Kaipara Harbour
Estuary Monitoring Programme 2014

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Executive summary

In 2014, Northland Regional Council (Council) sampled 44 intertidal sites throughout the northern Kaipara Harbour in order to survey the sediment quality and ecological status of the harbour. The survey methods were adapted from the Estuary Monitoring Protocol (Robertson *et al.* 2002), which was developed by Cawthron for use by regional councils. The survey involved sampling the physical and chemical properties of the sediment (metal and nutrient concentrations), and the ecological communities of intertidal habitats. The survey will provide baseline data to track changes in the health of the harbour over time and complement the existing data from Council's two estuary monitoring sites in the Arapaoa River arm of the Kaipara Harbour.

Sediment grain size

The sediment grain size characteristics displayed a general pattern of high proportions of mud in tidal creek environments such as the Arapaoa River, Otamatea River and the Oruawharo River, giving way to more fine and medium sand in the main Wairoa River arm and towards the harbour entrance.

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 and have adverse effects on the health of the harbour. 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), 13 sites were classified as 'enriched' for total organic carbon (TOC), ten sites were classified as 'enriched' for phosphorus and four sites were 'enriched' for nitrogen. In addition, the mean nitrogen concentration in the northern Kaipara Harbour was higher than most values previously recorded in Northland estuaries. Higher mean nitrogen values have only previously been found by Council in the Bay of Islands and the Hokianga Harbour. The nitrogen concentration recorded at K36 Matanginui, in the upper Wairoa arm, was also particularly high in comparison to other sites surveyed recently by Council. The mean phosphorus and TOC levels recorded in the northern Kaipara Harbour were towards the middle of the range of values recorded for other estuaries surveyed by Council.

A similar pattern was observed for levels of TOC, nitrogen and phosphorus, with the highest levels recorded at mud dominated sites in the upper reaches of the different arms of the harbour, with levels generally decreasing down each arm towards the entrance of the harbour. This pattern is consistent with these sites being located close to potential freshwater inputs of nutrients, in depositional tidal creek environments with higher proportions of mud. Sediment carbon and nutrients absorb onto mineral surfaces and tend to increase with decreasing sediment grain size. Potential sources of nutrients to the Kaipara Harbour include municipal wastewater treatment plants, seepage from the wastewater network and septic tanks, stormwater, runoff from agricultural land and discharges from farm dairy effluent systems and dairy processing plants.

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.

The concentration of nickel at K34 Burgess Island Inner exceeded 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 concentration of copper exceeded the threshold effect level developed by MacDonald *et al*. (1996). The relatively high concentrations of nickel and copper at this site are surprising as there are no obvious sources of metal contaminants in the vicinity and two other sites located relatively close to this site did not have elevated metal concentrations. The concentration of copper at K41 Kaiwaka River also exceeded the threshold effect level. Potential sources of metal contaminants at this site include discharges from a waste water treatment plant, road run off and stormwater discharges. At the other 42 sites all of the metal concentrations were below (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 at most sites in the northern Kaipara are unlikely to be having an adverse effect on the ecology.

Within the northern Kaipara Harbour the highest concentrations of metals were generally recorded in the upper reaches of the Wairoa River and in tidal creek environments of the other arms of the harbour. These sites are generally located in depositional 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 onto the large surface area of fine grained sediments rich in clay minerals (Abrahim *et al.* 2007). The lowest concentrations were generally recorded along the Pouto shoreline in the main Wairoa arm of the harbour.

Ecology

The intertidal habitats surveyed were reasonably varied, including sheltered muddy tidal creek environments, sand flats, sand banks, and exposed sandy beaches. One sample was also collected from an area of Pacific oyster reef. Sites were located on the mid inter-tidal so no mangrove forests were sampled. No seagrass beds were encountered and we are not aware of any intertidal or subtidal seagrass beds in the northern Kaipara Harbour.

Cluster analysis and non-metric multi-dimensional scaling (MDS) ordination was undertaken 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. This analysis identified four main groups. The first group (Group A) included sites found on sheltered mud flats in the different arms of the harbour and was characterised by polychaete worms, and the invasive bivalve *Theora lubrica*. A second group (Group B) comprised sites found in the upper reaches of the estuarine arms of the harbour with a high proportion of mud and was characterised by oligochaete and polychaete worms. A third group (Group C) included sites found on more sandy sites in the main Wairoa arm of the harbour. This group was characterised by the cockle *Austrovenus stutchburyi*, the polychaete worm *Aonides trifida*, and the wedge shell *Macomona liliana*. The fourth group (Group D) comprised four sites located on exposed sand flats and sand banks in the main Wairoa arm of the harbour. This group was characterised by the bivalves Soletellina sp., the wedge shell *Macomona liliana* and the cockle *Austrovenus stutchburyi*.

Sites in Group A and Group B tended to have lower species richness, lower total number of individuals and lower Shannon-Wiener diversity scores than sites in Group C and Group D. In addition, although biomass was not measured in this survey it is likely that sites in Group C and D had much higher biomass than sites in Group A and Group B. This is likely because sites in Group A and B were characterised by small animals (marine worms) and generally had low abundances of large bodied animals (e.g. cockles, pipi and wedge shells), while sites in Groups C and D were characterised by high abundances of large bodied shellfish.

The cluster analysis and MDS ordination also identified a fifth group (Group E) comprising just two sites, which were both located in the upper reaches of the Oruawharo River. A further four sites were not part of these five groups: K18 Tauhara, K19 Tauhara Creek K28 Sandy Beach, and K27 Moturoa Island. K18 Tauhara, K19 Tauhara Creek and K28 Sandy Beach all had low species richness and low abundances of animals. Only two cores were analysed from K27 Moturoa Island and the taxa found in these two cores were quite different resulting in a very low within-site similarity.

Relating ecological and sediment data

A distance-based linear model (DISTLM) showed that all the sediment properties, except coarse sand had significant relationships to the intertidal community structure. When examined individually the proportion of mud and TOC explained the highest amount of the variation in the ecological data with these properties able to explain 17% and 16% of the variation in the ecological data respectively. DISTLM also showed that the combination of mud, medium sand, TOC, lead, chromium, zinc and phosphorus explained 39% of the variation in the community structure. Previous analysis of data collected from Council's two sentinel sites in the Arapaoa River arm of the Kaipara Harbour also showed that the sediment properties were significantly related to the ecological data (Griffiths 2013a). 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 northern Kaipara Harbour.

1 Introduction

1.1 Background

Council has implemented Estuary Monitoring Programmes in the Whāngārei Harbour, Kerikeri Inlet, Ruakaka Estuary, Whangaroa Harbour, and the Arapaoa arm of the Kaipara Harbour. In total 13 'sentinel' sites are surveyed in these five estuaries. 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 ecological communities. They are currently sampled every two years.

In order to provide more spatial information about the sediment quality and ecological status of the northern Kaipara Harbour, Council undertook a survey of 44 intertidal sites throughout the harbour in 2014. This survey will provide baseline data to track changes in the health of the harbour over time. It will also complement the existing data from the two sentinel sites in the Arapaoa River (Griffiths 2013a) and previous surveys of the Whāngārei Harbour (Griffiths 2012) and Waitangi Estuary (Griffiths 2013b).

The monitoring methods have 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 in the Arapaoa River (Griffiths 2013a) and those used in Council's previous surveys of the Whāngārei Harbour and Waitangi Estuary (Griffiths 2012 & Griffiths 2013b).

1.2 Study area

1.2.1 The harbour

The Kaipara Harbour is a drowned river valley system located on the west coast of the Northland peninsula. The harbour covers an area of approximately 743km^2 and is the largest estuarine system in the southern hemisphere. The harbour is connected to the Pacific Ocean via an entrance 6km wide between Kaipara Head and Papakanui Spit. The northern portion of the harbour consists of four main arms: the Wairoa River arm, the Oruawharo River, the Otamatea River and the Arapaoa River, with numerous smaller creeks and rivers feeding into these arms. The southern Kaipara comprises a large basin with a number of creeks and rivers feeding into it.

1.2.2 The catchment

The northern portion of the catchment comprises 450,000ha. Catchment analysis using the land use classification from the New Zealand Land Cover Database LCDB2 (2001) indicated that in 2001, 62% (278,670ha) of the catchment was covered by high producing exotic grassland, 13% (57,142ha) with plantation forestry, and 15% (68,411ha) with indigenous forest (Figure 1 & Appendix 1).

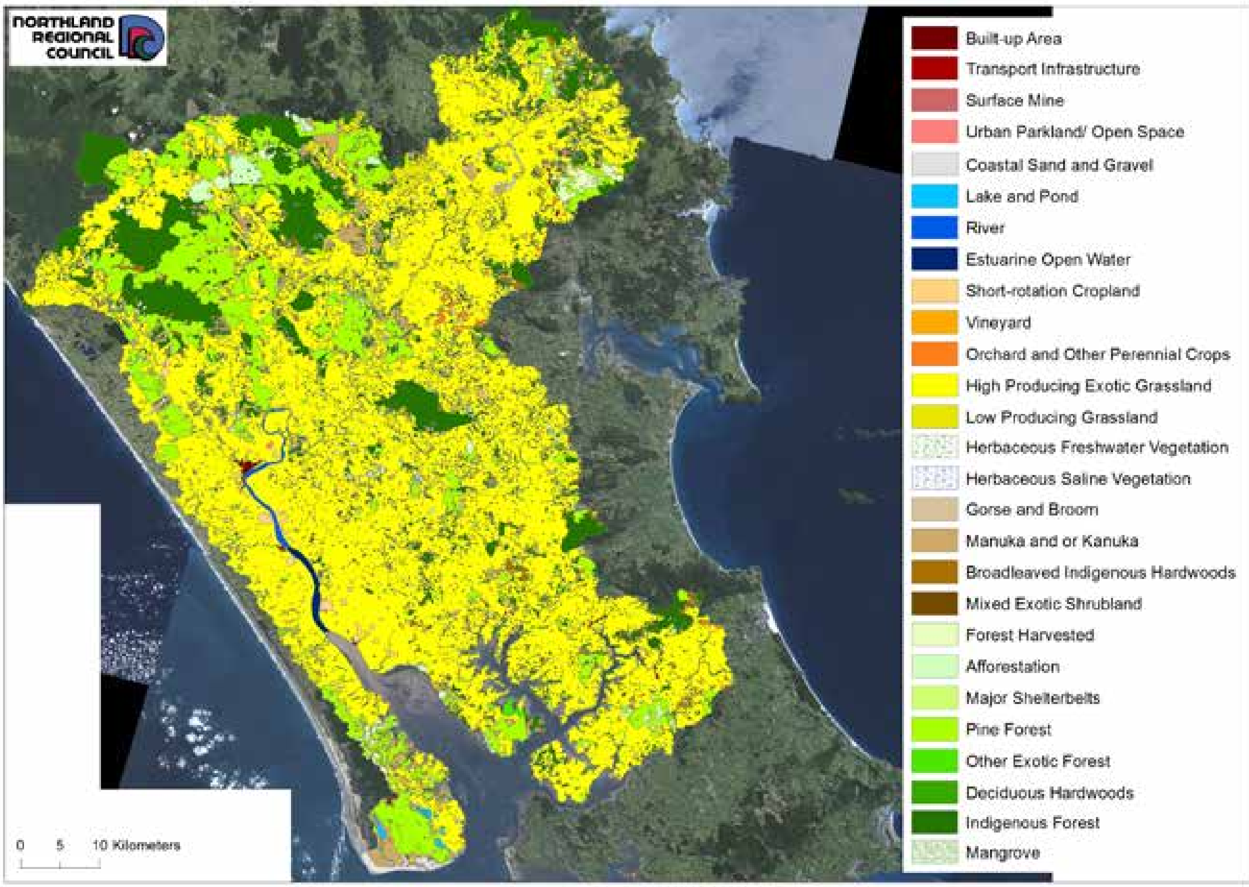


Figure 1. Land use in the Kaipara Harbour catchment, from the New Zealand Land Cover Database (2001).

1.2.3 Sediment characteristics

Although no dedicated sediment survey has been conducted in the northern Kaipara, surficial sediment has been collected as part of a number of surveys. Inglis *et al*. (2010) analysed sediment from 16 sites in 2006 as part of a baseline survey of non-indigenous marine species for Biosecurity New Zealand and a number of other sites have been surveyed in the different arms of the harbour. Most of these surveys have focused on the Otamatea River (Robertson *et al.* 2002, Poynter 2014) with some information available from the Arapaoa River (Griffiths 2013). In addition, a habitat map of the Otamatea River was produced by Robertson *et al*. (2002), which shows sediment characteristics of the intertidal areas in this river.

Inglis *et al.* (2010) reported that there was little variation in particle size between sites and that the sediment was strongly dominated by fine sand-sized particles, with the remainder of the particles mostly medium and very fine sand.

Robertson *et al*. (2002) mapped the intertidal habitat of the Otamatea River and sampled three sites during the development of the Estuary Monitoring Programme. The sediment at the two uppermost sites contained high proportion of mud (~70%), while the lower site contained mostly sand (50%) with a lower proportion of mud (33%). Two of these sites K30 Otairi Creek and K40 Wahiwaka Creek have been resurveyed in the current study. The habitat map showed that the intertidal areas of the Otamatea River were dominated by unvegetated substrate, which was primarily very soft mud.

More recently Poynter (2014) has sampled four sites in the Otamatea River from 2009-2014, as part of resource consent monitoring for a discharge from Fonterra's Maungaturoto milk processing plant. The three upper most sites had high proportions of mud in all six years, while the lower site (close to K39 Hanerau Stream in this survey) contained approximately equally proportions of mud, and sand.

Results from Council's two sentinel sites in the Arapaoa (K2 Te Kopua Point and K38 Whakapirau in this survey) showed that the proportions of different sediment grain sizes had remained relatively stable over the three years of sampling (2009-2011) (Griffiths 2013). Sediment collected from Te Kopua had a high proportion of mud (~40%) and fine sand (~57%) while sediments collected from Whakapirau consisted of approximately 65% fine sand, 25% mud and 10% medium sand in all three years.

1.2.4 Sediment nutrients

Again no dedicated survey of sediment nutrients has been conducted but other surveys have also analysed sediment nutrient concentrations. In addition to the surveys discussed in the previous section Boffa Miskell also sampled 10 sites in the Otamatea River and two sites in the Oruawharo River (Boffa Miskell Ltd. 2000) as part of an investigation of the ecology of the Otamatea River and any effects arising from the discharge of process water from Kiwi Dairy's processing plant at Maungaturoto.

Inglis *et al.* (2010) analysed the organic content of sediments (loss on ignition) at 16 sites in the northern Kaipara Harbour. They reported that organic content was generally higher at upper harbour sites and lower in the outer harbour around the heads. The results ranged from 0.5% at Waionui Inlet to a maximum of 5.7% at Hargreaves Point.

In the Otamatea River, Boffa Miskell (2000) reported that TOC ranged from 1.1 to 2.8g/100g and showed a general pattern of decreasing levels with distance down the estuary. Using an enrichment classification developed by Robertson and Stevens (2007) eight sites would have been classified as 'enriched' and two sites as 'low to moderately enriched' for TOC. Concentrations of total nitrogen ranged from 1400 to 2400mg/kg and were fairly uniform in the mid and upper estuary with the lowest values recorded at the two lowermost sites. Six sites would have been classified as 'enriched' and four sites as 'low to moderately enriched' using Robertson and Stevens's classification for nitrogen. Total phosphorus showed a pattern of higher concentrations in the lower part of the estuary, with the exception of the lowermost site and values ranged from 363 to 533mg/kg. Seven sites would have been classified as 'low to moderately enriched' and three sites as 'enriched' using Robertson and Stevens's classification for phosphorus. At the two sites in the Oruawharo River , the values were at levels which indicate the sites were 'enriched' for TOC and total nitrogen, and 'low to moderately enriched' for phosphorus.

Robertson *et al*. (2002) reported that nitrogen concentrations at the three sites sampled in the Otamatea ranged from 1192 – 1942mg/kg and phosphorus concentrations ranged from 468 to 572mg/kg. All three sites would have been classified as 'low to moderately enriched' for nitrogen. One site (K40 Wahiwaka Creek in this survey) would have been classified as 'low to moderately enriched' for phosphorus and the other two sites as 'enriched' (one of these sites is K30 Otairi Creek in this survey).

