Waitangi Estuary Monitoring Programme

2013

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Executive summary

The Waitangi river catchment has been identified by Northland Regional Council (Council) as a priority catchment for the implementation of the National Freshwater Policy. The estuary drains a catchment of 31,630 ha and the land use in the catchment has been heavily modified, with a considerable proportion of the catchment cleared for agricultural land use.

In 2013, Council sampled 10 sites (WAT1-WAT10) throughout the Waitangi estuary in order to assess the sediment quality and ecological status of the estuary. This survey will also provide baseline data to track changes in the health of the estuary over time. The survey methods were adapted from the Estuary Monitoring Protocol (Robertson *et al.* 2002), which was developed by Cawthron for use by regional councils, and are consistent with other surveys conducted by Council.

Sediment grain size

The proportion of mud found at sites in the Waitangi estuary tended to be high compared to other estuaries and harbours surveyed by Council. Within the estuary, the highest proportions of mud were generally found at sites in sheltered tidal creek environments furthest from the entrance of the estuary, in particular at sites WAT 8 and WAT 10. Tidal creeks are generally low energy depositional environments and tend to be more influenced by inputs of fine grain terrigenous sediment than coarse marine sediment from the open coast. In contrast the highest proportions of coarse sand and medium sand were found near the entrance of the estuary at WAT 1 and WAT 5.

Sediment nutrients

While nutrients are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertiliser, stormwater and treated wastewater may exceed the needs of an ecosystem. In an enriched environment the sediment may become oxygen depleted and animals may die or migrate from the affected area. Consequently the community may become less diverse as it is recolonised by a smaller number of opportunist species that are tolerant of low oxygen conditions.

Using criteria developed by Robertson and Stevens (2007), six sites in the estuary were classified as ‘enriched’ for total organic carbon (TOC), one site was classified as ‘enriched’ for nitrogen and eight sites were ‘enriched’ for phosphorus. The mean nitrogen, phosphorus and TOC concentrations in the Waitangi estuary were higher than the means previously recorded in most other estuarine sediment surveys conducted by Council. The potential sources of nutrients to the Waitangi estuary include seepage from septic tanks and the wastewater network, stormwater, runoff from agricultural land and discharges from farm dairy effluent systems.

Within the estuary, a similar spatial pattern was observed for levels of TOC, nitrogen and phosphorus, with the highest levels generally recorded at WAT 8 and the lowest values at WAT 1. The high levels of nutrients measured at WAT 8 is consistent with this site having a high proportion of mud as sediment carbon and nutrients absorb onto mineral surfaces and tend to increase with decreasing sediment grain size. WAT 8 is also located furthest from the entrance of the estuary and is close to potential freshwater sources of nutrients. The low TOC and nutrient levels at WAT 1 are also consistent with the low proportion of mud and the relatively high proportion of coarse sand at this site.

Sediment metals

Heavy metals can have lethal and sub lethal effects on benthic invertebrates. 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.

All of the metal concentrations were well below the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) ISQG-Low effect trigger values (Australian New Zealand Environment Conservation Council 2000) and the threshold effect levels developed by MacDonald *et al*. (1996). This suggests that the concentrations of metals in the estuary are unlikely to be having an adverse effect on the ecology. The concentrations found in this survey were generally consistent with results previously recorded at Council's sediment monitoring site in Waitangi (2010 and 2012) and similar to the mean metal concentrations recorded in sediment surveys of the Bay of Islands and Whāngārei in 2012 (Griffiths 2013).

Within the estuary the highest concentrations of metals were generally recorded at WAT 8 and WAT 10. These two sites are located in tidal creek environments where there were high proportions of mud. Heavy metal absorption tends 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.* 2007).

Ecological communities

The intertidal habitats surveyed comprised mainly sheltered soft mud flats. No sandy beaches, sand banks, shell banks, seagrass beds or stone/pebble shorelines were sampled or observed. The shallow subtidal habitats also appeared to be relatively homogenous consisting of soft sediment with no biogenic structures or seagrass encountered.

The species identified in the Waitangi estuary appeared to be similar to other sheltered tidal creek estuarine environments surveyed in Northland. The most abundant taxa were oligochaete worms, and the polychaete worms *Prionospio aucklandica*, *Cossura consimilis*, Paraonidae and *Capitella capitata*. Bivalves were the other main taxonomic group found with the invasive window shell *Theora lubrica* and the cockle *Austrovenus stutchburyi* the most abundant bivalves.

Particularly high densities of cockles (*Austrovenus stutchburyi*) were found at WAT 4 and WAT 5 with reasonably high density also found at WAT 6. If similar densities of cockles are present on the large intertidal mud flats surrounding WAT 4 and WAT 5 there is likely to be a significant population of cockles in the estuary.

The invasive window shell (*Theora lubrica*) is an indicator species for eutrophic and anoxic areas and other taxa that are tolerant of nutrient enriched sediment including oligochaete worms and the polychaete worm *Capitella capitata* were also abundant throughout the estuary. The presence of these taxa is consistent with the sediment nutrient data, which indicated that several of the sites were 'enriched' using the criteria developed by Robertson and Stevens (2007).

Cluster analysis and non-metric multi-dimensional scaling (MDS) ordination of the ecological data were used to examine the ecological data. Cluster analysis and MDS ordination are visual displays of a species similarity matrix which can help to identify groups of samples. The analyses showed that the communities at WAT 7 and WAT 8 were different to the other eight sites. The MDS also showed that the samples from these two sites are quite dispersed, which indicates that these samples were dissimilar to each other and that there was a high degree of within-site variability at these two sites. The cluster analysis and MDS ordination did not indicate any strong groupings among the other eight sites although the samples from the three subtidal sites (WAT 1-3) were all located close to each other on the MDS ordination, which indicates that the ecological communities at these sites are similar to each other.

Relating ecological communities to sediment data

A distance-based linear model (DISTLM) was used to model the relationship between the ecological data and the sediment data. The DISTLM showed that fine sand, nitrogen, mud and coarse sand all had a significant relationship to the ecological data. Fine sand (22%) explained the highest proportion of variation in the community structure followed by coarse sand (18.5%). DISTLM conducted using a forward selection procedure also showed that the combination of fine sand and coarse sand explained 40% of the variation in the community structure. The significant relationships between these sediment properties and ecological data indicate that the physical and chemical characteristics of the sediment have influenced the ecological communities found in the Waitangi estuary.

1 Introduction

1.1 Background

Northland Regional Council (Council) has implemented estuary monitoring programmes in the Whāngārei harbour, Kerikeri inlet, Ruakaka estuary, Whangaroa harbour, and Kaipara harbour. These programmes assess the health of representative 'sentinel' sites and provide baseline data, which can be used to track changes in the health of these sites over time. These sites were initially sampled annually (2008-2011) in order to determine the baseline conditions and the natural variability of the biological communities. They are currently sampled every two years.

In 2013, Council identified the Waitangi river catchment as a priority catchment for the implementation of the National Policy Statement for Freshwater Management 2014. Council subsequently undertook a survey of 10 sites throughout the Waitangi estuary in order to assess the health of the estuary and to provide baseline data to track changes over time.

The monitoring methods 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 ecological communities of representative intertidal habitats. The methods are similar to those used to monitor the ecological communities and sediment quality at Council's existing sentinel sites and consistent with Council's survey of Whāngārei harbour in 2012 (Griffiths 2013).

1.2 Study area

1.2.1 The estuary

The Waitangi estuary is a drowned river valley system located on the east coast of the Northland peninsula. The estuary is connected to the Bay of Islands, a large coastal embayment, via a relatively narrow inlet approximately 140 m wide. The estuary divides into two arms, the Hutia creek to the north and the main Waitangi river channel to the south. The Hutia creek is a narrow sheltered tidal creek flanked by narrow mudflats and fringing mangrove forest. The Hutia creek has a very small sub-catchment with the majority of the catchment flowing into the Waitangi river arm of the estuary. The Waitangi river channel is also flanked by narrow mudflats and fringing mangrove forest and is tidal up to the Haruru Falls. The Kaipatiki stream also forms a tidal creek which flows into the Waitangi river channel from the south. The Kaipatiki stream also has a relatively small sub-catchment.

Plate 1. Waitangi estuary, looking west from the entrance of the estuary.

1.2.2 The catchment

The estuary drains a catchment of 31,630 ha and the land use in the catchment has been heavily modified, with a considerable proportion of the catchment cleared for agricultural land use. Catchment analysis using the land use classification from the New Zealand Land Cover Database (LCDB2) indicated that in 2001, 67% of the catchment was covered by high producing exotic grassland, 7% with plantation forestry, 7% with Manuka and Kanuka, and 14% with indigenous forest (Figure 1 & Table 1).

Table 1. Land use in the Waitangi catchment, from the New Zealand Land Cover Database (2001).

1st Order Class	2nd Order Class	Area (Ha)	Percentage
Artificial surfaces **(1%)**	Built-up Area	102	<1
	Urban Parkland/ Open Space	92	<1
	Surface Mine	33	<1
	Dump	1	<1
Water bodies **(1%)**	Lake and Pond	153	<1
	River	36	<1
Cropland **(<1%)**	Short-rotation Cropland	15	<1
	Vineyard	2	<1
	Orchard and Other Perennial Crops	161	1
Grassland **(67%)**	High Producing Exotic Grassland	20,781	66
	Low Producing Grassland	87	<1
	Herbaceous Freshwater Vegetation	247	1
	Herbaceous Saline Vegetation	5	<1
Scrub **(9%)**	Gorse and Broom	118	<1
	Manuka and or Kanuka	2091	7
	Broadleaved Indigenous Hardwoods	565	2
	Mixed Exotic Shrubland	93	<1
Forest **(22%)**	Major Shelterbelts	20	<1
	Afforestation	95	<1
	Forest Harvested	335	1
	Pine Forest	1727	5
	Other Exotic Forest	318	1
	Deciduous Hardwoods	47	<1
	Indigenous Forest	4496	14
	Mangrove	11	<1
Total		**31,630**	**100**

