera, Orewa, Okura, Mangemangeroa, Turanga and Waikopua (Figure 2.1). These estuaries have been sampled for varying lengths of time: Okura from April 2000; Puhoi, Waiwera, Orewa Mangemangeroa from August 2002; and Turanga and Waikopua from August 2004; and Whangateau from October 2009.

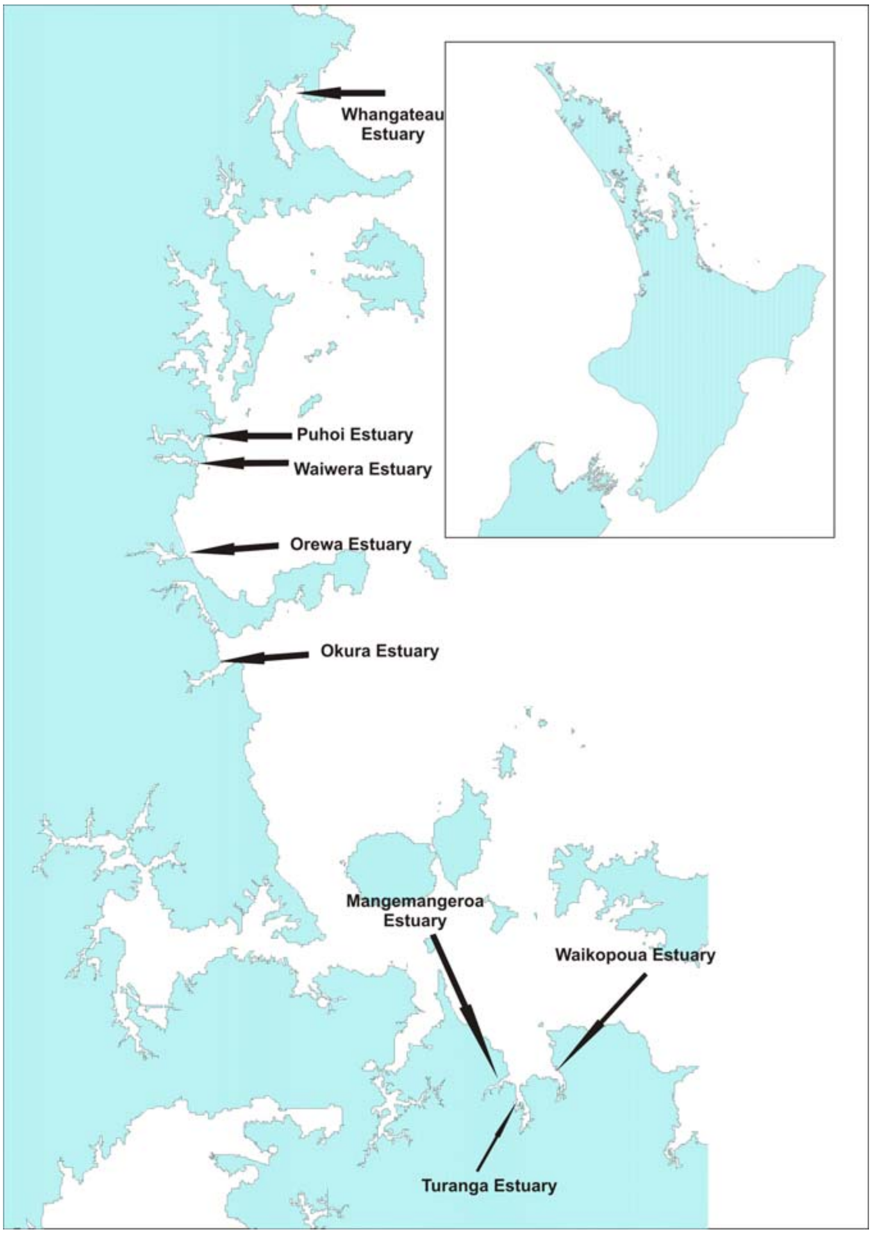


Figure 2:1: Location of the 8 monitored estuaries.

Initially 10 sites were sampled within each estuary (with the exception of Whangateau) with 1 being closest to and 10 being furthest from the mouth of the estuary (see Appendix 1 for placements of the sites). Sites are located at mid-tide (ranging from -0.6 to 1.6 m tidal height relative to mean sea level) and have dimensions of 50 m (parallel to the waterline) x 25 m (perpendicular to the waterline). Placement was chosen to cover a range of sediment types (mud to coarse sand).

Since August 2009, 7 of the sites across the gradient in each estuary have continued to be monitored (core sites) with the remaining sites sampled on a rotational basis over a 5 year period (Table 2.1). In 2009-2010, all sites in Turanga were monitored as was a single extra site in Okura (7 core sites plus 1). In 2010-2011, the remaining Okura sites were sampled as were two sites in Waiwera, and in September 2011, the remaining Waiwera site and the three extra sites in Mangemangeroa were sampled.

Table 2.1: Sites retained as core sites in each estuary and sites for 5 yearly rotation. All 7 sites in Whangateau are core sites.

Estuary	Core sites	Sites for rotation
Puhoi	1–4, 6,7, 9	5, 8, 10
Waiwera	1-3, 5, 6, 8, 9	4, 7, 10
Orewa	1–6, 8	7, 9, 10
Okura	1–4, 7–9	5, 6, 10
Mangemangeroa	2, 3, 5–7, 9, 10	1, 4, 8
Turangi	1, 3, 4, 6–8, 10	2, 5, 9
Whangateau	1-7	
Waikopua	1, 3, 4, 6–9	2, 5, 10

2.2 Macrofauna

Initially, sampling occurred twice (after rain, and after a dry period) within each of two discrete seasonal three month blocks (winter/spring: August–October and summer/autumn: February–April), yielding four sampling times per year. In 2007, this was altered; the dry sampling was maintained, but the rainfall sampling was changed to being triggered by rainfall in excess of 60, 57.5 and 50.6 mm over a 24 hr period recorded at gauging stations in Orewa, Okura and Mangemangeroa respectively. Only estuaries where the trigger occurred were sampled and sampling occurred within 7 to 10 days of the trigger event. Now sampling occurs in October and April when no events have been recorded in the prior 2 weeks. The rainfall over the previous 24 hrs, 2 week and 3 week period from the gauging stations is recorded to help explain any variability not related to seasonality.

At each site, six replicate faunal cores (130 mm in diameter x 150 mm deep) are taken from random positions at each site, excluding the area within 5 m of a core location for the previous 6 months. Cores are sieved on a 0.5 mm mesh and the material retained preserved in 70% isopropyl alcohol with 0.01% rose bengal. Later the fauna are identified to the lowest practical taxonomic level (usually species) and counted. Anderson et al. (2007) noted that the level of taxonomic resolution has increased markedly through time, and that community-level analyses use data only from August 2002 onwards. Throughout the analysis in this report the level of taxonomic resolution reported in Appendix 5 (Anderson et al. 2007) has been used.

Individuals from three bivalve species (the cockle *Austrovenus stutchburyi*, the wedge shell *Macomona liliana* and the pipi *Paphies australis*) were placed into size classes to allow some assessment of changes in the population structure of these large and long-lived animals.

2.3 Sediment

2.3.1 Ambient sediment

Sampling of ambient sediment to determine changes in sediment grainsize is coincident with macrofaunal sampling. Initially, ambient sediment samples were obtained adjacent to each faunal core using a 38 mm diameter x 15 cm deep corer. This however dilutes any recent changes in sediment characteristics by the bulk of the material collected in the core. In August 2004, sampling changed to using a 20 ml syringe sampling to a depth of approximately 2 cm.

The six sediment cores from a single site were combined into a single sample which was frozen until grainsize analysis could occur. Prior to grainsize analysis, organic matter was removed using 9% hydrogen peroxide until fizzing ceased. Samples were then dried and weighed to obtain a total dry weight. They were then deflocculated for at least 4 hours (using Calgon 5 g per litre) and wet-sieved on a stack of sieves (500, 250, 125 and 63 µm). Each fraction was dried, weighed and calculated as a percentage of the total weight. The fraction less than 63 µm was calculated by subtraction of all other dry weights from the initial dry weight. Sediment % weight was then expressed for coarse sand (> 500), medium sand (250–499), fine sand (125–249), very fine sand (63–124) and mud (< 63 µm). Due to the change in depth sampled and the sizes of the sieves used, only data from August 2004 onwards are used for subsequent analyses.

Sampling in Whangateau initially used the sampling protocol in the ecological monitoring programmes conducted in Manukau, Mahurangi and Central and Upper Waitemata Harbours. In these programmes, very fine sand and fine sand were not separated, but three additional fractions were calculated: % gravel (>2 mm); and the mud component was separated by pipette analysis into % silt (4 – 63 □m) and % clay (<3.9 □m). However, from 2011, samples have been analysed as above.

Contamination was measured in Whangateau in November 2009 and at three sites in each of the other estuaries in November 2010. Three replicates cores of the top 2 cm of sediment were collected per site and analysed by R J Hill Laboratories Ltd (Hamilton) using standard Auckland Council methods and protocols as outlined in Mills and Williamson (2008). Measurements were made of total organic content, PAHs (polycyclic aromatic hydrocarbons) and total PAH from one site in each estuary only. Heavy metals (iron, manganese, arsenic, cadmium, chromium, mercury, nickel, copper, lead and zinc) were analysed from 3 replicates at each site. Chemical analysis was performed on total recoverable acid digested < 500 µm dry sieved fractions for all metals, and also, for copper, lead and zinc, on weak acid digestion of the < 63 µm wet sieved fraction.

2.3.2 Terrestrial sediment inputs

Depth-of-disturbance rods were used to gauge relative change in the height of the bed using the poles that held the sediment traps. Measurements were taken between the top of the sediment trap holder and the ambient sediment surface at least once a month to measure the net erosion or accretion at a site. When scour was present at the base of the marker poles the height of the top of the holder was estimated in relation to the ambient bed height at the pole independent of any local scouring using a ruler.

On every sampling occasion, at each site, sediment samples were collected from the surface 2–3 mm, particularly focusing on the troughs of any ripples, as this is where recently transported fine sediment would accumulate. These samples were analysed for grainsize (as per section 2.3.1).

3.0 Whangateau comparison with other estuaries

Here we ask whether the sites in Whangateau are comparable with the sites in the other seven estuaries. In order for this new estuary to fit into this monitoring programme it is important that the sites monitored within it do not have sediment and benthic macrofaunal community characteristics outside the range of the presently monitored sites. In particular, if the model of macrofaunal community response to mud developed for the other estuaries is to be extended to this estuary, a similar response to mud content is required.

3.1 Methods

Sediment characteristics and macrofaunal community composition between estuaries in October 2011 were compared visually using Principal Component Analysis (PCA) and nonmetric multidimensional scaling (MDS) in Primer E (Clarke and Gorley 2006). MDS was based on Bray-Curtis similarities of square root transformed data.

Following this, the Spearman's correlation between a similarity matrix, based on Euclidean distances of sediment characteristics and the Bray-Curtis similarities of macrofaunal community composition, was conducted (RELATE, Primer E).

Finally, consistency in responses between macrofaunal community composition and mud in the different estuaries was examined by performing Canonical Analysis of Principle Coordinates (CAP, Anderson and Willis 2003) with respect to sediment mud content.

3.2 Results

Similar sediment characteristics were observed in Whangateau sites as in the other estuaries sampled in October 2011. The Whangateau sites mainly fall towards the bottom of the ordination (Figure 3.1), near sites from Turanga, Waikopua, Okura and Puhoi.