More recently Poynter (2014) has sampled four sites in the Otamatea River between 2009 and 2014. Levels at the three uppermost sites were generally higher than at the lower site for TOC, nitrogen and phosphorus. TOC at the three uppermost sites ranged from 1.4 – 2 g/100g and these sites would be classified as 'low to moderately enriched' using Robertson and Stevens's classification, while the lower site would be classified as 'good'. Concentrations of nitrogen at the three upper sites ranged from < 1300 to 2600mg/kg and from 700-1500 mg/kg at the lowest site between 2009 and 2014. Using Robertson and Stevens's classification all four sites would have been classified as 'low to moderately enriched' for nitrogen in 2014.

Phosphorus levels at the lowest site were lower between 2009 and 2013 but there was little difference between concentrations at the four sites in 2014 (values ranged from 510 to 580mg/kg) and all four sites would have been classified as ‘low to moderately enriched’ for phosphorus in 2014.

Data previously collected by Council from the two sentinel sites in the Arapaoa River (K2 Te Kopua Point and K38 Whakapirau in this survey) showed that the concentrations of nitrogen, phosphorus and ash free dry weight in the sediment at both sites appear to be similar to concentrations recorded in similar monitoring programmes elsewhere in New Zealand and were generally at levels that indicate the sites were ‘low to moderately enriched’ using criteria developed by Robertson and Stevens (2007). A similar spatial pattern was observed for concentrations of nitrogen, phosphorus and ash free dry weight, with higher concentrations generally recorded at Te Kopua compared to Whakapirau.

1.2.5 Sediment metals

There is limited data available about metal concentrations in the northern Kaipara Harbour, aside from data collected from Council’s two sentinel sites in the Arapaoa River (Griffiths 2013a) and three sites sampled by Robertson *et al.* (2000) in the Otamatea River. Robertson *et al.* (2002) reported that metal concentrations were generally low and below ANZECC ISQG-Low trigger values (Australian New Zealand Environment Conservation Council 2000) for all parameters at all three sites (including two sites K40 Wahiwaka Creek and K30 Otairi Creek in this survey). Results from Council’s two sentinel sites in the Arapaoa River (K2 Te Kopua Point and K38 Whakapirau in this survey) showed that between 2009 and 2011 concentrations of metal contaminants were all below ANZECC ISQG-Low trigger values (Australian New Zealand Environment Conservation Council 2000) and the lower threshold effect levels developed by MacDonald *et al*. (1996).

1.2.6 Ecology

The surveys described above have all included some sampling of the benthic ecology and in addition to the habitat map of the Otamatea River produced by Robertson *et al.* (2002), Council has also mapped saltmarsh and mangrove habitat throughout the northern Kaipara Harbour.

Boffa Miskell Ltd. (2000) found a total of 315 organisms from 25 different taxa at 15 sites in the Otamatea River, which included 10 polychaete worms, four gastropods, six bivalves and five crustaceans. They reported that the fauna was relatively sparse. Cockles were the most abundant taxon but were only found in high abundances at four sites. Cockles were rare at the ‘upper sites’ but became more common in the lower estuary, with particularly high abundances at Site 14 near the marae at Tanoa. Capitellid was the next most abundant taxon and was found at all 15 sites, followed by the mud crab (*Helice crassa*) and the polychaete worm *Nicon aestuariensis.* At the one site surveyed in the Oruawharo River 12 taxa were found from nine samples, with the polychaete worm Capitellid, the most abundant taxon followed by the amphipod Orchestia sp. and the mud crab *Helice crassa.*

Robertson *et al.* (2002) found a total of 40 taxa from the three sites and reported that the communities were dominated by deposit feeding polychaetes and filter-feeder bivalves (primarily cockles). The most abundant taxa were the polychaete worm *Heteromastus filiformis*, the cockle *Austrovenus stutchburyi* and oligochaete worms. Robertson *et al.* (2002) also used quadrats to survey the epifauna. No animals were found at the uppermost sites but the lower site (K30 Otairi in this survey) was dominated by gastropods (marine snails) both in terms of abundance and species present.

More recently Poynter (2014) found 44 taxa at four sites in the Otamatea River. In 2014 Site 1 was dominated by oligochaete worms, the polychaete worm paranoid sp1 and the invasive bivalve *Theora lubrica*. Between 2009 and 2013 oligochaete worms, the polychaete worm paranoid sp1 and copepod sp. 1 were numerically dominant. At Site 2 oligochaete worms and the polychaete worm paranoid sp.1 were the most abundant taxa throughout the study period with copepod sp1 and the polychaete worms *Boccardia (Paraboccardia) syrtis* and *Heteromastus filiformis* also abundant. At Site 3 the polychaete worms *Boccardia (Paraboccardia) syrtis*, paranoid sp1, *Heteromastus filiformis,* oligochaete *worms* and the copepod sp1 were abundant throughout the study period. Site 4 was characterised by Paranoid sp1 and Paranoid sp2. The invasive bivalve *Theora lubrica* was also abundant.

Data from Council's two sentinel sites in the Arapaoa River (K2 Te Kopua Point and K38 Whakapirau in this survey) showed that the ecological communities at both these sites were dominated by the invasive bivalve *Theora lubrica* and polychaete worms (Griffiths 2013). At Te Kopua (K2 in the current study) the invasive bivalve *Theora lubrica* and the polychaete worms Paraonidae sp.#2 and *Heteromastus filiformis were* abundant while at Whakapirau *(*K38 in the current study) the invasive bivalve, *Theora lubrica* and the polychaete worms Paraonidae sp.#2 and Paraonidae sp.#1 were abundant.

Council has mapped the extent of mangrove and saltmarsh habitats in the northern Kaipara Harbour. Saltmarsh and mangrove habitat were hand digitalised at a scale of 1:2000 using aerial images from both 1977 and 2002. In 2002 saltmarsh habitat covered 340.8 ha and mangrove forest covered 2386.1 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 existing Estuary Monitoring Programme in the Kaipara Harbour (Griffiths 2013a) and recent surveys of the Whangarei Harbour (Griffiths 2012) and Waitangi Estuary (Griffiths 2013b).

2.1.1 Sampling sites

A total of 44 intertidal sites were sampled in the current survey. This included the two sentinel sites (K2 Te Kopua Point Bay and K38 Whakapirau) that are monitored in Council's Estuary Monitoring Programme (Griffiths 2013) and two sites (K30 Otairi Creek and K40 Wahiwaka Creek) previously sampled by Robertson *et al*. (2002) during the development of the Estuary Monitoring Protocol. The remaining sample sites were selected in order to ensure a good geographical spread throughout the harbour. All the site co-ordinates were fixed with a GPS (Appendix 2). Field notes made at each site are presented in Appendix 3.

2.1.2 Timing of sampling

Sampling was conducted between 18 March and 4 April 2014.

2.1.3 Ecological sampling

The ecology was sampled using a perspex core (with a diameter of 150mm and 150mm deep). Three core samples were collected at each site, with replicates taken at 15m intervals along a 30m transect positioned parallel to the shoreline. All core samples were sieved through a 500µm mesh 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. One of the core samples from both K27 and K35 were compromised during processing and were therefore not included in the analysis. Fish (Osteicthyes) and insects (Insecta) identified from the samples were excluded from analysis as these animals are not marine benthic invertebrates and copepods, nematodes and ostracods were also excluded as these are considered meiofauna (J. Hewitt 2014. pers. Comm. 2/10). Individuals identified as belonging to the taxon categories 'Nereididae (unidentified juveniles)', 'Gatropoda unidentified juveniles', 'Bivalves unidentified', 'Bivalves unidentified juveniles', 'Decapoda (interminable)' and 'Decapoda juvenile' were not used in the calculations of biodiversity indices or multivariate analysis because these group are composites of several species and if they were included the adults would also need to be aggregated. This data was included in the calculations of 'number of individuals' and the 'number of taxonomic groups' at each site.

2.1.4 Sediment properties

One surface sediment sample of approximately 200 grams wet weight (consisting of the surface 2cm) was collected at each site. The sample was collected from the centre of the 30m transect within 1m 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 ash

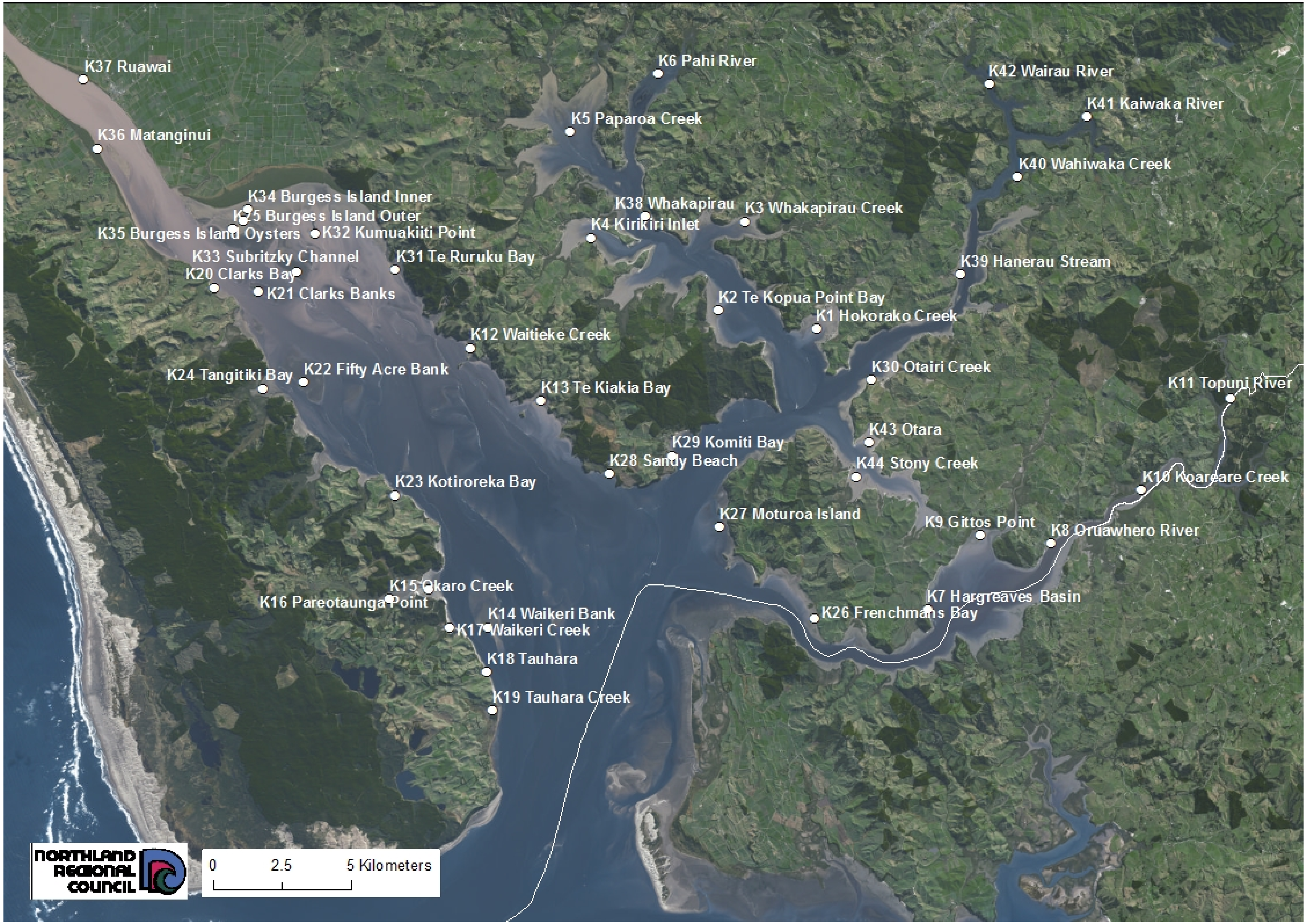


Figure 2. Location of sampling sites in the northern Kaipara Harbour.

free dry-weight (AFDW) using the formula =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 4.

2.2 Data analysis

The sediment metal results were assessed against ANZECC ISQG-Low trigger values (Australian New Zealand Environment Conservation Council 2000) and the threshold effect levels developed by MacDonald *et al*. (1996) (Table 1). ANZECC guidelines do not include trigger values for nutrients or TOC in marine sediments and there are currently no nationally accepted guideline values. Instead sediment TOC and nutrient concentrations were assessed against a classification developed by Robertson and Stevens (2007) (Table 2).

Table 1. Sediment quality guidelines. All units are mg/kg.

	MacDonald *et al. (1996)*	ANZECC (2000)	
	TEL	ISQG-Low	ISQG-High
Copper	18.7	65	270
Lead	30.2	50	220
Zinc	124	200	410
Chromium	52.3	80	370
Nickel	15.9	21	52
Cadmium	0.68	1.5	10

Table 2. Sediment nutrient guidelines. Nitrogen and phosphorus units are mg/kg.

	Good	Low to moderately enriched	enriched	Very enriched
Nitrogen	<500	500-2000	2000-4000	>4000
Phosphorus	<200	200-500	500-1000	>1000
TOC	<1%	1-2%	2-5%	5%

The ecological data was analysed using PRIMER v6.1.12 & PERMANOVA V1.0.2 (Plymouth Marine Laboratory, Plymouth, UK). Three measures of biological diversity were calculated: species richness (s); the total number of individuals (n); and the Shannon-Wiener diversity index 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 biodiversity scores are presented in Appendix 5.

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 a species similarity matrix which can help to identify groups of samples. Samples close to each other on the MDS plot are more similar to each other. The mean species abundances from the three core samples were used for this analysis. A square root transformation was also performed on the species abundance data in order to downplay the influence of numerically dominant taxa (Clark & Warwick 2001). Cluster analysis was also used to examine the ecological data. An arbitrary similarity of 30% was used with the cluster analysis to separate sites into ‘groups’ containing similar ecological communities. Permanova, using permutations, was then performed to test for differences between the species assemblages of these groupings. Primer’s similarity percentage routine (SIMPER) (Clarke & Warwick 1994) was then performed to examine which taxa contributed most to the similarity of the ecological communities of each 'group'. Results of the SIMPER analysis are presented in Appendix 6. A system of ecological classification rules developed by Hewitt and Funnel (2005), in their survey of benthic habitats of the southern Kaipara was also used (Box 1), to allow for comparisons with their work.

A distance-based linear model (DISTLM) was then used to model the relationship between the ecological data and physical and sediment chemical properties (McArdle & Anderson 2001). Prior to this analysis the sediment data was $\log_{10}$ transformed. Cadmium was not included in this analysis as all of the results were below laboratory detection limits.

Box.1

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

3 Results

3.1 Sediment grain size

The sediment grain size characteristics displayed a general pattern of higher proportions of mud in tidal creek environments such as the Otamatea River and the Oruawharo River, giving way to more fine sand and medium sand in the main Wairoa River arm and towards the harbour entrance (Figure 3). At more exposed higher energy environments, such as K28 Sandy Bay, high proportions of coarse sand were found. The proportion of mud found at K30 Otairi Creek (23% in 2014 versus 33% in 2002) and K40 Wahiwaka Creek (64% versus 67%) was similar to the proportions previously found by Robertson *et al.* (2002). At Council's two sentinel sites in the Arapaoa (K2 Te Kopua Point and K38 Whakapirau in this survey) the proportions of the different sediment grain sizes was very similar to what was previously found between 2009 and 2011 (Griffiths 2013).

