Ruakaka Estuary

Estuary Monitoring Programme

Results from 2008 - 2010

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NORTHLAND REGIONAL COUNCIL

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1 Introduction

1.1 Background

Estuaries are very productive environments that play important roles in the functioning of coastal ecosystems (Knox, 1980). Estuaries also play important roles in the transport and transformation of nutrients, sediments and pollutants (Thrush *et al.* 2004). In addition estuaries are important economic, social and cultural assets, with harbour and estuarine systems such as Whangarei Harbour and the Bay of Islands contributing significantly to the Northland economy and the environment of its inhabitants.

Despite their many values for people and wildlife, Northland's estuaries have been heavily modified and impacted by human activities (Morrison 2005). Extensive vegetation clearance for agriculture and urban development has increased sediment, nutrient and metal contaminant loads reaching estuarine environments (Webster 2000, NRC 2003, Morrison 2005).

Because of the importance of estuaries to both man and the environment, and because of their susceptibility to anthropogenic impacts, Northland Regional Council (NRC) has recently implemented an estuary monitoring programme. The objective of this programme is to assess the health of Northland's estuaries and to provide baseline data, which can be used to track changes in the health of these systems over time.

The monitoring programme has been adapted from the Estuary Monitoring Protocol (Robertson *et al* 2002), which was developed by Cawthron for use by regional councils, and involves sampling the physical and chemical properties of the sediment, and the benthic invertebrate communities of representative intertidal habitats. This protocol has been adopted by a number of regional councils and there are now a number of similar estuarine monitoring programmes throughout New Zealand (Bolton-Ritchie 2007, Robertson & Stevens 2007). In addition, Auckland Regional Council and Environment Waikato have long established marine monitoring programmes, which use similar methodologies (Nicholls *et al.* 2002, Ford and Anderson 2005, Halliday *et* al. 2006, Kim 2007). The adoption of this standardised method ensures that the results are scientifically credible and comparable to those collected across New Zealand.

The results from this programme will provide resource planners, politicians and the public with information regarding the health of Northland's estuaries, identify environmental issues impacting these systems and enable informed decision making relating to activities which impact these systems. Importantly the programme will help assess the effectiveness of NRCs Coastal Plan and Water and Soil Plan and help determine if these plans need to be reviewed and improved.

The programme therefore addresses NRC's responsibilities under the Resource Management Act (1991) in relation to sustainable management principals set out in Part II (Section 5) and directives to monitor the state of the environment as set out Part IV (section 35; 1 & 2a section 30; 1a). The programme also addresses objective 3.1 of the New Zealand Biodiversity Strategy (2000), which relates to improving our knowledge of coastal and marine ecosystems.

1.2 Ruakaka Estuary

Ruakaka Estuary (Latitude 35^{o}54'S, Longitude 174^{o}27'E) is a drowned river valley system located on the east coast of the Northland peninsula, on the North Island of New Zealand. The system is approximately 'L' shaped with the main channel of the Ruakaka River running approximately north-south, protected from the Pacific Ocean by a large sand barrier. The estuary is connected to Bream Bay, a large coastal embayment, via a single inlet and is bordered on each side by sand spits.

The estuary covers an area of 0.5 km^2 and receives fresh water flow from the Ruakaka River, which drains a catchment of 92 km^2. The catchment consists primarily of flat land, covered predominantly with exotic grassland, for dairy and cattle faming (Figure 1) with two patches of native forest on steeper ground on the northern and southern margins of the catchment (Figure 1). GIS analysis of land use in the catchment, using the land use classification from the New Zealand Land Cover Database LCDB2 (New Zealand Land Cover Database 2001), indicated that in 2001, 68% (6237 Ha) of the catchment was covered by high producing exotic grassland, for cattle and dairy farming and that native forest covered a further 22% (2017 Ha) of the catchment (Appendix 1).

The small town of Ruakaka is located along the margin of the estuary. Ruakaka was originally a small beachside community but has expanded in recent years due to its proximity to the Marsden Point oil refinery and North Port. Recent subdivision and development has occurred within the town, particularly on the barrier system, and further urban and industrial development is expected within the catchment.

1.3 Site locations

Two sites were located in the Ruakaka Estuary (Figure 2). Site 1 (Tamure) was located on a sand/mud intertidal bank adjacent to the Ruakaka River channel (Figure 3) and site 2 (Ruakaka) was located on a sandy intertidal flat near the entrance of the estuary (Figure 4). Both sites were located on unvegetated intertidal habitat, away from known point source discharges. The site co-ordinates were fixed with Trimble GEO XT and marked by wooden stakes (Appendix 2).

Both sites were rectangular in shape and measured 60m by 30m, with the longest 'edge' of each site positioned parallel to the waters edge. To provide adequate dispersion of sampling within each site, sites were subdivided into 12 equal sized subplots (10m by 15m) and 10 of these 12 subplots were sampled at each site.

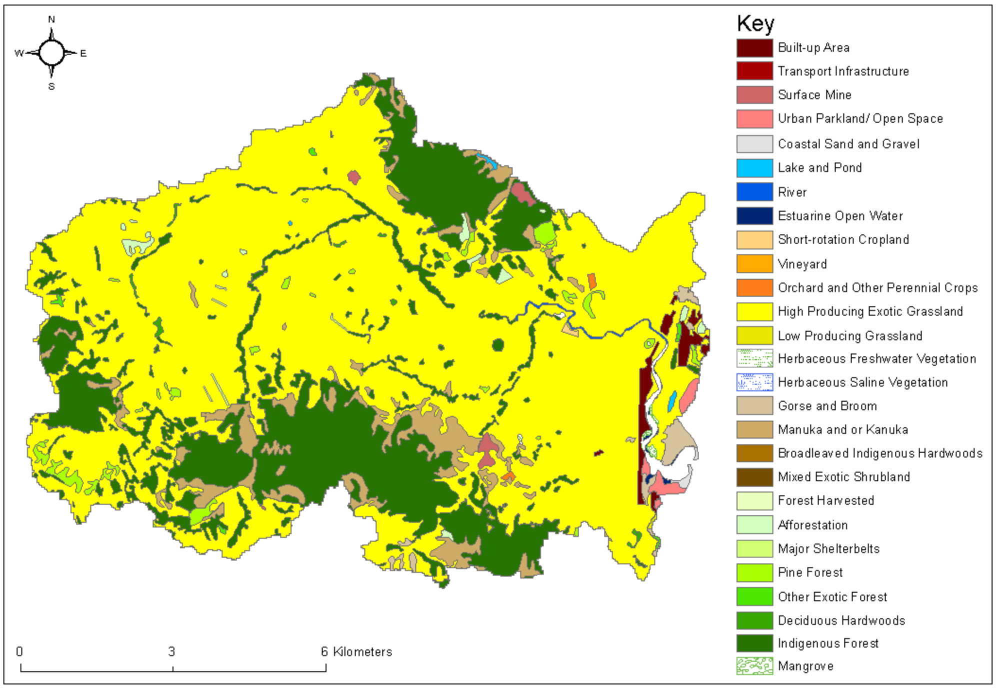

Figure 1. Land use in the Ruakaka Estuary catchment, from the New Zealand Land Cover Database (2001).

Figure 2. Location of sampling sites in Ruakaka Estuary.


Figure 3. Photograph of Tamure site.


Figure 4. Photograph of Ruakaka site.

2 Methods

2.1 Field methods

Methods and techniques used for sampling are consistent with those outlined in the Estuarine Monitoring Protocol by Robertson *et al*. (2002) and identical to those used in NRC's Estuary Monitoring Programmes in Kerikeri Inlet, Whangarei Harbour, Whangaroa Harbour and Arapaoa Estuary.

2.1.1 Sampling sites

Both sites were rectangular in shape and measured 60 m by 30 m, with the longest 'edge' of each site positioned parallel to the shoreline. To provide adequate dispersion of sampling within each site, sites were subdivided into 12 equal sized subplots (10 m by 15 m) and each year 10 of these 12 subplots were selected at random for sampling, as per Robertson *et al*. (2002). Samples were collected from the centre of these subplots.

2.1.2 Timing of sampling

Sites are monitored annually in March of each year. Both sites were sampled on 11/03/08, 01/03/2009 and 17/03/2010.

2.1.3 Benthic invertebrates

Core samples (each with a diameter of 150 mm and 150 mm deep) were collected from 10 of the 12 subplots, at each site using a perspex core. The 10 subplots were selected at random. Core samples were sieved through a 500 µm mesh and the material retained in the sieve brought back to NRC's laboratory for sorting and identification. All organisms retained were preserved with ethanol and stained with rose bengal. Initial sorting and identification of large organisms was conducted at NRC's laboratory. Small and/or cryptic fauna were later sent to an external taxonomic expert for identification.

Individuals identified by the external taxonomist as belonging to the taxon category 'Nereidae (unidentified juveniles)' were omitted from analysis because individuals in this group were a composite of several species. If this group had been included the adults would also need to be aggregated. Fish (Osteicthyes) and insects (Insecta) identified from the samples were also excluded as these animals are not marine benthic invertebrates.

2.1.4 Sediment characteristics

Surface sediment samples (consisting of the surface 2 cm) were collected, from five of the ten subplots, sampled for benthic infauna cores at each site (in 2008 ten sediment samples were collected). A sterile plastic scoop was used to collect approximately 200 grams wet weight at each subplot. The five subplots were selected at random. The samples were collected from within 1 m of the invertebrate core samples and stored on ice in zip lock bags. Sediment samples were analysed externally by Water Care Laboratory Services to determine sediment grain size, ash free dry weight (AFDW), total nitrogen, total phosphorus, total cadmium, total chromium, total copper, total zinc, total nickel and total lead. When results were below the laboratory detection limits, this was replaced with a value half of the detection limit. In 2008, sediment samples were analysed by Water Care Laboratory Services to determine sediment grain size using a wet sieving method. In 2009 and 2010 samples were analysed by Auckland University Services Ltd with a laser diffraction particle analyser (Malvern Mastersizer 2000). The following size fractions were determined: <63 µm (mud); 63 -230 µm (fine sand); 250-500 µm (medium sand); and >500 µm (coarse sand). The raw sediment data are presented in Appendix 3.

2.2 Data analysis

Sediment data is displayed as boxplots. The box displays the interquartile range (middle 50% of the data) with the middle line indicating the median. The upper whisker extends to the maximum data point within 1.5 box heights from the top of the box and the lower whisker extends to the minimum data point within 1.5 box heights from the bottom of the box. Outliers are depicted by an asterisk (*). Sediment results were assessed against the relevant Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) default trigger values (Australian New Zealand Environment Conservation Council 2000).

2.2.1 Univariate analysis

Differences between the proportion of mud, AFDW and the concentrations of nutrients and metals at the two sites and between the three sampling years were examined with analysis of variance (ANOVA), using Minitab 16 (Minitab Inc, Pennsylvania, USA). When significant differences were detected (p-value < 0.05), multiple comparisons between site means were conducted using Tukey's method. The Anderson-Darling test for normality and Bartlett's test for equal variance were conducted prior to ANOVA to ensure that the data complied with the assumptions of normality and homogeneity of variance. When necessary, transformations were performed to ensure that these assumptions were met. In situations when the results for the Anderson-Darling test found that the data was not normal but the plot of the residuals indicated that the data was approximately normal, Levene's test for equal variance was used. The results of tests for normality and equal variance of the physical and chemical properties of sediment samples are presented in Appendix 4. ANOVA was not performed on cadmium or zinc because all of the concentrations were below or very close to the detection limits. Pearson correlations were also performed on the $\log_{10}(n+0.1)$ transformed sediment grain size fractions, nutrient concentrations and metal concentrations to examine any relationships between these characteristics. Because the method for determining sediment grain size changed only 2009 and 2010 data was used. A large number of metal concentrations measured in 2008 were also below the laboratory detection limit.

2.2.2 Multivariate analysis

Principal component analysis (PCA) was performed using the sediment grain size fractions, nutrient concentrations and metal concentrations, in order to examine differences between the sediment properties of samples collected from the different sites. Prior to the PCA the sediment properties were $\log_{10}$ transformed in order to obtain data that was approximately normally distributed. The data was also normalised.

The benthic invertebrate infauna data were analysed using PRIMER v6.1.12 & PERMANOVA V1.0.2 (Plymouth Marine Laboratory, Plymouth, UK). Five measures of biological diversity were calculated: species richness (s); total individuals (n); Margalef's index (D); Pielou's evenness index (J'); and Shannon-Wiener diversity index (H'). The benthic invertebrate abundance data was also examined with non-metric multidimensional scaling (MDS) using a Bray-Curtis similarity matrix. Prior to this analysis, a square root transformation was performed on the benthic infauna abundance data in order to downplay the influence of numerically dominant taxa (Clark and Warwick 2001). PERMANOVA, using permutations, was then performed to test for any differences between the species assemblages at the two sites and between the three years. Tests of the homogeneity of dispersions (PERMDISP) between the different sites and the different years were also conducted. Primer's similarity percentage routine (SIMPER Clarke & Warwick, 1994) was also performed to examine which taxa typified the community at each site and which taxa contributed most to the separation of the communities at the different sites. A distance-based linear model (DISTLM) was then used to model the relationship between the benthic invertebrate data and the $\log_{10}$ transformed sediment grain size fractions, nutrient concentrations and metal concentrations (McArdle and Anderson, 2001). Because the method for determining sediment grain size changed, DISTLM was performed using only 2009 and 2010 data. Cadmium was also excluded from the analysis because most of the concentrations measured were below the laboratory detection limits.