Macrofaunal community composition was not markedly dissimilar between Whangateau and the other estuaries, with Whangateau sites being similar to those from a number of other estuaries (Figure 3.2). However, the sites formed a tighter cluster than those of the other sites, near one edge of the ordination plot.

Figure 3.1: PCA ordination of similarities between estuaries based on sediment characteristics. Sites closest together are more similar.

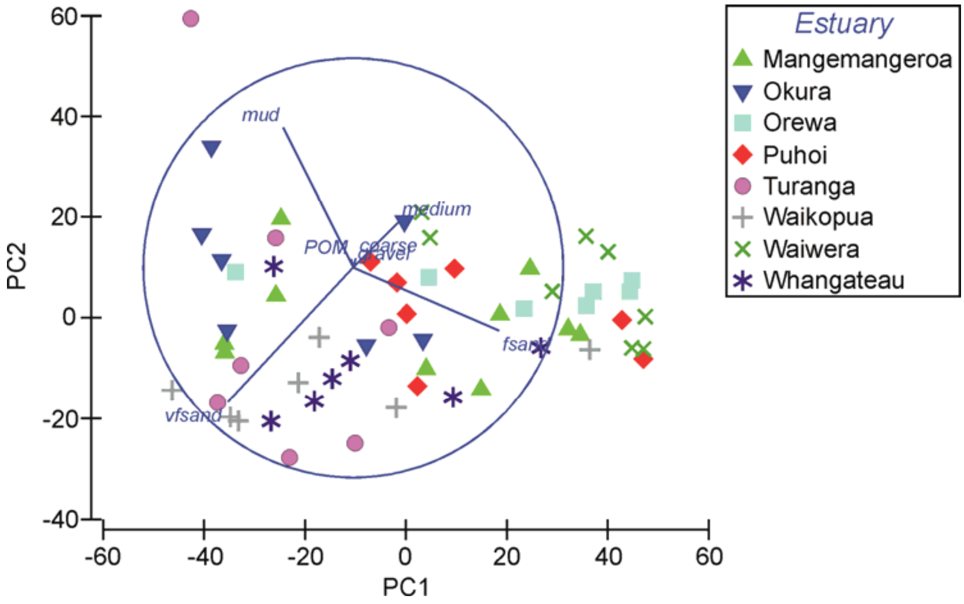
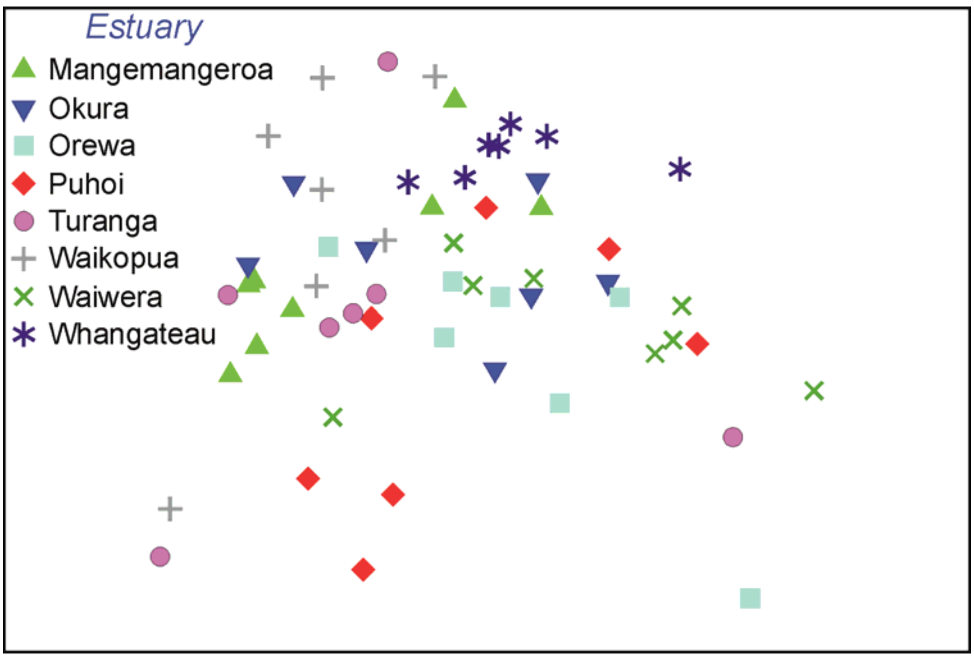
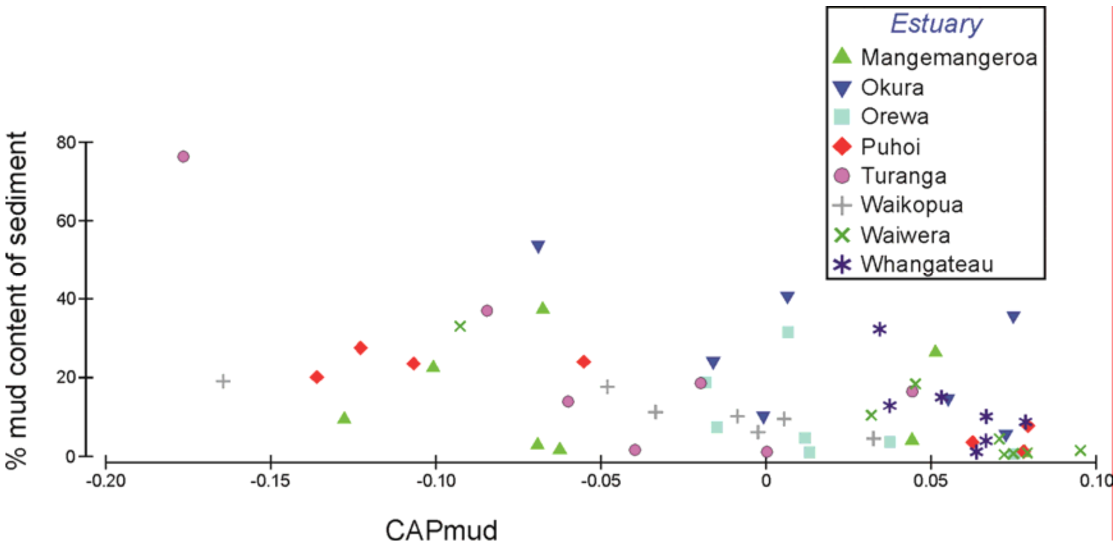


Figure 3.2: MDS ordination of similarities between estuaries based on macrofaunal communities. Sites closest together are more similar. Stress = 0.17, indicating the ordination is a reasonable fit to the data.



The two similarity matrices, sediment characteristics and macrofaunal communities, were not well correlated (Spearman's rho = 0.067, p = 0.126). The CAP analysis suggested that in October 2011, there were marked differences between estuaries in their relationships between macrofaunal community composition and sediment mud content (Figure 3.3). Greatest reductions in CAP score with mud content were observed at Waikopua, Puhoi and Waiwera. Whangateau exhibited a similar relationship to Turanga and a stronger relationship than observed in Okura, Orewa and Mangemangeroa.

Figure 3.3: CAP analysis of the relationship between macrofaunal community composition and sediment mud content. Overall correlation r = 0.53.



4.0 Are there ecological changes over time associated with increased terrestrial sedimentation?

Macrofaunal communities are not expected to remain consistent over time. There will always be some temporal shifts, for example, seasonal patterns and longer-term cyclic patterns associated with recruitment patterns of particular species or El Nino events. However, the ecological monitoring over time in the Manukau and Mahurangi Harbours, conducted by the Auckland Council, demonstrate that these natural changes generally do not prevent detection of impacts associated with human use (Hewitt & Thrush 2007, Hailes & Hewitt 2009, Hewitt & Thrush 2010). So, it is not enough to describe changes in the communities at the different sites and estuaries; rather we need to know whether any observed changes are associated with increased terrestrial sedimentation.

Initially 10 sites were sampled in each estuary, but in August 2009, this was decreased to 7. Analyses in the previous report confirmed that decreasing the number of sites monitored to 7 core sites would not adversely affect the ability of the programme to detect changes in each estuary. However, it is also important to know whether rotating monitoring of the other 3 sites (non-core) in each estuary from not being monitored to being monitored for a year, is effective. Since the last report, non-core sites have been monitored in Okura, Waiwera and Mangemangeroa, in that order. Here we investigate whether there are any indications that any changes have occurred at these non-core sites that are not apparent in the time signal of the core sites from these estuaries and whether there is a distinct lack of trends detected at the non-core versus the core sites.

4.1 Methods

CAP was used to model macrofaunal community composition, based on Bray-Curtis similarities of square-root transformed data, along a gradient in the percentage mud of ambient sediments across the region. In 2007, a model was created using averages in both faunal abundances and percentage mud from time 20 (August 2004) onwards, on dry sampling occasions, at each of the 70 sites, thus integrating temporal variation. However, this averaging over time integrates any possible changes in community composition relating to increased terrestrial sedimentation occurring over time. This may have had limited effect in 2007, due to the short time series. However, the longer the time series included in producing the averages, the more effects of increased terrestrial sedimentation may bias the results. For this reason, for the 2010 report the averaging was undertaken on sampling conducted from spring 2004 (the earliest date that all estuaries were sampled) to autumn 2007 only. Unfortunately, this model does not contain any samples from Whangateau, however, analyses conducted in the previous section suggests that this should be of little consequence.

Once the model had been produced, temporal changes in macrofaunal community composition over time were mapped onto the canonical axis of the mud gradient model using the 'add samples' option available in Primer V6. The resultant scores (CAPmud) from each site were then analysed by regression to determine trends over time. The potential for temporal autocorrelation was investigated but proved not to be important within this short time period.

Whangateau values were calculated and stored but not included in the trend analysis as only 5 data points were available.

Anderson (2008) also determined a number of dominant taxa that showed responses to mud content of sediment using quantile regression (Table 4.1). Five taxa (*Paphies australis, Colurostylis* spp., *Anthopleura aureoradiata, Waitangi brevirostris* and *Aonides oxycephala*) were found to strongly prefer low mud content and three taxa (crabs, Nereididae polychaetes and Corophidae amphipods) were found to prefer high mud content. The results were similar to those found by Thrush et al. (2003) using maximum density models and thus seem likely to be robust. However, the models developed in Thrush et al. (2003) were also developed from data sets gathered over different spatial scales: regional, estuary and sandflat (Thrush et al. 2005). In this analysis, at the estuary-scale, the models report a strong positive relationship between % mud content and Nereididae abundance, and a stronger negative relationship with % mud content for *Austrovenus* and *Macomona*. Therefore, changes in abundance of these taxa at each site over time were also analysed in this section to determine whether any changes were consistent with the predicted response to increasing mud content.

Taxa	Optimum mud content (%)	Analysis category
Paphies australis	3.4	S
Colurostylis spp.	3.4	S
Anthopleura aureoradiata	3.4	S
Waitangi brevirostris	7.5	S
Aonides trifida (oxycephala)	8.1	S
Austrovenus stutchburyi	0–10	S
Macomona liliana	0–10	S
Nucula hartvigiana	12.0	
Prionospio (Aquilaspio) aucklandica	12.0	
Barnacles	13.4	
Exogoninae	14.2	
Arthritica bifurcata	17.4 15–25	
Heteromastus filiformis	23.2 20–25	
Orbinids	23.2 20–30	
Capitella spp. and Oligochaetes	28.5 20–40	
Polydorid complex	29.2	
Corophidae	41.2	M
Austrohelice (Helice), Hemigrapsus, Hemiplax (Macrophthalmus)	41.2	M
Nereididae (Nereidae)	40	M
Paracalliope spp.	NA	

Table 4.1: Results of analyses (Anderson et al. 2007, Thrush et al. 2005) of the response of the 20 most dominant taxa at the sites to % sediment mud content, showing optimum mud content (range given if differences are observed between studies) and categories used in analyses. S = taxa that have optimal abundances at < 10% mud; M = taxa that have optimal abundances at > 30% mud. Taxa not designated as preferring either mud or sand are those that either prefer intermediate levels of mud, or have optima that occur over a large range of mud content.