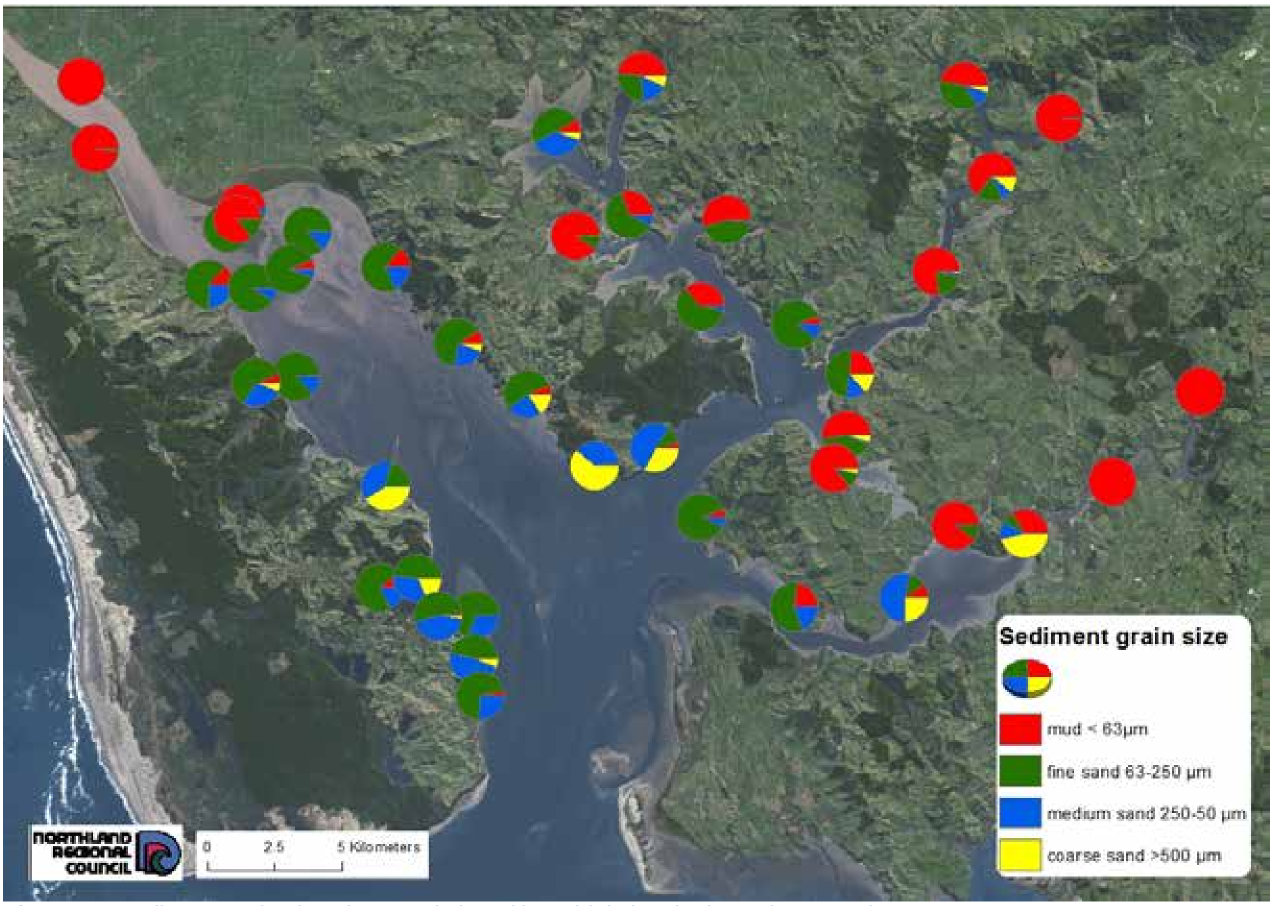


Figure 3. Sediment grain size characteristics of intertidal sites in the Kaipara Harbour.

Figure 4. Firm sandy substrate at K38 Sandy Bay.

Figure 5. Soft mud at K41 Kaiwaka River.

3.2 Sediment TOC and nutrient concentrations

3.2.1 TOC

The highest concentrations of TOC were generally found in tidal creek environments in the upper reaches of the different arms of the harbour (Figure 6) with lower concentrations found in the main Wairoa River arm and towards the harbour entrance. The highest concentrations of TOC were found at K36 Matanginui (3.9%w/w), K10 Koareare Creek (3.8%w/w), K11 Topuni River (3.71%w/w) and K37 Ruawai (3.6%w/w). The lowest values were recorded at K28 Sandy Bay (0.2%w/w) and K19 Tauhara Creek (0.2%w/w).

The ANZECC guidelines do not include trigger values for TOC in marine sediments and there are currently no nationally accepted guideline values. Using a classification system developed by Robertson and Stevens (2007), 16 sites were classified as 'very good', 15 sites were 'low to moderately enriched' and 13 sites were 'enriched' for TOC (Figure 6).

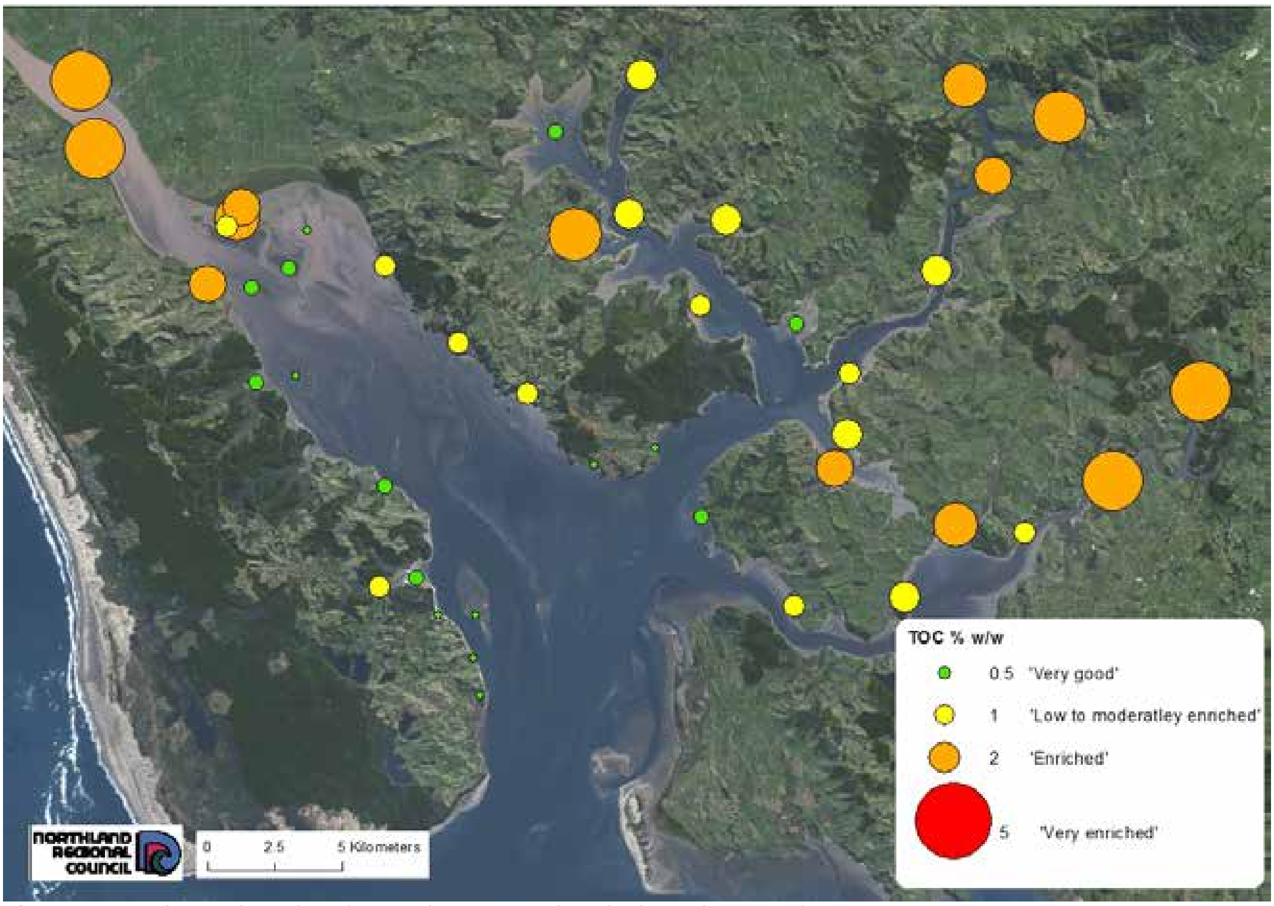


Figure 6. Total organic carbon (TOC %) concentrations in the Kaipara Harbour 2014.

3.2.2 Total nitrogen

The highest concentrations of nitrogen were generally recorded in the upper reaches of the different arms of the harbour, at K36 Matanginui (3900mg/kg), K11 Topuni River (2700mg/kg), K41 Kaiwaka River (2300mg/kg) and K37 Ruawai (2200mg/kg) (Figure 7). The lowest concentrations were found towards the harbour entrance at K14 Waikeri Bank (55mg/kg) and K18 Tauhara (33mg/kg).

The ANZECC guidelines do not include trigger values for nitrogen in marine sediments and there are currently no nationally accepted guideline values. Using a classification system developed by Robertson and Stevens (2007), four sites were classified as 'enriched', 21 sites were 'low to moderately enriched' with the remaining 19 sites classified as 'very good' for nitrogen (Figure 7). The concentration of nitrogen at K36 Matanginui was very close to the threshold for sediment that is 'very enriched' (Figure 7).

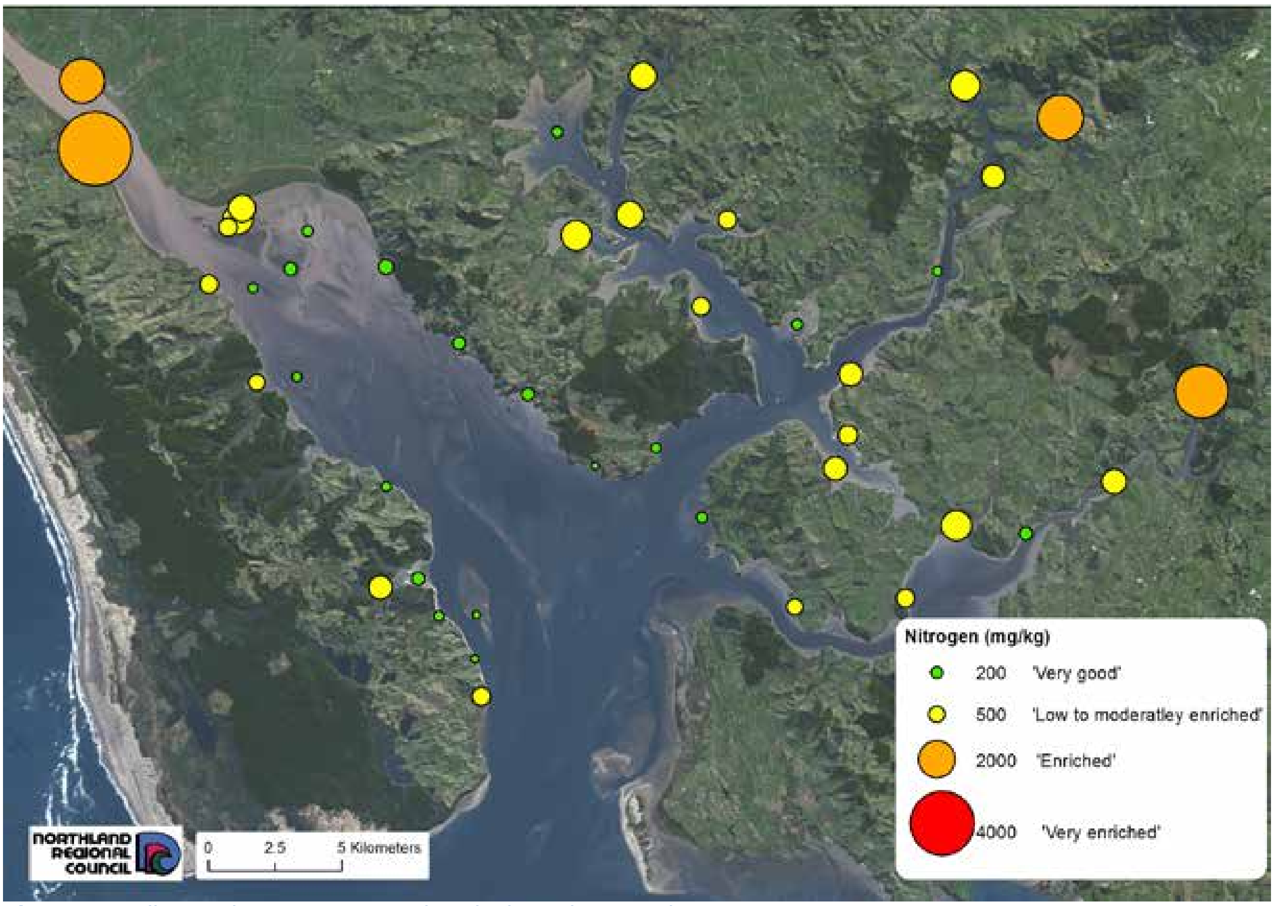


Figure 7 Sediment nitrogen concentrations in the Kaipara Harbour 2014.

3.2.3 Total phosphorus

The highest concentration of phosphorus was recorded at K11 Topuni River (700mg/kg) with high concentrations generally found in tidal creek environments in the upper reaches of the different arms of the harbour (Figure 8). One exception to this was the relatively high concentration recorded at K13 Te Kiakia Bay on the Tinopai peninsula in the main Wairoa arm of the harbour. The lowest concentrations were generally found along the Pouto peninsula in the main Wairoa arm of the harbour (Figure 8), with the lowest concentrations recorded at K18 Tauhara (27mg/kg) and K17 Waikeri Creek (41mg/kg).

The ANZECC guidelines do not include trigger values for phosphorus in marine sediments and there are currently no nationally accepted guideline values but using a classification system developed by Robertson and Stevens (2007) 15 sites were classified as ‘very good’, 19 as ‘low to moderately enriched’ and 10 as ‘enriched’ for phosphorus (Figure 8).

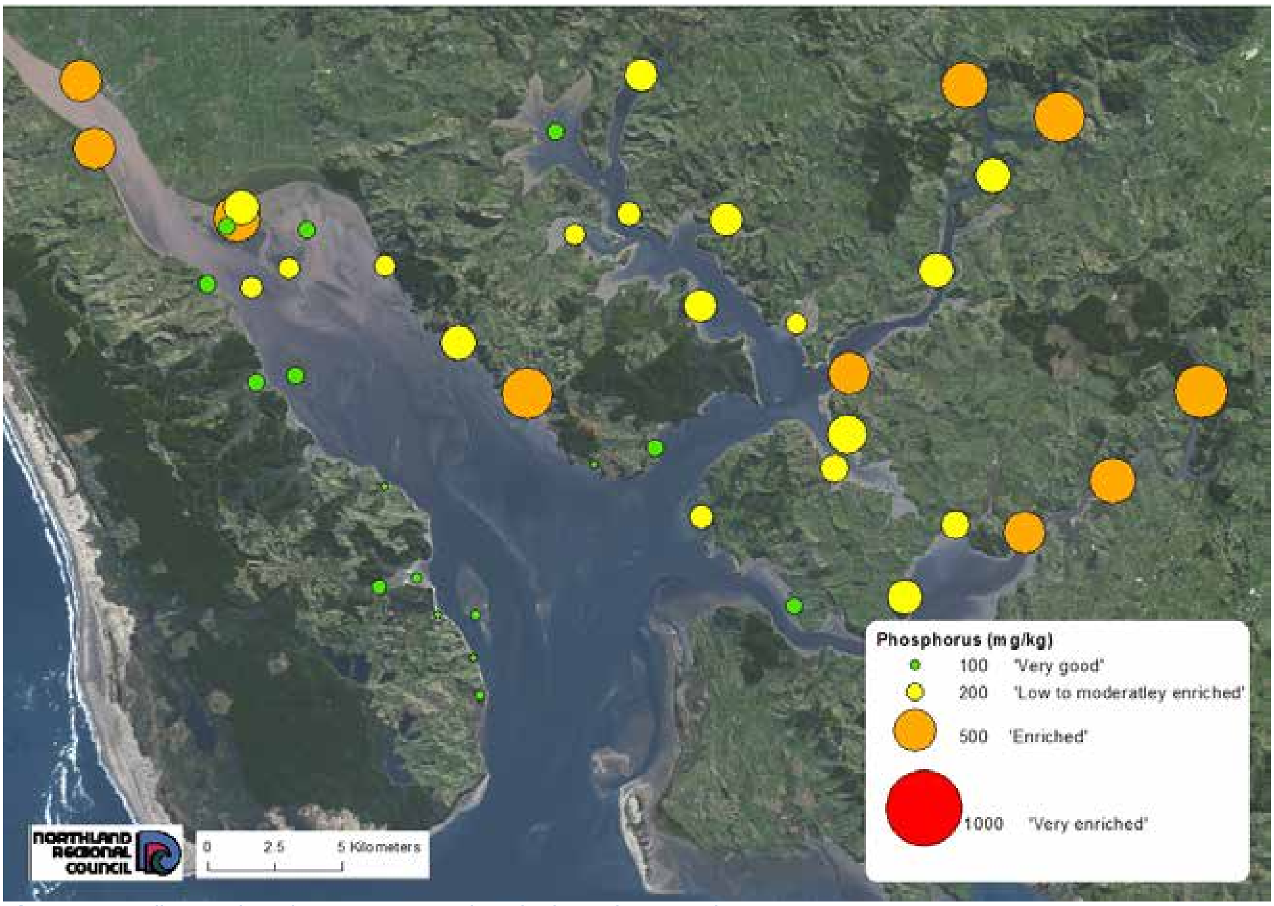


Figure 8. Sediment phosphorus concentrations in the Kaipara Harbour 2014.