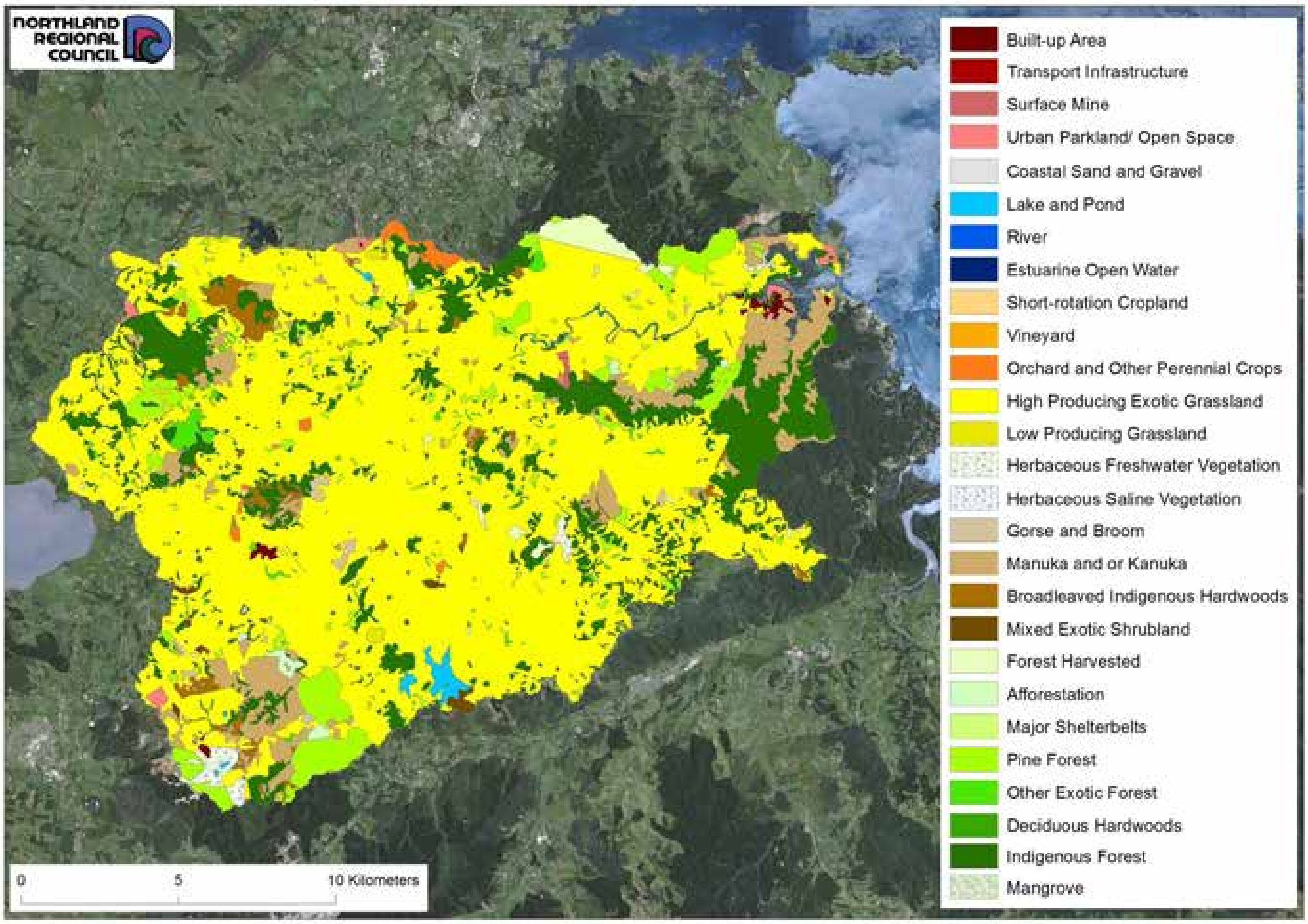

Figure 1. Land use in the Waitangi estuary catchment, from the New Zealand Land Cover Database (2001).

1.2.3 Estuarine sediment properties

Sediment grain size has been surveyed in the Bay of Islands in 2010 (Northland Regional Council 2011) and 2012 (Northland Regional Council unpublished data) with one sample collected in the Waitangi estuary from the main channel near the entrance of the Waitangi estuary, at the same location as WAT 1 in the current survey. In 2010 the sediment at this site composed 31% mud, 36% fine sand, 23% medium sand and 10% coarse sand. In 2012 the sediment comprised just 8% mud, 7% fine sand, 14 % medium sand and 71% coarse sand. The big difference in the sediment grain size in just two years suggests that the sediment in the channel is either very heterogeneous or there was channel movement.

1.2.4 Estuarine sediment nutrients

There is limited information available about estuarine sediment nutrient concentrations in the Waitangi estuary. The only known data is one sample collected by Council as part of the Bay of Islands sediment survey in 2012 (Northland Regional Council unpublished data), also at the same location as WAT 1 in the current survey. In 2012 the levels of TOC, nitrogen and phosphorus were high in comparison to the concentrations recorded at other sites in the Bay of Islands. The concentrations of phosphorus (530 mg/kg) and TOC (1.47 %w/w) were at levels which suggested that this site was ‘enriched’, using criteria developed by Robertson and Stevens (2007). The concentration of nitrogen (530 mg/kg) indicates that this site was ‘low to moderately enriched’ using Robertson and Stevens’s criteria.

1.2.5 Estuarine sediment metals

Estuarine sediment metal concentrations have been surveyed in the Bay of Islands in 2010 (Northland Regional Council 2011) and 2012 (Northland Regional Council unpublished data), with one sample collected from the main channel near the entrance of the Waitangi estuary, again at the same location as WAT 1 in the current survey. These surveys both showed that all metal concentrations were below the ANZECC ISQG-Low trigger values (Australian New Zealand Environment Conservation Council 2000) and the threshold effect levels (TEL) developed by MacDonald *et al*. (1996) (Table 2). There was a small increase in concentrations of chromium, copper, lead and zinc between 2010 and 2012.

Table 2. Sediment metal concentrations previously recorded by Council at the entrance of the Waitangi estuary.

	2010	2012	TEL	ANZECC
Cadmium	0.13	0.099	0.68	1.5
Chromium	9.5	12	52.3	80
Copper	6.3	13	18.7	65
Lead	6.1	7.8	30.2	50
Zinc	46	50	124	200

1.2.6 Ecology

There is limited information on the ecology of the Waitangi estuary. The only known ecological sampling within the estuary was one sample collected by NIWA in 2009 as part of the Bay of Islands Ocean Survey 20/20 (Hewitt *et. al.* 2010). This site was located on intertidal flats at the junction of the Waitangi river and the Hutia creek at the approximate location of WAT 5 in the current survey. The site was described as low sloped and the sediment muddy overlying coarse sand and the surface was littered with cockle shell hash. Macrofauna observed on the sediment surface included the gastropods *Cominella glandiformis*, *Diloma subrostrata* and *Zeacumantus lutulentus*, the crab *Halicarcinus whitei* and cockles (*Austrovenus stutchburyi*). Hewitt *et al*. (2010) collected three cores (13 cm diameter, 15 cm deep) at this site which were sieved with a 1 mm mesh. They found a total of 186 individuals belonging to 18 taxa. The most abundant taxa were the cockle *Austrovenus stutchburyi* and the polychaete worms Ceratonereis sp., *Prionospio aucklandica* and *Heteromastus filiformis*.

Council has mapped the extent of mangrove and saltmarsh habitats in the Waitangi estuary. Saltmarsh and mangrove habitat were hand digitalised at a scale of 1:2000 using aerial images from both 1978 and 2009. In 2009 saltmarsh habitat covered 14.2 ha and mangrove forest covered 133.6 ha.

2. Methods

2.1 Field methods

The methods and techniques used in the current survey have been adapted from those outlined in the Estuarine Monitoring Protocol by Robertson *et al*. (2002) and are similar to those used in Council's previous ecological survey of the Whāngārei harbour in 2012 (Griffiths 2013).

2.1.1 Sampling sites

Figure 2. Location of sampling sites in the Waitangi estuary.

A total of seven intertidal sites and three shallow subtidal sites were sampled. The sample sites were selected in order to ensure a good geographical spread throughout the estuary. WAT 1 was located at the same location as Council's previous sediment sampling site in the Waitangi estuary (Northland Regional Council 2011) and WAT 5 is at the approximate location of the ecological site sampled by NIWA in 2009 (Hewitt *et al*. 2010). All the site co-ordinates were fixed with a GPS (Appendix 1). Field notes made at each site and photographs are presented in Appendix 2.

2.1.2 Timing of sampling

The survey was conducted on 8 May 2013.

2.1.3 Ecological sampling

The ecology was sampled using a perspex core (with a diameter of 150 mm and 150 mm deep). Three replicates were made at 15 m intervals along a 30 m transect positioned parallel to the shoreline. At subtidal sites the perspex core was also used by free diving. At subtidal sites samples were collected approximately 15 m apart along a transect parallel to the channel. All core samples were sieved through a 500 µm mesh on site and the material retained in the sieve brought back to Council's laboratory. All organisms retained were preserved with ethanol and stained with rose bengal. Sorting and identification of all organisms was conducted by the Cawthron Institute.

Insects larvae (Insecta) identified from the samples were excluded from any analysis as these animals are not marine invertebrates. Unidentified decapod larvae were also excluded from the analysis as larvae were not considered to be part of the infauna ecology.

2.1.4 Sediment sampling

One surface sediment sample of approximately 200 grams wet weight (consisting of the surface 2 cm) was collected at each site. The sample was collected from the middle of the 30 m transect within 1 m of the central ecological core sample. Samples were stored on ice, in zip lock bags. Sediment samples were analysed externally by Water Care Laboratory Services to determine ash free dry weight (AFDW), total nitrogen, total phosphorus, total cadmium, total chromium, total copper, total zinc, total nickel and total lead. Total organic carbon (TOC) was calculated from AFDW using the formula TOC = 0.4 x (AFDW) + 0.0025 x $(AFDW)^2$ (Robertson *et al.* 2002). Sediment grain size was analysed by Waikato University with a laser diffraction particle analyser. The raw sediment data is presented in Appendix 3.

2.2 Data analysis

The sediment metal results were assessed against ANZECC ISQG-Low Trigger values for sediment (Australian New Zealand Environment Conservation Council 2000) and threshold effect levels developed by MacDonald *et al*. (1996). Sediment TOC and nutrient concentrations were assessed against a classification developed by Robertson and Stevens (2007).

The ecological data was analysed using PRIMER v6.1.12 & PERMANOVA V1.0.2 (Plymouth Marine Laboratory, Plymouth, UK). Four measures of biological diversity were calculated: species richness (s); the total number of individuals (n); the Shannon-Wiener diversity index and Pielou's evenness index (J') for each core sample. Mean values were then calculated for each site. An expression of within-site variability was also calculated by determining the Bray-Curtis similarity between individual site replicates.

The species abundance data was also examined with cluster analysis and non-metric multidimensional scaling (MDS) using a Bray-Curtis similarity matrix. Cluster analysis and MDS ordination are visual displays of the species similarity matrix which can help to identify groups of samples. Samples close to each other on an MDS plot are more similar to each other. This analysis was performed on the mean species abundance for each site. A square root transformation was performed on the benthic infauna abundance data in order to downplay the influence of numerically dominant taxa (Clark & Warwick 2001). Samples located close to each on the plots are more similar to each other.

A distance-based linear model (DISTLM) was then used to model the relationship between the square root transformed ecological data and the physical and sediment chemical properties (McArdle & Anderson, 2001). Prior to this analysis the sediment data was $\log_{10}$ transformed. Site averaged abundance data was used for the DISTLM. Cadmium was not included in this analysis because most values were below or very close to the laboratory detection limit.

3. Results

3.1 Sediment grain size

Most sites had a high proportion of mud with the sediment at eight of the 10 sites comprising more than 60% mud. Within the estuary, the highest proportions of mud were generally found at sites in sheltered tidal creek environments furthest from the entrance of the estuary giving way to more medium and coarse sand towards the mouth of the estuary (Figure 3). WAT 8 which is located furthest up the main Waitangi river arm of the estuary comprised more than 98% mud. In contrast WAT 1, which is located close to the estuary entrance, had the lowest proportions of mud and the highest proportions of coarse sand.