Analyses were also conducted on different size classes of the measured bivalves (*Austrovenus, Macomona* and *Paphies*).

We also incorporated number of taxa into this analysis. Experiments manipulating terrestrial sedimentation events, conducted in Okura, Mahurangi and Whitford, all observed decreases in number of taxa. A survey conducted across a number of Auckland estuaries, measuring rates of sediment accumulation over the last 50 years, observed that muddy sites were not necessarily less diverse than sandy sites, but that higher rates of sediment accumulation were associated with decreased number of taxa (Lundquist et al. 2003). Similarities between both the short term manipulative studies and the time-integrative survey emphasises that decreases in species diversity and richness are linked with increased terrestrial sedimentation.

It is this analysis that may be sensitive to the lack of continual monitoring at some sites. A simple way of assessing this is to compare the number of trends detected at the core sites with those detected at the sites monitored less frequently. The maximum and minimum number of trends consistent with increased sedimentation were compared for core and non-core monitored sites for each estuary separately. Comparisons were also made between the non-core site and the core sites located on either side of the non-core site.

4.2 Results- ecological changes over time

Cyclic patterns in community composition driven by mud (represented by CAP scores) over time and the abundance of many taxa were still common, varying from relatively long cycles (e.g., 6 years at Orewa site 9; Figure 4.1) to well-defined 2–3 year cycles (e.g., Waikopua site 2 and site 6 and Orewa site 7; Figure 4.1).

Within increasing length of time sampled we expect some previously detected trends to be revealed to be part of long-term cycles. Of the 29 decreasing trends at core sites predicted to represent responses to increased sedimentation content previously reported on, 87% were still detected (Table 4.2). All of these trends previously observed in Okura, Orewa, Puhoi, Waikopua and Waiwera were still present. In Mangemangeroa, a decreasing trend detected at site 2 was no longer present and in Turanga 3 out of 5 decreasing trends were not detected (sites 1, 8 and 10). All decreasing trends in number of taxa, *Paphies*, *Aonides*, *Austrovenus*, *Colurostylis* and *Waitangi* were still detected; 4 out 6 and 2 out 4 decreasing trends in CAPmud and *Macomona* respectively were not detected.

Trends in species predicted to increase in abundance to increased sedimentation were not so consistent, with only 2 out of the 4 previous trends still detectable. Trends in Corophidae were no longer found and only two of the trends in Nereididae.

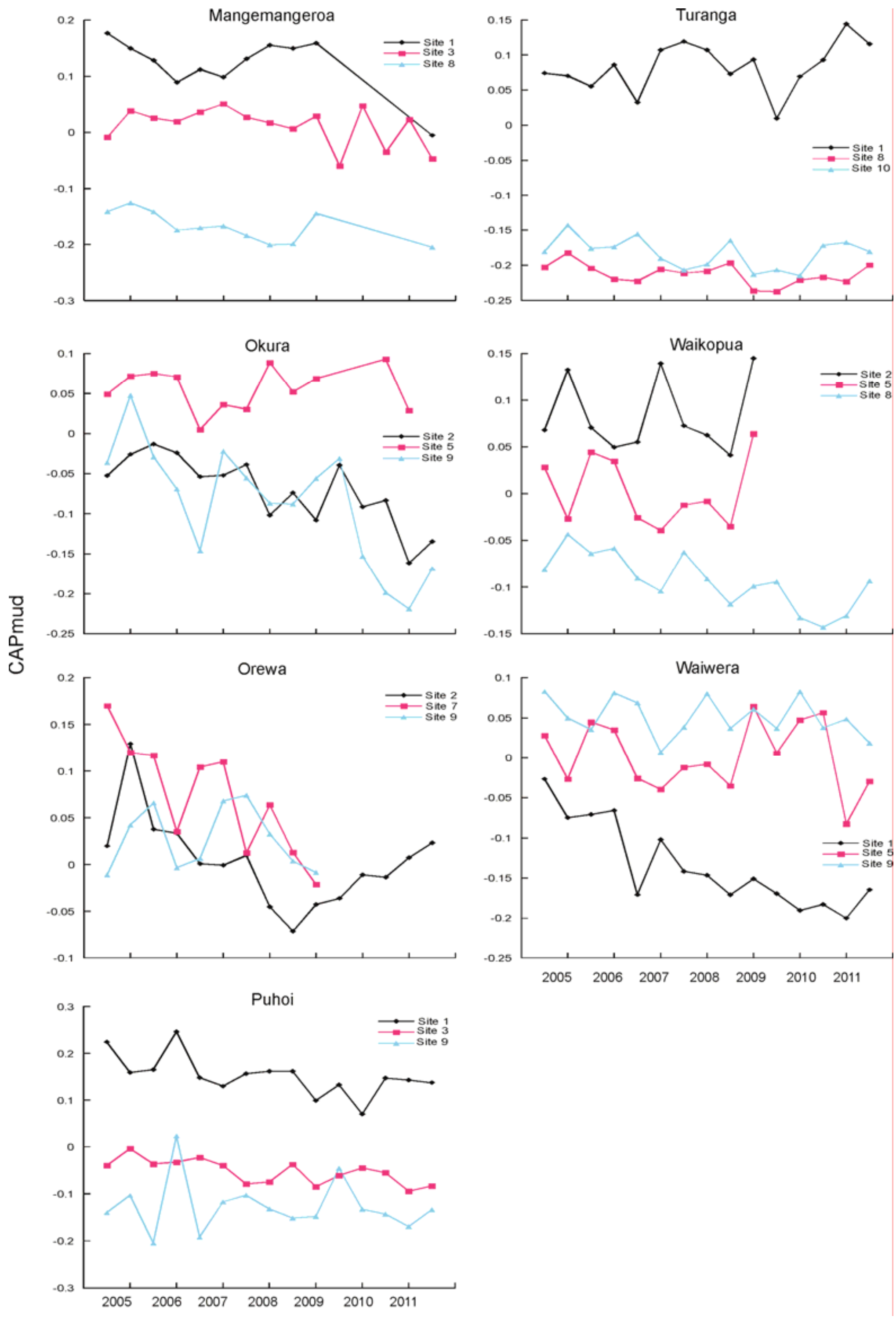


Figure 4.1: Temporal patterns observed in CAP scores related to mud (CAPmud) at 3 sites from each estuary. As presented here, decreasing CAPmud scores represent a community related to increasing muddiness. The sites have been selected to show not only the decreasing trends detected and recorded in Table 4.2, but also cyclic patterns (e.g., site 9 Orewa and site 2 Waikopua) and random variation.

Table 4.2: Trends previously detected at core sites and whether they were detected after an additional 2 years of monitoring. S = still detected, R = not. Ntaxa = number of taxa, Pap= *Paphies*, T = total, j = juvenile, Aon= *Aonides*, Aus= *Austrovenus*, a = adult, Col = *Colurostylis*, Mac = *Macomona*, Wai = *Waitangi*, Ner = Nereididae, Cor = Corophidae.

SITE	Ntaxa	CAPmud	Pap T	Papj	Aon	AusT	Ausa	Col	Mac	Wai	Ner	Cor
Mang2									R			
Mang3									S			
Mang8							S					
Okur1					S	S	S				R	R
Okur2		S										
Okur4											S	
Okur9	S							S				
Orew2												
Orew4			S	S						S	S	
Orew8	S											
Puho1		S										
Puho2	S											
Puho3		S										
Puho7										S		
Tura1									R			
Tura3					S							
Tura7									S			
Tura8		R										
Tura10		R										
Waik6	S											
Waik7					S							
Waiw1		S										
Waiw3								S				
Waiw5	S											
Waiw9					S			S				

A number of new trends were detected[1], some of these were not consistent with increased sedimentation (Table 4.3). For example, all 5 of the trends detected for *Anthopleura* were increases, rather than decreases. For *Austrovenus*, 4 of the 6 trends in total numbers, 4 of the 5 in juveniles, 2 of the 5 trends in mid-size individuals (5 – 15 mm size class) and half of the trends in adults were increases rather than decreases, related to strong recruitment events moving through the populations (Figure 4.2). Juvenile *Paphies* also showed strong recruitment at some sites resulting in increasing trends being detected (Figure 4.2). Finally 4 of the 6 trends in Nereididae detected were decreases rather than increases.

[1] Trends are defined as those significant at p = 0.05, however, screening removed any trends that were driven by one or 2 high points at the beginning or end of the time series, or where abundances were generally very low (average < 2 individuals).

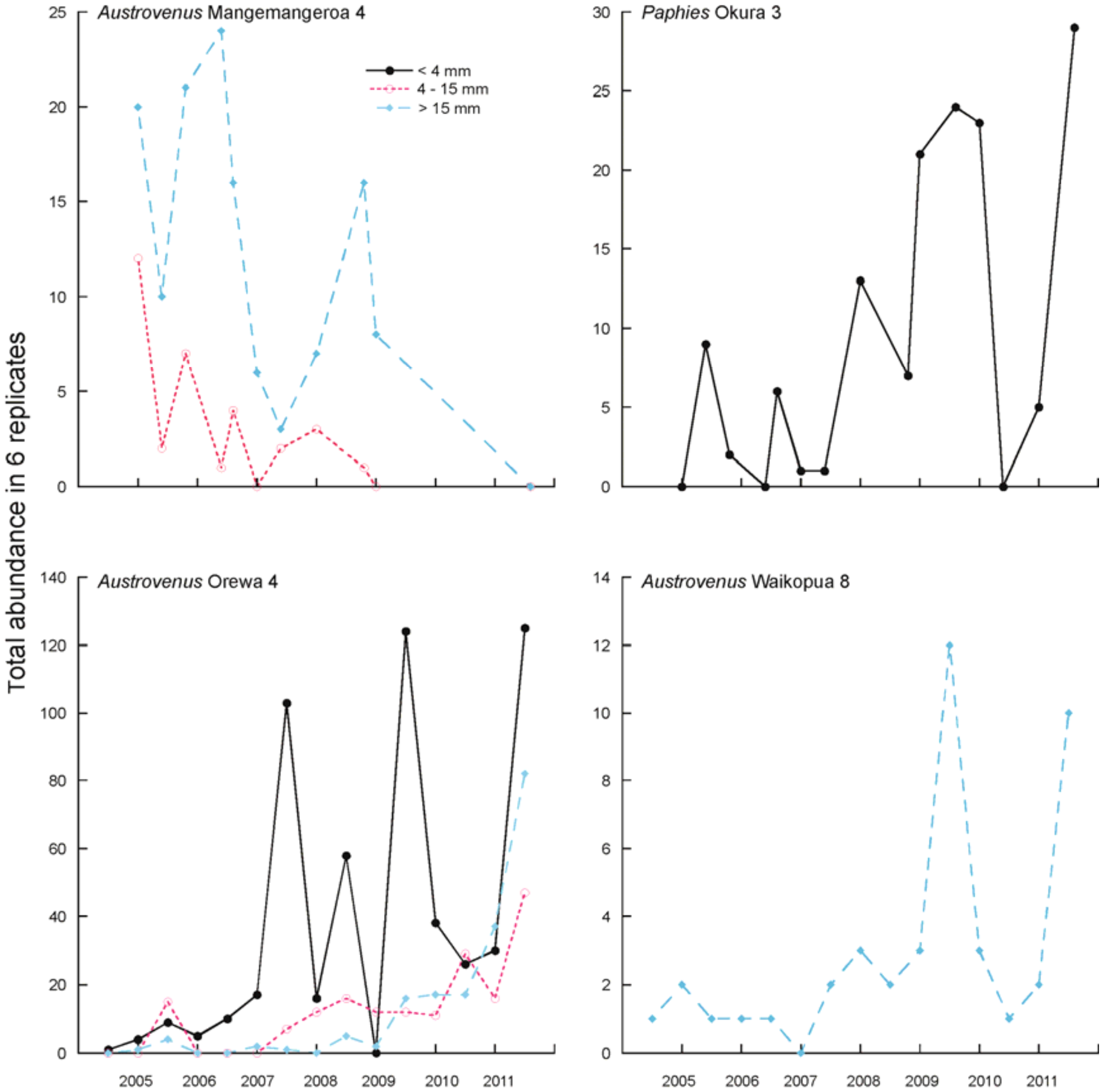


Figure 4.2: Temporal patterns in bivalve size classes for those species/sites for which significant trends in the species abundances were detected.