3.2.4 Comparison with previous nutrient concentrations in the Kaipara Harbour

Nutrient concentrations have previously been measured at four of the sites sampled in the current study. K38 Whakapirau and K2 Te Kopua Point were last surveyed by council in 2011 and K30 Otairi Creek and K40 Wahiwaka Creek were previously surveyed by Robertson *et al.* (2002). Nutrient concentrations in the current survey were generally lower than levels previously recorded at these four sites (Table 3). The exceptions to this were increases in total nitrogen and AFDW at K38 Whakapirau. There was also a small increase in nitrogen at K2 Te Kopua Point.

Table 3. Concentrations of nutrients and AFDW at four sites previously surveyed. Previous survey results in brackets.

	K38 Whakapirau	K2 Te Kopua Point	K 30 Otairi Creek	K40 Wahiwaka Creek
n	1 (5)	1 (5)	1 (10)	1 (10)
AFDW	4.2 (3.2)	2.9 (4.2)	22 (4.5)	5.5 (5.9)
Nitrogen	1200 (506)	620 (537)	1000 (1192)	930 (1942)
Phosphorus	270 (334)	370 (372)	530 (572)	400 (537)

3.2.5 Comparison of nutrient concentrations in Northland estuaries

The mean nitrogen concentration in the northern Kaipara Harbour was higher than most values previously reported in sediment surveys of estuaries in Northland (Table 4). Higher mean nitrogen values were only found in the Bay of Islands and Hokianga Harbour. The nitrogen concentration recorded at K36 Matanginui, in the upper Wairoa arm, 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), Orira River in the Hokianga Harbour (Northland Regional Council 2013) and at WAT 8 in the Waitangi Estuary (Griffiths 2013). The mean phosphorus and TOC levels recorded in the northern Kaipara Harbour were towards the middle of the range of values reported at other estuaries surveyed recently by Council (Table 4).

Table 4. 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)
Kaipara Harbour	2014	44	804 (33 – 3900)	313 (27 – 700)	1.53 (0.2 -3.9)
Waitangi	2013	10	803 (220 – 2600)	647 (410 – 850)	2.6 (1.0 – 4.2)
Pārengarenga North	2013	12	263 (62-1300)	102 (28-180)	0.92 (0.3 - 2.5)
Pārengarenga South	2013	10	218 (25-500)	60 (18-200)	0.43 (0.1 – 1.0)
Houhora	2013	6	688 (270 – 1100)	129 (52 – 220)	1.26 (0.6 - 1.9)
Rangaunu	2013	10	318 (64-920)	122 (24 -360)	0.76 (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)	3.26 (0.2 - 5.2)
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)

3.3 Sediment metal concentrations

3.3.1 Cadmium

All of the cadmium concentrations were below the laboratory detection limit (<0.09mg/kg) and therefore both the ANZECC ISQG-Low effect trigger value of 1.5mg/kg and the threshold effect level of 0.68mg/kg developed by MacDonald *et al*. (1996) (Figure 9).

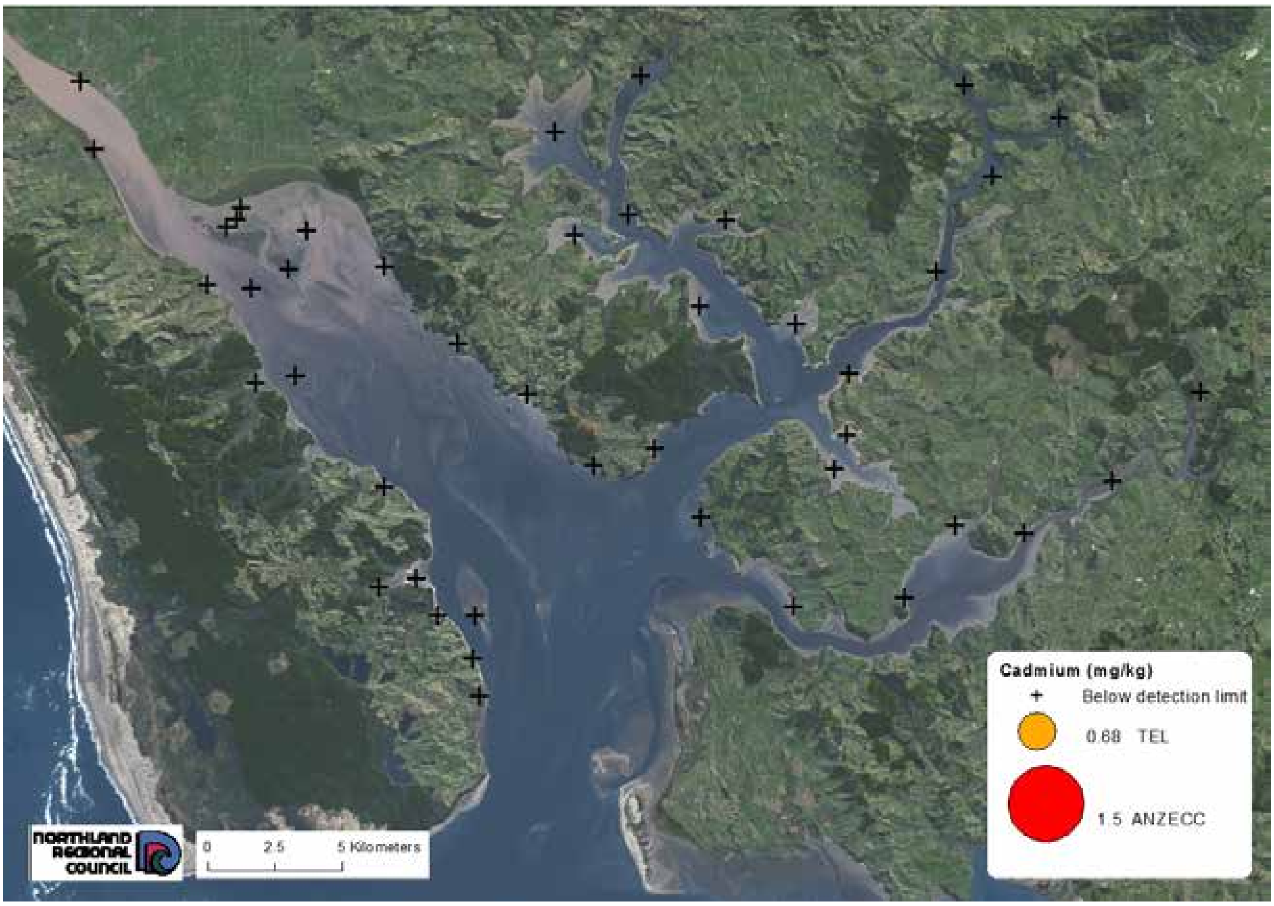


Figure 9. Sediment cadmium concentrations in the Kaipara Harbour, 2014.

3.3.2 Chromium

The highest concentrations of chromium were recorded in the Wairoa arm of the harbour at K36 Matanginui, (24mg/kg), K37 Ruawai (22mg/kg) and K38 Burgess Island (21mg/kg) (Figure 10). The lowest concentration was recorded at K28 Sandy Beach (0.73mg/kg). All of the chromium concentrations were below the ANZECC ISQG-Low effect trigger value of 80mg/kg and the threshold effect level of 52.3mg/kg developed by MacDonald *et al*. (1996) (Figure 10).

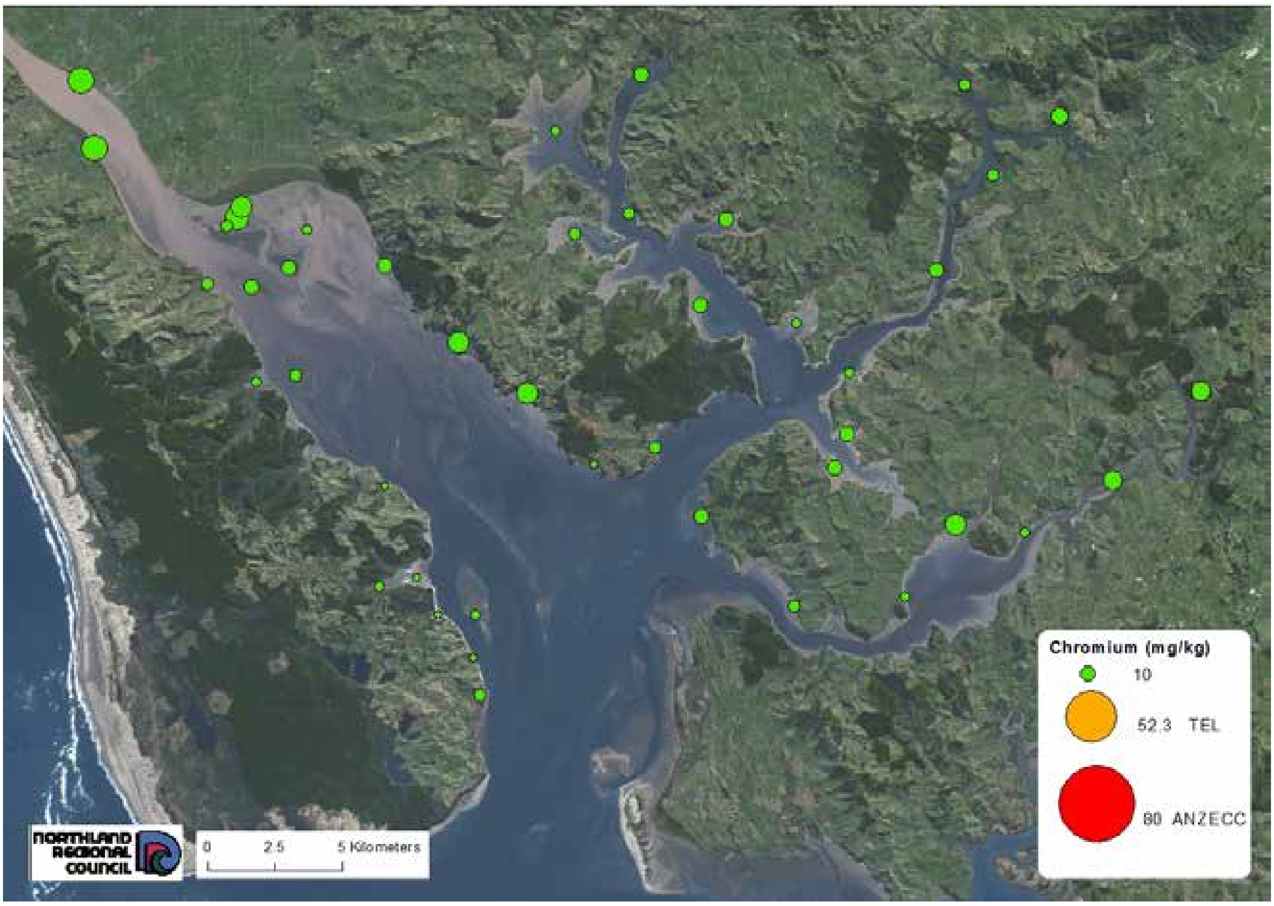


Figure 10. Sediment chromium concentrations in the Kaipara Harbour, 2014.

3.3.3 Copper

The highest concentration of copper was recorded at K34 Burgess Island Inner (45mg/kg), which was more than double the concentration at the next highest site K41 Kaiwaka River (21mg/kg). The copper concentrations at these two sites exceeded the threshold effect level of 18.7mg/kg developed by MacDonald *et al*. (1996) (Figure 11), but were below the ANZECC ISQG-Low effect trigger value of 65mg/kg. All of the other copper concentrations measured were below the threshold effect level. The lowest concentrations were recorded along the shoreline of the Pouto peninsula in the main Wairoa arm of the harbour and three sites along the peninsula had concentrations below the laboratory detection limit (<0.45mg/kg) (Figure 11).

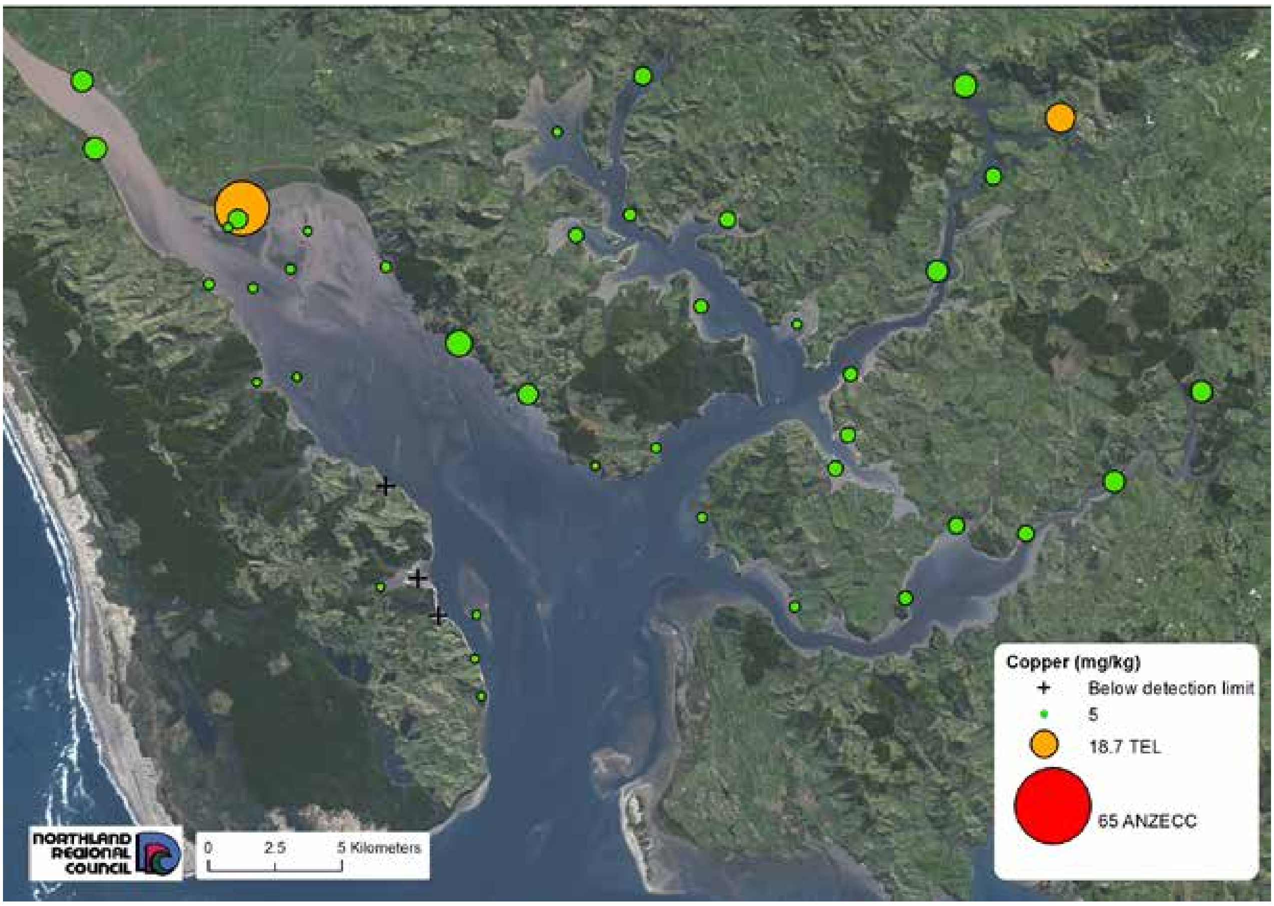


Figure 11. Sediment copper concentrations in the Kaipara Harbour, 2014.