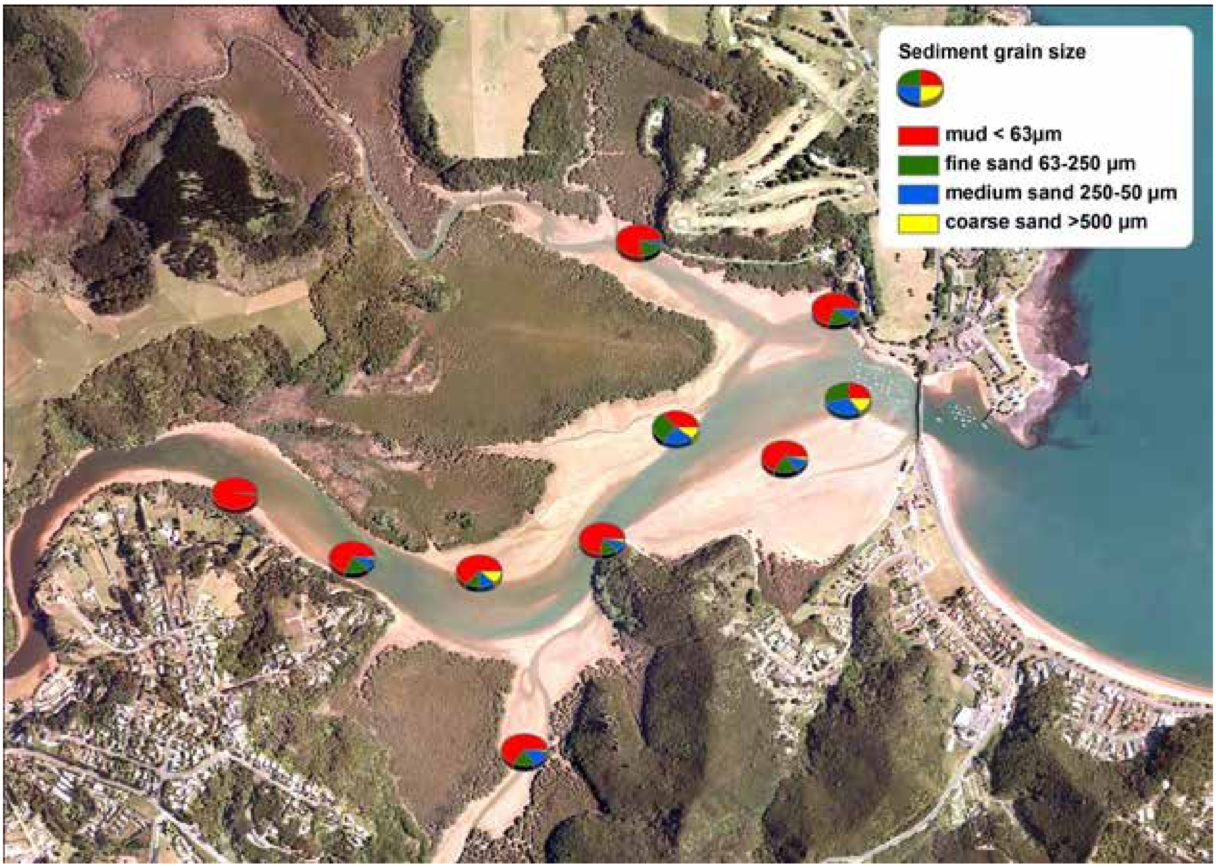

Figure 3. Sediment grain size characteristics in the Waitangi estuary 2013.

3.2 Sediment TOC and nutrient concentrations

3.2.1 TOC

The highest levels of TOC were found at WAT 5 (4.21 %w/w) and WAT 8 (4.03 %w/w). The lowest values were recorded at WAT 1 (0.97 %w/w) and WAT 7 (1.13 %w/w) (Figure 4). ANZECC guidelines do not include trigger values for TOC in marine sediments and there are currently no nationally accepted guideline values. Robertson and Stevens (2007) have developed their own classifications for TOC. In their classification levels below 1% are classified as 'very good', levels between 1-2% are classified as 'low to moderately enriched', levels between 2-5% are classified as 'enriched' and levels above 5% as 'very enriched'. Using this criteria one site was classified as 'very good', three sites as 'low to moderately enriched' and six sites as 'enriched' (Figure 4). In 2013, TOC at WAT1 (0.97 %w/w) was lower than the level previously recorded at this site by Council in 2012 (1.47 %w/w).

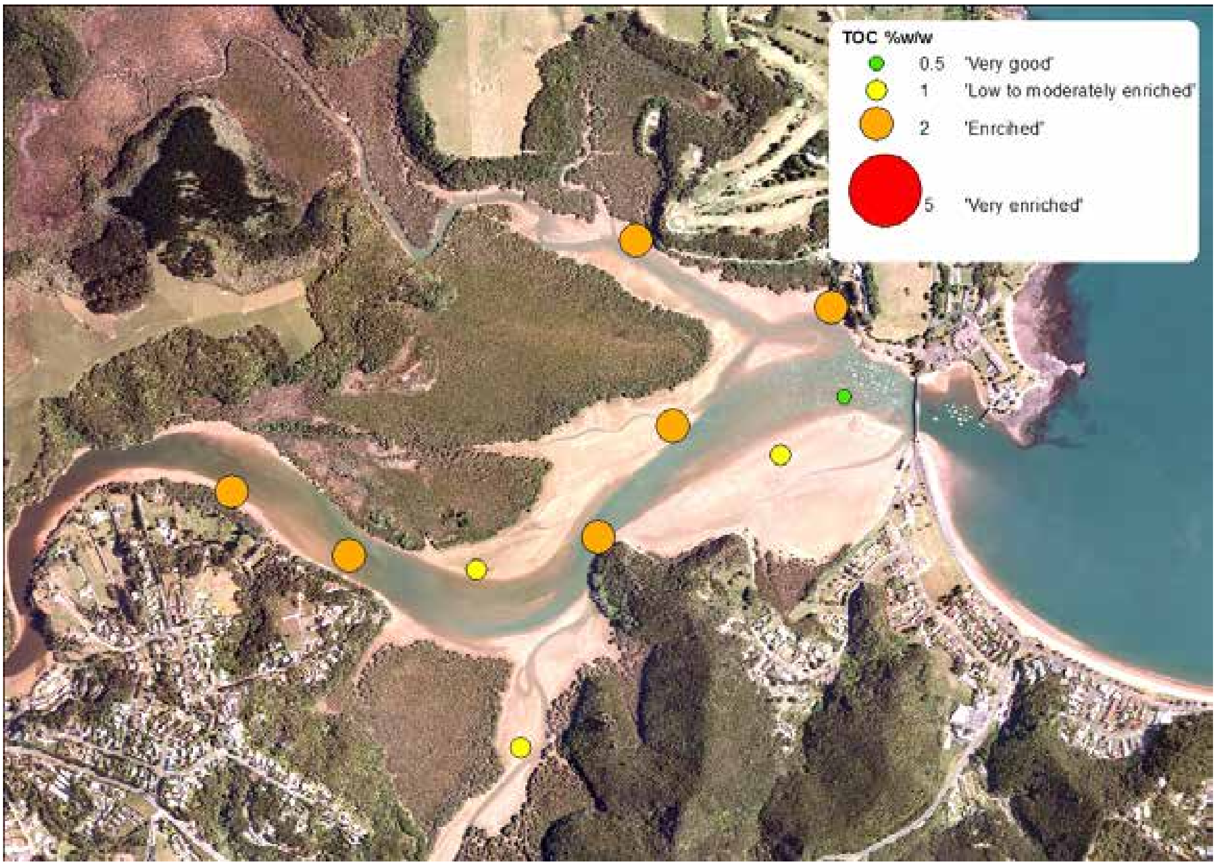

Figure 4. TOC concentrations in the Waitangi estuary 2013.

3.2.2 Total nitrogen

The highest concentration of nitrogen was recorded at WAT 8 (2600 mg/kg), which was more than double the next highest concentration (Figure 5). The lowest values were recorded at WAT 5 (220 mg/kg) and WAT 1 (230 mg/kg) (Figure 5). ANZECC guidelines do not include trigger values for nitrogen in marine sediments and there are currently no nationally accepted guideline values. Robertson and Stevens (2007) have developed their own classifications for sediment nitrogen concentrations. In their classification concentrations below 500 mg/kg are classified as 'very good', concentrations between 500-2000 mg/kg are classified as 'low to moderately enriched', concentrations between 2000-4000 mg/kg are classified as 'enriched' and concentrations above 4000 mg/kg as 'very enriched'. Using this criteria the concentrations of nitrogen at three sites were classified as 'very good', six sites as 'low to moderately enriched' and one site WAT 8 was 'enriched' (Figure 5). In 2013, nitrogen (230 mg/kg) at WAT1 was much lower than the level previously recorded at this site by Council in 2012 (530 mg/kg).

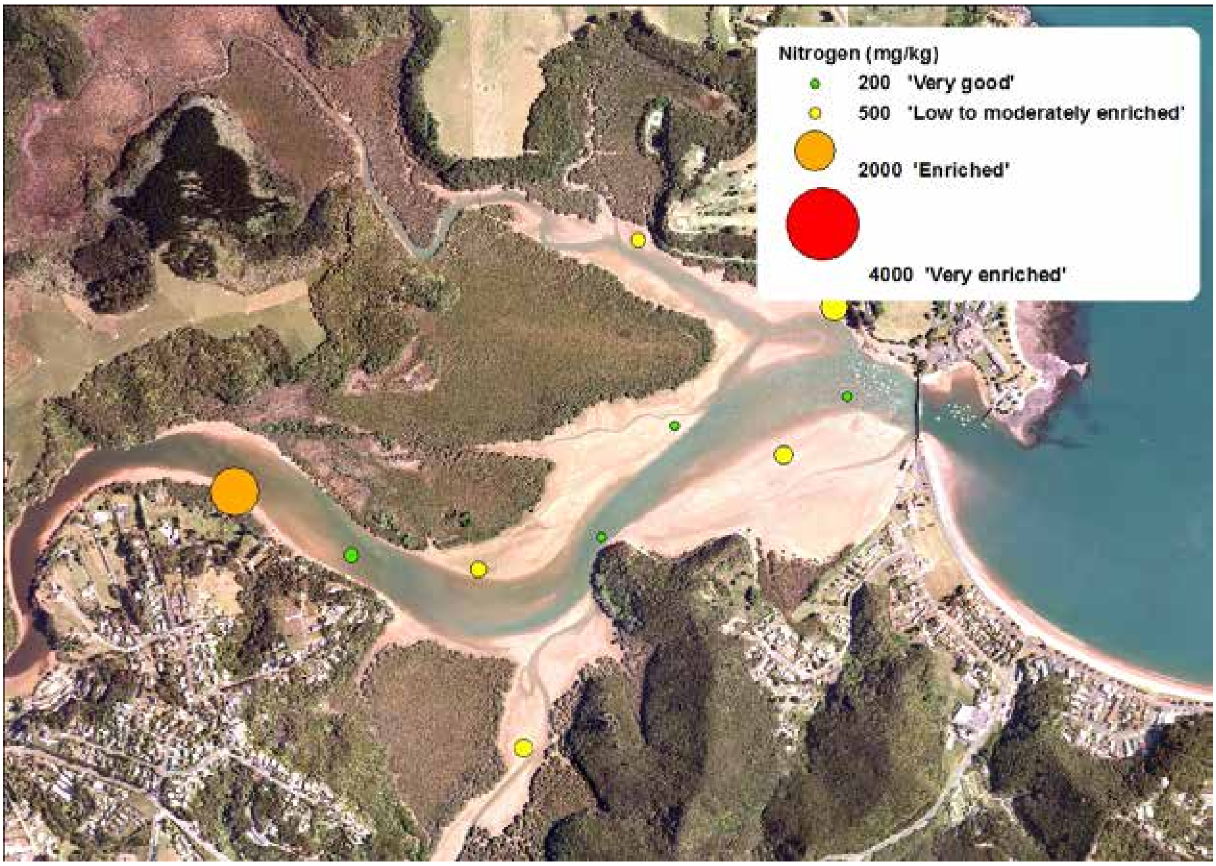

Figure 5. Sediment nitrogen concentrations in the Waitangi estuary 2013.