3 Results

3.1 Sediment physical properties

In 2008 sediment grain size was determined by wet sieving, but in 2009 and 2010 grain size was determined with a laser diffraction particle analyser. In 2008 sediment collected from Ruakaka had a high proportion of medium sand (79%) and small proportions of fine sand (14%) and coarse sand (6%). In 2009 and 2010 sediment collected from Ruakaka also had a high proportion of medium sands (~60%) but slightly higher proportions of fine sand (~25%) and coarse sands (11-13%). It is not clear whether the difference in the proportion of the different sediment fractions at the Ruakaka site is the result of the change of method or due to natural variation. Sediments collected from Tamure had similar proportions of the different grain size fractions in all three years. The sediment consisted of approximately 5% mud, 45 % fine sand, 40% medium sand and 10% coarse sand in all three years (Figure 5).

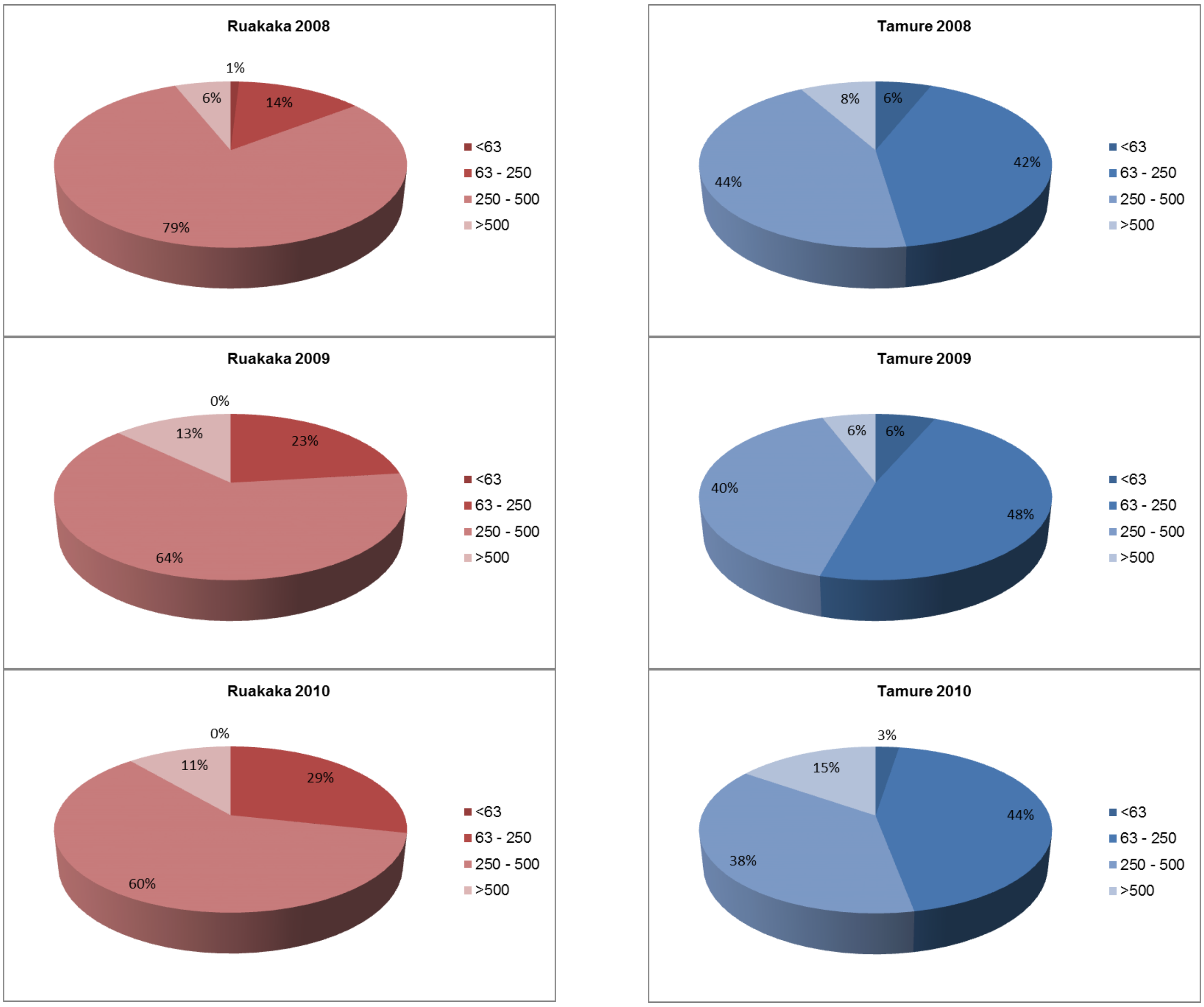

Figure 5. Mean sediment grain size characteristics of sediment samples collected from two sites in Ruakaka Estuary 2008-2010. *In 2008 sediment grain size was determined by wet sieving. In 2009 and 2010 grain size was determined with a laser diffraction particle analyser.

The different grain size properties of sediment collected from the two sites probably reflects the different hydrodynamic environments at the site locations. The Ruakaka site is located close to the entrance of the estuary in a relatively high energy environment, while the Tamure site is located further up the river in a more sheltered tidal creek environment, where higher rates of sediment deposition are likely.

Principal component analysis performed using normalised $\log_{10}(n+0.1)$ transformed sediment grain size characteristics from 2009-2010 separated the samples into two groups, which corresponded to the different sampling sites (Figure 6). Samples collected from Ruakaka were more tightly grouped than samples collected from Tamure, which indicates that the sediment characteristics at Ruakaka were more homogeneous, than the sediment at Tamure. Observations during site visits also found that the surface sediment at Ruakaka was very uniform with sand covering the entire site, while the site at Tamure was more heterogeneous with sand covering the western section of the site closest to the channel and an area of fine sediment on the eastern section of the site in an area of depression.

The first principal component explained approximately 55% of the variation in the grain size characteristics and examination of the eigenvalues indicates that the location of a sample along the first PC axis is influenced positively by both mud (< 63 µm) and fine sand (63-250 µm) and negatively by medium sand (250-500 µm) and coarse sand (>500 µm). Samples collected from Tamure generally had higher values along the first PC axis indicating that these samples had higher proportions of mud (< 63 µm) and fine sand (63-250 µm) fractions. In contrast samples from Ruakaka generally had negative values on the first PC axis indicating that these samples had higher proportions of medium sand (250-500 µm) and coarse sand (>500 µm) fractions. The second PC axis accounted for 36% of the variation and examination of the eigenvalues indicates that the location of a sample along the second PC axis is influenced most by medium sand (positive) and coarse sand (negative). One sample collected from Tamure in 2010 had a particular low value on the second PC axis. This suggests that this sample had particularly high proportions of coarse sand and low proportion of medium sand. This sample was collected from the centre of the site and no field notes were made during sample collection that the sediment characteristics at this subplot were noticeable different to the rest of the site.

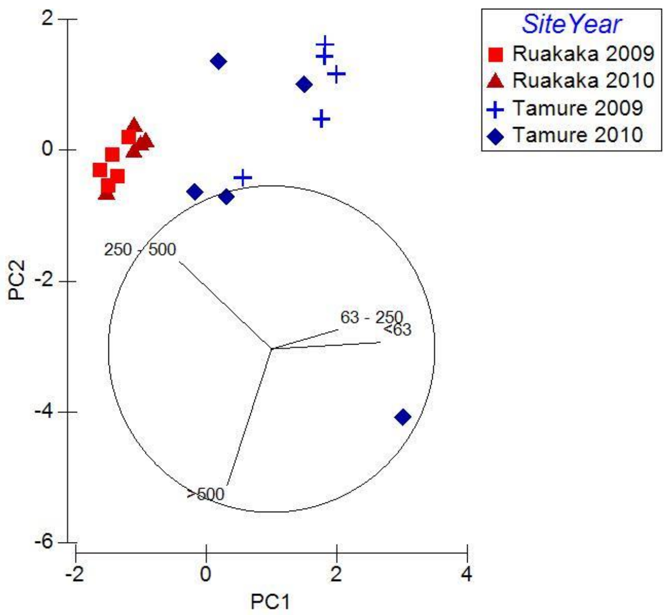

Figure 6. Principal component analysis (PCA) of normalised $\log_{10}(n+0.1)$ transformed sediment grain size characteristics of sediment samples collected from two sites in Ruakaka Estuary in 2009-2010.

3.2 Sediment nutrient concentrations and AFDW

3.2.1 Total nitrogen

ANZECC guidelines do not include trigger values for nitrogen in sediments and there are currently no nationally accepted guideline values for nitrogen concentrations in marine sediment. However Robertson and Stevens (2007) have developed their own classifications for sediment nitrogen concentrations and this has been used in similar monitoring programmes by Southland Regional Council and Tasman District Council. In their classification concentrations below 500 mg/kg are classified as 'very good', concentrations between 500-2000 mg/kg as 'low to moderately enriched', concentrations between 2000-4000 mg/kg as 'enriched' and concentrations above 4000 as 'very enriched'. In 2008 the concentrations of nitrogen at both sites were at levels which indicate that these sites were 'low to moderately enriched', using this criteria. In 2009 and 2010 the mean nitrogen concentrations were at levels that indicate that both sites were 'very good',

The mean concentration of nitrogen at Tamure (598 mg/kg) appeared to be higher than at Ruakaka (342 mg/kg) (Figure 7) and ANOVA found a significant difference between the two sites ($F_{1, 24}$ = 27.20, P-value < 0.001). Nitrogen concentrations also appeared to be higher in 2008 and ANOVA found a significant difference between the three years ($F_{2, 24}$ = 36.41, P-value < 0.001). Pairwise comparisons indicated that the nitrogen concentration in 2008 (763 mg/kg) was significantly higher than in both 2009 (358 mg/kg) and 2010 (289 mg/kg). There was no significant interaction between the two factors (site and year) ($F_{2, 24}$ = 2.59, P-value = 0.096).

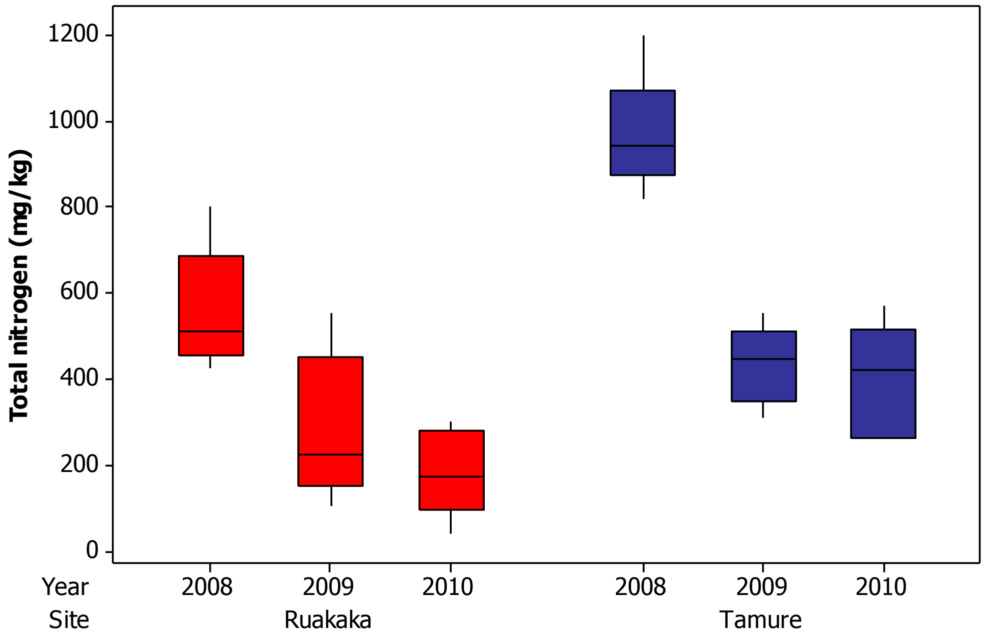

Figure 7. Concentrations of total nitrogen (mg/kg dry weight) in sediments collected from two sites in Ruakaka Estuary River in 2008-2010.

3.2.2 Total phosphorus

ANZECC guidelines do not include trigger values for phosphorus in sediments and there are currently no nationally accepted guideline values for phosphorus in marine sediment. However Robertson and Stevens (2007) have also developed their own classifications for sediment phosphorus concentrations and this has been used in similar monitoring programmes by Southland Regional Council and Tasman District Council. In their classification concentrations below 200 mg/kg are classified as 'very good', concentrations between 200-500 mg/kg as 'low to moderately enriched', concentrations between 500-1000 mg/kg as 'enriched' and concentrations above 1000 as 'very enriched'. Under this classification system the concentrations of phosphorus measured at the Ruakaka site were at levels which indicate it was 'very good', in all three years. At Tamure, the phosphorus concentrations indicate the site was 'very good' in 2008, and 'low to moderately enriched' in 2009 and 2010.