3.3.4 Nickel

The highest concentration of nickel was recorded at K34 Burgess Island Inner (26mg/kg), which was more than double the concentration at the next highest site and exceeded the ANZECC ISQG-Low effect trigger value of 21mg/kg. No other sites exceeded the ANZECC ISQG-Low effect trigger or the threshold effect level of 15.9mg/kg developed by MacDonald *et al*. (1996). The lowest concentrations were again found along the Pouto shoreline of the main Wairoa River arm of the harbour (Figure 12). One site (K17 Waikeri Creek) along the peninsula had a nickel concentration below the laboratory detection limit (<0.45mg/kg).

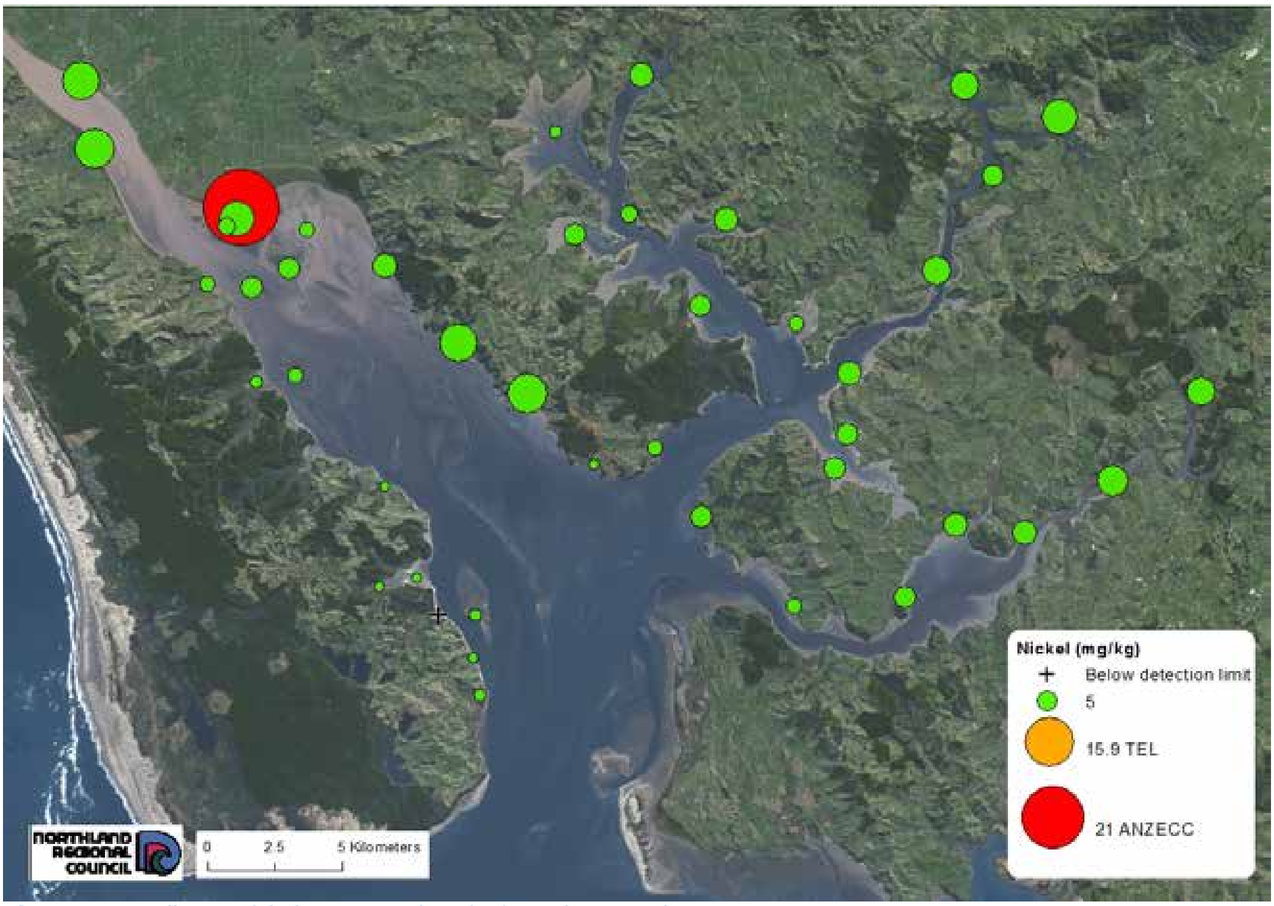


Figure 12. Sediment nickel concentrations in the Kaipara Harbour, 2014

3.3.5 Lead

All of the lead concentrations were well below the ANZECC ISQG-Low trigger value of 50mg/kg and the threshold effect level of 30.2mg/kg developed by MacDonald *et al*. (1996) (Figure 13). The highest concentration was recorded at K41 Kaiwaka River (10mg/kg) with the lowest concentration recorded at K17 Waikeri Creek (0.44mg/kg).

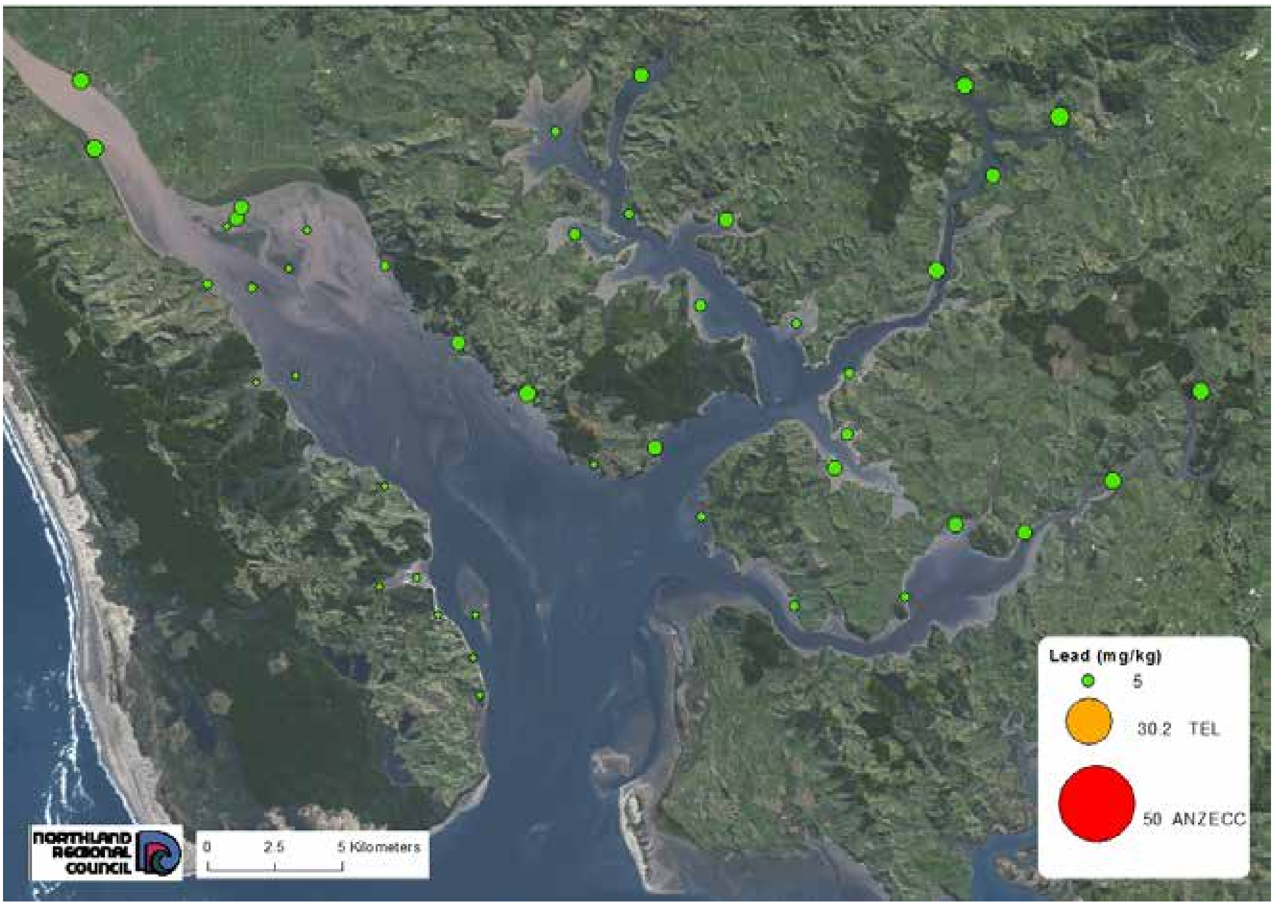


Figure 13. Sediment lead concentrations in the Kaipara Harbour, 2014

3.3.6 Zinc

All of the zinc concentrations were well below the ANZECC ISQG-Low trigger value of 200mg/kg and the threshold effect level of 124mg/kg developed by MacDonald *et al*. (1996). The highest concentrations were generally found in upper estuarine or tidal creek locations with the highest concentration recorded at K36 Matanginui (62mg/kg) in the upper Wairoa arm. The lowest concentrations were recorded along the shoreline of the Pouto peninsula in the main Wairoa arm of the harbour and three sites along this peninsula (K16 Pareotaunga Point, K17 Waikeri Creek and K23 Kotiroreka Bay) had concentrations below the laboratory detection limit (<6.8 mg/kg) (Figure 11).

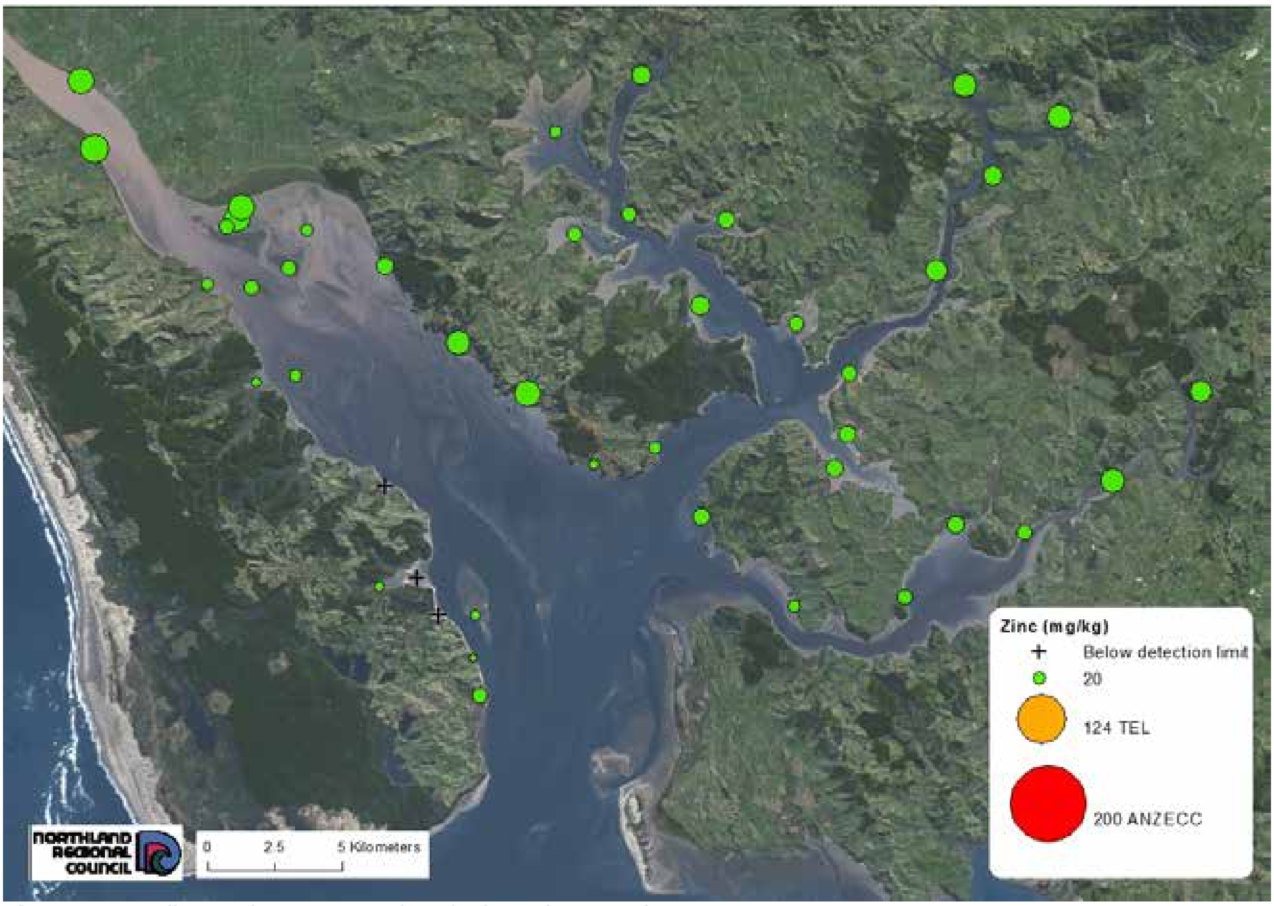


Figure 14. Sediment zinc concentrations in the Kaipara Harbour, 2014

3.3.7 Comparison with previous metal concentrations recorded in the Kaipara Harbour

Metal concentrations have previously been measured at four of the sites sampled in the current study. K38 Whakapirau and K2 Te Kopua Point were last surveyed by Council in 2011 and K30 Otairi Creek and K40 Wahiwaka Creek were previously surveyed by Robertson *et al.* (2002. Metal concentrations in the current study were all lower than levels previously recorded at these four sites (Table 5).

Table 5. Concentrations of metals at four sites previously surveyed. Previous survey results in brackets.

	K2 Te Kopua Point Bay	K38 Whakapirau	K30 Otairi Creek	K40 Wahiwaka Creek
n	1 (5)	1 (5)	1 (10)	1 (10)
Mud			23.4 (49.6)	
Cadmium	<0.09 (<0.09)	<0.09 (<0.09)	<0.09 (1.0)	<0.09 (0.1)
Chromium	9.7 (11.2)	6.7 (10.3)	4.5 (18.6)	6.7(22.4)
Copper	6.6 (8.1)	5.6 (7.4)	6.3 (9.0)	9.2 (16.3)
Nickel	5.8 (6.8)	4.7 (6.5)	6.3 (7.9)	5.8 (11.0)
Lead	2.3 (5.6)	4.0 (5.0)	3.2 (14.8)	5.7 (10.4)
Zinc	21 (36)	25 (37)	22 (43)	35 (62)

3.3.8 Comparison of metal concentrations in Northland estuaries

The mean metal concentrations recorded in this survey of the northern Kaipara Harbour were generally lower than those measured in recent sediment surveys conducted by Council in the Waitangi Estuary (2013), Bay of Islands and Whāngārei Harbour (both 2012) (Table 6).

Table 6. Mean metal concentrations recorded in Northland estuaries with range in brackets.

	Kaipara (2014)	**Waitangi (2013)**	**Bay of Islands (2012)**	**Whāngārei (2012)**
Number of samples	44	10	16	41
Cadmium	NA (<0.09)	NA (<0.09 – 0.13)	NA (< 0.09 – 0.09)	NA (<0.09 – 0.16)
Chromium	9 (0.7 – 24)	13 (5 -17)	19 (8 – 42)	12 (2 – 57)
Copper	7 (<0.45 – 45)	11 (4 – 17)	9 (2 – 17)	10 (<0.05 – 79)
Nickel	6 (<0.45 – 26)	8 (5 – 10)	Not recorded	6 (1 – 30)
Lead	4 (0.4 – 10)	8 (4 – 10)	10 (4 – 17)	8 (0.5 – 51)
Zinc	29 (<6.8 – 62)	56 (33 – 84)	49 (17 – 71)	44 (<7.5 – 160)

3.4 Ecology

The intertidal habitats surveyed were reasonably varied, including sheltered muddy tidal creek environments, exposed sand flats, sand banks and exposed sandy beaches. One oyster reef (K35 Burgess Island Oyster reef) was also sampled. No shell banks, seagrass beds or stone/pebble shorelines were sampled.