However, all the trends detected for number of taxa, community composition, *Macomona*, *Aonides*, *Colurostylis* and *Waitangi* were consistent with increases in sedimentation (Table 4.3). There were 60 of these (some examples of which are given in Figure 4.3), although 7 (2 for number of taxa and 5 for community composition) were driven by the last 3 data points.

Table 4.3: Total number of trends detected at p = 0.05 significance level, consistent with increased sedimentation

		Consistent with increased sedimentation
Number of taxa		11
Community composition		11
Aonides		4
Colurostylis		4
Waitangi		3
Austrovenus	Total	2
	Juveniles	1
	Medium	3
	Adults	7
Macomona	Total	2
	Juveniles	4
	Adults	4
Paphies	Total	1
	Juveniles	1
Nereididae		2
Total		54

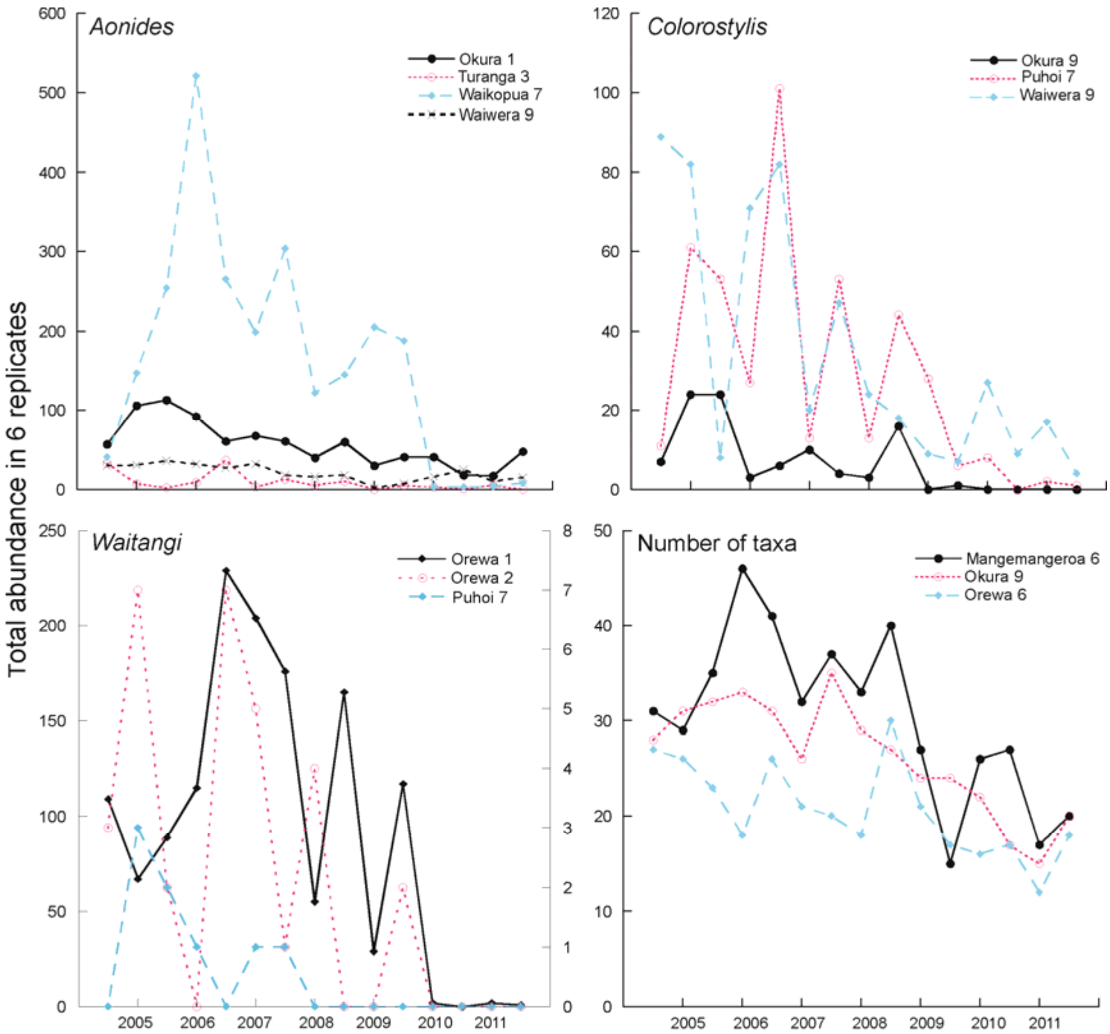


Figure 4.3: Selected trends in abundance consistent in direction with those predicted to occur as a result of increased sediment mud content.

More trends over time consistent with increased sedimentation were detected in Okura and fewest in Turanga and Waiwera (Table 4.4). However, unlike the analyses conducted in 2010, trends were not more likely to occur higher up the estuary.

Table 4.4: Summary of number of trends over time consistent with increased sedimentation at each site, with 1 being closest to and 10 being furthest from the mouth of the estuary. Average number of trends per estuary is given in bold at the bottom of the table. Highlighted cells represent non-core sites sampled between April 2010 and October 2011. Blank cells are sites where no monitoring has been conducted since April 2010. See Appendix 3 for full set of trends.

Site#	Mangemangeroa	Okura	Orewa	Puhoi	Turanga	Waikopua	Waiwera
1	0	3	2	1	1	0	3
2	1	2	1	1			0
3	1	1	0	4	3	1	1
4	2	2	3	0	0	0	0
5	0	0	0				1
6	2		0	0	0	3	1
7	3	0		3	1	2	0
8	1	1	1		0	2	0
9	1	5		0		0	2
10	1	2			0		0
	1.2	**1.8**	**1**	**1.3**	**0.7**	**1.1**	**0.8**

4.3 Results - comparisons between core and non-core sites

The numbers of trends detected at non-core sites were not less than those detected at the core sites in each estuary, nor were more trends detected in non-core sites (Table 4.5). While the maximum number of trends in an estuary was always detected in a core site, this may well be a result of there being 7 core sites and 2 – 3 non-core sites. Spatial comparisons did also not suggest an effect of the reduced monitoring. In Mangemangeroa, site 1 had no trends detected whereas site 2 (the core site next to it) had 1. Site 4 had 2 trends detected with the sites closest having 0 and 1 trend detected, and site 8 had 1 trend detected with the sites closest having 1 and 3 trends detected. Similarly, in Okura, non-core site 5 had 0 trends detected and was surrounded by sites with 2 and 0 trends, while site 10 had 2 detected trends and was next to a site with 5 detected trends. In Waiwera, no trends were detected at the non-core sites, however two of these sites were next to sites with either 0 or 1 trends detected.

While the trend detected at the non-core site may not always have been for the same variable as at the nearby core sites, they were always in the same direction relative to predictions of increased sedimentation. For example, site 4 in Mangemangeroa exhibited negative trends in medium and adult sized Austrovenus, while site 3 exhibited a negative trend in total numbers of Macomona. Site 8 exhibited a negative trend in Austrovenus adults, as did sites 7 and 9.

Table 4.5: Maximum and minimum number of trends consistent with increased sedimentation, detected in core and non-core sites monitored between April 2010 and October 2011.

		Mangemangeroa	Okura	Waiwera
core	maximum	3	5	3
non-core	maximum	2	2	0
core	minimum	0	0	0
non-core	minimum	0	0	0

5.0 Sediment characteristics

In this section we discuss both temporal trends in sediment mud content and spatial patterns in metals.

Sediment grain size characteristics have been monitored at each site, but no significant increases in mud content over time have been observed. In fact up to April 2010, decreases in sediment mud content had been observed. These decreases seemed driven by a slight change in sediment grainsize around the 63 µm size fraction, as the trends disappeared when the very fine silt fraction was amalgamated with the mud fraction. As the very fine silt fraction is also often a part of the terrestrial sediment load in the Auckland region (Lohrer et al. 2004), trend analysis will now be done on the sum of the mud and very fine silt portions of the sediment.

In 2009 and 2010, AC expanded the sites at which contaminant data was collected. In 2009, all the Whangateau sites were sampled and three sites (mouth, middle and upper estuary) from each of the other 7 estuaries in 2010. The Whangateau data is discussed by Townsend et al. 2010, but a general description will be included here.

5.1 Methods

Trend analysis was conducted on the dry weight of sediment sized < 125 µm (mud and very fine sand defined as very fine sediment) as outlined in section 4.1.

Comparisons of contaminant concentrations between sites were conducted visually on heavy metal data from all seven sites in Whangateau and the three sampled sites in the other estuaries. Cadmium and Mercury were removed from the analysis because they were recorded as mainly below the detection limit in all estuaries but Whangateau, where the values were lower than the detection limit recorded for the other sites (see Appendix 4 for full results). PAH information was also not included as it was only collected from one site in each of Mangemangeroa, Okura, Orewa, Puhoi, Waikopua and Waiwera (see Appendix 4). A Principle components analysis (PCA) was conducted on normalized data from all the other variables to display similarities between estuaries and sites (upper, mid and lower parts of estuaries).

The concentrations observed in copper, zinc and lead in the < 500 mm fraction of sediment was used to determine health of the sites relative to the Benthic Health Model (BHM; Anderson et al. 2006). This may be problematic as the BHM was developed from sampling 10 replicates at a site, whereas this monitoring programme only collects 6. This may diminish the health score (as expressed by CAP scores produced by a PCA axis that expresses the sites in terms of copper, lead and zinc) as the number of taxa collected will be lower than would be observed in 10 samples.

5.2 Results - trends in mud content

Contrary to the trend analysis conducted in 2010, 5 trends of increasing very fine sediment content were detected (Figure 5.1). Four of these were in the upper sites in estuaries (Mangemangeroa site 7, Okura site 8, Puhoi site 9 and Turanga site 10), but one was at the mouth of the Waiwera Estuary (site 1). Multi-year cycles were also observed (e.g., Waikopua site 1, Figure 5.1). There were also a number of sites where increasing variation in very fine sediment content in the last 4 years was observed.