The mean total phosphorus at Tamure (200 mg/kg) was higher than at Ruakaka (71 mg/kg) (Figure 8) and ANOVA found a significant difference between the two sites ($F_{1, 24}$ = 86.43, P-value < 0.001). The concentrations of phosphorus also appeared to decrease over the three years at both sites (Figure 8) and ANOVA found a significant difference between years ($F_{2, 24}$ = 3.69, P-value = 0.040). Pairwise comparisons indicted that the concentration of phosphorus in 2008 was significantly lower than the concentration in 2009. No significant interaction between the two factors (site and year) was found ($F_{2, 24}$ = 2.10, P-value = 0.144).

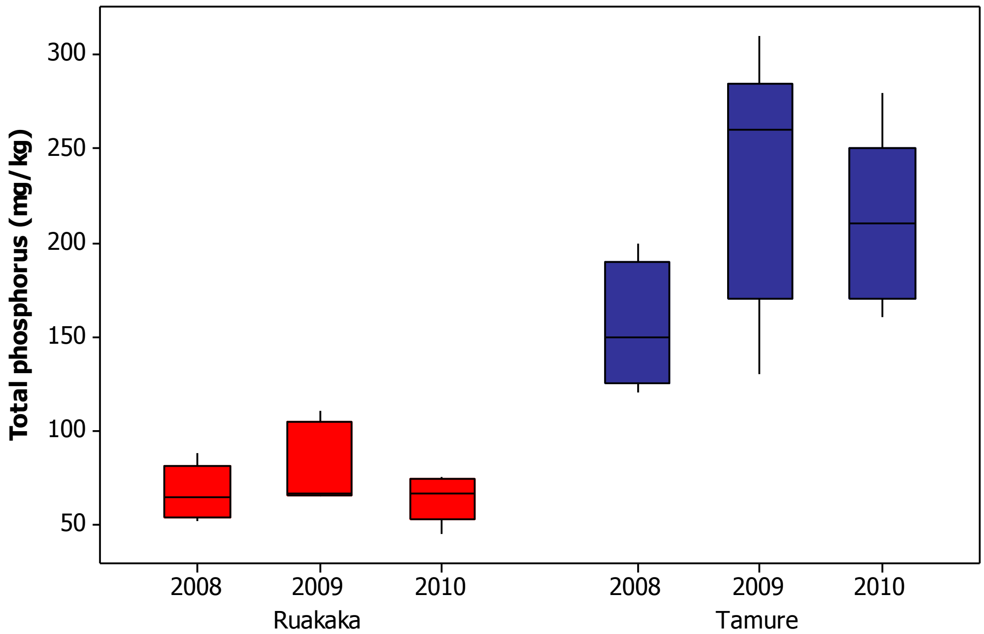

Figure 8. Concentrations of total phosphorus (mg/kg dry weight) in sediments collected from two sites in Ruakaka Estuary in 2008-2010.

3.2.3 Ash free dry weight

ANZECC guidelines do not include trigger values for ash free dry weight in sediments and there are currently no nationally accepted guideline values. The mean ash free dry weight at Tamure (2.4) was higher than at Ruakaka (1.0) in all three years (Figure 9) and ANOVA found a significant difference between ash free dry weight at the two sites ($F_{1, 24} = 31.82$, P-value < 0.001). ANOVA found no a significant difference between the three years ($F_{2, 24} = 0.38$, P-value = 0.686) and no significant interaction between the two factors (site and year) ($F_{2, 24} = 0.65$, P-value = 0.531).

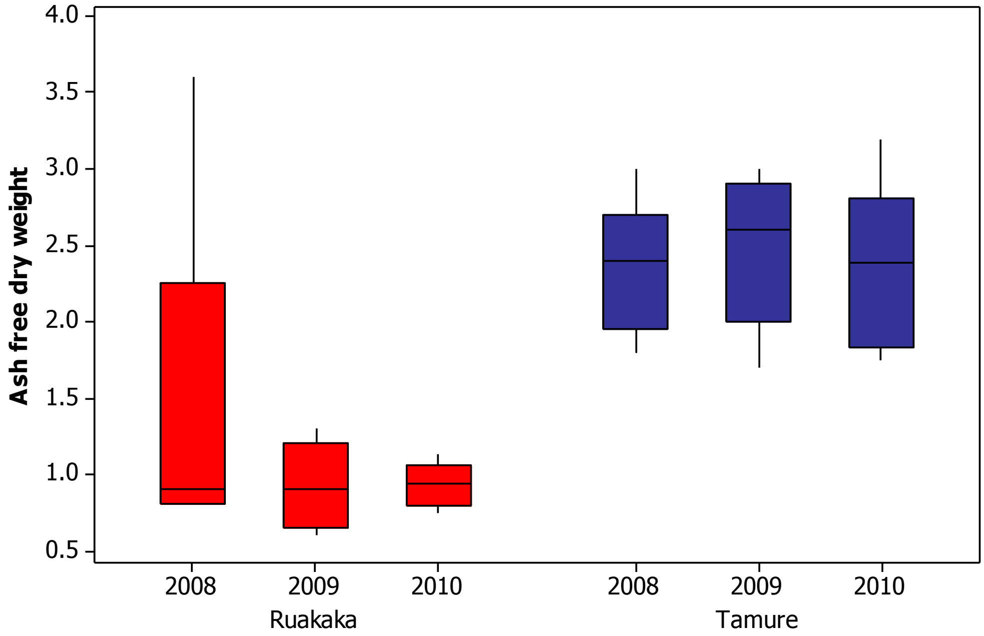

Figure 9. Ash free dry weight (%) of sediments collected from two sites in Ruakaka Estuary in 2008-2010.

3.2.4 PCA using nutrient concentrations

Principal component analysis performed using $\log_{10}(n+0.1)$ concentrations of total nitrogen and total phosphorus separated the sediment samples into two groups (Figure 10), which corresponded to the two sampling sites. There was also some further separation of samples according to the different sampling years. In particular samples collected in 2008 were grouped quite tightly but samples collected in 2009 and 2010 were more widely spaced. The first principal component explained approximately 71% of the variation in the $\log_{10}$ nutrient concentrations. The value of a particular sample along the first PC axis is therefore a good measure of the degree of nutrient enrichment of the sediment, with increasing values along PC1 corresponding to an increase in nutrient concentrations in the sediment. Samples from Tamure generally had the highest values along the first PC axis (Figure 10) indicating that these samples had the highest concentrations of nutrients.

The second principal component explained approximately 29% of the variation of these variables and examination of the eigenvalues indicates that the location of a sample along the second PC axis is influenced positively by phosphorus and negatively by nitrogen. Samples collected in 2008 had lower values on the second PC axis which suggests that concentrations of nitrogen concentrations were higher and phosphorus was lower in 2008 compared to 2009 and 2010. This corroborates the results of the statistical analysis and the patterns described in sections 3.2.1 and section 3.2.2.

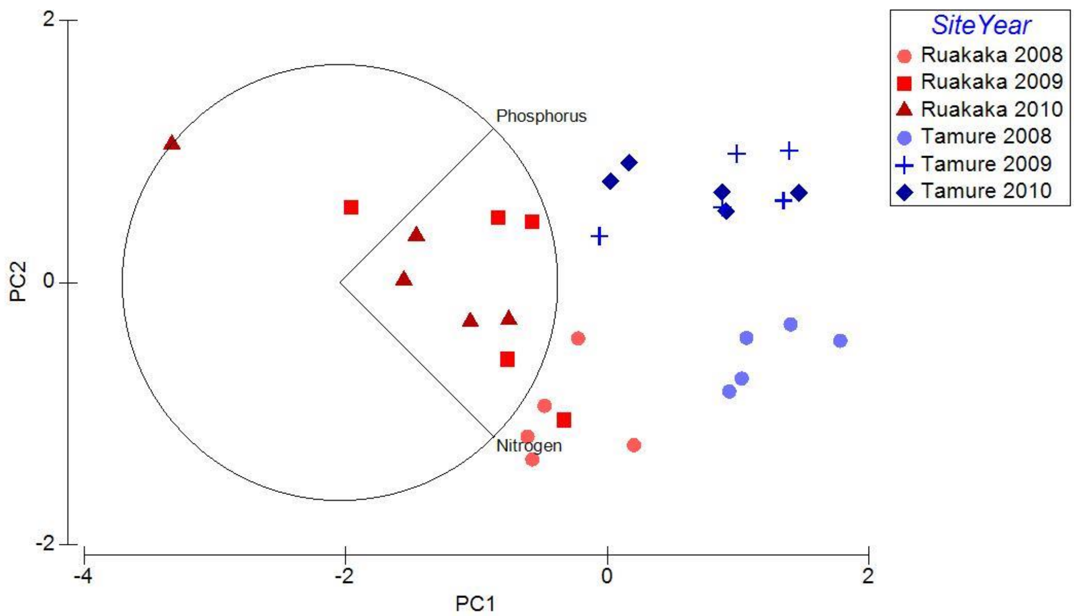

Figure 10. Principal component analysis (PCA) of normalised $\log_{10}$ (n+0.1) transformed nitrogen and phosphorus concentrations of sediment samples collected from two sites in Ruakaka Estuary in 2008-2010.

3.3 Sediment metal concentrations

3.3.1 Cadmium

All the cadmium concentrations were below the ANZECC ISQG low effect trigger value of 1.5 mg/kg and the threshold effect level of 0.68 mg/kg developed by MacDonald *et al*. (1996). All of the cadmium concentrations measured in 2008 and 2010 were below the detection limit and the concentrations in 2009 were either below the detection limit or very low (Figure 11). The apparent increase in cadmium concentrations in 2010 is therefore an artefact of changes in the laboratory detection limits. Because the concentration of cadmium was below or very close to the detection limit on a number of occasions no statistical analysis was performed on these results.

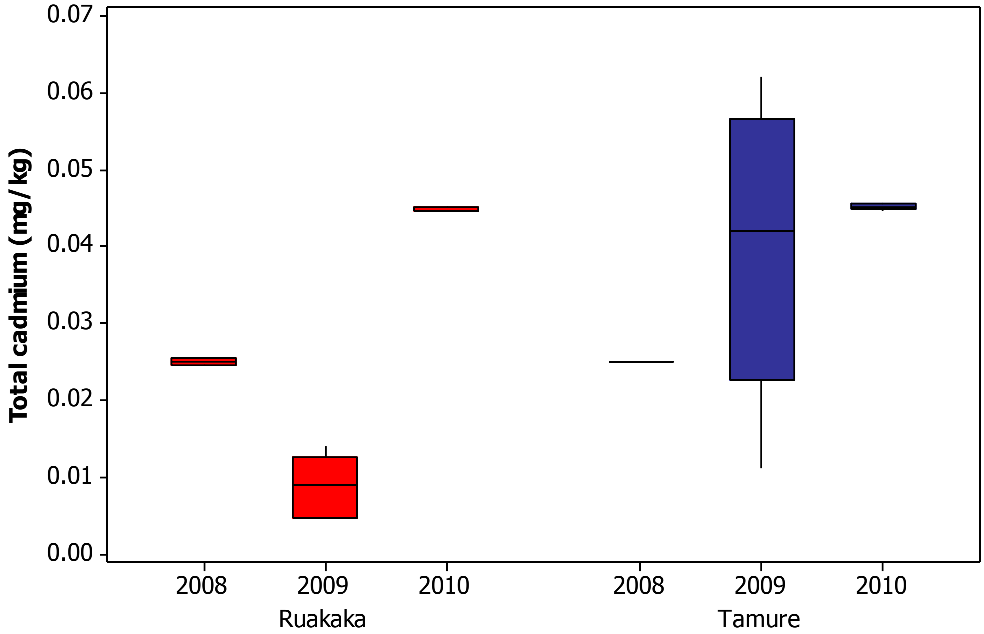

Figure 11. Concentrations of total cadmium (mg/kg dry weight) in sediments collected from two sites in Ruakaka Estuary in 2008-2010. Note: All values in 2008 and 2010 were below detection levels.

3.3.2 Chromium

All of the chromium concentrations were below the ANZECC ISQG low effect trigger value of 80 mg/kg and the and the threshold effect level of 52.3 mg/kg developed by MacDonald *et al*. (1996). The concentration of chromium at Tamure (5 mg/kg) was slightly higher than at Ruakaka (3 mg/kg) (Figure 12) and ANOVA found a significant difference between the two sites ($F_{1, 24}$ = 114.88, P-value < 0.001). There was no significant difference between the three years ($F_{2, 24}$ = 0.46, P-value = 0.635) and no significant interaction was found ($F_{2, 24}$ = 0.74, P-value < 0.486).