3.2.3 Total phosphorus

The highest concentration of phosphorus was also recorded at WAT 8 (850 mg/kg) with the lowest concentrations found at WAT 1 (410 mg/kg) (Figure 6). ANZECC guidelines do not include trigger values for phosphorus in sediments and there are currently no nationally accepted guideline values but Robertson and Stevens (2007) have also developed a classification for sediment phosphorus concentrations. In their classification concentrations below 200 mg/kg are classified as 'very good', concentrations between 200-500 mg/kg are classified as 'low to moderately enriched', concentrations between 500-1000 mg/kg are classified as 'enriched' and concentrations above 1000 mg/kg as 'very enriched'. Under this classification two sites were classified as 'low to moderately enriched' and eight sites were classified as 'enriched' (Figure 6). In 2013, phosphorus (410 mg/kg) at WAT1 was lower than the level previously recorded at this site by Council in 2012 (530 mg/kg).

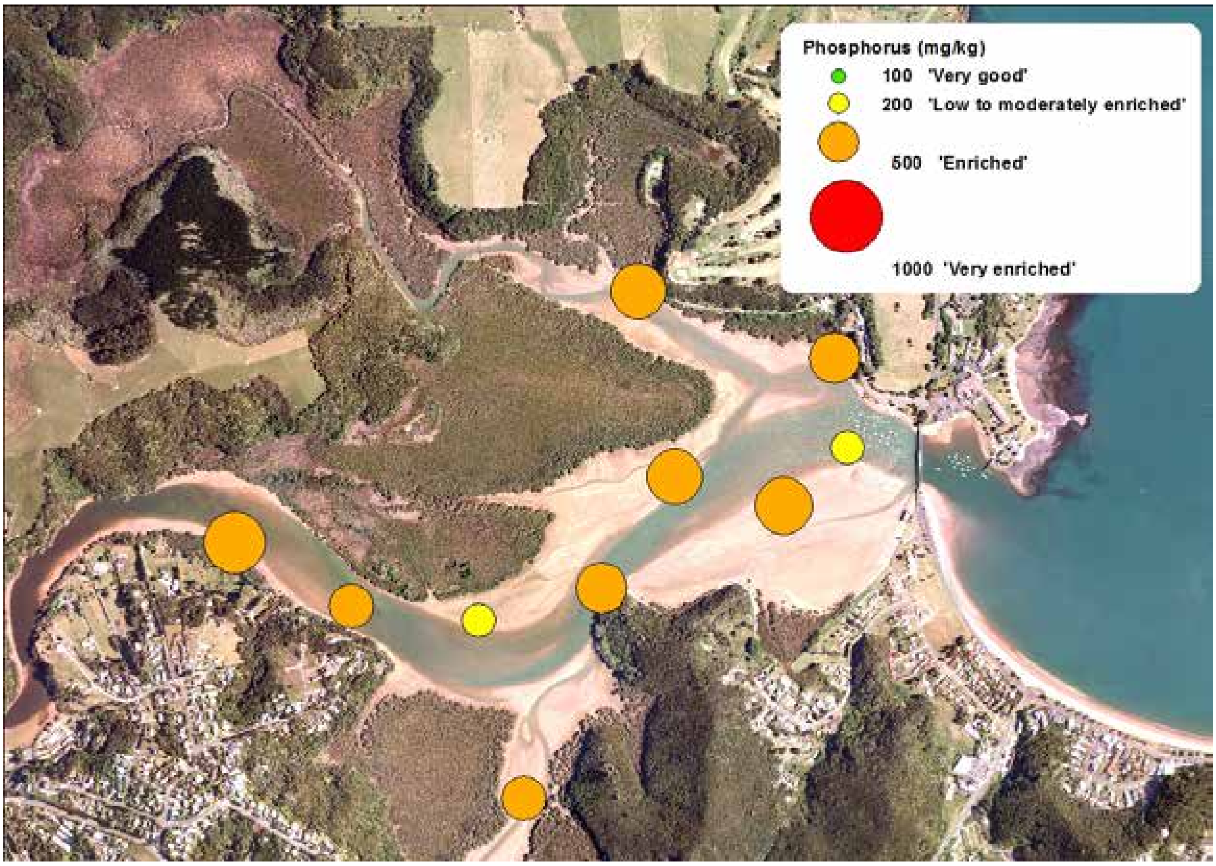

Figure 6. Sediment phosphorus concentrations in the Waitangi estuary 2013.

3.2.4 Comparison of nutrient concentrations in Northland estuaries

The mean nitrogen concentration in the Waitangi estuary was higher than the means previously recorded in most other sediment surveys of estuaries in Northland (Table 3). Higher mean values were only found in surveys of the Bay of Islands (which included one site in the Waitangi estuary) and Hokianga harbour (Table 3). The nitrogen concentration recorded at WAT 8 was particularly high in comparison to other sites monitored by Council. In recent surveys conducted by Council higher concentrations of nitrogen have only been recorded at Limeburners creek in Whāngārei harbour (Griffiths 2013) and Orira river in Hokianga harbour (Northland Regional Council 2013).

The mean phosphorus concentration recorded in the Waitangi estuary was also higher than levels recorded at most other estuaries surveyed recently by Council (Table 3). A higher mean phosphorus was only previously recorded in a survey of the Bay of Islands (Table 3).

The mean TOC in Waitangi estuary was also higher than means recorded at most other estuaries (Table 3). Higher mean TOC values were only found in the Whangaroa harbour and Hokianga harbour (Table 3).

Table 3. Mean sediment nutrient concentrations in Northland estuaries with range presented in brackets.

	Year	Number of samples	Nitrogen (mg/kg)	Phosphorus (mg/kg)	TOC (%w/w)
Waitangi	2013	10	803 (220 – 2600)	647 (410 – 850)	2.6 (1.0 – 4.2)
Bay of Islands*	2012	16	914 (260 – 1600)	654 370 – 1000)	2.4 (1.0 – 4.8)
Whāngārei	2012	42	691 (14 – 4900)	341 (50 – 1200)	1.5 (0.2 – 6.0)
Pārengarenga North	2013	12	263 (62-1300)	102 (28-180)	0.9 (0.3 - 2.5)
Pārengarenga South	2013	10	218 (25-500)	60 (18-200)	0.4 (0.1 – 1.0)
Houhora	2013	6	688 (270 – 1100)	129 (52 – 220)	1.3 (0.6 - 1.9)
Rangaunu	2013	10	318 (64-920)	122 (24 -360)	0.8 (0.2 -2.2)
Taipā/Mangonui	2013	6	354 (59 – 990)	490 (280 – 710)	1.9 (1.2 – 2.5)
Whangaroa	2013	7	800 (130 – 1600)	518 (390 – 710)	3.3 (1.3 - 6.0)
Hokianga	2013	11	1102 (43-2700)	512 (54 -800)	3.3 (0.2 - 5.2)

*Included one site (WAT 1) in the Waitangi estuary.

3.3 Sediment metal concentrations

3.3.1 Cadmium

The concentrations of cadmium were below the laboratory detection at eight of the 10 sites. The concentrations at WAT 4 (0.11 mg/kg) and WAT 5 (0.13 mg/kg) were below the ANZECC ISQG-Low trigger value of 1.5 mg/kg (Australian New Zealand Environment Conservation Council 2000) and the threshold effect level (TEL) of 0.68 mg/kg developed by MacDonald *et al*. (1996). The cadmium concentration at WAT1 (<0.091 mg/kg) in this survey was lower than the level previously recorded at this site by Council in 2012 (0.099 mg/kg).

3.3.2 Chromium

All of the chromium concentrations were well below the ANZECC ISQG-Low effect trigger value of 80 mg/kg (Australian New Zealand Environment Conservation Council 2000) and the threshold effect level of 52.3 mg/kg developed by MacDonald *et al*. (1996). The highest concentrations of chromium was at WAT 10 (17mg/kg) and higher concentrations tended to be found in the tidal creek environments furthest from the estuary entrance with the lowest value found at WAT 1 (5.4 mg/kg) near the entrance of the estuary (Figure 7). Chromium at WAT1 (5.4 mg/kg) was lower than the level previously recorded at this site by Council in 2012 (12mg/kg).

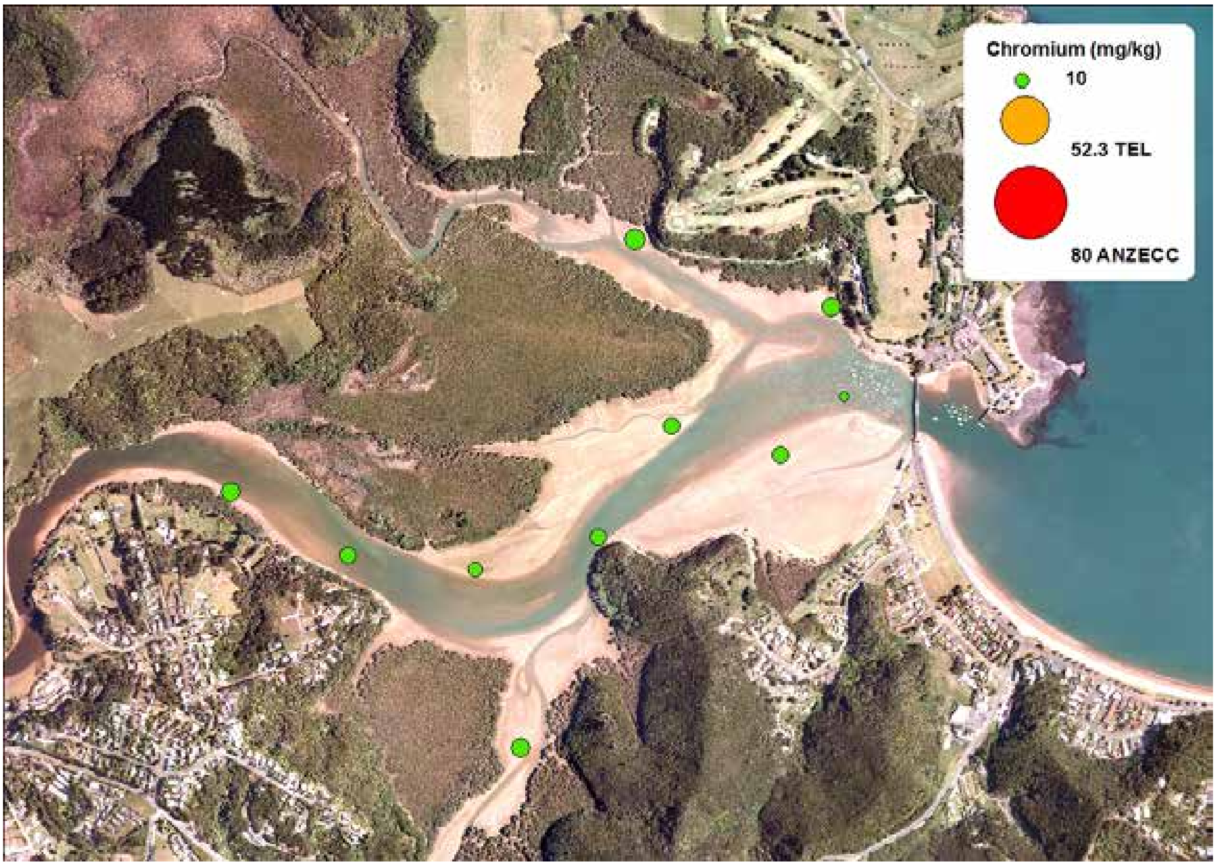

Figure 7. Sediment chromium concentrations in the Waitangi estuary 2013.