3.4.1 Biodiversity

A total of 108 taxa were identified from the 44 sites. The total number of taxa varied from just two at K19 Tauhara Creek to 39 at K26 Frenchman's Bay (Figure 15). With the exception of K18 Tauhara and K19 Tauhara Creek generally fewer taxa were found at sites in the upper reaches of the different arms of the harbour with more taxa found in the main Wairoa River arm of the harbour (Figure 15). Higher numbers of taxonomic groups were also generally found in the main Wairoa River arm of the harbour with fewer taxonomic groups found at sites in the Otamatea River, Arapaoa River and the Whakaki River (Figure 17). Again K18 Tauhara and K19 Tauhara Creek stood out with just two taxonomic groups represented at both of these sites. The total number of individuals at K18 Tauhara and K19 Tauhara Creek was also low with just 13 and seven individuals at these sites (Figure 16). The highest Shannon-Wiener diversity scores were generally recorded in the main Wairoa arm of the harbour although high scores were also found at K3O Otairi, K26 Frenchmans and K8 Oruawharo River. The lowest Shannon-Wiener diversity scores were generally found in tidal creek environments in the upper reaches of the different arms of the harbour.

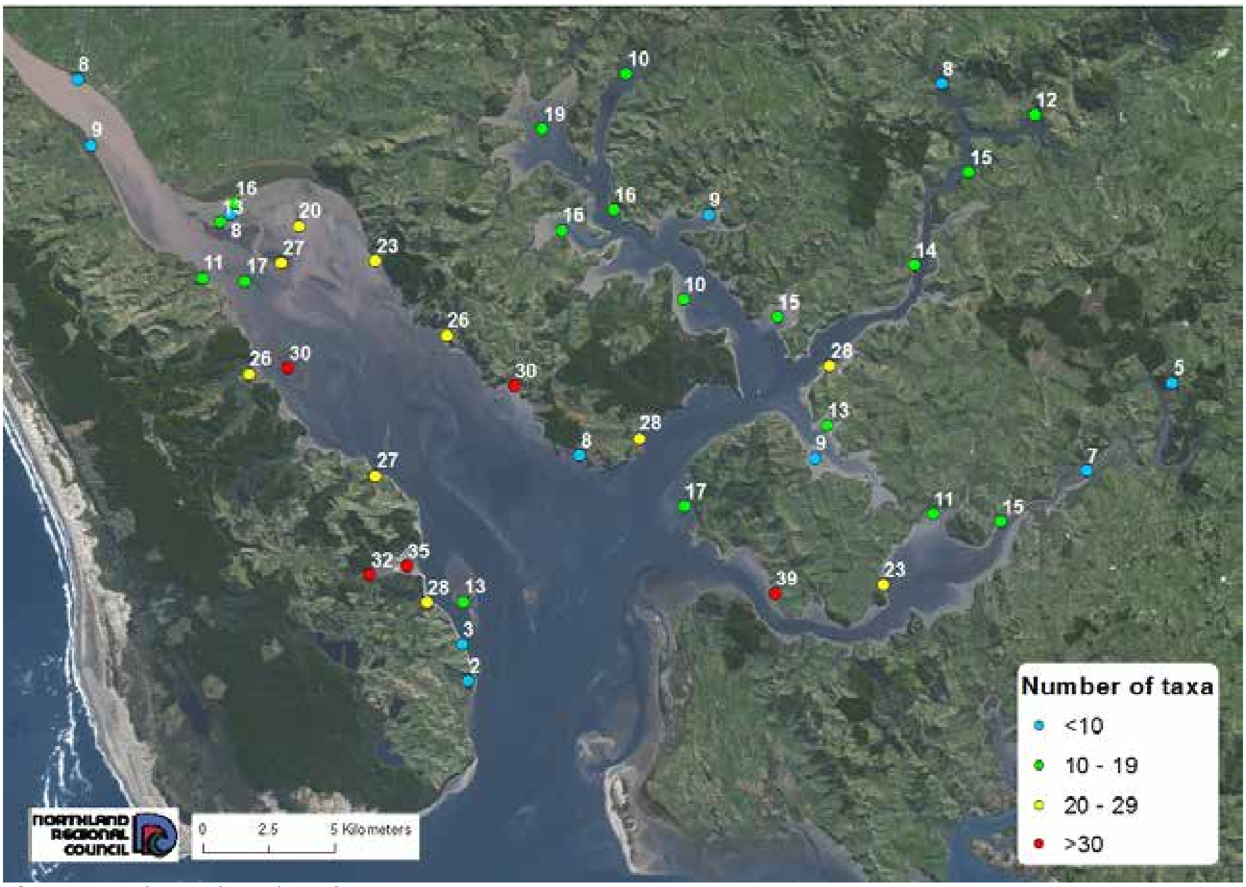


Figure 15. The total number of taxa.

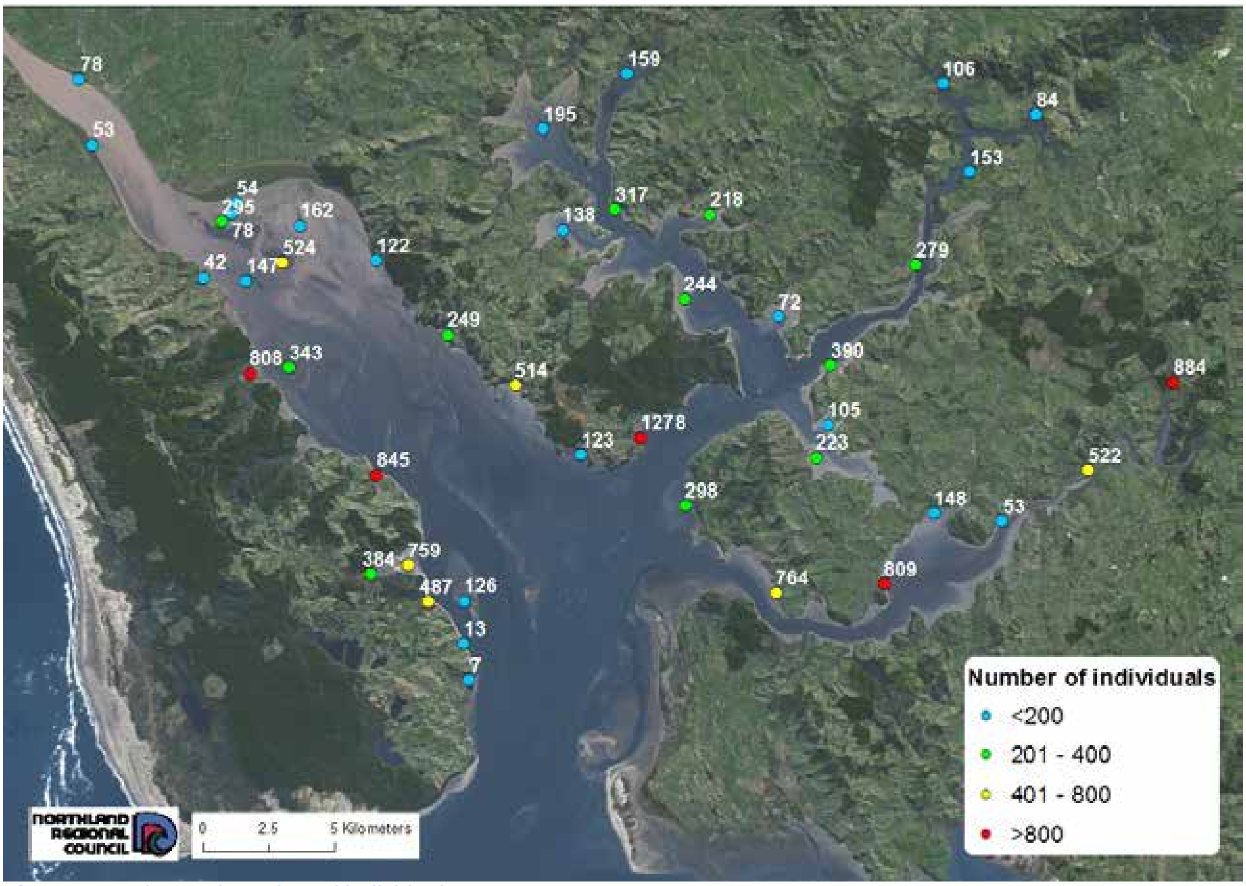


Figure 16. The total number of individuals.

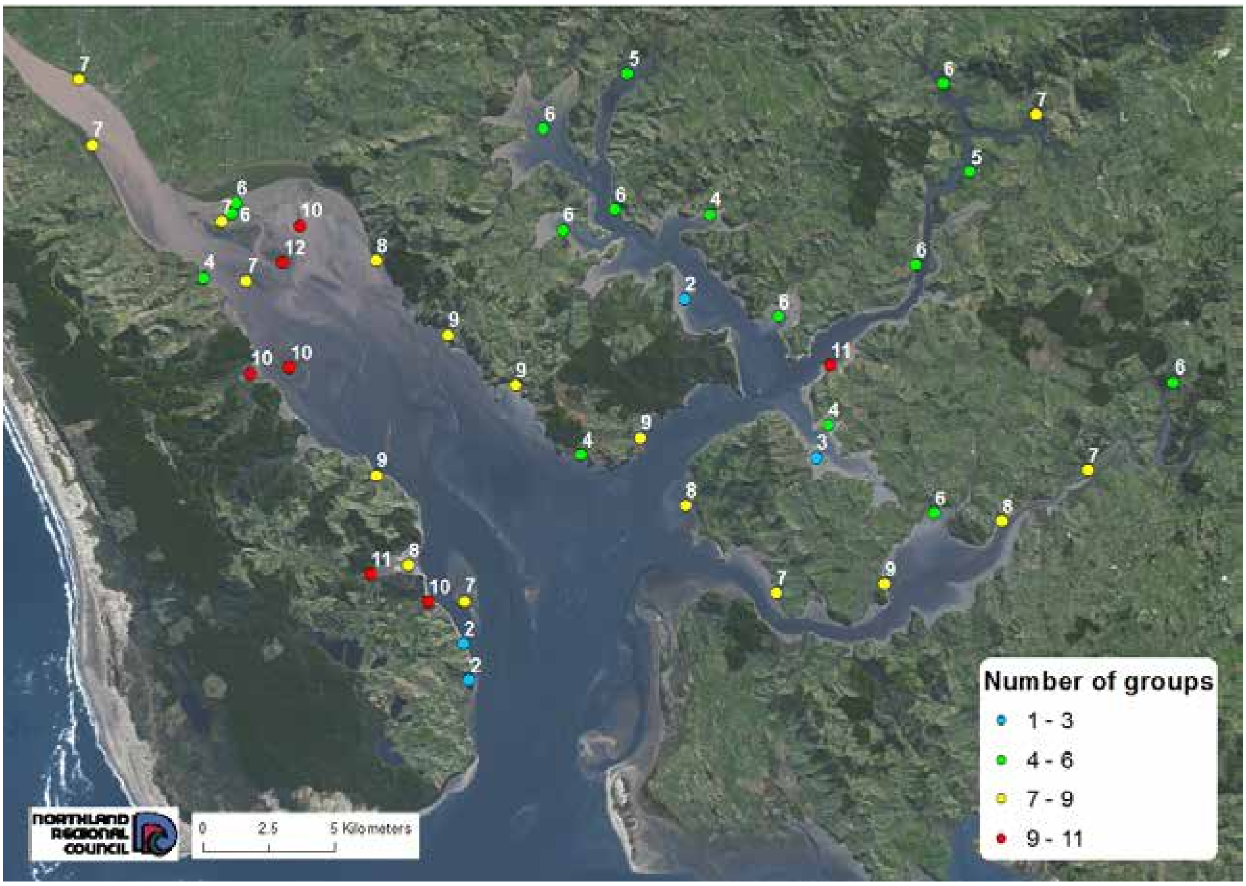


Figure 17. Taxonomic groups.

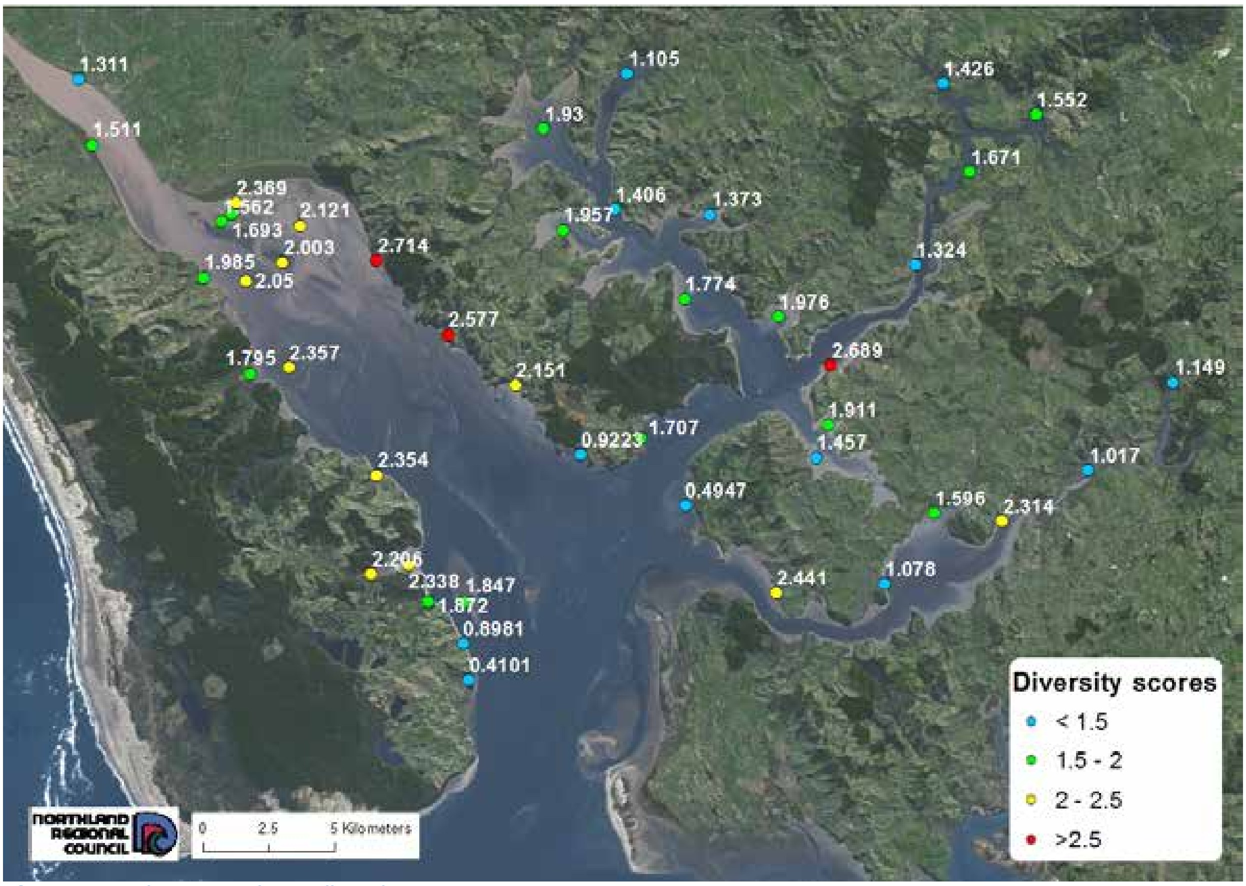


Figure 18. Shannon-Wiener diversity.