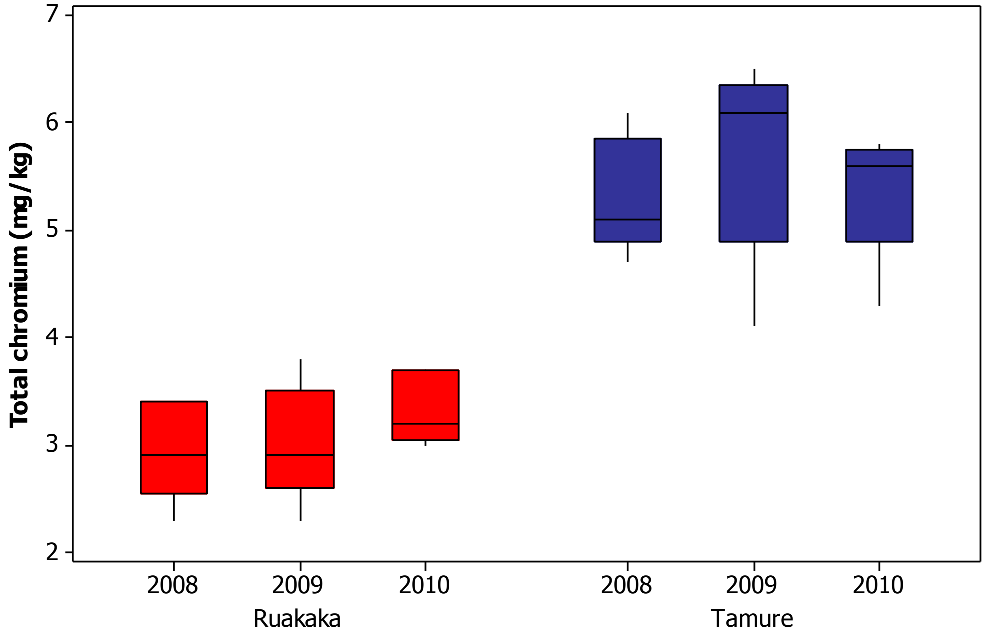

Figure 12. Concentrations of total chromium (mg/kg dry weight) in sediments collected from two sites in Ruakaka Estuary in 2008-2010.

3.3.3 Copper

All of the copper concentrations measured were below the ANZECC ISQG low effect trigger value of 65 mg/kg and the threshold effect level of 18.7 mg/kg developed by MacDonald *et al*. (1996). All of the copper concentrations measured at Ruakaka were below the detection limit and three samples analysed from Tamure in 2008 were below the detection limit. Because the concentration of copper was below or very close to the detection limit on a number of occasions no statistical analysis was performed on these results.

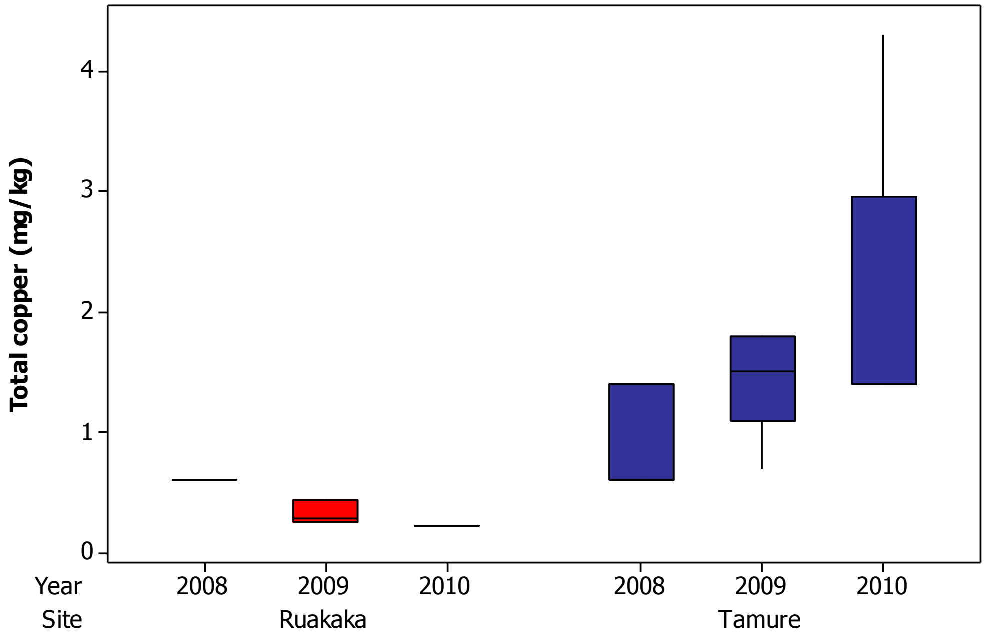

Figure 13. Concentrations of total copper (mg/kg dry weight) concentrations of sediments collected from two sites in Ruakaka Estuary in 2008-2010. Note: All samples analysed at Ruakaka were below detection levels.

3.3.4 Nickel

The nickel concentrations at both sites were low and well below the ANZECC ISQG low effect trigger value of 21 mg/kg and the threshold effect level of 15.9 mg/kg developed by MacDonald *et al*. (1996). The mean concentration of total nickel at Tamure (1.8 mg/kg) was slightly higher than at Ruakaka (0.9 mg/kg) (Figure 14) and ANOVA found a significant difference between the two sites ($F_{1, 24}$ = 55.11, P-value < 0.001). There also appeared to be a small increase in concentrations of nickel in 2010 and ANOVA also found a significant difference between the three years ($F_{2, 24}$ = 10.09, P-value = 0.001). Pairwise comparisons found that the concentration of in 2010 was significantly higher than in both 2009 (1.1 mg/kg) and 2008 (1.1 mg/kg). There was no significant interaction between the two factors (site and year) ($F_{2, 24}$ = 1.26, P-value = 0.303).

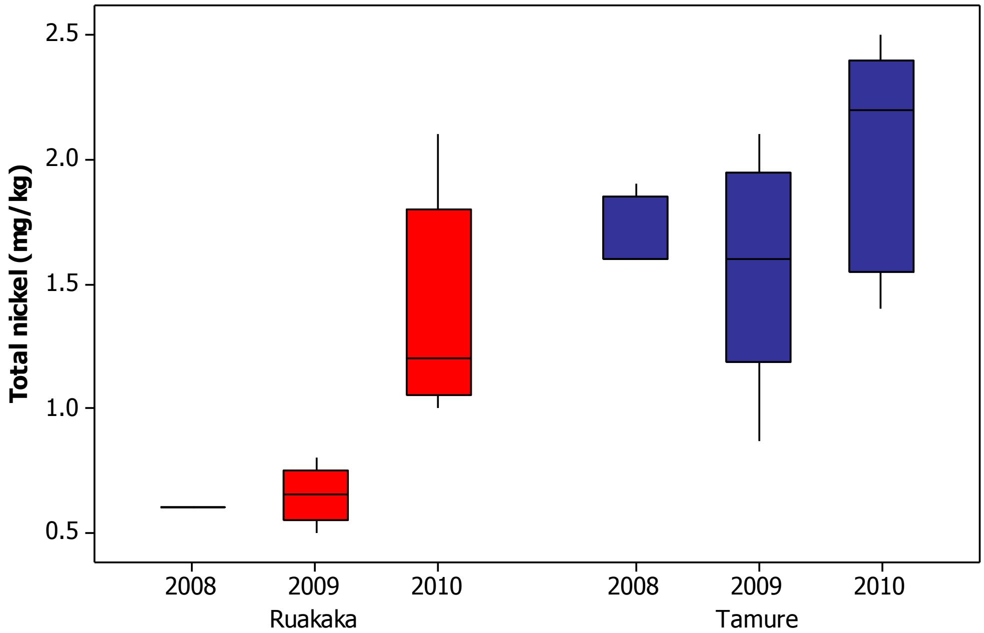

Figure 14. Concentrations of total nickel (mg/kg dry weight) in sediments collected from two sites in Ruakaka Estuary in 2008-2010. Note: All samples analysed at Ruakaka in 2008 were below detection levels.

3.3.5 Lead

The concentrations of lead at both sites were low and below the ANZECC ISQG low effect trigger value of 50 mg/kg and the threshold effect level of 30.2 mg/kg developed by MacDonald *et al*. (1996). In 2008, all concentrations of lead were below the laboratory detection limits (5 mg/kg). The apparent decrease in concentrations in 2009 and 2010 is therefore an artefact of an increase in the detection limits. The concentrations of lead in 2009 and 2010 appeared to be slightly higher at Tamure than at Ruakaka (Figure 15) but ANOVA found no significant difference between the two sites ($F_{1, 24} = 0.314$, P-value < 0.141). ANOVA also found no significant differences between the two years (2009 and 2010) ($F_{2, 24} = 1.08$, P-value = 0.314) and there was no significant interaction between the two factors (site and year) ($F_{2, 24} = 1.08$, P-value = 0.314).

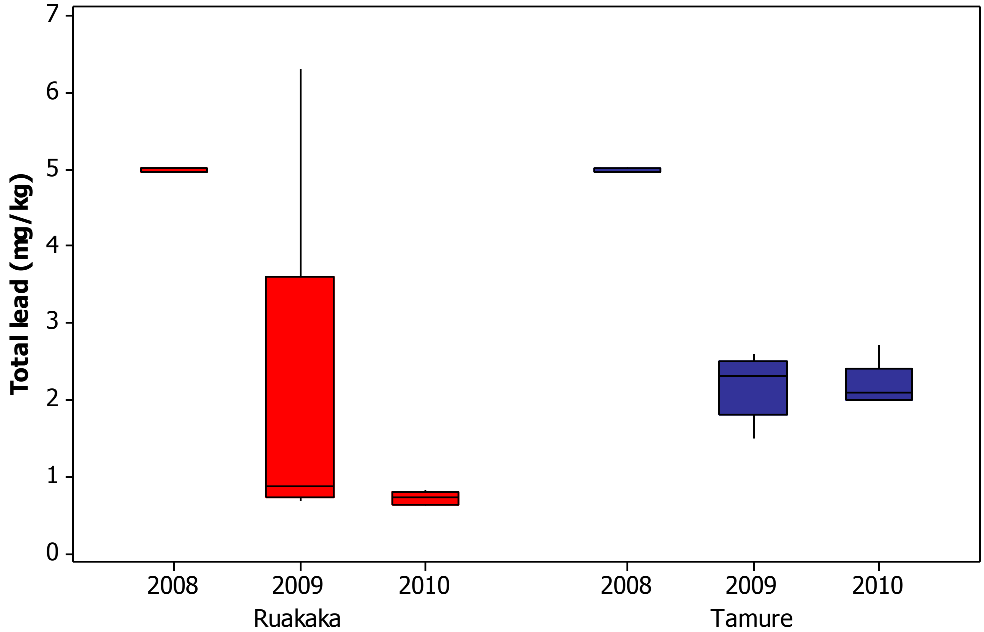

Figure 15. Concentrations of total lead (mg/kg dry weight) in sediments collected from two sites in Ruakaka Estuary in 2008-2010. Note: All values in 2008 were below detection levels.

3.3.6 Zinc

All the zinc concentrations were below the ANZECC ISQG low effect trigger value of 200 mg/kg and the threshold effect level of 124 mg/kg developed by MacDonald *et al*. (1996). All of the zinc concentrations measured in 2008 were below the detection limit and four of the samples analysed at Ruakaka in 2009 were below the detection limit. The apparent decrease in zinc (Figure 16) is therefore an artefact of a lower laboratory detection limits in 2009 and 2010. Results from samples that were above the laboratory detection limits suggest that the concentration of zinc at Tamara was slightly higher than at Ruakaka. Because the concentration of zinc was generally below or very close to the detection limit on a number of occasions no statistical analysis was performed on these results.

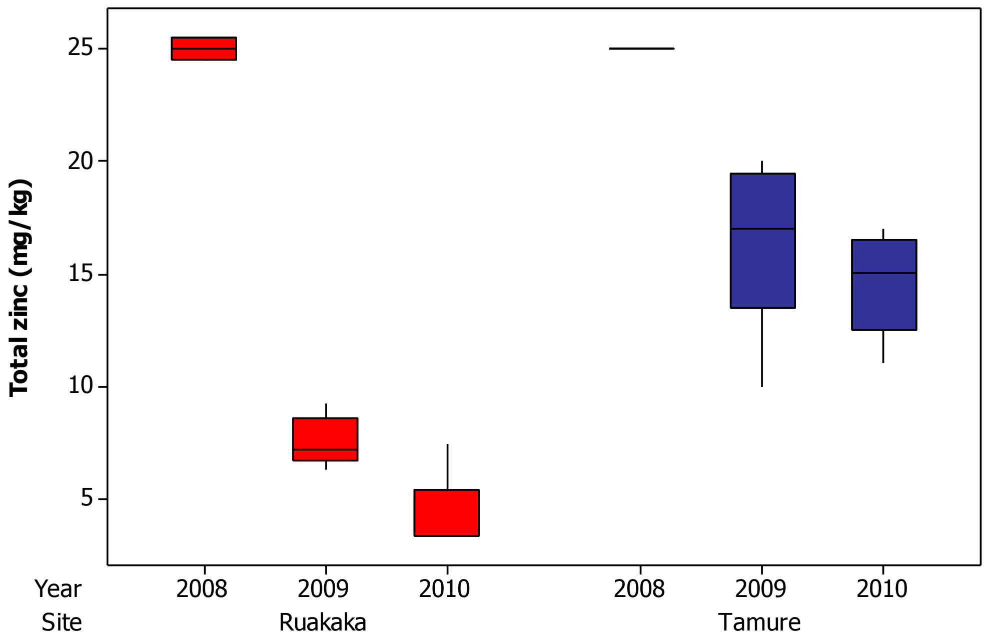

Figure 16. Concentrations of total zinc (mg/kg dry weight) in sediments collected from two sites in Ruakaka Estuary in 2008-2010. Note: All values in 2008 were below detection levels.