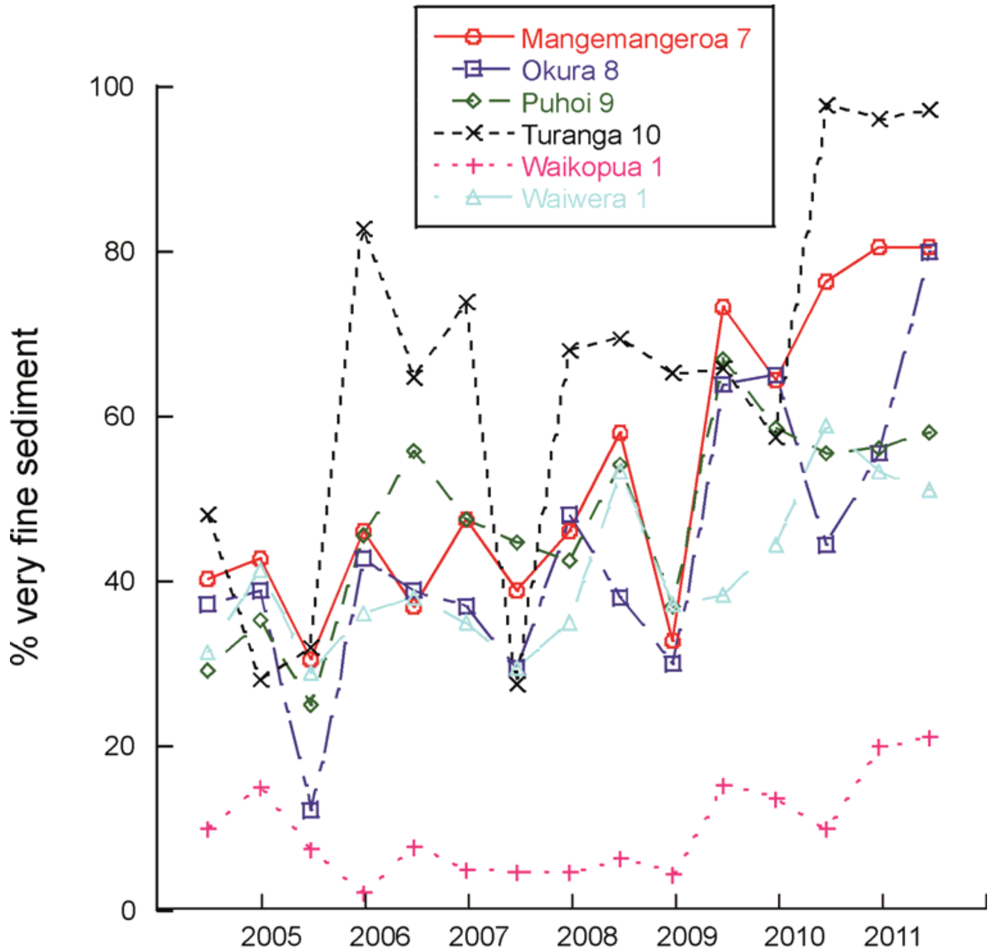


Figure 5.1: Temporal patterns observed in very fine sediment content over the monitored period, including positive trends and a multi-year cycle.

5.3 Results - sediment contamination

Total PAH's were below the detection limit al Whangateau sites 1-5 and site 7 and for Puhoi site 9. They were also low at the sites monitored in all the other estuaries with the exception of Waiwera (site 1 0.356 mg.kg^{-1}) and Okura (site 9 0.102).

The first 3 axes of the PCA explained 59%, 22% and 10% respectively, with only the first 2 axes (82% of the variability) presented. Zinc, copper and chromium were most strongly aligned with axis 1, the <63mm fraction metals and Manganese and Nickel were more strongly aligned with axis 2 (Figure 2). The PCA ordination demonstrates that Whangateau (with the exception of site 6) is most similar in heavy metal characteristics to Okura (Figure 5.2). Orewa and Waikopua sites form relatively, non over-lapping clusters nearby. Turanga and Mangemangeroa sites overlap, with Turanga sites being variable in characteristics. Similarly, Waiwera and Puhoi sites overlap with Waiwera sites being most variable. There was no evidence for strong estuarine gradients in heavy metal characteristics, although sites nearest the mouths of estuaries are generally around the outside of the ordination (Figure 5.2).

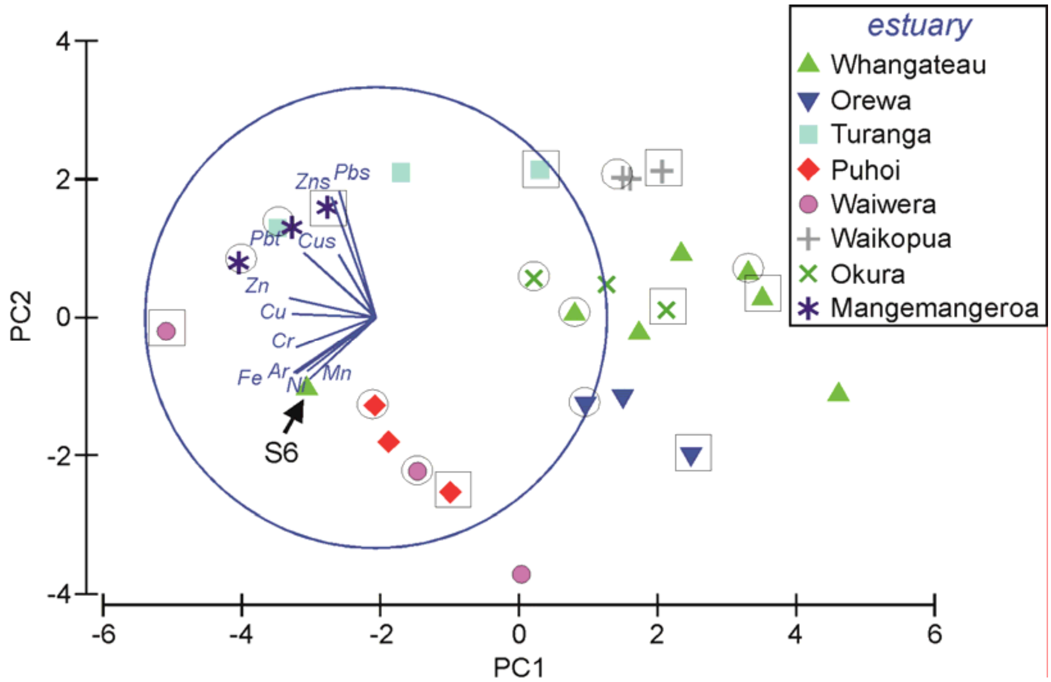


Figure 5.2: Principal component analysis ordination plot of the first 2 axes which explain 82% of the variation in heavy metal characteristics at the samples sites. Sites near the mouth of each estuary are indicated by a square, innermost sites by a circle. Cu = copper, Pb = lead, Zn = zinc, Fe = iron, As = arsenic, Cd = cadmium, Cr = chromium, Ni = nickel, s = in 63 m fraction of sediment with weak extraction.

Only one exceedance was observed in heavy metal concentrations, Arsenic concentrations at Waiwera site 3 (Table 5.1). However, there were variations between sites and estuaries. Whangateau was generally variable. Orewa exhibited the lowest concentrations for copper, both in the < 63 µm and < 500 µm fractions. Turanga, Mangemangeroa and Waikopua all had the highest lead values in the < 63 µm fraction. Puhoi had the lowest zinc concentrations in the < 63 mm fraction and Mangemangeroa the highest Zn concentrations in both grain size fractions. Arsenic was lowest in Whangateau and Waikopua. Chromium and iron was also low in Waikopua. Puhoi was relatively high in iron, manganese and nickel. Mangemangeroa also had relatively high manganese and nickel concentrations and Waiwera had relatively high nickel concentrations.

Table 5.1: Mean concentrations (mg/kg dry wt) of metals in the top sediment collected in November 2010, with exceedances of the Threshold Effect Concentration (TEL) (shaded) and Effect Range Low (ERL) (bold red) shown. Cu = copper, Pb = lead, Zn = zinc, Fe = iron, As = arsenic, Cd = cadmium, Cr = chromium, Ni = nickel. Letter "s" next to a metal species indicates <63 m grain size fraction of sediment using a weak acid extraction methodology.

Estuary	Site	Cus	Pbs	Zns	Cu	Pb	Zn	Ar	Cr	Fe	Mn	Ni
Whangateau	1	9.4	5.7	35.0	0.9	0.8	8.3	1.6	5.6	3133	26.0	1.9
Whangateau	2	4.7	1.3	8.3	0.4	0.6	5.9	1.5	4.3	2143	21.7	1.4
Whangateau	3	10.4	7.5	42.0	1.6	1.2	10.9	2.5	7.5	4067	30.3	2.8
Whangateau	4	7.9	5.6	30.7	0.8	0.7	7.3	1.6	5.8	2900	26.3	2.1
Whangateau	5	9.1	6.3	43.0	2.8	2.0	20.2	2.9	11.0	7967	75.0	4.3
Whangateau	6	10.3	7.4	37.7	7.2	4.5	33.0	5.5	18.2	15767	116.7	8.0
Whangateau	7	8.6	5.7	32.7	2.2	1.3	14.5	2.8	9.3	5933	66.3	3.8
Orewa	1	3.3	2.5	15.7	1.9	1.7	13.3	6.0	5.0	7000	62.0	3.0
Orewa	4	4.8	6.0	26.3	1.9	2.5	18.7	5.0	8.0	8400	68.0	4.0
Orewa	8	4.9	5.0	31.3	2.0	2.9	22.7	5.0	9.0	9300	75.0	5.0
Turanga	4	8.3	15.5	64.3	2.7	5.8	25.0	4.0	8.0	7300	60.0	3.0
Turanga	7	8.7	16.6	67.0	3.7	9.4	41.0	6.0	9.0	10400	96.0	4.0
Turanga	8	8.2	15.0	61.0	5.7	12.0	51.7	7.0	13.0	13400	129.0	5.0
Puhoi	1	8.2	3.0	23.0	3.0	2.0	25.7	7.0	11.0	15400	159.0	7.0
Puhoi	4	9.2	5.3	38.3	3.7	2.3	28.0	7.0	13.0	16100	152.0	8.0
Puhoi	9	9.8	5.0	32.7	6.0	4.0	30.7	4.0	16.0	17900	106.0	7.0
Waiwera	1	9.5	11.0	55.7	8.0	9.6	52.0	7.0	17.0	18400	152.0	9.0
Waiwera	3	3.0	1.4	10.7	2.0	2.4	24.0	8.0	9.0	13300	181.0	6.0
Waiwera	8	9.6	3.9	31.3	3.0	2.9	24.3	7.0	10.0	13600	270.0	6.0
Waikopua	1	8.5	14.2	57.7	1.9	2.9	14.3	2.0	5.0	4500	52.0	2.0
Waikopua	3	8.7	14.5	58.0	1.9	3.7	16.0	3.0	5.0	4900	79.0	2.0
Waikopua	9	7.9	14.8	53.0	2.4	5.3	18.0	3.0	5.0	5500	53.0	2.0
Okura	1	6.2	7.5	41.0	1.9	2.3	14.7	4.0	5.0	6100	52.0	3.0
Okura	7	7.5	9.7	49.7	1.9	3.0	16.3	6.0	5.0	7500	68.0	3.0
Okura	9	7.6	9.8	50.3	3.0	5.1	26.7	4.0	7.0	9300	103.0	4.0
Mangemangeroa	3	9.3	15.3	70.0	5.0	9.1	42.0	6.0	13.0	12600	127.0	8.0
Mangemangeroa	6	9.0	16.8	71.0	4.0	9.1	39.3	7.0	12.0	12100	127.0	6.0
Mangemangeroa	9	7.8	14.1	61.0	6.0	12.6	49.7	7.0	14.0	14000	153.0	7.0
	ERL	*34*	*46.7*	*150*	*34*	*46.7*	*150*	*8.2*	*81*			*20.9*
	TEL	*18.7*	*30.2*	*124*	*18.7*	*30.2*	*124*	*7.24*	*52.3*			15.9

CAP scores produced by the BHM were in the lower half of the ordination plot (Figure 5.3) indicating generally moderate to high health. All outer sites had lower CAP scores (indicating relatively better health) with the exception of Waiwera. Fit to the BHM model data was satisfactory for Mangemangeroa and Turanga and for 2 of the three sites in Okura, Puhoi, Orewa and Waiwera but very poor for Whangateau and Waikopua, which had much higher CAP scores (lower health) than would be expected for their contaminant score (PC1). This was an expected effect of fewer samples affecting the average number of taxa found per site.