3.3.3 Copper

All of the copper concentrations were well below the ANZECC ISQG-Low effect trigger value of 65 mg/kg (Australian New Zealand Environment Conservation Council 2000) and the threshold effect level of 18.7 mg/kg developed by MacDonald *et al*. (1996). The highest concentrations of copper tended to be found in tidal creek environments at WAT 8 (17 mg/kg) and WAT 10 (14 mg/kg) with the lowest value found at WAT 1 (4.1 mg/kg), at the entrance of the estuary (Figure 8). The concentration of copper at WAT1 was lower than the level previously recorded at this site by Council in 2012 (13 mg/kg).

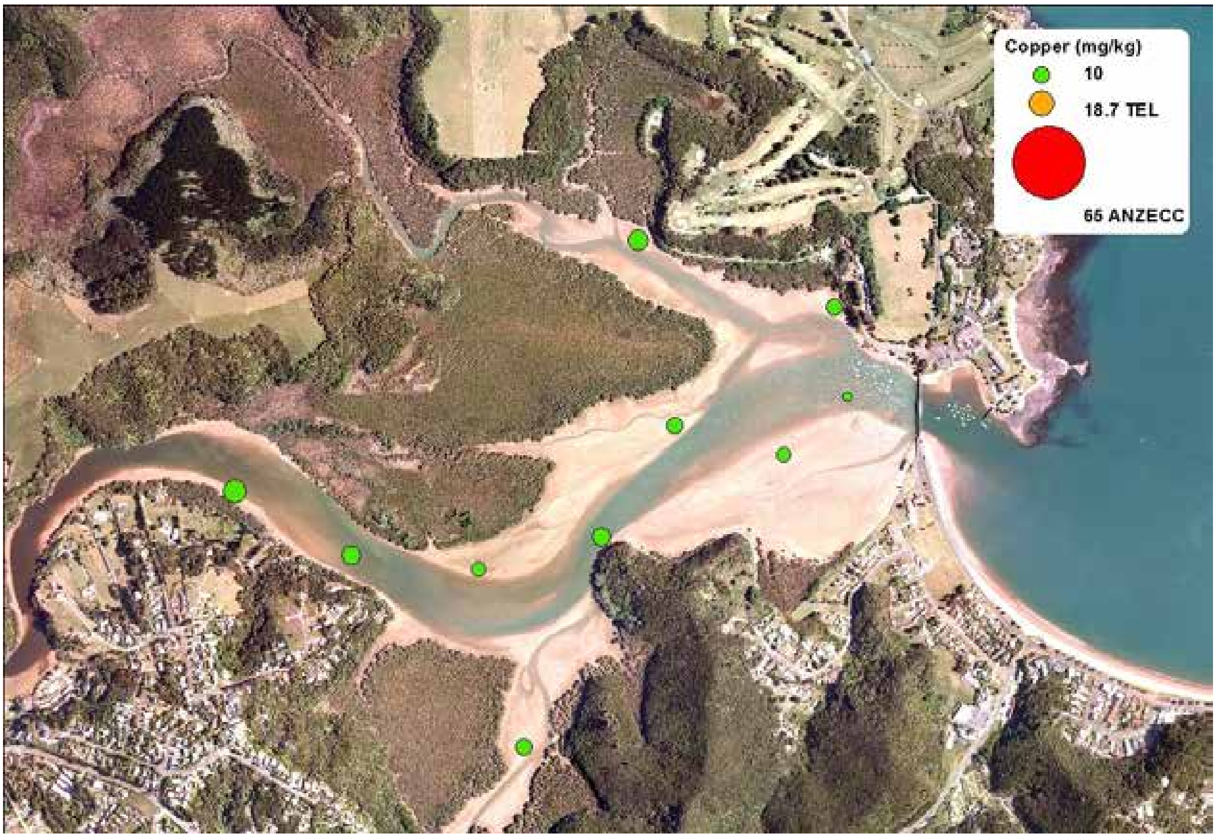

Figure 8. Sediment copper concentrations in the Waitangi estuary 2013.

3.3.4 Nickel

All of the nickel concentrations were below the ANZECC ISQG-Low effect trigger value of 21 mg/kg (Australian New Zealand Environment Conservation Council 2000) and the threshold effect level of 15.9 mg/kg developed by MacDonald *et al*. (1996). The highest concentrations of nickel tended to be found in tidal creek environments at WAT 8 (9.5 mg/kg) and WAT 10 (9 mg/kg) with the lowest value found at WAT 1 (4.9mg/kg), at the entrance of the estuary (Figure 9).

Figure 9. Sediment nickel concentrations in the Waitangi estuary 2013.

3.3.5 Lead

All of the lead concentrations were below the ANZECC ISQG-Low effect trigger value of 50 mg/kg (Australian New Zealand Environment Conservation Council 2000) and the threshold effect level of 30.2 mg/kg developed by MacDonald *et al*. (1996). The highest concentrations of lead tended to be found in tidal creek environments at WAT 8 (9.8 mg/kg) and WAT 10 (9.8 mg/kg) with the lowest value found at WAT 1 (4.2 mg/kg), at the entrance of the estuary (Figure 10). The lead concentration at WAT1 was lower than the level previously recorded at this site by Council in 2012 (7.8 mg/kg).

Figure 10. Sediment lead concentrations in the Waitangi estuary 2013.

3.3.6 Zinc

All of the zinc concentrations were below the ANZECC ISQG-Low effect trigger value of 200 mg/kg (Australian New Zealand Environment Conservation Council 2000) and the threshold effect level of 124 mg/kg developed by MacDonald *et al*. (1996). The highest concentrations of lead tended to be found in tidal creek environments at WAT 6 (84 mg/kg) and WAT 9 (72 mg/kg) with the lowest value found at WAT 1 (33 mg/kg), at the entrance of the estuary (Figure 11). The concentration of zinc at WAT1 was lower than the level previously recorded at this site by Council in 2012 (50 mg/kg).

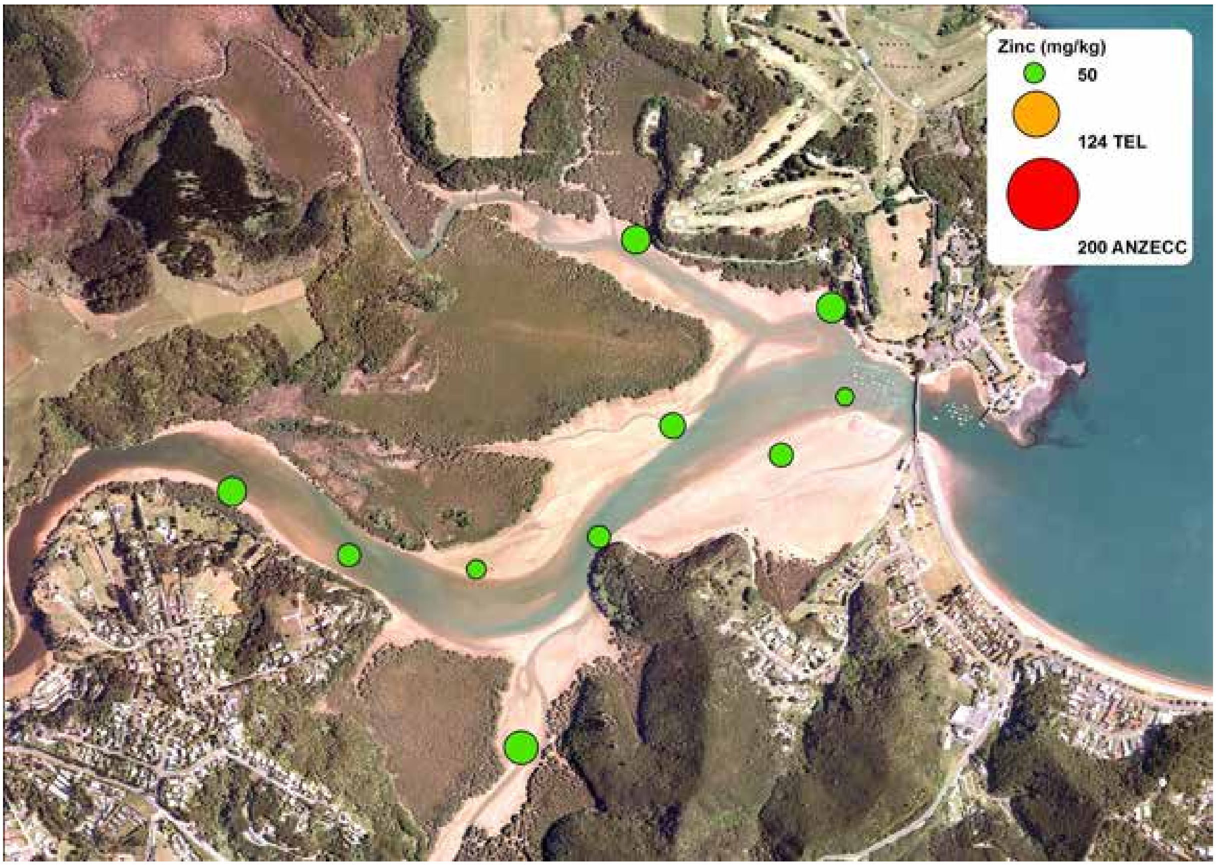

Figure 11. Sediment zinc concentrations in the Waitangi estuary 2013.

3.3.7 Comparison of metal concentrations in Northland estuaries

The metal concentrations recorded in the Waitangi estuary were generally similar to means reported in recent sediment surveys conducted by Council in the Whāngārei harbour and the Bay of Islands (which included one site in the Waitangi estuary) in 2012 (Table 4).

Table 4. Mean metal concentrations recorded in Northland estuaries with range in brackets.