3.4.2 Multivariate analysis of intertidal ecological data

Cluster analysis and MDS ordination of the ecological data showed that the intertidal sites could be separated into four main groups with a fifth group containing just two sites (Figure 21 & 22). Four sites were not included in any of these five groups. The first group (Group A) included sites found on sheltered mud flats in the different estuarine arms of the harbour (Figure 23). Sites in Group A were characterised by the polychaete worms *Heteromastus filiformis*, Paraonidae and *Nicon aestuariensis*, and the invasive bivalve *Theora lubrica* (Table 7). The low abundance of oligochaete worms, large bivalves (such as cockles, pipis and wedge shells), gastropods and crustaceans was also a feature of sites in this group. The species richness, the number of individuals and the Shannon-Wiener diversity scores of sites in Group A were all lower than Groups C and D (Table 7).

A second group (Group B) comprised sites found in the upper reaches of the different arms of the harbour, which had high proportions of mud. Sites in Group B were characterised by oligochaete worms and the polychaete worms Polydorid, Paraonidae and *Heteromastus filiformis*. The low abundance of large bivalves (cockles, pipis and wedge shells) and gastropods was also a feature of sites in this group. The species richness, the number of individuals and the Shannon-Wiener diversity scores of sites in Group B were all lower than Groups C and D (Table 7).

A third group (Group C) included sites found on more sandy habitats in the main Wairoa arm of the harbour. These sites were dominated by the cockle *Austrovenus stutchburyi* and the polychaete worm *Aonides trifida*, with the nut shell *Nucula hartvigiana*, the wedge shell *Macomona liliana* and the polychaete Prionospio sp. also characteristic of these sites. Sites in Group C had high species richness, high numbers of individuals and high Shannon-Wiener diversity scores (Table 7).

The fourth group (Group D) comprised four sites located on exposed sand flats and sand banks in the main Wairoa arm of the harbour. These sites were dominated by the bivalves Soletellina sp., the wedge shell *Macomona liliana* and the cockle *Austrovenus stutchburyi*. Sites in Group D also had high species richness, high numbers of individuals and higher Shannon-Wiener diversity scores (Table 7).

A fifth group (Group E) comprised just two sites K10 Koareare Creek and K11 Topuni River located in the upper reaches of the Oruawharo River. These sites were both located on narrow mud flats close to fringing mangrove forest and field notes described the sediment at both sites as soft mud. Sediment grain size analysis found that both these sites consisted of 100% mud. These sites were characterised by the small bivalve *Arthritica bifurca*, the polychaete worm *Nicon aestuariensis* and oligochaete worms.

All the groups identified from the cluster and MDS analyses had similarity of at least 35% and were more than 83% dissimilar to each other, with most more than 90% dissimilar. The lowest dissimilarity was found between Group A and Group B, and between Group C and Group D.

Four sites were not included in these five groups: K18 Tauhara, K19 Tauhara Creek, K28 Sandy Beach, and K27 Moturoa Island.

K18 Tauhara (Group F) is a steep sandy beach on the Pouto peninsula (Figure 19). Field notes described the sediment at this site as golden sand with sand ripples. Only 13 individuals belonging to just three taxa were found at this site: the polychaete worms Glyceridae and *Prionospio aucklandica*, and the amphipod Lysianassidae.

K19 Tauhara Creek (Group G) was located in Tauhara Creek, a small sheltered estuary on the Pouto peninsula. Field notes described the sediment at this site as soft ‘spongy’ sand. Just seven individuals belonging to two taxa were found at this site: the polychaete worm *Scolecolepides benhami* and the crab *Brachyura* sp.

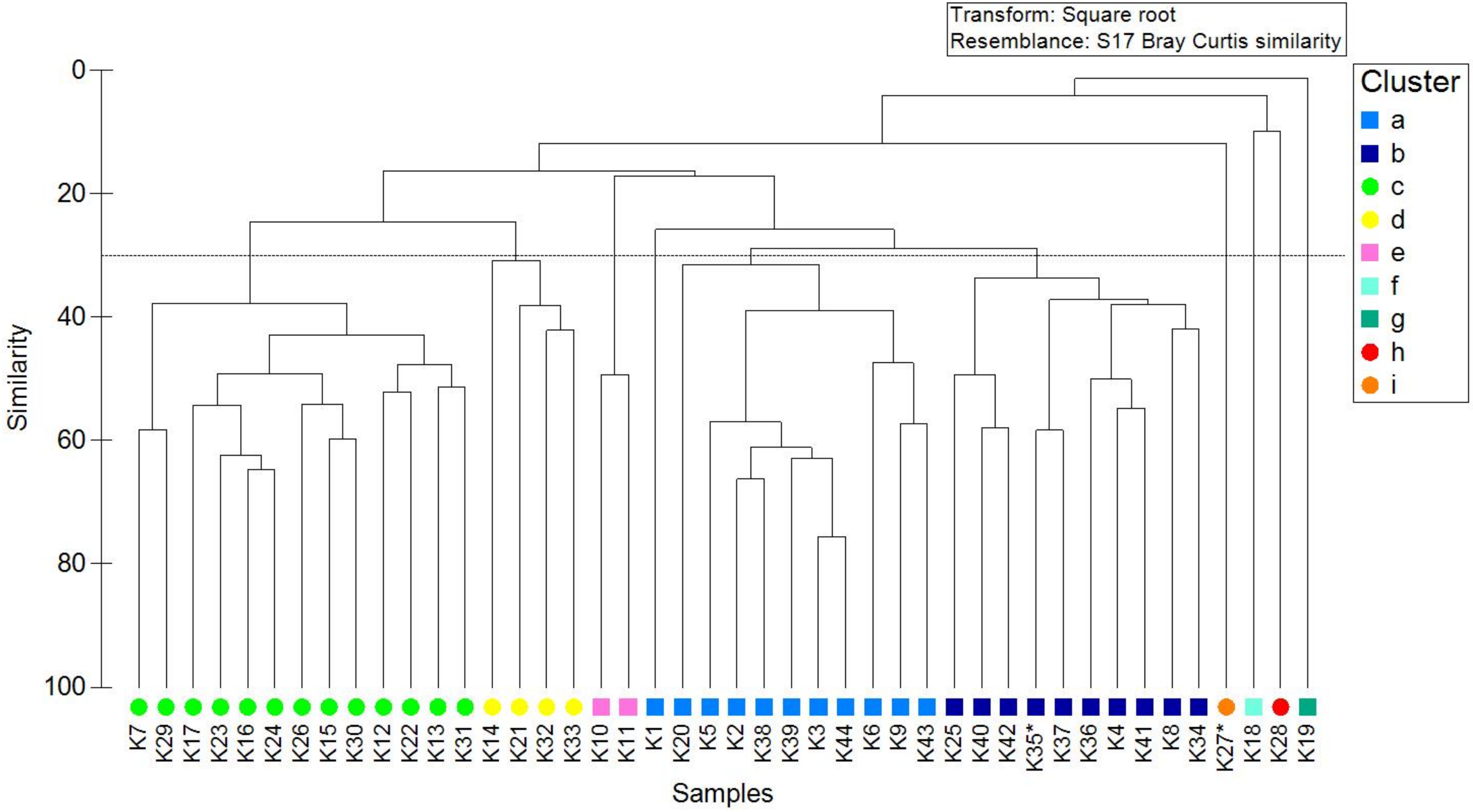
Figure 19. K18 Tauhara.

Figure 20. K28 Sandy Beach.

K28 Sandy Beach (Group H) was located on a relatively steep sandy beach on the south western tip of the Tinopai peninsula (Figure 20). Field notes described the sediment as firm sand. Eight taxa were found, with the isopod *Natatolana pellucida* numerically dominant. The pipi was also relatively abundant.

K27 Moturoa Island (Group I) was located on expansive intertidal flats on the western shore of the Puketotara peninsula. Field notes described the sediment as firm mud. Only two cores were analysed at this site because one core sample was compromised. Nineteen taxa were identified in the two cores but most taxa were found in low numbers. Only four of the taxa were in both core samples. The most abundant taxon was the invasive Asian date mussel (*Musculista senhousia*) (273 individuals), but almost all individuals (272) were found in just one core.

Figure 21. Group average linkage cluster of Bray-Curtis similarities from square root transformed abundance data collected from Kaipara harbour 2014



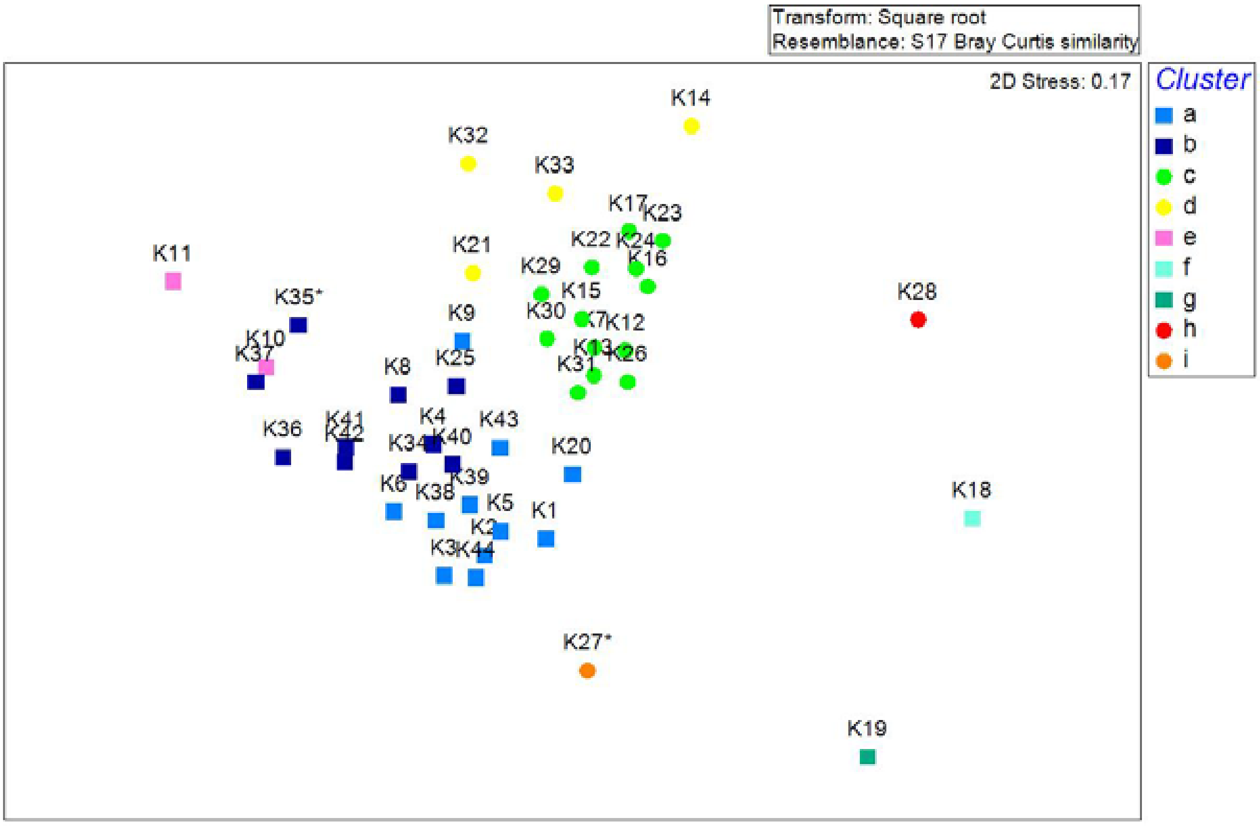


Figure 22. Non-metric MDS ordination of Bray-Curtis similarities from square root transformed abundance data collected from the Kaipara Harbour in 2014**.** Sites closest together are more similar.

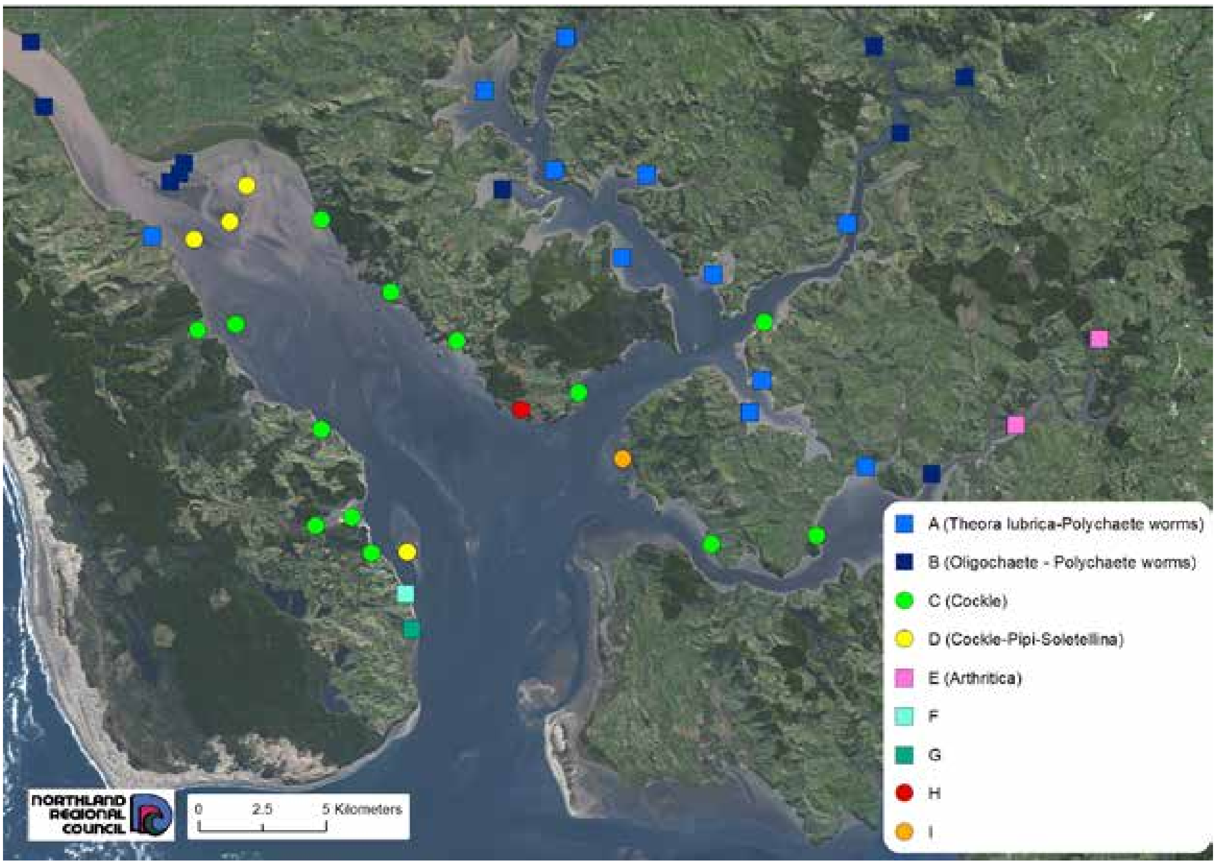


Figure 23. Ecological community groupings of intertidal sites based on cluster and MDS analysis of abundance data from the Kaipara Harbour in 2014

Table 7. Community types, based on MDS and cluster analysis in the Kaipara Harbour 2014, together with average group similarity, mean species richness, mean number of individuals and mean Shannon-Wiener diversity scores.

Group	Community type	Characteristic taxa	Sediment type	Average similarity	Species richness	No of individuals	Diversity
A (11 sites)	*Theora lubrica*-Polychaete worms	*Heteromastus filiformis* Paraonidae *Nicon aestuariensis* *Theora lubrica*	Mud – fine sand	43%	12	182	1.62
B (10 sites)	Oligochaete-Polychaete Worms	Oligochaete worms Polydorid, Paraonidae *Heteromastus filiformis*	Mud	38%	12	109	1.74
C (13 sites)	*Austrovenus stutchburyi*	*Austrovenus stutchburyi* *Aonides trifida* *Nucula hartvigiana* *Macomona liliana* Prionospio sp.	Fine sand-medium sand	45%	29	596	2.18
D (4 sites)	*Austrovenus stutchburyi-Macomona liliana* - Soletellina sp.	*Austrovenus stutchburyi* *Macomona liliana* Soletellina sp.	Fine sand	35%	19	239	2.01
E (2 sites)	*Arthritica bifurca*	*Arthritica bifurca* *Nicon aestuariensis* Oligochaete worms	Mud	49%	6	703	1.02

A system of ecological classification rules developed by Hewitt and Funnell (2005), in their survey of benthic habitats of the southern Kaipara, was also used to identify ecological communities to allow for comparisons with their survey of the southern Kaipara. Using this classification system 13 community types were identified (Table 8 & Figure 24). Most sites belonged to just two community types: a Polychaete–Deposit feeder community type, and an Austrovenus community type. Sites belonging to the Polychaete-Deposit feeder community type were generally located on sheltered mud flats in the different arms of the harbour, while sites belonging to the Austrovenus community type tended to be located on more exposed sand flats (Figure 24). An Austrovenus/Macomona community and an Oligochaete community contained three sites each and a Surface bioturbators group contained two sites. The remaining eight communities types identified contained just one site each.