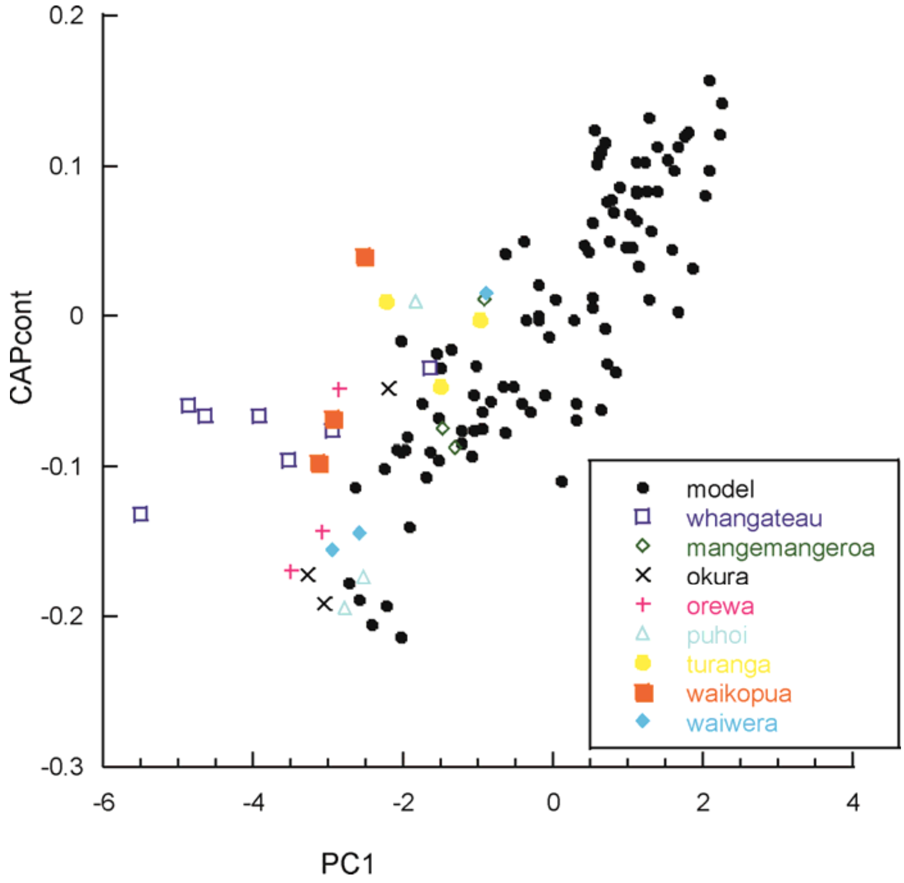


Figure 5.3: Results of the Benthic Health Model allocation of sites. Low CAPcont scores indicate better health, Lower PC1 scores represent lower values of copper, zinc and lead.

6.0 Summary and Recommendations

6.1 Observed changes in benthic macrofauna

The majority of temporal patterns observed in macrofaunal community composition and the abundance of dominant taxa were associated with seasonal or multiyear cycles. These types of patterns are expected and have been observed in other macrofaunal monitoring programmes conducted in the region. It is important that we understand these natural fluctuations if we are to tease apart the effects of human activities in our estuaries.

Some changes consistent with those predicted to occur as a result of increased sediment mud content or sedimentation had been observed with the data collected up to April 2010. Within increasing length of time sampled we expect some previously detected trends to be revealed to be part of long-term cycles. However, as in this study we were focusing on trends in direction that we predicted to be consistent with changes in sediment mud input, we expected this to be lower than would otherwise be the case. This was indeed what we observed. Of the 29 decreasing trends at core sites predicted to represent responses to increased sedimentation content previously reported on, 87% were still detected. This is a much higher number than was observed in Manukau Harbour in 1995 where, after an additional 2 years of monitoring only 59% of trends were still present. Turanga was the estuary where the majority of these previously reported trends proved to be part of longer-term cycles and overall community composition and abundance of *Macomona liliana* were the variables that exhibited these changes.

A number of new trends were detected; some of these were not consistent with increased sedimentation. For *Anthopleura* this is contrary to findings from previous studies (Gibbs and Hewitt 2004), for Nereididae and Corophidae, it could be due to one of two factors. Firstly, the particular species found in previous studies may be more sensitive than the species found here and, secondly, as both prefer relatively high levels of mud, they may require higher sedimentation rates in order to show a response. *Austrovenus stutchburyi* and *Paphies australis* also exhibited strong temporal patterns in recruitment that in the case of *Austrovenus* flowed through to the larger size classes over time, making identification of subtle changes difficult for some sites.

However, all the trends detected for number of taxa, community composition, *Macomona*, *Aonides*, *Colurostylis* and *Waitangi* were consistent with increases in sedimentation. There were 60 of these, although a proportion of these are likely to turn out to be parts of multiyear cycles. More trends over time consistent with increased sedimentation were detected in Okura and fewest in Turanga and Waiwera, suggesting Okura is most likely to be exhibiting long-term changes related to increased terrestrial sedimentation.

6.2 Effect of rotational sampling

Since August 2009, the number of sites routinely sampled in each estuary has decreased from 10 to 7 core sites. Analyses in the previous report confirmed that decreasing the number of sites monitored to 7 would not adversely affect the ability of the programme to detect changes in each estuary. However, it is also important to know whether rotating monitoring of the other 3 sites in each estuary from not being monitored to being monitored for a year, is effective. This technique has proven very effective in other AC ecological monitoring programmes, but needs to be assessed on a case-by-case basis. At this stage, with monitoring gaps of only 1 – 2 years, effects are likely to be minimal, still it was considered worthwhile to make a brief assessment.

Since the last report, non-core sites have been monitored in Okura, Waiwera and Mangemangeroa, in that order. There is no indication that changes have occurred at these non-core sites that are not apparent in the time signal of the core sites from these estuaries, with the maximum number of trends consistent with increased sedimentation generally slightly less in non-core sites. At the same time there is not a distinct lack of trends detected at the non-core versus the core sites, suggesting that the reduced sampling is not having an adverse effect on detectability of trends.

6.3 Entry of Whangateau into the monitoring programme

Whangateau Estuary has recently been added to the estuaries monitored in this programme. The sites monitored in Whangateau have similar sediment characteristics to sites from Turanga, Waikopua, Okura and Puhoi. Macrofaunal community composition at Whangateau sites are also similar to those from a number of other estuaries. Importantly, the response of the macrofaunal communities at the sites in Whangateau to sediment mud content are not dissimilar to those observed across the other estuaries. Thus, in future with more sampling occasions, Whangateau will be able to be analysed by the multivariate model developed from the other estuaries.

6.4 Sediment characteristics

Contrary to the trend analysis conducted in 2010, which observed no trends consistent with increasing sedimentation, analyses for this report detected 5 trends of increasing very fine sediment content (Mangemangeroa, Okura, Puhoi, Turanga and Waiwera). All of these were in the upper sites in estuaries except for Waiwera Estuary, where one was found at site 1 at the outer end of the estuary, although in a depositional zone.

Total PAH's were below the detection limit al Whangateau sites 1-5 and site 7 and for Puhoi site 9. They were also low at the sites monitored in all the other estuaries with the exception of Waiwera (site 1) and Okura (site 9). Only one exceedance was observed in heavy metal concentrations, arsenic concentrations at Waiwera site 3 were just over the TEL guideline value utilized by AC. However, there were variations between sites and estuaries, with Whangateau generally exhibiting highest variability and Mangemangeroa most likely to exhibit relatively higher concentrations. There was no evidence for strong estuarine gradients in heavy metal characteristics.

Use of the BHM in this programme may be problematic as the BHM was developed from sampling 10 replicates at a site, whereas this monitoring programme only collects 6. This may diminish the health score (as expressed by CAP scores produced by a PCA axis that expresses the sites in terms of copper, lead and zinc) as the number of taxa collected will be lower than would be observed in 10 samples. The BHM generally assigned moderate to high health for the sites sampled. Fit to the BHM model data was very poor for Whangateau and Waikopua, which had lower health than would be expected for their contaminant score (PC1), although the fit was good for Mangemangeroa, Okura, Puhoi and Waiwera Although. All outer sites had relatively better health than sites further up the estuary with the exception of Waiwera.

6.5 Recommendations

Incorporation of Whangateau into this monitoring programme has been successful, with the chosen sites sediment and macrofaunal characteristics fitting well into the range of the 7 other presently sampled estuaries. Analyses which include the two new years of data found that over 80 % of trends consistent with increased sedimentation were still detected, confirming that these trends are most likely a real response to changing conditions within the estuaries. A number of other trends consistent with increased sedimentation were also detected with the increasing length of the time sampled, including, for the first time, increases in the very fine sediment fraction at 5 sites in depositional zones.

These results suggest that ongoing monitoring of the 7 cores sites is worthwhile. The rotational sampling of the other 3 sites in each estuary also seems to be effective as data from non-core sites monitored during the reporting period did not indicate that anything different was occurring at these sites. However, we recommend that in another 2 years, when the time series approaches 10 years, the data should be analysed to determine:

1. whether the number of core sites could be further scaled back
2. whether sampling in both spring and autumn is required or whether sampling once per year would be sufficient.

7.0 Acknowledgements

Field work was conducted by many people in NIWA Auckland, but mainly Pete Pattinson and Christian Hyde, and many people in NIWA (Hamilton, Auckland and Christchurch) worked on the identification.

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9.0 Appendices

9.1 Appendix 1: Placement of sites with each estuary

Plate 1: Location of sites in Whangateau Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red.

Plate 2: Location of sites in Puhoi Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites are circles.

Plate 3: Location of sites in Waiwera Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites are circles.

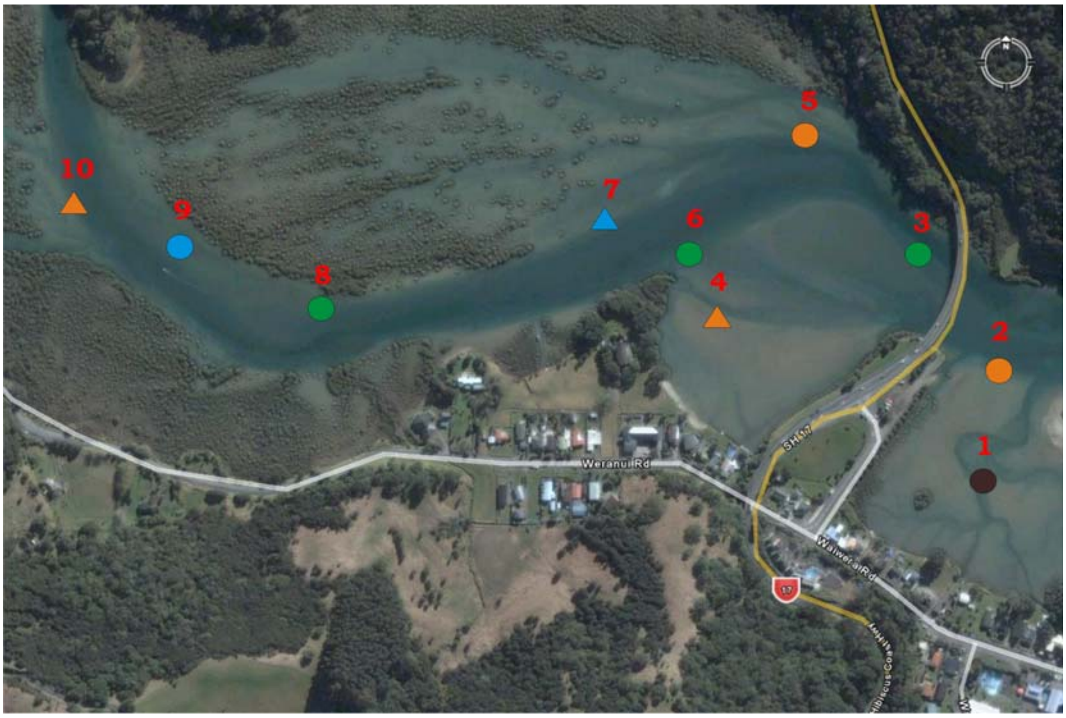

Plate 4: Location of sites in Orewa Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites are circles.