	Waitangi (2013)	Bay of Islands (2012)	Whāngārei (2012)
Number of samples	10	16	41
Cadmium	NA (<0.09 – 0.13)	NA (< 0.09 – 0.09)	NA (<0.09 – 0.16)
Chromium	13 (5 -17)	19 (8 – 42)	12 (2 – 57)
Copper	11 (4 – 17)	9 (2 – 17)	10 (<0.05 – 79)
Nickel	8 (5 – 10)	Not recorded	6 (1 – 30)
Lead	8 (4 – 10)	10 (4 – 17)	8 (0.5 – 51)
Zinc	56 (33 – 84)	49 (17 – 71)	44 (4 – 160)

3.4 Ecology

3.4.1 Biodiversity

A total of 5150 individuals belonging to 92 different taxa were identified in Waitangi estuary. The mean number of taxa varied from five at WAT 8 to 22 at both WAT 1 and WAT 9 (Table 5). WAT 1 and WAT 9 are both located near the entrance of the estuary while WAT 8 is located furthest from the entrance.

The highest number of individuals was found at WAT 9 and WAT 10 (Table 5). These sites are both located in the Hutia creek. The lowest number of animals was found at WAT 7 and WAT 8. These are both intertidal sites located on opposite banks of the main Waitangi river channel. The lowest Shannon-Wiener diversity was also found at WAT 7 and WAT 8 (Table 5). The highest diversity was found at WAT 4, which is located on an expansive intertidal flat near the entrance of the estuary. The highest evenness was also at WAT 4. The lowest evenness was at WAT 5 which is on an intertidal flat opposite WAT 4 (Table 5).

Bray-Curtis similarity indicated that the similarity at WAT 7 and WAT 8 was low compared to the other sites (Table 5). A low Bray-Curtis similarity indicates that the species (and their abundance) found in the three replicates were dissimilar to each other. These sites are located on intertidal flats either side of the main Waitangi river channel, furthest from the entrance. The highest Bray Curtis similarity was at WAT 4 which is a sheltered sand flat near the estuary entrance. A high Bray-Curtis similarity indicates that the taxa (and their abundance) in the three replicates were similar to each other.

Table 5. Mean diversity indices and Bray Curtis similarity at sites in the Waitangi estuary in 2013.

	Species richness	Number of individuals	Shannon-Wiener diversity	Pielou's Evenness	Bray-Curtis similarity
WAT 1	22	209	2.02	0.65	65.6
WAT 2	15	99	1.92	0.71	53.6
WAT 3	11	67	1.85	0.77	65.8
WAT 4	17	133	2.24	0.80	70.7
WAT 5	21	299	1.80	0.59	52.2
WAT 6	18	111	1.99	0.70	51.7
WAT 7	6	25	1.39	0.78	21.8
WAT 8	5	42	0.90	0.68	33.0
WAT 9	22	346	1.89	0.61	65.0
WAT 10	16	386	1.67	0.61	61.8

3.4.2 Multivariate analysis of ecological data

Analysis of the average linkage clustering and MDS ordination (Figures 12 & 13) of the species abundance data indicated that the communities at WAT 7 and WAT 8 were quite different to the other sites. The MDS also shows that the replicates from these two sites are quite dispersed. This indicates that the replicates were dissimilar to each other and that there was a higher degree of within-site variability at these two sites. As discussed in Section 3.4.1 these two sites had a low Bray-Curtis Similarity (Table 5).

Further analysis of the MDS ordination and the clustering did not indicate any strong groupings of sites although samples from the three shallow subtidal sites (WAT 1 - 3) were all located close to each other in the top right-hand side of the MDS plot (Figure 13). This indicates that these sites are similar to each other. Another feature was the tight grouping of the three samples from WAT 4, which indicates that these samples are very similar to each other. The MDS plot is constructed from a similarity matrix using Bray-Curtis similarity and the high Bray Curtis Similarity at WAT 4 was noted in the previous Section 3.4.1. Finally the MDS plot shows an overlap between samples from WAT 9 and 10, which indicates that samples from these two sites are similar to each other (which is discussed further in Section 3.4.3.

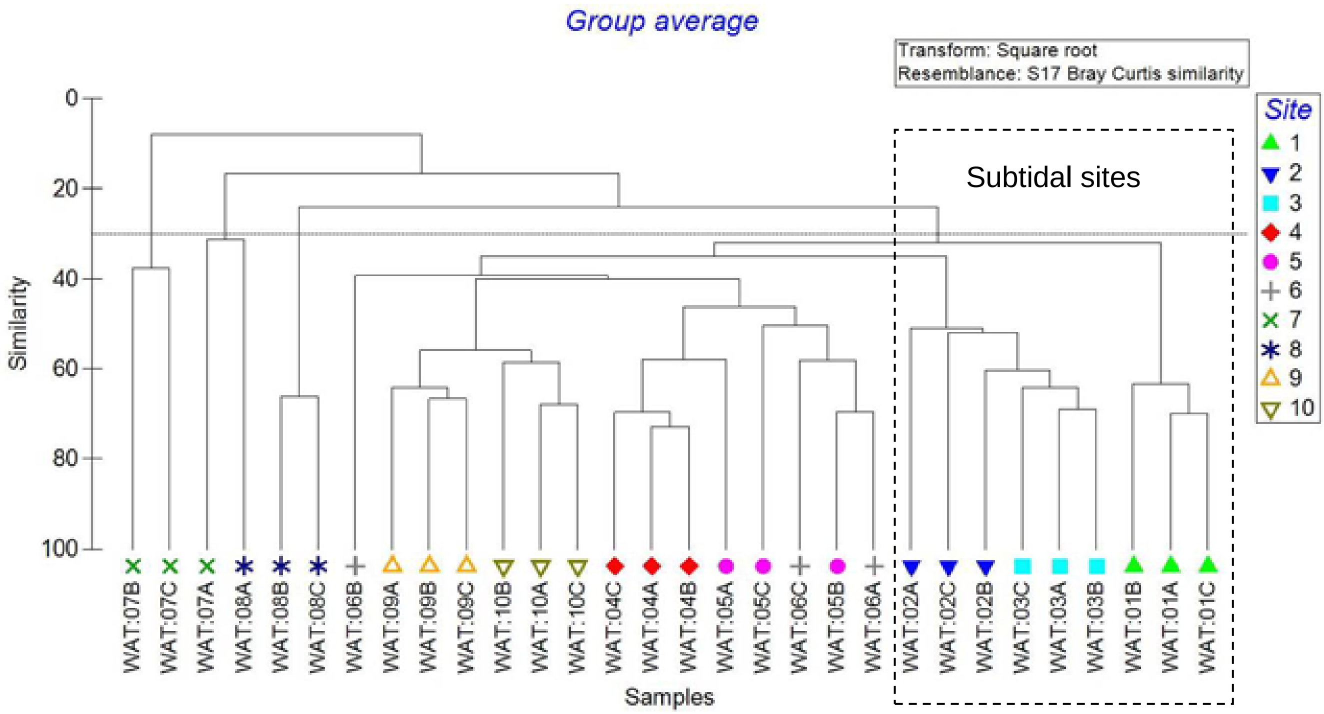

Figure 12. Group average linkage cluster of Bray-Curtis similarities from square root transformed abundance data collected from 10 sites in the Waitangi estuary in 2013.

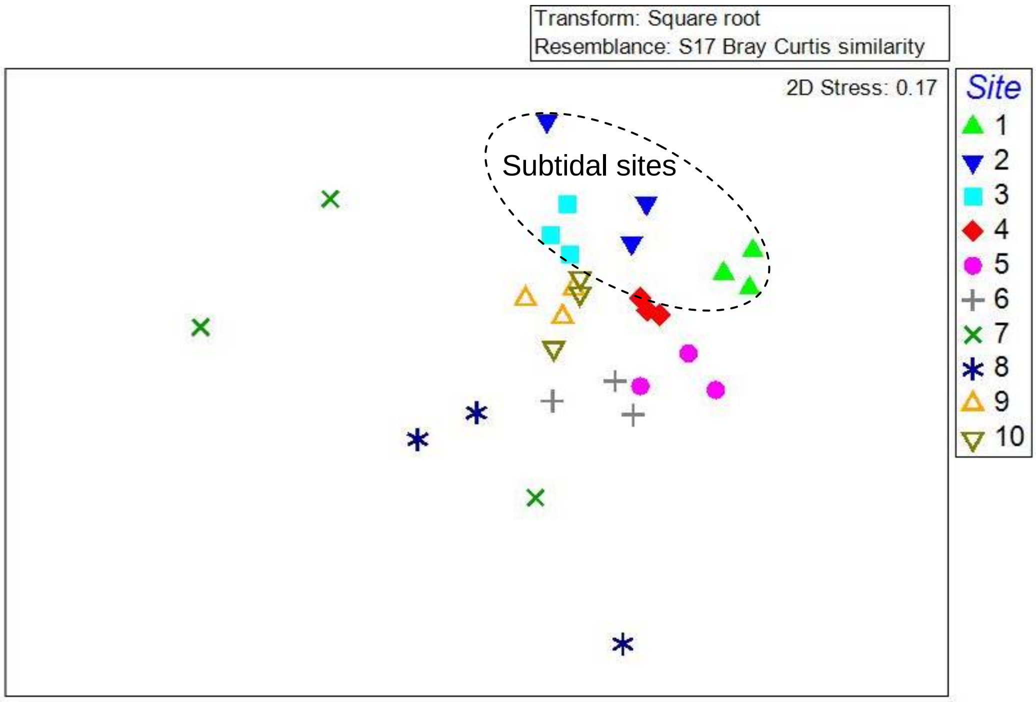

Figure 13. Non-metric MDS ordination of Bray-Curtis similarities from square root transformed abundance data collected from 10 sites in the Waitangi estuary in 2013. Sites closest together are more similar.

3.4.3 Species abundance

The community at most sites were dominated by polychaete and oligochaete worms and overall these two taxonomic groups accounted for 51% and 32% of all individuals identified. Bivalves were the other main group accounting for 10% of individuals.

WAT 1

At WAT 1, 627 individuals belonging to 35 taxa were identified. Polychaete worms accounted for over 90% of all the individuals found. The polychaete worm *Prionospio aucklandica* was by far the most abundant taxon (Table 6). The polychaete worms, *Barantolla lepte* and *Armandia maculata* were the next most abundant taxa.

Table 6. Mean abundance of taxa collected from WAT 1 in 2013.

Taxon	Description	Mean abundance
Prionospio aucklandica	Polychaete worm	81
Barantolla lepte	Polychaete worm	36
Armandia maculata	Polychaete worm	33
Heteromastus filiformis	Polychaete worm	11
Oligochaeta	Oligochaete worm	7

WAT 2

At WAT 2, 298 individuals belonging to 29 taxa were found. Polychaete worms were again the most dominant group accounting for 70% of all individuals identified with bivalves accounting for a further 24%. The most abundant taxa were the polychaete worm *Cossura consimilis*, the invasive bivalve *Theora lubrica* and the polychaete worm *Heteromastus filiformis* (Table 7).

Table 7. Mean abundance of taxa collected from WAT 2 in 2013.

Taxon	Description	Mean abundance
Cossura consimilis	Polychaete worm	33
Theora lubrica	Invasive bivalve	20
Heteromastus filiformis	Polychaete worm	13
Prionospio aucklandica	Polychaete worm	9
Oligochaeta	Oligochaete worm	4
Paraonidae	Polychaete worm	4

WAT 3

At WAT 3, 202 individuals belonging to 18 taxa were found. Polychaete worms accounted for 45% of all individuals, bivalves 28% and oligochaete worms 27%. The most abundant taxa were the oligochaete worm, the invasive bivalve *Theora lubrica* and the polychaete worm *Cossura consimilis* (Table 8).