3.3.7 Identification of a pollution gradient using PCA

Principal component analysis performed using $\log_{10}$ (n+0.1) transformed metal concentrations separated the samples into groups, which corresponded closely to the different sampling sites and years (Figure 17). The first principal component explained approximately 58% of the variation in the $\log_{10}$ metal concentrations. The value of a particular sample along the first PC axis is therefore a reasonable measure of the degree of metal contamination of the sediment, with increasing values along PC1 corresponding to an increase in metal concentrations. Samples from Tamure generally had the highest values along the first PC axis indicating that these samples had the highest concentrations of metals. Samples collected from Ruakaka in 2009 and 2010 had lower values along the first PC axis than samples collected in 2008, suggesting that there was a decrease in metal contaminant levels since 2008.

The second principal component explained approximately 30% of the variation in the $\log_{10}$ metal concentrations and examination of the eigenvalues indicates that the location of a sample along the second PC axis is influenced most by lead (negative), zinc (negative) and nickel (positive). Samples collected from Ruakaka and Tamure in 2009 and 2010 had higher values along the second PC axis than samples collected in 2008, suggesting that there was a decrease in lead and zinc concentrations and an increase in nickel. The apparent decrease in the concentrations of lead and zinc was an artefact of changes in the laboratory detection limits described in section 3.3.5 and 3.3.6. The increase in nickel corroborates the results of the ANOVA and the pattern described in section 3.3.4.

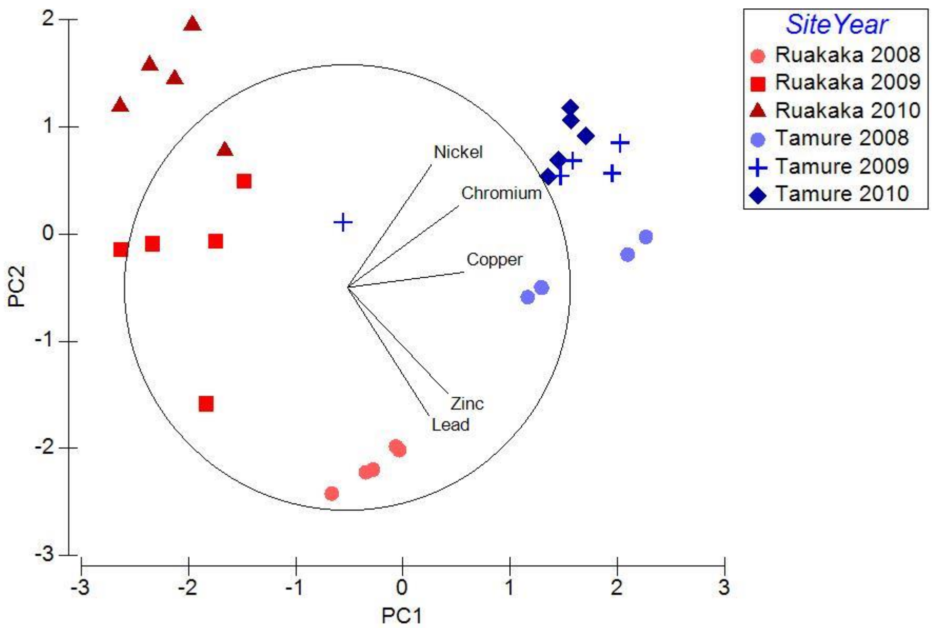

Figure 17. Principal Component Analysis (PCA) of $\log_{10}$(n+0.1) metal concentrations of sediment samples collected from two sites in Ruakaka Estuary, 2008-2010.

3.4 Inter-relationship between physical and chemical sediment properties

3.4.1 Pearson correlations

Pearson correlations carried out on $\log_{10}(n+0.1)$ transformed physical and chemical sediment properties indicated that mud was positively correlated to most sediment parameters (Table 1). The percentage of mud had strong positive correlations (>0.8) with AFDW, phosphorus, chromium and zinc. AFDW, phosphorus, zinc and chromium were also all strongly positively correlated to each other.

Table 1. Pearson correlation matrix of $\log_{10}(n+0.1)$ transformed mud, nutrient and metal concentrations of samples collected from two sites in Ruakaka Estuary in 2009 and 2010. Percentage of mud (<63 µm) ash free dry weight (AFDW), total nitrogen (N), total phosphorus (P) cadmium (Cd), chromium (Cr) copper (Cu) nickel (Ni) lead (Pb) and zinc (Zn). Bold indicates correlation coefficients > 0.8.

	< 63 µm	AFDW	N	P	Cr	Cu	Ni	Pb
AFDW	**0.839**							
N	0.599	0.694						
P	**0.856**	**0.984**	0.698					
Cr	**0.828**	**0.942**	0.591	**0.945**				
Cu	0.455	0.624	0.339	0.641	0.597			
Ni	0.449	0.665	0.282	0.641	0.711	0.441		
Pb	0.306	0.313	0.716	0.356	0.209	0.277	0.148	
Zn	**0.859**	**0.906**	0.673	**0.940**	**0.919**	0.614	0.551	0.368

3.4.2 PCA using all sediment properties

Principal component analysis performed using percentage $\log_{10}(n+0.1)$ sediment grain size fractions, nutrient concentrations and metal concentrations (excluding cadmium) separated the samples into two groups along the first PC axis which corresponded to the two sample sites (Figure 18). Samples collected at Ruakaka appeared to be more tightly grouped than samples from Tamure. This suggests that the sediment characteristics at Ruakaka are more homogeneous than at Tamure.

The first principal component explained approximately 66% of the variation in the sediment properties of the sediment collected from Ruakaka estuary in 2009-2010. Examination of the eigenvalues indicates that the location of a sample along the first PC axis is influenced positively by all of the sediment properties except medium sand and coarse sand. Increasing values along the first PC axis therefore represent increasing proportions of mud, fine sand and increasing concentrations of all metals, nitrogen, phosphorus and ash free dry weight. Samples from Tamure all had higher values along the first PC axis (Figure 18), which indicates that these samples had higher proportions of mud, fine sand and higher concentrations of metals, nitrogen, phosphorus and ash free dry weight than samples collected from Ruakaka.

The second principal component explained 13% of the variation, with the location of a sample on this axis influenced most by concentrations of medium sand (positive), and coarse sand (negative). Samples collected from Ruakaka generally had similar values on the second PC axis, while samples from Tamure, were spread more widely along this axis. One sample collected from Tamure in 2010 had a particular low value on the second PC axis, similar to the PCA described in section 3.1. Again this suggests that this sample had particularly high proportions of coarse sand and low proportion of medium sand.

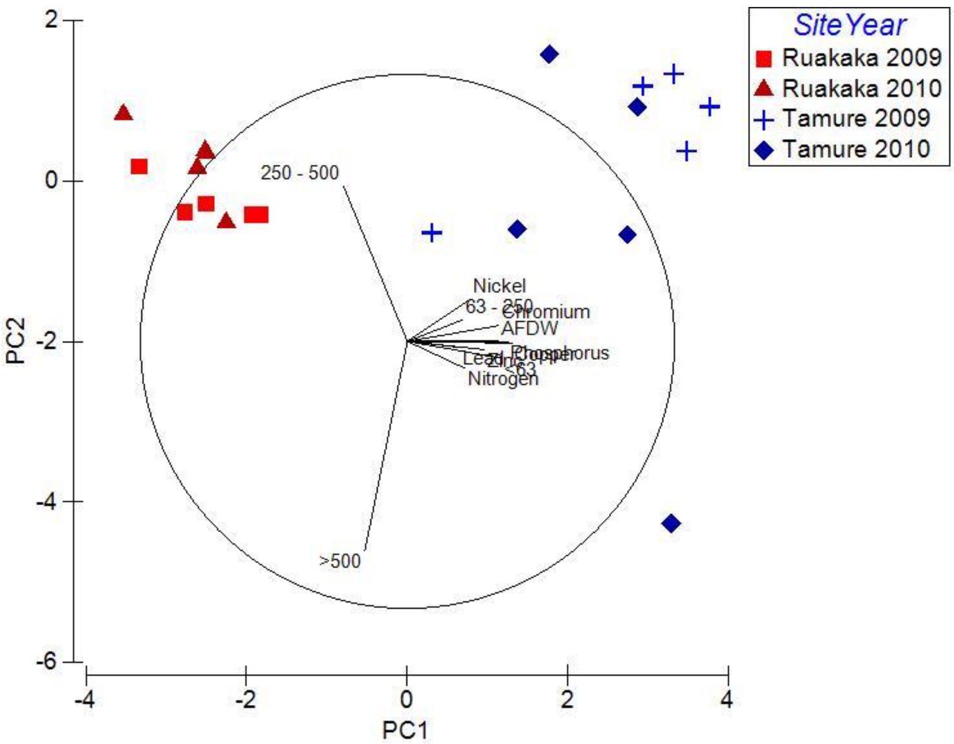

Figure 18. Principal Component Analysis (PCA) of normalised $\log_{10}(n+0.1)$ sediment grain size, metal and nutrient concentrations of sediment samples collected from two sites in Ruakaka Estuary in 2008-2010.

3.5 Benthic infauna

A total of 8358 individuals belonging to 65 taxa were identified from samples collected from Ruakaka Estuary between 2008 and 2010. A higher mean number of individuals, number taxa, Margalef's index and Shannon-Wiener index were found at Tamure (Table 2). The mean Pielou's evenness index and Simpson's index were similar at both sites (Table 2).

Table 2. Mean ± standard error of: the total number of taxa (S); the number of individuals (N); Margalef's index (D); Pielou's evenness index (J'); and the Shannon-Wiener index (H') and Simpsons index (λ) of benthic infauna collected from two sites in Ruakaka Estuary between 2008-2010.

	S	N	D	J'	H	λ
Ruakaka 2010	16	34	4.22	0.93	2.57	0.93
Ruakaka 2009	13	31	3.40	0.90	2.26	0.90
Ruakaka 2008	11	30	2.91	0.88	2.08	0.87
Tamure 2010	17	40	4.35	0.92	2.57	0.93
Tamure 2009	16	43	4.02	0.91	2.51	0.91
Tamure 2008	18	38	4.71	0.93	2.68	0.94

MDS ordination (Figure 19) of the benthic abundance data showed a clear separation of samples from the two sample sites, which suggests that the communities at the two sites are distinct. Two samples collected from Tamure appeared to be quite distinct from the other samples. Both these samples were collected from the same subplot (but in different years). This subplot is located on the corner of the site.

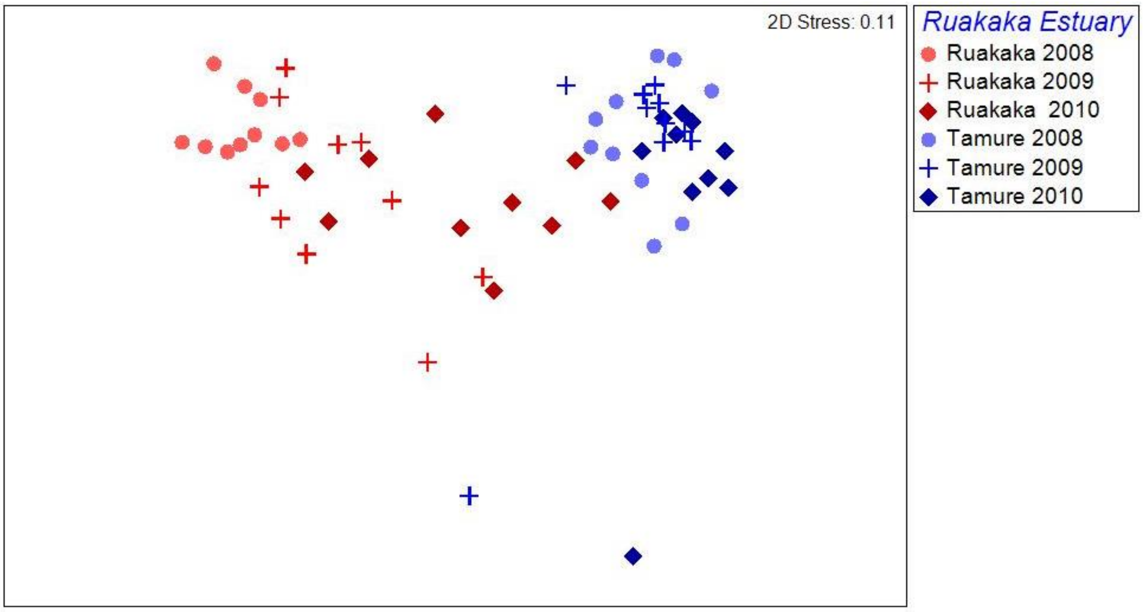

Figure 19. Non-metric multidimensional scaling (MDS) ordination of Bray-Curtis similarities from square root transformed species abundance data collected from two sites in Ruakaka Estuary, 2008-2010. Sites closest together are more similar.

PERMANOVA showed that there were significant differences between the two sites (Pseudo $F_{1,\ 54}$ 46.831, P-value < 0.001) and between the three years (Pseudo $F_{2,\ 54}$ 6.6206, P-value < 0.001). Pairwise tests indicated that the benthic assemblages' at the two sites were significantly different from each other in all three years. The communities at each of the sites were also different in each of the three years. The average similarity at Tamure (58%) was higher than at Ruakaka (51%) and noticeably higher than the between site similarity (Table 3). The within year similarity was also generally higher than the between year similarity (Table 4).