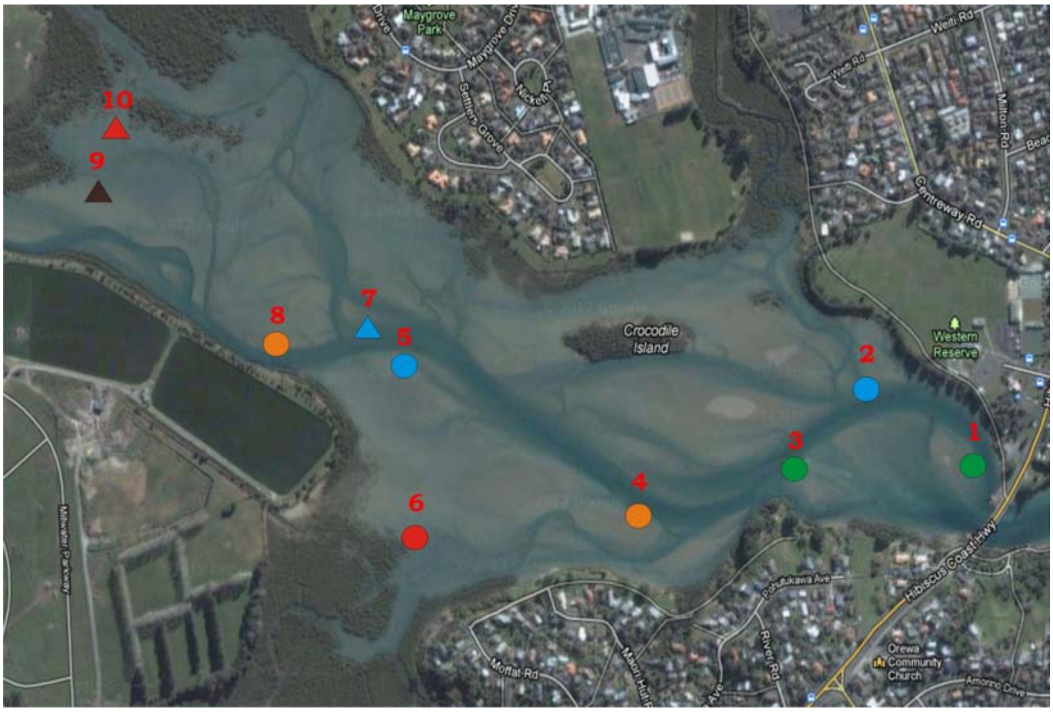

Plate 5: Location of sites in Okura Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites are circles.

Plate 6: Location of sites in Mangemangeroa Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites are circles.

Plate 7: Location of sites in Turanga Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites are circles.

Plate 8: Location of sites in Waikopua Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites are circles.

9.2 Appendix 2: Taxonomic changes

9.2.1 Taxonomic groups for which a lower taxonomic resolution is now available

Previous taxonomic level	Present taxonomic level
Xymene sp.	*X. ambiguous, X plebius*
Unidentified Gastropod	*Eatoniella abscindostoma*
Spionidae	*Spionid spA, Spiophanes bombyx*
Sipunculid	*Paracaudina chilensis, Sipunculid sp2*
Polydora complex	*Boccardia syrtis, Polydora cornuta, Pseudopolydora paucibranchiata*
Phoxocephalidae	*Phoxocephalidae, Torridoharpinia sp.*
Paraonid other	*Levinsenia gracilis, Paradoneis lyra*
Orbiniidae	*Orbinia papillosa, Scoloplos cylindifera*
Previous taxonomic level	Present taxonomic level
Nuculidae	*Lasea parenganensis*
Nereididae	*Ceratonereis sp, Nicon aestuarenisis, Perenereis vallata, Platynereis sp.*
Neoguraleus sp.	*N. manukauensis, N. sinclairi*
Isopod other	Valifera
Halicarcinus spp.	*Halicarcinus whitei*
Goniadidiae	*Glycinde trifida, Goniada grahami*
Exosphaeroma spp.	*E. chilensis, E. falcatum, E. planum*
CapOlig	*Capitella spp, Oligochaete*
Crabs	*Austrohelice crassa, Hemiplax hirtipes, Hemigrapsus crenulatus*
Amphipod other	*Melita awa, Dexaminidae, Gammaropsis spp.,* Lljeborgidae, *Methlimedon sp, Paramoera cheveraux, Parawaldekia sp., Urothidae*
Stomatopoda	*Heterosquilla sp.*
Sabellidae	*Pseudopontamilla sp.*

9.2.2 Taxa not observed over the last 3 years sampling

Caecum digitulum	*Lysidice ninetta*	*Priapulopsis australis*
Chaetognatha	*Melanochlamys cylindrica*	Pycnogonidae
Charybdis japonica	*Modiolarca impacta*	*Rissoidae*
Cirsonella sp.	Munnidae	*Zenatia sp.*
Cominella maculosa	*Mytilus galloprovinciallis*	
Cominella quoyana quoyana	*Odostomia spp.*	
Dorvilleidae	*Onchidella nigricans*	
Dosinia spp.	*Pagurus sp.*	
Holothuroidia other	*Paphies subtriangulata*	
Ligia novaezelandiae	*Perna cannaliculus*	.

9.3 Appendix 3: Summary of all trends detected at all sites.

Trend analysis was conducted on #taxa, CAP, Antho (Anthopleura), Aontri (Aonides), Col (Colurostylis), Wai (Waitangi), Ausstu (Austrovenus), Mac (Macomona), Paphies, Ner (Nereididae), Cor (Corophidae) and Crabs. Tot = total numbers, Juv = <5mm, Med = 5 to 15 mm, Ad = >15 mm longest shell dimension. Trend direction is given as pos (positive) and neg (negative). Trends in the direction predicted to be consistent with increased sedimentation are negative for all but Ner, Cor and Crabs, where they are positive.

	#taxa	CAP	Antho	Aontri	Col	Wai	Aus				Mac				Paphies				Ner	Cor	Crab
							Tot	Juv	Med	Ad	Tot	Juv	Med	Ad	Tot	Juv	Med	Ad			
Mang1																					
Mang2		neg	pos																		
Mang3			pos								neg										
Mang4			pos						neg	neg											
Mang5																					
Mang6	neg	neg																	neg		
Mang7		neg					neg			neg									neg		
Mang8										neg											
Mang9										neg											
Mang10	neg																				
	#taxa	CAP	Antho	Aontri	Col	Wai	Aus				Mac				Paphies				Ner	Cor	Crab
							Tot	Juv	Med	Ad	Tot	Juv	Med	Ad	Tot	Juv	Med	Ad			

Okur1				neg			neg			neg						pos					
Okur2		neg												neg							
Okur3									neg							pos					
Okur4					neg														pos		
Okur5							pos			pos										neg	
Okur6																					
Okur7								pos								pos					
Okur8	neg																				
Okur9	neg				neg			neg	neg	neg											
Okur10	neg	neg																			
Orew1		neg				neg															
Orew2			pos			neg															
Orew3																			neg		
Orew4							pos	pos	pos	pos					neg	neg			pos		
Orew5																					
Orew6																					
	#taxa	CAP	Antho	Aontri	Col	Wai	Aus				Mac				Paphies				Ner	Cor	Crab
							Tot	Juv	Med	Ad	Tot	Juv	Med	Ad	Tot	Juv	Med	Ad			
Orew7																					
Orew8	neg																				

Orew9																					
Orew10																					
Puho1		neg																			
Puho2	neg																				
Puho3	neg	neg									neg	neg									
Puho4			pos				pos			pos											
Puho5																					
Puho6							pos			pos											
Puho7		neg			neg	neg				pos											
Puho8																					
Puho9																					
Puho10																					
Tura1	neg																				
Tura2																					
	#taxa	CAP	Antho	Aontri	Col	Wai	Aus				Mac				Paphies				Ner	Cor	Crab
							Tot	Juv	Med	Ad	Tot	Juv	Med	Ad	Tot	Juv	Med	Ad			
Tura3				neg								neg		neg							
Tura4																					
Tura5																					
Tura6																					

Tura7											neg										
Tura8																					
Tura9																					
Tura10																					
Waik1																					
Waik2																					
Waik3	neg																		neg		
Waik4																					
Waik5																					
Waik6	neg	neg										neg									
Waik7				neg										neg							
Waik8		neg								pos		neg									
	#taxa	CAP	Antho	Aontri	Col	Wai	Aus				Mac				Paphies				Ner	Cor	Crab
							Tot	Juv	Med	Ad	Tot	Juv	Med	Ad	Tot	Juv	Med	Ad			
Waik9																					
Waik10																					
Waiw1	neg	neg								neg											
Waiw2																					
Waiw3					neg																
Waiw4								pos	pos							pos					

Waiw5	neg																				
Waiw6														neg							
Waiw7								pos		pos											
Waiw8																					
Waiw9				neg	neg																
Waiw10																					

9.4 Appendix 4: Metal data (mg/kg)

		Total Recoverable										<63um		
		Copper	Lead	Zinc	Arsenic	Cadmium	Chromium	Iron	Manganese	Mercury	Nickel	Copper	Lead	Zinc
Whangateau	S1	0.9	0.85	8.3	1.7	< 0.010	5.5	3100	26	0.018	1.9	8.7	6	34
Whangateau	S1	0.9	0.84	7.9	1.6	< 0.010	5.6	3200	26	0.027	1.9	10.7	5.4	34
Whangateau	S1	0.9	0.84	8.6	1.6	< 0.010	5.6	3100	26	0.027	2	8.7	5.8	37
Whangateau	S2	0.4	0.55	5.7	1.4	< 0.010	4.2	2200	22	< 0.010	1.3	5.1	1.1	8
Whangateau	S2	0.5	0.61	6.3	1.6	< 0.010	4.7	2300	23	< 0.010	1.5	5	1.6	9
Whangateau	S2	0.4	0.55	5.6	1.4	< 0.010	4	1930	20	< 0.010	1.3	4.1	1.2	8
Whangateau	S3	1.7	1.27	10.9	2.6	0.023	7.6	4400	33	0.019	2.9	11	7.4	42
Whangateau	S3	1.6	1.19	11.5	2.5	0.027	7.9	4000	30	0.028	2.9	9.7	7	40
Whangateau	S3	1.5	1.13	10.3	2.4	0.017	6.9	3800	28	0.024	2.5	10.5	8.1	44
Whangateau	S4	0.8	0.69	7	1.5	0.011	5.6	2800	26	< 0.010	2.1	7.7	5.5	29
Whangateau	S4	0.8	0.73	7.2	1.6	< 0.010	5.8	2700	25	< 0.010	2	8	5.3	31
Whangateau	S4	0.8	0.74	7.6	1.7	< 0.010	6.1	3200	28	0.016	2.1	7.9	6.1	32
Whangateau	S5	2.5	1.96	21	2.8	0.018	11	7700	75	0.027	4.2	9	6.1	42
Whangateau	S5	2.6	1.9	19.5	2.9	0.019	10.7	7900	74	0.023	4.3	8.8	6.4	43
		Total Recoverable										<63um		
		Copper	Lead	Zinc	Arsenic	Cadmium	Chromium	Iron	Manganese	Mercury	Nickel	Copper	Lead	Zinc