Table 8. Mean abundance of taxa collected from WAT 3 in 2013.

Taxon	Description	Mean abundance
Oligochaeta	Oligochaete worm	18
Theora lubrica	Invasive bivalve	15
Cossura consimilis	Polychaete worm	15
Heteromastus filiformis	Polychaete worm	4
Paraonidae	Polychaete worm	4
Austrovenus stutchburyi	Cockle	3

WAT 4

At WAT 4, 398 individuals belonging to 25 taxa were found. Polychaete worms accounted for 54% of all individuals with bivalves and oligochaete worms accounting for 22% and 16% respectively. The most abundant taxa were the polychaete worm *Prionospio aucklandica*, oligochaete worm, and the cockle *Austrovenus stutchburyi* (Table 9).

Table 9. Mean abundance of taxa collected from WAT 4 in 2013.

Taxon	Description	Mean abundance
Prionospio aucklandica	Polychaete worm	29
Oligochaeta	Oligochaete worm	21
Austrovenus stutchburyi	Cockle	19
Cossura consimilis	Polychaete worm	15
Heteromastus filiformis	Polychaete worm	10

WAT 5

At WAT 5, 896 individuals belonging to 37 taxa were found. Oligochaete worms accounted for 35%, of all individuals, polychaete worms 28%, cirripedia 21% and bivalves 10%. The oligochaete worm was by far the most abundant taxon followed by the barnacle *Austrominius modestus*, the polychaete worm *Prionospio aucklandica* and the cockle *Austrovenus stutchburyi* (Table 10).

Table 10. Mean abundance of taxa collected from WAT 5 in 2013.

Taxon	Description	Mean abundance
Oligochaeta	Oligochaete worm	105
Austrominius modestus	Barnacles	51
Prionospio aucklandica	Polychaete worm	42
Austrovenus stutchburyi	Cockle	23
Cirripedia	Cirripedia	11

WAT 6

At WAT 6, 333 individuals belonging to 31 taxa were found. Oligochaete worms accounted for 45% of all individuals with polychaete worms accounting for 28 % and bivalves 15%. Oligochaete worms were again by far the most abundant taxa, followed by the cockle *Austrovenus stutchburyi* and the small bivalve *Arthritica bifurca* (Table 11).

Table 11. Mean abundance of taxa collected from WAT 6 in 2013.

Taxon	Description	Mean abundance
Oligochaeta	Oligochaete worm	50
Austrovenus stutchburyi	Cockle	8
Arthritica bifurca	Small bivalve	7
Capitella capitata	Polychaete worm	7
Prionospio aucklandica	Polychaete worm	6

WAT 7

Only 75 individuals from 14 taxa were found at WAT 7, with most taxa found in very low numbers. The most abundant taxa were oligochaete worms, the polychaete worm Capitellidae and the crab *Austrohelice crassa* (Table 12). No taxonomic groups were particularly dominant with polychaete worms accounting for 32% of individuals and oligochaete worms 25%.

Table 12. Mean abundance of taxa collected from WAT 7 in 2013.

Taxon	Description	Mean abundance
Oligochaeta	Oligochaete worm	6
Capitellidae	Polychaete worm	6
Austrohelice crassa	Stalk eyed mud crab	4
Austrovenus stutchburyi	Cockle	2
Nereidae (juvenile)	Rag worm	1

WAT 8

Only 125 individuals belonging to nine taxa were found at WAT 9. The most abundant taxa were the polychaete worm *Capitella capitata* and oligochaete worms (Table 13). All other taxa were found in low numbers. Polychaete worms accounted for 60% of individuals and oligochaete worms 34%.

Table 13. Mean abundance of taxa collected from WAT 8 in 2013.

Taxon	Description	Mean abundance
Capitella capitata	Polychaete worm	22
Oligochaeta	Oligochaete worm	14
Capitellidae	Polychaete worm	1
Austrovenus stutchburyi	Cockle	1
Heteromastus filiformis	Polychaete worm	1
Nemertea sp. 3	Proboscis worm	1

WAT 9

At WAT 9, 1039 individuals were found belonging to 31 taxa. Oligochaete worms accounted for 53% of individuals with polychaete worms accounting for 37%. Oligochaete worms were by far the most abundant taxa, with the polychaete worms *Cossura consimilis*, *Capitella capitata* and *Prionospio aucklandica* the next most abundant taxa (Table 14).

Table 14. Mean abundance of taxa collected from WAT 9 in 2013.

Taxon	Description	Mean abundance
Oligochaeta	Oligochaete worm	183
Cossura consimilis	Polychaete worm	33
Capitella capitata	Polychaete worm	28
Prionospio aucklandica	Polychaete worm	26
Theora lubrica	Invasive bivalve	17

WAT 10

1157 individuals belonging to 28 taxa were found at WAT 10. Polychaete worms accounted for 62% of individuals and oligochaete worms accounted for 34%. The dominant taxa were very similar to WAT 9 with oligochaete worms again numerically dominant and the polychaete worms *Cossura consimilis*, *Capitella capitata* and *Prionospio aucklandica* the next most abundant taxa (Table 14 and Table 15). The similarity in the taxa found at WAT 9 and WAT 10 was also evident in the MDS plot, which showed a lot of overlap between samples collected from these two sites (Figure 13).

Table 15. Mean abundance of taxa collected from WAT 10 in 2013.

Taxon	Description	Mean abundance
Oligochaeta	Oligochaete worm	133
Cossura consimilis	Polychaete worm	51
Capitella capitata	Polychaete worm	44
Prionospio aucklandica	Polychaete worm	26
Theora lubrica	Invasive bivalve	5

3.5 Shellfish

Cockles

High densities of cockles (*Austrovenus stutchburyi*) were found at WAT 4 and WAT 5 with a reasonably high density also found at WAT 6 (Figure 14). WAT 4 tended to have mainly larger cockles (>16mm), while WAT 5 also had high densities of smaller size classes (<4mm and 4-16mm). WAT 4 and WAT 5 are located on relatively expansive sand and mud flats near the estuary entrance.

Figure 14. Length frequency distribution of cockles (*Austrovenus stutchburyi*) in the Waitangi estuary 2013.

3.6 Relating ecological community structure and sediment properties

A distance-based linear model (DISTLM) using the Bray-Curtis similarity matrix, and the $\log_{10}$ transformed sediment data similarity matrix, showed that fine sand, nitrogen, mud and coarse sand all had a significant relationship to the ecological data (Table 16). Fine sand (22%) explained the highest proportion of variation in the community structure followed by coarse sand (18.5%). DISTLM conducted using a forward selection procedure showed that the combination of fine sand and coarse sand explained 40% of the variation in the community structure (Pseudo-F = 2.07, P-value = 0.021).

Table 16. DISTLM marginal tests for $\log_{10}$ sediment properties and species abundance data from 10 sites in the Waitangi estuary, 2013. Values in bold were significant at the 5% level.

Sediment properties	Pseudo-F	P-value	Proportion of variation explained
Fine sand	**2.29**	**0.009**	**22.3**
Nitrogen	**1.80**	**0.042**	**18.3**
Mud	**1.76**	**0.044**	**18.0**
Coarse sand	**1.81**	**0.052**	**18.5**
Nickel	1.57	0.080	16.4
Medium sand	1.96	0.087	19.7
Copper	1.58	0.119	16.5
Zinc	1.47	0.126	15.5
Chromium	1.45	0.148	15.4
Lead	1.45	0.151	15.3
Phosphorus	1.14	0.340	12.5
Total organic carbon	0.97	0.482	10.8

4 Discussion

4.1 Sediment grain size

Within the estuary, the highest proportions of mud were generally found at sites in sheltered tidal creek environments furthest from the entrance of the estuary, in particular at sites WAT 8 and WAT 10. Tidal creeks are generally low energy depositional environments and tend to be more influenced by inputs of terrigenous sediment than marine sediment from the open coast. In contrast the highest proportions of coarse sand and medium sand were found near the entrance of the estuary, at WAT 1 and WAT 5. These two sites are more exposed than the sites in the tidal creeks and are likely to be better flushed higher energy environments. The proximity of these sites to the entrance of the estuary also means they are also likely to receive more inputs of coarser grain marine sediment. The proportion of mud at sites in the Waitangi estuary was generally higher than results from sediment surveys carried out by Council in Pārengarenga harbour, Houhora harbour, Whangaroa harbour and Rangaunu harbour in 2013 (Northland Regional Council 2013).

4.2 Sediment TOC and nutrient concentrations

While nutrients are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertilizer, stormwater 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. However, 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.

Using criteria developed by Robertson and Stevens (2007), six sites were classified as 'enriched' for TOC, one site was classified as 'enriched' for nitrogen and eight sites were 'enriched' for phosphorus. The potential sources of nutrients to the Waitangi estuary include septic tanks, seepage from the wastewater network, stormwater, runoff from agricultural land and discharges from farm dairy effluent systems.

The mean nitrogen concentration in the Waitangi estuary was higher than the means previously recorded in other sediment surveys of Northland estuaries, with higher means only found in the Bay of Islands and Hokianga harbour. The nitrogen concentration recorded at WAT 8 was also particularly high in comparison to other sites monitored by Council. In recent surveys conducted by Council higher concentrations of nitrogen have only been recorded at Limeburners creek in Whāngārei harbour (Griffiths 2013) and at Orira river in Hokianga harbour (Northland Regional Council 2013). The mean phosphorus and TOC concentrations recorded in the Waitangi estuary were also higher than levels recorded at most other estuaries surveyed by Council. A higher mean phosphorus concentration was only previously recorded in a survey of the Bay of Islands, and only Hokianga harbour and Whangaroa harbour had higher mean TOC values (Northland Regional Council 2013).

Within the estuary, a similar spatial pattern was observed for levels of TOC, nitrogen and phosphorus, with the highest levels generally recorded at WAT 8 and the lowest values at WAT 1. The high levels of nutrients measured at WAT 8 is consistent with this site having a high proportion of mud as sediment carbon and nutrients absorb onto mineral surfaces and tend to increase as sediment grain size decreases. The low TOC and nutrient levels at WAT 1 are also consistent with the low proportion of mud at this site and the relatively high proportion of coarse sand. WAT 8 is also located close to the main freshwater inputs to the estuary and is likely to be poorly flushed compared to WAT 1, which is very close to the entrance. The levels of TOC, nitrogen and phosphorus recorded at WAT 1 in the current survey were all lower than levels previously recorded at this site in 2012.

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 & Warwick 2001). All of the metal concentrations measured in the Waitangi estuary were well below the ANZECC ISQG-Low effect trigger values (Australian New Zealand Environment Conservation Council 2000) and the threshold effect levels developed by MacDonald *et al*. (1996). This suggests that the concentrations of metals are unlikely to be having an adverse effect on the benthic ecology, although work by Hewitt *et al.* (2009) found community responses below these guideline values. The concentrations of all metals at WAT 1 in the current survey were lower than levels previously recorded at this site in 2012 (Northland Regional Council unpublished data). The mean metal concentrations for the Waitangi estuary as a whole were similar to the mean metal concentrations found in sediment surveys of the Bay of Islands and Whāngārei harbour in 2012 (Griffiths 2013 and Northland Regional Council unpublished data).