Table 3. Mean within site similarity of benthic invertebrate data (2008-2010) collected from Ruakaka Estuary, in 2008-2010.

	Ruakaka	**Tamure**
Ruakaka	51	
Tamure	30	58

Table 4. Mean between year similarity of benthic invertebrate data collected from the Ruakaka Estuary.

	2010	**2009**	**2008**
2010	48		
2009	43	43	
2008	38	40	43

The MDS ordination (Figure 19) also suggested that samples collected from Ruakaka were more dispersed compared to the samples collected from Tamure and the test of homogeneity of dispersions (PERMDISP) indicated that there was a significant difference (Pseudo $F_{1, 57}$ 4.7929, P-value = 0.039) (Table 5). Dispersion in 2008 and 2009 was slightly higher than in 2010 (Table 6) but PERMDISP indicated that there was no significant difference in the dispersion between the three years (Pseudo $F_{2, 57}$ 2.6752, P-value = 0.087).

Table 5. Mean dispersion of benthic invertebrate communities at two sites in Ruakaka Estuary, 2008-2010.

	Mean dispersion	Standard error
Ruakaka	35	1.43
Tamure	29	2.15

Table 6. Mean dispersion of benthic invertebrate communities in different years from two sites in Ruakaka, in 2008-2010.

	Mean dispersion	Standard error
2010	36	2.56
2009	41	1.35
2008	42	1.09

3.5.1 Ruakaka 2010

In 2010, 1046 individuals belonging to 36 taxa were identified from cores collected at Ruakaka. The cockle *Austrovenus stutchburyi* and the pipi *Paphies australis* were ubiquitous and numerically dominant in 2010 (Table 7). These two taxa were also identified by the SIMPER analysis as being the most important taxa accounting for the similarity of samples from Ruakaka, and accounted for 31% of the similarity between samples (Table 8).

Table 7. Total number of individuals, of benthic infauna taxa accounting for more than 1% of total abundance at Ruakaka in 2010.

Taxon	Description	Total number of Individuals	Frequency of Occurrence %
Austrovenus stutchburyi	Cockle	160	100
Paphies australis	Pipi	148	100
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	132	90
Exosphaeroma planulum	Crustacean	122	90
Capitella sp.#1	Polychaete worm	112	100
Amphipoda sp.#5	Crustacean	79	50
Prionospio aucklandica	Polychaete worm	54	50
Colurostylis lemurum	Hooded shrimp	36	100
Cominella glandiformis	Mud whelk	33	80
Macomona liliana	Wedge shell	31	100
Oligochaeta	Oligochaeta worm	26	60
Austrominius modestus	Barnacle	19	50
Nemertea sp.#1	Nemertean worm	14	50

Table 8. Average similarity of benthic infauna taxa at samples collected from Ruakaka in 2010 and their contribution to overall similarity. Average similarity = 55%.

Taxon	Description	% contribution towards similarity	% cumulative contribution towards similarity
Austrovenus stutchburyi	Cockle	17	17
Paphies australis	Pipi	14	31
Capitella sp.#1	Polychaete worm	12	43
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	10	53
Exosphaeroma planulum	Crustacean	10	62
Colurostylis lemurum	Hooded shrimp	8	70
Macomona liliana	Wedge shell	7	77
Cominella glandiformis	Mud whelk	4	81
Amphipoda sp.#5	Crustacean	3	84
Oligochaeta	Oligochaeta worm	3	87
Prionospio aucklandica	Polychaete worm	2	89
Linucula hartvigiana	Bivalve	2	91

3.5.2 Ruakaka 2009

In 2009, 1332 individuals belonging to 31 taxa were identified from cores collected at Ruakaka. The pipi *Paphies australis* and the marine crustaceans Amphipoda sp.#5 and *Exosphaeroma planulum* were numerically dominant (Table 9) and SIMPER analysis indicated that these three taxa accounted for 56% of the similarity between samples (Table 10).

Table 9. Total number of individuals, of benthic infauna taxa accounting for more than 1% of total abundance at Ruakaka in, 2009.

Taxon	Description	Total number of Individuals	Frequency of Occurrence %
Paphies australis	Pipi	440	100
Amphipoda sp.#5	Crustacean	354	70
Exosphaeroma planulum	Crustacean	178	100
Capitella sp.#1	Polychaete worm	85	100
Austrovenus stutchburyi	Cockle	72	100
Spionidae sp.#2	Polychaete worm	45	60
Macomona liliana	Wedge shell	23	100
Colurostylis lemurum	Hooded shrimp	17	50
Corophiidae	Crustacean	16	50
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	15	50

Table 10. Average similarity of benthic infauna taxa at samples collected from Ruakaka in 2009 and their contribution to overall similarity. Average similarity = 55%.

Taxon	Description	% contribution towards similarity	% cumulative contribution towards similarity
Paphies australis	Pipi	25	25
Exosphaeroma planulum	Crustacean	18	44
Amphipoda sp.#5	Crustacean	12	56
Austrovenus stutchburyi	Cockle	12	67
Capitella sp.#1	Polychaete worm	9	76
Macomona liliana	Wedge shell	7	83
Spionidae sp.#2	Polychaete worm	3	87
Cominella glandiformis	Mud whelk	2	89
Colurostylis lemurum	Hooded Shrimp	2	91

3.5.3 Ruakaka 2008

In 2008, 1392 individuals belonging to 28 taxa were identified from cores collected at Ruakaka. The pipi *Paphies australis* and the marine crustaceans Amphipoda sp.#5 and *Exosphaeroma planulum* were again numerically dominant in 2008 (Table 11) and SIMPER analysis indicated that these three taxa accounted for 68% of the similarity between samples (Table 12).

Table 11. Total number of individuals, of benthic infauna taxa accounting for more than 1% of total abundance at Ruakaka in, 2008.

Taxon	Description	Total number of Individuals	Frequency of Occurrence %
Paphies australis	Pipi	680	100
Exosphaeroma planulum	Crustacean	236	100
Amphipoda sp.#5	Crustacean	177	90
Spionidae sp.#2	Polychaete worm	136	100
Austrovenus stutchburyi	Cockle	35	90
Colurostylis lemurum	Hooded shrimp	26	70
Austrominius modestus	Barnacle	20	10
Halicarcinus whitei	Crab	14	60

Table 12. Average similarity of benthic infauna taxa at samples collected from Ruakaka in 2008 and their contribution to overall similarity. Average similarity = 68%.

Taxon	Description	% contribution towards similarity	% cumulative contribution towards similarity
Paphies australis	Pipi	37	37
Exosphaeroma planulum	Crustacean	20	57
Spionidae sp.#2	Polychaete worm	13	70
Amphipoda sp.#5	Polychaete worm	11	81
Austrovenus stutchburyi	Cockle	6	87
Colurostylis lemurum	Hooded shrimp	3	90

3.5.4 Tamure 2010

In 2010, 1469 individuals belonging to 34 taxa were identified from cores collected at Tamure. The polychaete worms *Prionospio aucklandica and* the bivalve marine *Austrovenus stutchburyi* were numerically the most dominant taxa in 2010 (Table 13) and SIMPER analysis found that these two taxa accounted for 39% of the similarity between samples (Table 14).

Table 13. Total number of individuals, of benthic infauna taxa accounting for more than 1% of total abundance at Tamure in 2010.

Taxon	Description	Total number of Individuals	Frequency of Occurrence %
Prionospio aucklandica	Polychaete worm	466	100
Austrovenus stutchburyi	Cockle	320	90
Oligochaeta	Oligochaete worm	139	90
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	104	80
Macomona liliana	Wedge Shell	88	90
Aonides sp.#1	Polychaete worm	53	90
Capitella sp.#1	Polychaete worm	53	90
Heteromastus filiformis	Polychaete worm	28	70
Anthopleura aureoradiata	Anemone	25	90
Haminoea zelandiae	Sea snail	24	70
Notoacmea helmsi	Limpet	23	70
Paphies australis	Pipi	22	50

Table 14. Average similarity of benthic infauna taxa at samples collected from Tamure in 2010 and their contribution to overall similarity. Average similarity = 57%.

Taxon	Description	% contribution towards similarity	% cumulative contribution towards similarity
Prionospio aucklandica	Polychaete worm	21	21
Austrovenus stutchburyi	Cockle	18	39
Macomona liliana	Wedge shell	9	47
Oligochaeta	Oligochaete worm	8	55
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	8	63
Aonides sp.#1	Polychaete worm	5	68
Capitella sp.#1	Polychaete worm	5	74
Anthopleura aureoradiata	Anemone	4	78
Notoacmea helmsi	Limpet	3	80
Nemertea sp.#1	Nemertean worm	3	83
Haminoea zelandiae	Sea snail	3	85
Heteromastus filiformis	Polychaete worm	3	88
Cominella glandiformis	Mud whelk	2	90

3.5.5 Tamure 2009

In 2009, 1864 individuals belonging to 31 taxa were identified from cores collected at Tamure. The polychaete worms *Prionospio aucklandica*, and the cockle *Austrovenus stutchburyi* were again numerically the most dominant taxa in 2009 (Table 15) and these two taxa accounted for 39% of the similarity between samples (Table 16).

Table 15. Total number of individuals, of benthic infauna taxa accounting for more than 1% of total abundance at Tamure in 2009.

Taxon	Description	Total number of Individuals	Frequency of Occurrence %
Prionospio aucklandica	Polychaete worm	588	90
Austrovenus stutchburyi	Cockle	391	100
Paphies australis	Pipi	153	100
Oligochaeta	Oligochaete worm	126	100
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	107	100
Corophiidae	Crustacean	107	30
Macomona liliana	Wedge Shell	90	90
Heteromastus filiformis	Polychaete worm	39	70
Zeacumantus lutulentus	Mud snail	36	90
Boccardia (Paraboccardia) acus	Polychaete worm	35	80
Anthopleura aureoradiata	Anemone	26	80
Notoacmea helmsi	Limpet	24	40
Austrominius modestus	Barnacle	21	40

Table 16. Average similarity of benthic infauna taxa at samples collected from Tamure in 2009 and their contribution to overall similarity. Average similarity = 61%.

Taxon	Description	% contribution towards similarity	% cumulative contribution towards similarity
Prionospio aucklandica	Polychaete worm	21	21
Austrovenus stutchburyi	Cockle	18	39
Oligochaeta	Oligochaete worm	10	49
Macomona liliana	Wedge Shell	8	57
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	8	65
Paphies australis	Pipi	7	73
Zeacumantus lutulentus	Mud snail	5	77
Boccardia (Paraboccardia) acus	Polychaete worm	3	81
Anthopleura aureoradiata	Anemone	3	84
Heteromastus filiformis	Polychaete worm	3	87
Capitella sp.#1	Polychaete worm	2	89
Cominella glandiformis	Mud whelk	2	91

3.5.6 Tamure 2008

In 2008, 1255 individuals belonging to 37 taxa were identified from cores collected at Tamure. The polychaete worm *Prionospio aucklandica*, the cockle Austrovenus stutchburyi and the wedge shell Macomona liliana were ubiquitous and numerically the most dominant taxa (Table 17). SIMPER analysis indicated that these taxa accounted for 46% of the similarity between samples (Table 18).

Table 17. Total number of individuals, of benthic infauna taxa accounting for more than 1% of total abundance at Tamure in 2008.

Taxon	Description	Total number of Individuals	Frequency of Occurrence %
Prionospio aucklandica	Polychaete worm	357	100
Austrovenus stutchburyi	Cockle	200	100
Macomona liliana	Wedge Shell	185	100
Oligochaeta	Oligochaete worm	139	100
Paphies australis	Pipi	72	90
Scolecolepides benhami	Polychaete worm	46	100
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	39	100
Notoacmea helmsi	Limpet	29	70
Aonides sp.#1	Polychaete worm	18	80
Zeacumantus lutulentus	Mud snail	17	90
Spionidae sp.#2	Polychaete worm	16	50
Nicon aestuariensis	Polychaete worm	15	90
Anthopleura aureoradiata	Anemone	14	60
Halicarcinus whitei	Crab	14	50
Heteromastus filiformis	Polychaete worm	13	70
Austrominius modestus	Barnacle	13	40

Table 18. Average similarity of benthic infauna taxa at samples collected from Tamure in 2008 and their contribution to overall similarity. Average similarity = 63%.