Whangateau	S5	3.3	2	20	2.9	0.018	11.4	8300	76	0.024	4.4	9.5	6.5	44
Whangateau	S6	9.3	5.3	38	6.1	0.049	21	19200	149	0.167	9.2	10.3	7.3	37
Whangateau	S6	6.8	4.3	33	5.5	0.047	18.4	14600	104	0.071	8.1	9.7	7.2	38
Whangateau	S6	5.6	3.8	28	4.9	0.038	15.3	13500	97	0.097	6.8	10.8	7.7	38
Whangateau	S7	2.7	1.54	16.3	3.1	0.016	10.4	6800	72	0.012	4.3	9.7	6.2	34
Whangateau	S7	1.6	1.11	12.3	2.4	0.011	8.3	5100	64	< 0.010	3.4	7.7	4.9	29
Whangateau	S7	2.3	1.36	14.9	2.8	0.018	9.2	5900	63	0.029	3.8	8.5	6	35
Orewa	S1	< 2	1.7	13	6	< 0.10	5	7000	62	< 0.10	3	2.5	1.9	12
Orewa	S1	< 2	1.7	14	-	-	-	-	-	-	-	3.9	2.5	18
Orewa	S1	< 2	1.6	13	-	-	-	-	-	-	-	3.4	3	17
Orewa	S4	< 2	2.6	19	5	< 0.10	8	8400	68	< 0.10	4	4.9	5.7	25
Orewa	S4	< 2	2.5	18	-	-	-	-	-	-	-	5.5	7.4	31
Orewa	S4	< 2	2.5	19	-	-	-	-	-	-	-	4.1	4.9	23
Orewa	S8	2	2.9	23	5	< 0.10	9	9300	75	< 0.10	5	5.9	5.5	34
Orewa	S8	2	2.9	23	-	-	-	-	-	-	-	4.1	4.5	28
Orewa	S8	2	3	22	-	-	-	-	-	-	-	4.8	5.1	32
		Total Recoverable										<63um		
		Copper	Lead	Zinc	Arsenic	Cadmium	Chromium	Iron	Manganese	Mercury	Nickel	Copper	Lead	Zinc
Turanga	S4	3	5.9	26	4	< 0.10	8	7300	60	< 0.10	3	7.8	15	61
Turanga	S4	3	6.2	26	-	-	-	-	-	-	-	8.8	16.4	68
Turanga	S4	2	5.4	23	-	-	-	-	-	-	-	8.3	15.1	64
Turanga	S7	3	8.7	37	6	< 0.10	9	10400	96	< 0.10	4	9.1	17	69

Turanga	S7	4	9.9	43	-	-	-	-	-	-	-	8.4	16.3	65
Turanga	S7	4	9.5	43	-	-	-	-	-	-	-	8.7	16.6	67
Turanga	S8	5	10.7	47	7	< 0.10	13	13400	129	< 0.10	5	7.7	13.8	57
Turanga	S8	6	12.3	52	-	-	-	-	-	-	-	8.5	16	64
Turanga	S8	6	12.9	56	-	-	-	-	-	-	-	8.3	15.1	62
Puhoi	S1	3	1.9	26	7	< 0.10	11	15400	159	< 0.10	7	10.6	3	22
Puhoi	S1	3	1.9	25	-	-	-	-	-	-	-	5.7	2.5	20
Puhoi	S1	3	2.1	26	-	-	-	-	-	-	-	8.2	3.6	27
Puhoi	S4	4	2.3	28	7	< 0.10	13	16100	152	< 0.10	8	10.3	6.2	45
Puhoi	S4	4	2.3	29	-	-	-	-	-	-	-	8.9	4.8	35
Puhoi	S4	3	2.3	27	-	-	-	-	-	-	-	8.5	5	35
Puhoi	S9	6	3.9	30	4	< 0.10	16	17900	106	< 0.10	7	8.5	4.5	30
		Total Recoverable										<63um		
		Copper	Lead	Zinc	Arsenic	Cadmium	Chromium	Iron	Manganese	Mercury	Nickel	Copper	Lead	Zinc
Puhoi	S9	6	4	31	-	-	-	-	-	-	-	11.1	5.6	35
Puhoi	S9	6	4.1	31	-	-	-	-	-	-	-	9.7	4.9	33
Waiwera	S1	8	9.6	51	7	< 0.10	17	18400	152	< 0.10	9	9.8	11.3	57
Waiwera	S1	7	9.4	49	-	-	-	-	-	-	-	8.9	10.4	53
Waiwera	S1	9	9.9	56	-	-	-	-	-	-	-	9.8	11.2	57
Waiwera	S3	2	2.6	25	8	< 0.10	9	13300	181	< 0.10	6	2.9	1.3	8
Waiwera	S3	2	2.3	24	-	-	-	-	-	-	-	3.8	2.1	17
Waiwera	S3	2	2.3	23	-	-	-	-	-	-	-	2.3	0.8	7

Waiwera	S8	3	2.8	24	7	< 0.10	10	13600	270	< 0.10	6	11	4.3	36
Waiwera	S8	3	3.2	26	-	-	-	-	-	-	-	9.2	3.7	31
Waiwera	S8	3	2.8	23	-	-	-	-	-	-	-	8.5	3.6	27
Waikopua	S1	< 2	3.1	15	2	< 0.10	5	4500	52	< 0.10	2	8.4	14.8	62
Waikopua	S1	< 2	2.7	13	-	-	-	-	-	-	-	8.7	14.4	56
Waikopua	S1	< 2	3	15	-	-	-	-	-	-	-	8.3	13.3	55
Waikopua	S3	< 2	3.6	16	3	< 0.10	5	4900	79	< 0.10	2	9	15	60
Waikopua	S3	< 2	4	17	-	-	-	-	-	-	-	8.7	14.5	58
		Total Recoverable										<63um		
		Copper	Lead	Zinc	Arsenic	Cadmium	Chromium	Iron	Manganese	Mercury	Nickel	Copper	Lead	Zinc
Waikopua	S3	< 2	3.5	15	-	-	-	-	-	-	-	8.4	14.1	56
Waikopua	S9	< 2	4.7	14	3	< 0.10	5	5500	53	< 0.10	2	7.3	15.3	48
Waikopua	S9	3.8	6.3	24	-	-	-	-	-	-	-	8.4	14.9	57
Waikopua	S9	< 2	5	16	-	-	-	-	-	-	-	8.1	14.1	54
Okura	S1	< 2	2.3	15	4	< 0.10	5	6100	52	< 0.10	3	5.7	7.1	38
Okura	S1	< 2	2.2	14	-	-	-	-	-	-	-	6.2	7.8	41
Okura	S1	< 2	2.4	15	-	-	-	-	-	-	-	6.6	7.7	44
Okura	S7	< 2	3.4	18	6	< 0.10	5	7500	68	< 0.10	3	7.6	9.9	51
Okura	S7	< 2	2.5	14	-	-	-	-	-	-	-	7.5	8.6	45
Okura	S7	< 2	3.1	17	-	-	-	-	-	-	-	7.5	10.5	53
Okura	S9	3	5	27	4	< 0.10	7	9300	103	< 0.10	4	7.5	9.5	50
Okura	S9	3	5.4	27	-	-	-	-	-	-	-	7.6	10	52

Okura	S9	3	5	26	-	-	-	-	-	-	-	7.6	9.8	49
Mangemangeroa	S3	5	9.4	44	6	< 0.10	13	12600	127	< 0.10	8	8.5	14.7	67
Mangemangeroa	S3	5	9	41	-	-	-	-	-	-	-	10.1	16	72
Mangemangeroa	S3	5	8.9	41	-	-	-	-	-	-	-	9.4	15.2	71
		Total Recoverable										<63um		
		Copper	Lead	Zinc	Arsenic	Cadmium	Chromium	Iron	Manganese	Mercury	Nickel	Copper	Lead	Zinc
Mangemangeroa	S6	4	9.6	42	7	< 0.10	12	12100	127	< 0.10	6	8.7	16.5	69
Mangemangeroa	S6	4	9	39	-	-	-	-	-	-	-	9.3	17.4	74
Mangemangeroa	S6	4	8.8	37	-	-	-	-	-	-	-	9.1	16.6	70
Mangemangeroa	S9	6	12.3	49	7	< 0.10	14	14000	153	< 0.10	7	7.8	14.2	62
Mangemangeroa	S9	6	12.7	50	-	-	-	-	-	-	-	8.1	13.8	63
Mangemangeroa	S9	6	12.8	50	-	-	-	-	-	-	-	7.4	14.2	58

9.5 Appendix 5: Polycyclic Aromatic Hydrocarbons (mg/kg, <0.5 mm) data

	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Orewa	Turanga	Puhoi	Waiwera	Waikopua	Okura	Mangemangeroa
Site	1	2	3	4	5	6	7	8	8	9	1	9	9	9
Total Organic Carbon (g/100 g, <0.5 mm)	0.2	0.13	0.47	0.17	0.31	0.61	0.28	0.3	0.95	0.45	1.14	0.45	0.5	0.87
Acenaphthene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Acenaphthylene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Anthracene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	<0.002	<0.002	0.004	<0.002	0.002	<0.002
Benzo[a]anthracene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.002	< 0.002	<0.002	0.003	<0.002	0.028	<0.002	0.008	0.005
Benzo[a]pyrene (BAP)	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	0.005	<0.002	0.037	0.002	0.01	0.007
Benzo[b]fluoranthene + Benzo[j]fluoranthene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.004	< 0.002	0.002	0.007	<0.002	0.049	0.003	0.013	0.011

	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Orewa	Turanga	Puhoi	Waiwera	Waikopua	Okura	Mangemangeroa
Benzo[g,h,i]perylene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	0.004	<0.002	0.022	<0.002	0.005	0.005
Benzo[k]fluoranthene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	0.003	<0.002	0.021	<0.002	0.006	0.005
Chrysene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.002	< 0.002	<0.002	0.003	<0.002	0.031	<0.002	0.008	0.006
Dibenzo[a,h]anthracene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	<0.002	<0.002	0.005	<0.002	<0.002	<0.002
Fluoranthene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.003	< 0.002	<0.002	0.007	<0.002	0.061	0.003	0.018	0.011
Fluorene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Indeno(1,2,3-c,d)pyrene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.002	< 0.002	<0.002	0.004	<0.002	0.022	<0.002	0.006	0.006
Naphthalene	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Whangateau	Orewa	Turanga	Puhoi	Waiwera	Waikopua	Okura	Mangemangeroa
Phenanthrene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	0.003	<0.002	0.013	<0.002	0.009	0.004
Pyrene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.004	< 0.002	<0.002	0.007	<0.002	0.063	0.003	0.017	0.01
Total PAH (<DL = 0)	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.002	0.046	0.000	0.356	0.011	0.102	0.070