The highest concentrations of metals were generally recorded at WAT 8 and WAT 10. These two sites are both located on intertidal flats, in tidal creek environments, where there were high proportions of mud. Sediment grain size is an important factor which influences the concentrations of heavy metals in estuarine sediments (Abrahim *et al.* 2007). Heavy metal absorption tends 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.* 2007).

4.4 Ecology

The intertidal habitats surveyed comprised mainly sheltered soft mud flats. No sandy beaches, sand banks, shell banks, seagrass beds or stone/pebble shorelines were sampled or observed. The shallow subtidal habitats also appeared to be homogenous soft sediment with no biogenic structures or seagrass encountered.

A total of 5150 individuals belonging to 92 different taxa were identified at the 10 sites. Polychaete and oligochaete worms were by far the most abundant groups accounting for 51% and 32% of all individuals identified. Bivalves were the other main group accounting for a further 10% of individuals. The most abundant taxa were oligochaete worms, and the polychaete worms *Prionospio aucklandica*, *Cossura consimilis*, Paraonidae and *Capitella capitata*.

The only known previous ecological sampling within the estuary was one site surveyed as part of the Bay of Islands OS20/20 survey (Hewitt *et. al.* 2010) although a different size core was used to sample the fauna and a different mesh size was used to sieve the samples. This site was at the approximate location as WAT 5 in this survey. Hewitt *et al*. (2010) found that the most abundant taxa were the cockle *Austrovenus stutchburyi* and the polychaete worms Ceratonereis sp., *Prionospio aucklandica* and *Heteromastus filiformis*. These four taxa were all found at WAT 5 in the current survey and these taxa were relatively abundant at other sites throughout the estuary. A further 13 of the 18 taxa identified by Hewitt *et al*. were also found at WAT 5 in this survey and only one of the taxon found by Hewitt *et al*., the gastropod *Zeacumantus lutulentus*, was not found at any of the 10 sites sampled in the current survey.

Cluster analysis and MDS ordination of the ecological data showed that the communities at WAT 7 and WAT 8 were quite different to the other sites. The MDS also showed that the samples from these two sites were quite dispersed, which indicates that the samples were dissimilar to each other and that there was a high degree of within-site variability at these two sites. WAT 7 and WAT 8 both had low species richness, low number of individuals and low diversity. These two sites are located on narrow intertidal mud flats on either sides of the main Waitangi river channel furthest from the entrance of the estuary. These sites are likely to be more influenced by freshwater inflows from the Waitangi river than other sites close to the entrance and in the other tidal creeks, which have relatively small sub catchments. Field observations described the surface sediment at WAT 8 as soft mud while the surface at WAT 7 appeared to consist of a layer of gravel covered with a fine layer of mud, which was firmer to walk on. It was also observed that when sieving the ecological samples collected from WAT 7, the material that washed off had the appearance of terrigenous sediment. The sediment grain size analysis indicated that WAT 8 comprised almost entirely of mud (98%), while WAT 7 comprised 63% mud, 12% fine sand, 14% medium sand and 12% coarse sand. The sediment analysis also showed that WAT 8 had relatively high levels of TOC, nitrogen and phosphorus, which indicated that the sediment was 'enriched' using Robertson and Stevens's classification (2007).

The cluster analysis and MDS ordination did not indicate any strong groupings among the other eight sites although the samples from the three subtidal sites (WAT 1-3) were all located close to each other on the MDS ordination. Samples close to each other on the MDS are more similar. The ordination also showed a tight grouping of the samples from WAT 4, which indicates that samples from this site are very similar to each other. WAT 4 was located on a relatively expansive sand flat near the estuary entrance. Finally the MDS ordination showed a lot of overlap between samples from WAT 9 and WAT 10 and analysis of the species abundance data from these sites found that these two sites had very similar taxa. These two sites were located geographically quite close to each other on intertidal flats in the Hutia creek.

High densities of cockles (*Austrovenus stutchburyi*) were found at WAT 4 (1094 cockles per m^2) and WAT 5 (1320 cockles per m^2) with reasonably high density also found at WAT 6 (434 cockles per m^2). WAT 4 and WAT 5 are both located near the entrance of the estuary on intertidal flats either side of the main channel. The sediment at WAT 5 had a relatively low proportion of mud (36%) and a higher proportion of coarse sand (11%) compared to the other sites but the sediment at WAT 4 had relatively high proportions of mud (65%). NIWA also found a high density of cockles when they sampled the Waitangi estuary as part of OS2020 in 2010 (Hewitt *et al*. 2010). They found 1582 cockles per m^2 site at their site which was in approximately the same location as WAT 5 in this current survey.

The cockle densities found at WAT 4 and WAT 5 were high compared to densities reported in a recent survey of recreational beds in Northland, Auckland and the Bay of Plenty Regions (Pawley 2011). Pawley reported cockle densities of between 146 and 1509 cockles per m^2. The density of large cockles (> 30mm) at WAT 4 (132 per m^2), WAT 5 (301 per m^2) and WAT 6 (56 per m^2) was also high compared to the densities of large cockles reported by Pawley (2011). The density of large cockles (> 30mm) reported by Pawley ranged from 0.2 to 53 cockles per m^2. If similar densities of cockles are present on the relatively expansive intertidal mud flats surrounding WAT 4 and WAT 5 there is likely to be a significant population of cockles in the estuary.

Another bivalve that was found in high numbers was the invasive window shell (*Theora lubrica*). The highest numbers were found at WAT 2, WAT 3 and WAT 9. *Theora lubrica* typically lives in muddy sediments from the low tide mark to 50m and in many localities it is an indicator species for eutrophic and anoxic areas (Inglis *et al.* 2005). Other taxa that are tolerant of nutrient enriched sediment including oligochaete worms and the polychaete worm *Capitella capitata* (Pearson & Rosenberg 1978) were also abundant throughout the estuary. The presence of these taxa is consistent with the sediment nutrient data, which indicated that several of the sites were enriched using the criteria developed by Robertson and Stevens (2007).

4.5 Relating ecological and sediment data

A distance-based linear model (DISTLM) showed that fine sand, nitrogen, mud and coarse sand all had a significant relationship to the ecological data. Fine sand (22%) explained the highest proportion of variation in the community structure followed by coarse sand (18.5%). DISTLM conducted using a forward selection procedure also showed that the combination of fine sand and coarse sand explained 40% of the variation in the community structure. The significant relationship between these sediment properties and the ecological data indicates that the physical and chemical characteristics of the sediment have influenced the ecological communities found in the Waitangi estuary.

5 Acknowledgements

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Appendix 1 Site co-ordinates (NZGD 2000 New Zealand Transverse Mercator)

Site Name	Site number	x	y
WAT1	300495	1698005	6096292
WAT2	300497	1697367	6095929
WAT3	300499	1696718	6095881
WAT4	300501	1697840	6096141
WAT5	300503	1697558	6096217
WAT6	300505	1697165	6095382
WAT7	300507	1697048	6095845
WAT8	300511	1696414	6096047
WAT9	300253	1697971	6096524
WAT10	300513	1697463	6096700

Appendix 2 Field notes and photographs

WAT1

Subtidal. Main channel near the mouth of the Waitangi Estuary. Surface layer of sediment hard, softer underneath. Shell has on surface.

WAT2

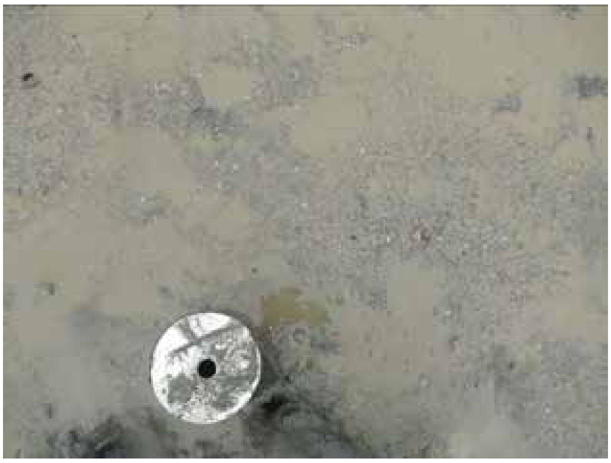
Subtidal. Main channel of Waitangi River. Soft mud.

WAT3

Subtidal. Main channel of Waitangi River Seabed firm.

WAT4

Large intertidal flat next to Waitangi River. Small amount of fine sediment on top of coarse sand. Easy to collect cores.

WAT 5

Large intertidal flat next to Waitangi River. Semi firm. Lots of cockle shells and the odd oyster shell on surface at two of the core sites (Cores A & C), Bare sediment (no shells) at the middle core site (Core B).


WAT 6

Tidal Creek (Kipatiki Stream) off main Waitangi River. Surface sediment soft mud. Shell material in core and core difficult to retrieve.

WAT 7

Intertidal flat next to Waitangi River. Gravelly with thin fine mud layer, similar to KAE site in Whangaroa. Semi firm to walk on. Crab holes on surface.

WAT 8

Narrow intertidal flat next to Waitangi River. Surface – soft mud. Cores collected from elbow deep water.

WAT 9

Lower Hutia Creek. First two cores (A & B) soft mud on top of a layer of firmer sediment. Very deep mud at the third core (C) (second picture).

WAT 10

Upper Hutia Creek. Soft mud, mangrove seedlings, crab holes and large cockles on surface. Shell hash underneath.

Appendix 3 Sediment results

Site Name	<63 (Mud)	63-250 (Fine sand)	250- 500 (medium sand)	>500 (coarse sand)
WAT1	24	30	32	14
WAT2	74	15	9	3
WAT3	69	21	9	2
WAT4	66	21	10	3
WAT5	36	28	25	11
WAT6	66	18	15	2
WAT7	63	12	14	12
WAT8	98	2	0	0
WAT9	69	21	9	1
WAT10	79	17	4	0

Site Name	AFDW	TOC	Nitrogen (mg/kg)	Phosphorus (mg/kg)
WAT1	2.4	1.0	250	410
WAT2	8.1	3.4	230	700
WAT3	6.5	2.7	500	590
WAT4	4.2	1.7	790	770
WAT5	9.9	4.2	220	720
WAT6	4.8	2.0	970	580
WAT7	2.8	1.1	610	420
WAT8	9.5	4.0	2600	850
WAT9	6.4	2.7	1300	680
WAT10	8.3	3.5	560	750

Site Name	Cadmium (mg/kg)	Chromiu m (mg/kg)	Copper (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
WAT1	<0.091	5.4	4.1	4.9	4.2	33
WAT2	<0.089	13	12	7.8	8	50
WAT3	<0.092	12	12	8.1	7.4	50
WAT4	0.11	12	9	7.4	7.5	54
WAT5	0.13	12	9.4	7	7.7	58
WAT6	<0.09	16	9.2	8.5	7.1	84
WAT7	<0.09	9.4	8.3	6.1	6.1	38
WAT8	<0.9	16	17	9.5	9.8	<67
WAT9	<0.89	16	11	8.3	8.6	72
WAT10	<0.89	17	14	9	9.8	67

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