Taxon	Description	% contribution towards similarity	% cumulative contribution towards similarity
Prionospio aucklandica	Polychaete worm	17	17
Austrovenus stutchburyi	Cockle	16	32
Macomona liliana	Wedge Shell	14	46
Oligochaeta	Oligochaete worm	10	56
Scolecolepides benhami	Polychaete worm	7	63
Scoloplos (Scoloplos) cylindrifer	Polychaete worm	6	69
Paphies australis	Pipi	6	75
Nicon aestuariensis	Polychaete worm	4	78
Zeacumantus lutulentus	Mud snail	4	82
Aonides sp.#1	Polychaete worm	3	85
Heteromastus filiformis	Polychaete worm	2	87
Notoacmea helmsi	Limpet	2	89
Anthopleura aureoradiata	Anemone	2	91

3.6 Relating benthic infauna community structure to sediment properties

DISTLM was performed using the Bray-Curtis similarity matrix, and the $\log_{10}$(n+.1) transformed sediment data collected in 2009 and 2010. The 2009 data was excluded because a different method was used to determine sediment grain size. In addition a large number of samples collected in 2009 had metal concentrations below the laboratory detection limits. Cadmium was also excluded because all of the concentrations were below or very close to the detection limits. DISTLM indicated that all of the sediment parameters explained some of the variation in the benthic invertebrate data (Table 19). Chromium, fine sand, AFDW and phosphorus explained the highest proportion of the variation in the benthic invertebrate data.

Table 19. DISTLM marginal tests for $\log_{10}$ (n+0.1) sediment properties and benthic invertebrate abundance data from samples collected from two sites in Ruakaka Estuary in 2009 and 2010.

Sediment properties	Pseudo-F	P value	Proportion of variation explained
Chromium	10.352	0.001	37
Fine sand (63 – 250 µm)	9.8204	0.001	35
AFDW	9.3427	0.001	34
Phosphorus	8.8671	0.001	33
Copper	7.4725	0.001	29
Nickel	7.3266	0.001	29
Mud (<63 µm)	6.5262	0.001	27
Zinc	6.2490	0.003	26
Nitrogen	3.2444	0.011	15
Lead	3.1772	0.017	15
Medium sand (250 – 500 µm)	3.0705	0.01	15
Coarse sand (>500 µm)	2.5126	0.045	12

DISTLM using both forward and backward selection procedure was then used to identify the best explanatory variables. This found that chromium, copper, lead, nitrogen, nickel, fine sand (63-250µm), coarse sand (>500 µm) and medium sand (250-500 µm) explained approximately 75% of the variation in the community structure (Table 20).

Table 20. DISTLM sequential tests for $\log_{10}$ transformed sediment properties and benthic invertebrate abundance data from samples collected from two sites in Ruakaka Estuary in 2009 and 2010.

Sediment properties	**Pseudo-F**	**P-value**	**Cumulative proportion of variation explained**
Chromium	10.352	0.001	37
+ Copper	4.5152	0.004	50
+ Lead	1.8759	0.09	55
+ Nitrogen	1.6514	0.113	60
+ Nickel	2.0611	0.074	65
+ Fine sand (63-250 µm)	1.1875	0.299	68
+ Coarse sand (>500 µm)	0.8411	0.455	70
+ Medium sand (250-500 µm)	2.5074	0.048	75

4 Discussion

This report presents the results from Northland Regional Council's estuary monitoring programme in Ruakaka Estuary for the years 2008-2010. The monitoring programme has been adapted from the Estuary Monitoring Protocol (Robertson *et al.* 2002), which was developed by Cawthron for use by regional councils, and involves sampling the physical and chemical (metals and nutrients) properties of the sediment, and the benthic invertebrate communities of representative intertidal habitats. The monitoring programme was implemented to assess the health of representative intertidal sites and provide baseline data, which can be used to track changes in the health of these sites over time. One site 'Ruakaka' was located on intertidal flats near to the mouth of the Ruakaka Estuary and another site 'Tamure' on intertidal flats flanking the Ruakaka River, approximately 800m upstream.

4.1 Sediment physical properties

Sediment collected from the Ruakaka site had high proportions of medium sand while the Tamure site contained high proportions of fine sand and medium sand. The different grain size properties of sediment collected from the two sites probably reflects the different hydrodynamic environments at the site locations. The Ruakaka site is located close to the entrance of the estuary in a relatively high energy environment, where the sorting, resuspension and the gradual movement of fine sediment out to the open coast is likely to take place. The Tamure site is located further up the river in a more sheltered tidal creek environment, where higher rates of sediment deposition are likely.

PCA analysis of sediment grain size characteristics showed that samples collected from Ruakaka were more tightly grouped than samples collected from Tamure, which indicates that the sediment characteristics at Ruakaka were more homogeneous, than the sediment at Tamure. Observations during site visits also found that the surface sediment at Ruakaka was very uniform with sand covering the entire site, while the site at Tamure was more heterogeneous with sand covering the western section of the site closest to the channel and an area of fine sediment on the eastern section of the site in an area of depression.

4.2 Sediment AFDW and nutrient concentrations

While nutrients are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertiliser, storm water and treated wastewater may exceed the needs of an ecosystem. Initially surplus nutrients may stimulate benthic communities because there is an increase in food via additional plant material and organic detritus. But as sediment organic matter increases the oxygenated portion of the sediment can become limited to the surface of the sediment or may be eliminated altogether, and dissolved oxygen concentrations can drop to levels that are lethal for some organisms. Under these conditions, animals may die or migrate from the affected area and the community may become less diverse as it is recolonised by a smaller number of opportunist species that are tolerant of low oxygen conditions.

The ANZECC guidelines do not include trigger values for nutrients or AFDW in sediments and there are currently no nationally accepted guideline values for nutrients in marine sediment. However, the levels of AFDW, nitrogen and phosphorus at both sites were similar to concentrations recorded in similar monitoring programmes elsewhere in New Zealand (Appendix 5) and were generally at levels that indicate the sites were either 'very good' or 'low to moderately enriched' using criteria developed by Robertson and Stevens (2007).

In general higher concentrations of nitrogen, phosphorus and AFDW, were measured at Tamure, which is consistent with the higher proportion of fine sediments at Tamure compared to Ruakaka, as sediment carbon and nutrients absorb onto mineral surfaces and have a high affinity for fine-grained sediment (Robertson *et al.* 2002). Tamure is also located further up the estuary, and is likely to be more influenced by freshwater inflow, which may contain nutrient runoff.

The concentration of nitrogen was significantly higher in 2008 than in both 2009 and 2010, while the concentration of phosphorus was higher in 2009 than in 2008. A similar pattern was observed in NRC's estuary monitoring programme in Kerikeri Inlet. With only three data points, no statistical trend analysis can be conducted, and with only three years of data, it is possible that these changes may be part of longer-term cyclic patterns which have been identified in similar monitoring programmes in the Auckland Region (Hewitt & Thrush 2007).

4.3 Sediment metal concentrations

Heavy metals can have lethal and sub lethal effects on benthic invertebrates and in a contaminated environment the species diversity and species richness may decrease as the community becomes dominated by a smaller number of more tolerant species, which are able to survive and reproduce in these conditions (Clarke and Warwick 2001). The metal concentrations recorded at both sites in Ruakaka Estuary were generally similar to levels reported for estuaries with rural catchments in similar monitoring programmes elsewhere in New Zealand (Appendix 5) and all metal concentrations were below the ANZECC ISQG low effect trigger values and the threshold effect levels developed by MacDonald *et al*. (1996). Indeed a number of samples analysed had metal concentrations below detection limits, particularly samples collected from the Ruakaka site.

The potential sources of different metal contaminants in the marine environment reflect their different uses and applications by man. Copper is used in roofing, guttering, drain pipes, piping, plumbing fittings, antifouling paint for ships hulls, algaecides, fungicides, electrical wiring, electronics, wood preservatives, and agrichemicals. Zinc is used in galvanised roofs, spouting, drainpipes, house paints, brake pads, tyres and some agrichemicals such as fertilizers and pesticides (Kennedy 2003). Vehicle brake pads and tyres are sources of lead and although leaded petrol was withdrawn from sale in 1996, lead from petrol is still likely to be present in the environment and may still be contaminating storm water discharges (Kennedy 2003). The Ruakaka catchment is predominantly rural in character although the township of Ruakaka and some light industrial activities are located within the catchment. The application of agrichemicals, road and stormwater runoff, and erosion of catchment soils are therefore the most likely sources of contaminants to the estuary.

A similar pattern was observed for metal contaminants, with higher concentrations recorded at the Tamure site than at the Ruakaka site. This is again consistent with the sediment characteristics of the two sites as sediment grain size is an important factor which influences the concentrations of heavy metals in estuarine sediments (Abrahim *et al.* 2006). Heavy metal absorption tend to increase as sediment grain size decreases, which reflects the tendency for heavy metals to be preferentially absorbed on the large surface area of fine grained sediments rich in clay minerals (Abrahim *et al* 2006).

No consistent trend was apparent in the concentration of metals over time, although ANOVA found that the concentration of nickel in 2010 was significantly higher than in both 2009 and 2008.

4.4 Benthic invertebrate data

The benthic invertebrate data indicated that the communities at the two sites were quite distinct. MDS ordination of the benthic abundance data showed a clear separation of samples collected from the different sampling sites and PERMANOVA analysis found that the species assemblages at the two sites were significantly different from each other.

At Ruakaka the pipi *Paphies australis*, the cockle *Austrovenus stutchburyi*, and the marine crustaceans Amphipoda sp.#5 and *Exosphaeroma planulum* were the numerically dominant taxa. At

Tamure the polychaete worm *Prionospio aucklandica*, the cockle *Austrovenus stutchburyi* and the wedge shell *Macomona liliana* were numerically dominant. Examination of the shell length data also showed that all the bivalve taxa identified included a number of adults.

The bivalves *Paphies australis, Austrovenus stutchburyi* and *Macomona liliana*, and the polychaete worm *Prionospio aucklandica* are taxa that Hewitt and Ellis (2010) found always decrease in abundance with increasing stormwater contamination in the Auckland Region. Their presence and their relatively high abundance at both sites therefore suggests that the sites were not subjected to high levels of contamination or anthropogenic disturbance.

4.5 Relating benthic infauna community structure to sediment properties

DISTLM indicated that all of the sediment properties explained some of the variation in the benthic community structures with chromium, fine sand, AFDW and phosphorus the strongest predictors of the benthic communities. DISTLM using both forward and backward selection procedure found that chromium, copper, lead, nitrogen, nickel, fine sand (63-250µm), coarse sand (>500 µm) and medium sand (250-500 µm) together explained approximately 75% of the variation in the community structure. This suggests that the sediment properties measured in this programme influenced the benthic communities at the two sites. It is however important to not place particular emphasis on any one sediment parameter as all of the sediment properties were positively correlated with each other and they could be acting as a proxy for other environmental variables that were not measured in this programme.

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Appendix 1: Land use in the Ruakaka catchment.

Land Classes in Ruakaka Estuary catchment from Zealand Land Cover Database (2001).

1st Order Class	2nd Order Class	Area (Ha)	Percentage
Artificial Surfaces **(2%)**	Built-up Area	84	1
	Urban Parkland/ Open Space	35	<1
	Surface Mine	31	<1
Lightly vegetated surfaces **(<1%)**	Coastal Sand and Gravel	7	<1
Water Bodies **(<1%)**	Lake and Pond	7	<1
	River	13	<1
	Estuarine Open Water	8	<1
Cropland **(1%)**	Short-rotation Cropland	4	<1
	Orchard and Other Perennial Crops	7	<1
Grassland **(68%)**	High Producing Exotic Grassland	6237	68
	Low Producing Grassland	4	<1
	Herbaceous Freshwater Vegetation	3	<1
Scrub/Shrubland **(6%)**	Gorse and Broom	64	1
	Manuka and or Kanuka	478	5
	Broadleaved Indigenous Hardwoods	0	<1
Forest **(24%)**	Major Shelterbelts	7	<1
	Afforestation	40	<1
	Forest Harvested	0	<1
	Pine Forest - Closed Canopy	16	<1
	Pine Forest - Open Canopy	83	<1
	Other Exotic Forest	9	<1
	Deciduous Hardwoods	18	<1
	Indigenous Forest	2017	22
	Mangrove	6	<1
Total		9177	100

Farming activity in Ruakaka Estuary.

Description	Area	%
Beef cattle farming	1441.115	25.53
Dairy cattle farming	3373.728	59.76
Dairy dry stock	258.248	4.57
Enterprises not covered by other classifications	8.376	0.15
Forestry	25.882	0.46
Fruit growing	2.369	0.04
Grazing other people’s stock	312.968	5.54
Horse farming and breeding	42.491	0.75
Lifestyle block	139.719	2.47
Mixed Sheep and Beef farming	15.353	0.27
New Record - Unconfirmed Farm Type	16.615	0.29
Sheep farming	2.759	0.05
Vegetable growing	3.784	0.07
Total	5645.598	100.00

Appendix 2: Site co-ordinates.

Global positioning system (GPS) coordinates for samples sites in Ruakaka Estuary, 2008.

Sample	RUA		TAM	
	Easting	Northing	Easting	Northing
1	1731118.110	6026171.709	1731192.546	6026826.537
2	1731106.898	6026181.597	1731184.891	6026839.882
3	1731095.685	6026191.484	1731177.193	6026853.205
4	1731084.473	6026201.372	1731160.348	6026862.020
5	1731111.464	6026164.480	1731167.990	6026848.626
6	1731100.027	6026174.443	1731183.246	6026822.010
7	1731088.589	6026184.406	1731173.783	6026817.482
8	1731077.152	6026194.368	1731166.372	6026830.916
9	1731104.819	6026157.251	1731158.839	6026844.317
10	1731093.156	6026167.289	1731151.239	6026857.679
11	1731081.493	6026177.327	1731169.580	6026866.512
12	1731069.831	6026187.364	1731175.634	6026835.344

Appendix 3: Physical and chemical properties of sediment samples collected from Ruakaka Estuary, 2008.

Site	<63	63-250	250-500	>500	AFDW	Total N	Total P	Cd	Cr	Cu	Ni	Pb	Zn
RUA	0.83	18.25	72.79	8.13	0.8	511	55	<0.05	2.8	1.2	1.2	10	50
RUA	0.75	13.44	81.22	4.6	0.9	484	64	<0.05	2.9	1.2	1.2	10	51
RUA	0.86	8.22	85.39	5.54	0.8	424	88	<0.049	3.4	1.2	1.2	9.9	49
RUA	0.75	21.9	70.94	6.41	3.6	569	52	<0.049	2.3	1.2	1.2	9.9	49
RUA	1.41	6.43	86.58	5.58	0.9	803	75	<0.051	3.4	1.2	1.2	10	51
TAM	3.86	41.28	48.88	5.97	1.8	946	120	<0.05	4.7	1.2	1.6	9.9	50
TAM	3.65	33.36	59.32	3.67	2.4	925	180	<0.05	5.6	1.4	1.8	10	50
TAM	7.94	43.15	34.89	14.02	2.1	944	130	<0.05	5.1	1.2	1.6	9.9	50
TAM	7.04	44.82	37.77	10.37	3	1199	200	<0.05	6.1	1.4	1.9	9.9	50
TAM	7.81	45.33	39.79	7.06	2.4	820	150	<0.05	5.1	1.2	1.6	10	50

Physical and chemical properties of sediment samples collected from Ruakaka Estuary, 2009.

Site	<63	63-250	250-500	>500	AFDW	Total N	Total P	Cd	Cr	Cu	Ni	Pb	Zn
RUA	0	22.23	66.20	11.58	0.7	552	65	<0.0091	2.3	0.25	0.7	6.3	6.3
RUA	0	24.98	60.89	14.13	1.3	223	110	0.014	3.2	0.43	0.65	0.86	9.2
RUA	0	19.58	66.86	13.56	0.9	349	66	0.009	2.9	0.29	0.6	0.75	7.9
RUA	0	26.57	63.88	9.54	0.6	104	65	<0.009	2.9	0.26	0.5	0.68	7.1
RUA	0	22.24	62.16	15.60	1.1	193	100	0.011	3.8	0.43	0.8	0.88	7.2
TAM	5.55	51.1	40.54	2.81	2.6	554	260	0.042	6.5	1.5	1.5	2.1	17
TAM	6.13	50.7	39.99	3.19	2.3	447	210	0.034	5.7	1.5	1.6	2.3	17
TAM	8.48	49.87	35.69	5.95	2.8	383	260	0.051	6.2	1.8	2.1	2.4	19
TAM	3.73	35.87	47.07	13.33	1.7	309	130	0.011	4.1	0.69	0.87	1.5	10
TAM	8.59	51.47	36.3	3.65	3	465	310	0.062	6.1	1.8	1.8	2.6	20

Physical and chemical properties of sediment samples collected from Ruakaka Estuary, 2010.

Site	<63	63-250	250-500	>500	AFDW	Total N	Total P	Cd	Cr	Cu	Ni	Pb	Zn
RUA	0	30.86	58.99	10.15	1.13	260	66	<0.089	3.1	<0.44	1	0.63	<6.7
RUA	0	29.01	59.95	11.03	0.85	150	73	<0.089	3.2	<0.45	2.1	0.72	<6.7
RUA	0	27.58	63.87	8.56	0.74	40	45	<0.09	3	<0.45	1.5	0.65	<6.7
RUA	0	32.47	57.86	9.67	0.99	170	61	<0.09	3.7	<0.45	1.2	0.78	<6.7
RUA	0	22.13	60.86	17	0.94	300	75	<0.089	3.7	<0.45	1.1	0.83	7.4
TAM	0	52.24	44.33	3.43	1.92	260	180	<0.089	5.5	1.4	2.5	2	15
TAM	3.94	51.06	40.59	4.41	2.42	460	210	<0.09	5.6	1.4	2.3	2	16
TAM	2.77	33.58	47.34	16.3	3.19	570	280	<0.09	5.7	1.6	2.2	2.7	14
TAM	5.06	53.48	4.79	36.67	2.38	420	220	<0.091	5.8	1.4	1.7	2.1	17
TAM	0.91	32.11	51.04	15.93	1.74	260	160	<0.091	4.3	4.3	1.4	2.1	11

Appendix 4: Tests for normality and equal variance

Results of tests for normality and equal variance of the physical and chemical properties of sediment samples collected from Ruakaka estuary, 2008-2010.

	Bartlett's Test	P-value	Anderson - Darling	P-value
Log_{10} mud (<63um)	0.457	0.467	0.283	0.555
Fine sand (63-250)	1.805	0.581	0.303	0.510
Medium sand (250-500mm)	0.518	0.539	0.400	0.294
Coarse sand (>500mm)	0.108	0.053	0.283	0.554

	Bartlett's Test	P-value	Anderson - Darling	P-value
AFDW	0.44	0.815	1.012	0.010*
TN	0.95	0.856	0.534	0.158
TP	1.34	0.282**	0.466	0.235
Cd			0.938	0.010
Cr	4.43	0.490	0.602	0.107
Cu	0.91	0.494**	2.365	< 0.005*
Ni	1.82	0.147**	0.609	0.103
Pb (2009-2010)***	0.84	0.492**	2.309	< 0.005*
Zn	1.56	0.210**	1.618	< 0.005*

* Although Anderson Darling test indicated that the data is not normally distributed a plot of the residuals indicated that there was a good fit.

** Levene's Test

***All sediment samples in 2008 were below detection limits

Appendix 5: Nutrient and metal concentrations in New Zealand estuarine sediments

Mean (± standard deviation) mud (sediment fraction < 63 um**)**, ash free dry weight (AFDW), total nitrogen (TP) and total phosphorus (TP) reported for estuarine sediments from sites located in a number of New Zealand estuaries.

	Data Source	**Samples**	**% Mud**	**Mean Ash (g/100g)**	**TP (mg/kg)**	**TN (mg/kg)**
Kerikeri Inlet	NRC 2011	30	29.3 ± 14.7	10.0 ± 4.4	715 ± 111	1469 ± 856
Ruakaka	NRC 2011	10	3.5 ± 3.1	1.9 ± 1.0	111 ± 53	763 ± 254
Whangarei	NRC 2011	30	37.9 ± 24.5	9.1 ± 6.2	543 ± 371	2009 ± 1081
Hokianga	NRC 2004 (n=7)	7	53.6	13.5	403 ± 231	1300 ± 56
Whangape	NRC 2004 (n=4)	4	50.2	13.2	376 ± 58	1500 ± 34
Herekino	NRC 2004 (n = 3)	3	9.7	4.5 ±	216 ± 75	900 ± 17
Parengarenga - North	NRC 2004 (n = 12)	12		2.4 ± 2.4	109 ± 84	5790 ± 612
Parengarenga - South	NRC 2004 (n =10)	10	5.7	1.1 ± 0.9	56 ± 28	5300 ± 7
Houhora	NRC 2004 (n = 7)	7	5.5	1.5 ± 0.4	95 ± 39	5440 ± 541
Ranguanu	NRC 2004(n=10)	10	11.6	4.0 ± 5.0	205 ± 178	730 ± 33
Taipa	NRC 2004 (n=2)	2	19.4	4.2 ± 0.4	562 ± 13	600 ± 10
Mangonui	NRC 2004 (n=3)	3	32.5	6.8 ± 3.4	690 ± 262	1200 ± 69
Whangaroa	NRC 2004 (n=6)	6	45.1	6.0 ± 1.9	703 ± 310	1070 ± 53
Otamatea	Robertson *et al* 2002	36	56.2 ± 19.8	5.7 ± 1.1	526 ± 53	1630 ± 391
Ohiwa	Robertson *et al* 2002	48	20.1 ± 11	3.0 ± 1.4	278 ± 39	650 ± 163
Ruataniwha	Robertson *et al* 2002	36	9.2 ± 0.8	1.2 ± 0	458 ± 11	263 ± 22
Waimea	Robertson *et al* 2002	48	24.5 ± 14.2	1.3 ± 0.6	433 ± 114	506 ± 242
Haverlock	Robertson *et al* 2002	24	19.1 ± 1.9	1.5 ± 0.3	330 ± 91	422 ± 190
Avon-Heathcote	Robertson *et al* 2002	36	5.4 ± 1.3	1 ± 0	327 ± 5	301 ± 89
Kaikorai	Robertson *et al* 2002	12	27.2	5.1	798.6	1650
New River	Robertson *et al* 2002	48	1.7 ± 0.5	0.7 ± 0.3	268.3 ± 67	250 ± 0
Waikawa	Robertson & Stevens 2007	6	6.6 ± 4.0 (n=6)	1.3% ± 0.2	263.5 ± 38.9	500 ± 0

Mean (± standard deviation) metal contaminant levels of estuarine sediments in New Zealand.

Estuary	Source	Samples	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Zn (mg/kg)
ANZECC ISQG Low			1.5	80	65	50	21	200
ANZECC ISQG High			10	370	270	220	52	410
Northland								
Kerikeri	NRC 2008 (2008)	30	0.09 ± 0.01	48.5 ± 8.5	20.0 ± 5.8	5.6 ± 1.4	18.8 ± 3.6	55.2 ± 7.0
Whangarei	NRC 2008	40	0.11 ± 0.02	12.2 ± 7.0	17.2 v 15.8	11.8 ± 10.7	6.7 ± 3.9	69.9 ± 62.6
Ruakaka	NRC 2008	20	0.05 ± 0.0	4.1 ± 1.3	1.2 ± 0.1	10.0 ± 0.1	1.5 ± 0.3	50 ± 0.7
Otamatea (Kaipara)	Robertson *el al* 2002	30	0.4 ± 0.5	20.5 ± 1.9	13.8 ± 4.2	11.4 ± 3.1	9.4 ± 1.6	54.5 ± 9.7
NZ Estuaries (urban)								
Kaikorai, Dunedin	Robertson *el al* 2002	10	0.1	48.4	16.8	45.3	15.6	184.2
Avon- Heathcote, Christchurch	Bolton-Ritchie 2007	30	0.1-0.2	11-38	2-22	7-35	6-15	35-156
Avon-Heathcote, Christchurch	Robertson *el al* 2002	30	0.1 ± 0	15.6 ± 1.6	3.2 ± 0.4	6.3 ± 1.6	6.6 ± 0.4	38.3 ± 5.0
Waimea, adjacent to Nelson	Robertson *el al* 2002	40	0.3 ± 0.2	67.6 ± 21.1	9.6 ± 2.2	7.4 ± 3	72.5 ± 15.6	41.8 ± 6.8
Firth of Thames, Waikato	Kim 2007 (2005)		0.15 ± 0.13	23.2 ± 3.5	16.0 ± 6.4	26.2 ± 7.2	8.3 ± 0.8	92.0 ± 28.6
New River , nr Invercargill	www.es.govt.nz 2004/05		<0.1	9.2 ± 1.7	3.7 ± 0.7	1.9 ± 0.3	6.5 ± 1.1	20.7 ± 6.0
New River, nr Invercargil	Robertson *el al* 2002	40	0.1 ± 0	11.1 ± 3.1	3.8 ± 0.5	0.7 ± 0.3	5.0 ± 0.7	17.1 ± 2.2
NZ Estuaries (rural)								
Haverlock, Malborough	Robertson *el al* 2002	20	0.3 ± 0.2	48.8 ± 30.2	10.7 ± 0.7	5.6 ± 0.1	26.5 ± 16.4	43 ± 11.5
Ohiwa, Bay of plenty	Robertson *el al* 2002	40	0.1 ± 0	7.4 ± 1.8	4.0 ± 1.4	3.4 ± 2.9	3.9 ± 1.2	27.7 8.2
Ruataniwha, Golden Bay	Robertson *el al* 2002	30	0.1 ± 0	24 ± 1.3	7.1 ± 0.1	4.7 ± 1.1	13.7 ± 0.4	37.5 ± 0.4
Raglan, Waikato	reported in Kim 2007		<0.1	14.4	6.76	6.09	8.06	47.7
Awarua Bay, Southland	www.es.govt.nz 2004/05		<0.1	5.1 ± 3.0	<1.4	<1.3	<3.2	<11.9
Bluff Harbour, Southland	www.es.govt.nz 2004/05		<0.1	9.9 ± 4.0	3.2 ± 1.4	1.6 ± 0.5	5.7 ± 2.8	<13.3
Fortrose Estuary, Southland	www.es.govt.nz 2004/05		<0.1	4.9 ± 0.3	2.0 ± 0.1	2.1 ± 0.1	3.0 ± 0.0	15.6 ± 3.2
Jacobs River Estuary	www.es.govt.nz 2004/05		<0.1	7.9 ± 8.7	5.66 ± 12.0	2.3 ± 0.7	5.4 ± 7.9	30.5 ± 15.9
Waikawa, Southland	Robertson & Stevens 2007	6	<0.1	7.3 ± 0.9	2.9 ± 0.4	1.6 ± 0.2	4.6 ± 0.6	13.3 ± 2.2

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