The average similarities of the Polychaete–Deposit feeder and the Austrovenus community types were relatively low (27% and 32% respectively) (Table 8) and the dissimilarity between the community types tended to be lower than the dissimilarity between groups identified by cluster and MDS analysis. In particular low dissimilarity was found between: the different types of Bivalve communities; the Polychaete–Tube builders and High Diversity–Tube builders communities; and between the Bivalve–Deposit feeder and Surface Bioturbators communities.

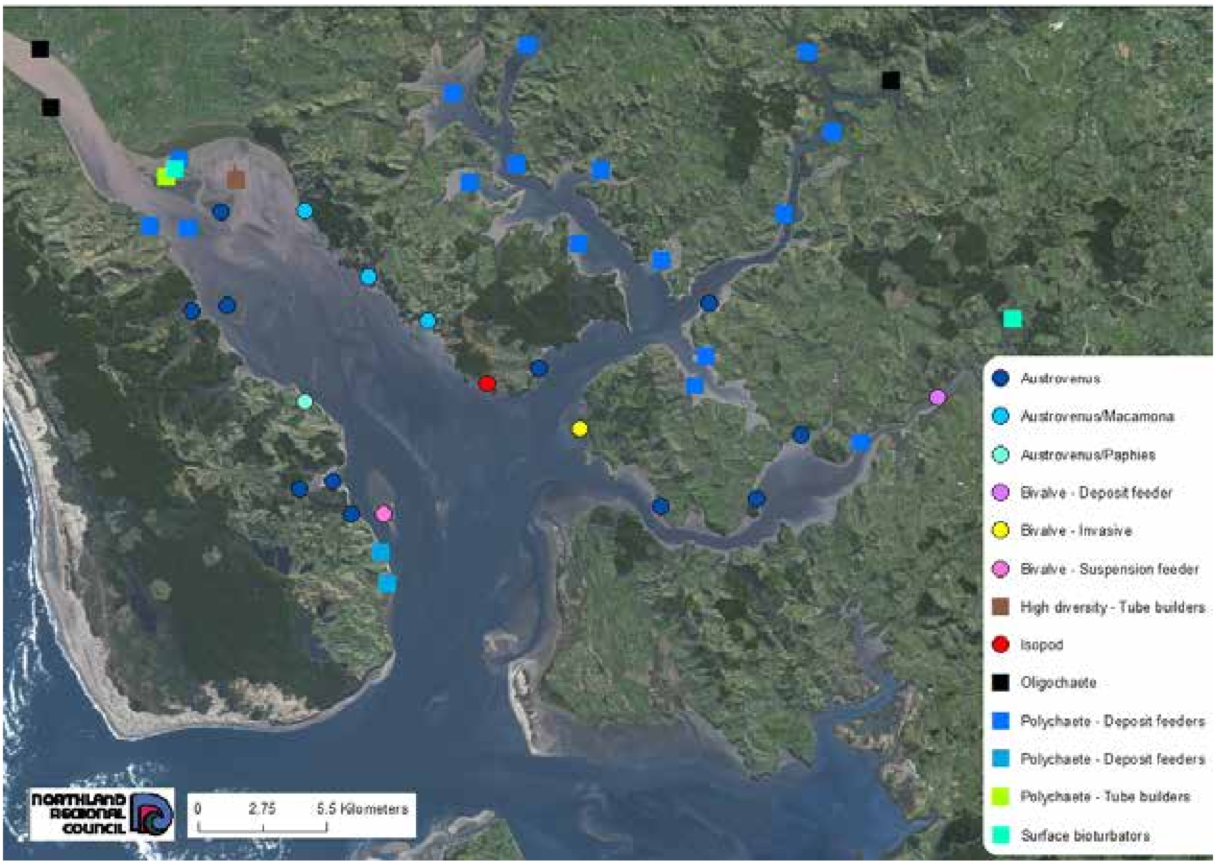


Figure 24. Ecological community types in the Kaipara Harbour 2014, based on Hewitt and Funnell's (2005) ecological classification rules

Table 8. Community types the Kaipara Harbour 2014, based on Hewitt and Funnell's (2005) ecological classification rules, together with average group similarity, mean species richness, mean number of individuals and mean Shannon-Wiener diversity.

Community type	Characteristic taxa	Sediment type	Average similarity	Species richness	No of individuals	Diversity	Bray Curtis
Polychaete – deposit feeder (16 sites)	*Heteromastus filiformis* Aricidea sp. Paraonidae *Theora lubrica*	Mud-fine sand	27%	13	157	1.75	52
Polychaete – deposit feeder (Impoverished) (2 sites)	No characteristic taxa (Low richness and abundance)	Fine sand-medium sand	0%	3	10	0.65	23
Polychaete – Tube builders (1 site)	Polydorid Paraonidae	Fine sand	Less than 2 sites	13	295	1.56	46
Austrovenus (11 sites)	*Austrovenus stutchburyi* *Aonides trifida*	Fine sand-medium sand	32%	28	609	2.01	66
Austrovenus/Macomona (3 sites)	*Austrovenus stutchburyi* Aricidea sp. *Macomona liliana*	Fine sand	37%	26	295	2.48	63
Austrovenus/Paphies (1 site)	*Aonides trifida Austrovenus stutchburyi* *Prionospio aucklandica*	Coarse sand–medium sand	Less than 2 sites	27	845	2.35	68
Bivalve - Suspension feeders (1 site)	Soletellina sp. *Macomona Liliana* *Austrovenus stutchburyi*	Fine sand	Less than 2 sites	13	126	1.85	57
Bivalve - Deposit feeders (1 site)	*Arthritica bifurca* Oligochaeta	Mud	Less than 2 sites	7	522	1.02	70
Bivalve invasive (1 site)	*Musculista senhousia*	Fine sand	Less than 2 sites	17	298	0.49	1
Oligochaete (3 sites)	Oligochaeta *Heteromastus filiformis*	Mud	54%	10	72	1.46	29
Surface bioturbators (2 sites)	*Potamopyrgus estuarinus* *Helice crassa*	Mud	7%	7	481	1.42	32
Isopod (1 site)	*Natatolana pellucida* *Paphies australis*	Coarse sand-medium sand	Less than 2 sites	8	123	0.92	29
High diversity - Tube builders (1 site)	Polydorid	Fine sand	Less than 2 sites	20	162	2.12	44

3.4.3 Shellfish

Cockles

Cockles (*Austrovenus stutchburyi*) were found at 22 of the 44 sites sampled (Figure 25) with adult cockles (>16mm) found at all of these 22 sites. Cockles were mainly located at sites with firm sandy substrate in the Wairoa arm of the harbour and very few cockles were found at sites located in muddy tidal creek environments (Figure 25). No cockles were found at any of the seven sites in the Arapaoa River or in the upper reaches of the Otamatea River and Oruawharo River.

The highest abundances were generally found along the shoreline of the Pouto peninsula in the Wairoa arm of the harbour, with the highest density found at K17 Waikeri Creek (4018m^2). A very high density was also recorded at K26 Frenchmans Bay (3263m^2), near the entrance of the Oruawharo River (Figure 25). Eleven sites had densities greater than 1000 per m^2 with particularly high densities found at K16 Pareotaunga Point (2974m^2), K15 Okaro Creek (2943m^2), K23 Kotiroreka Bay (2924m^2), K33 Subritzky Channel (2867m^2) and K24 Tangitiki Bay (2509m^2).

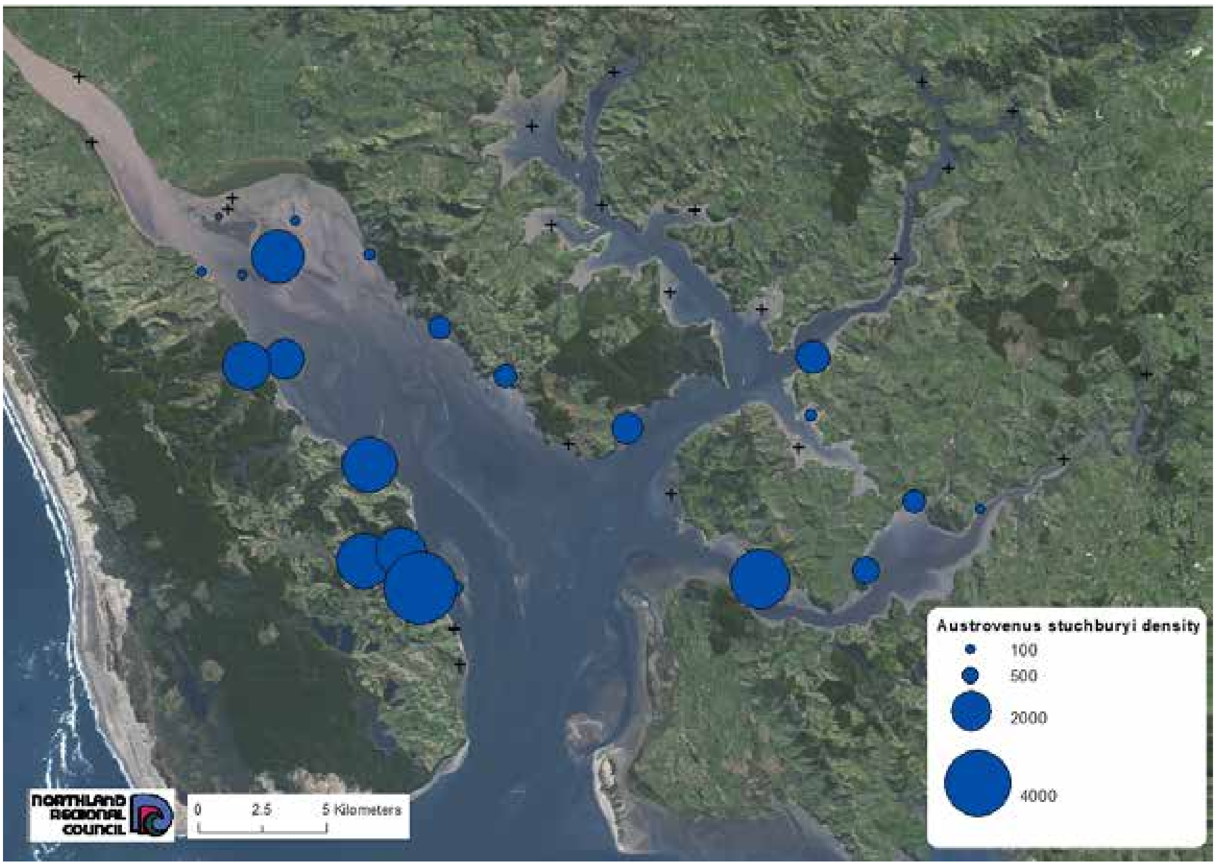


Figure 25. Density of cockles in cores collected in the Kaipara Harbour in 2014.

Pipi

Pipi (*Paphies australis*) were found at 14 sites but adult pipi (>30mm) were only found at seven of the 14 sites (K7, K16, K17, K23, K24, K28 and K29). Pipi were mostly found at sites with firm sandy substrate along the shoreline of the Tinopai and Pouto peninsulas in the Wairoa arm of the harbour (Figure 26). No pipi were found in the Arapaoa River or the Whakaki River and although pipi were found at K41 Kaiwaka River in the upper reaches of the Otamatea River and at K39 Hanerau Stream in the Oruawharo River, just one pipi was found at each of these sites and these were both juveniles (<6mm). The highest density was recorded at K29 Komiti Beach at Tinopai, (3565m^2) with high densities also found at K17 Waikeri Creek (1019m^2) and K23 Kotiroreka Bay (604m^2).

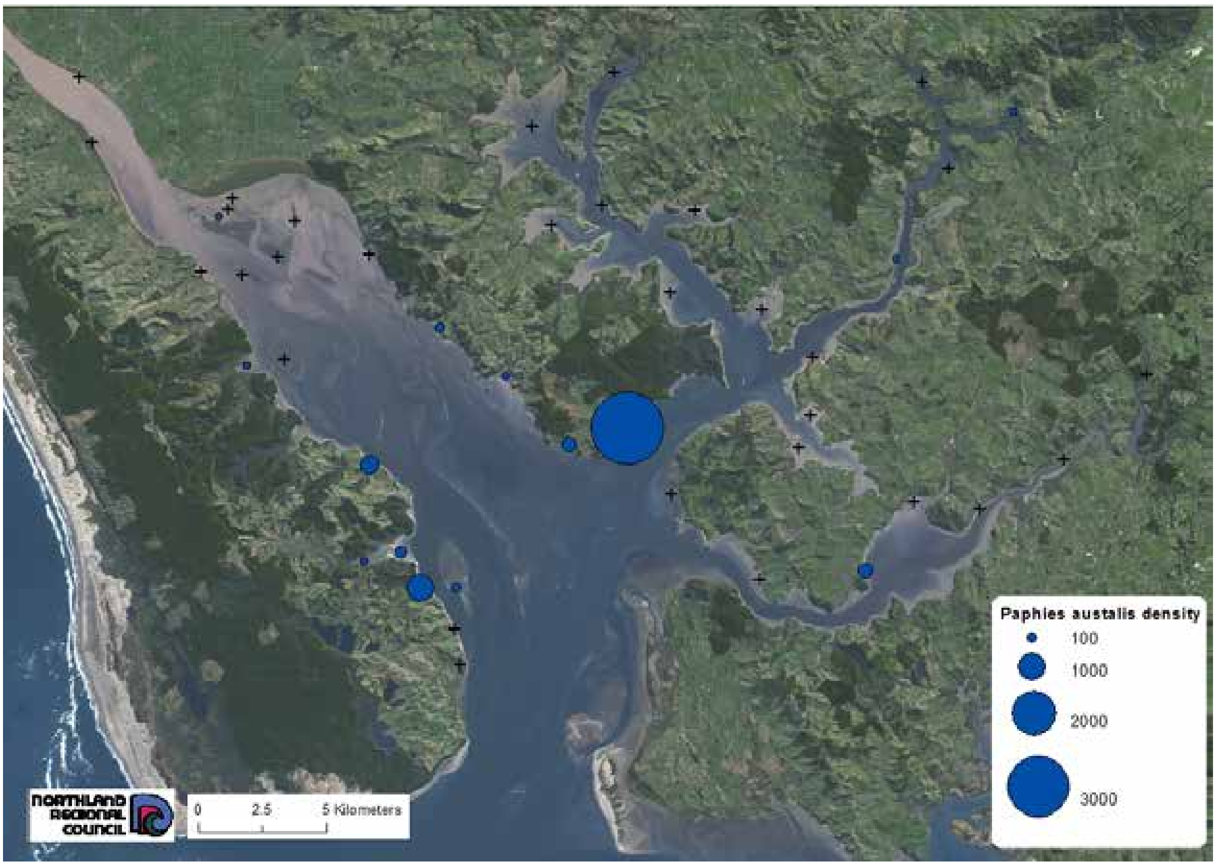


Figure 26. Density of pipi in cores collected in the Kaipara Harbour in 2014.

Wedge shells

Wedge shells were at 20 sites with adults (>20mm) found at 13 of these sites. Wedge shells were mostly found on firm sandy substrate in the Wairoa arm of the harbour. The highest density was found at K33 Subritzky Channel (2867m^2) (Figure 27). Lower densities were found at sites in Arapaoa River, Otamatea River and Oruawharo River.

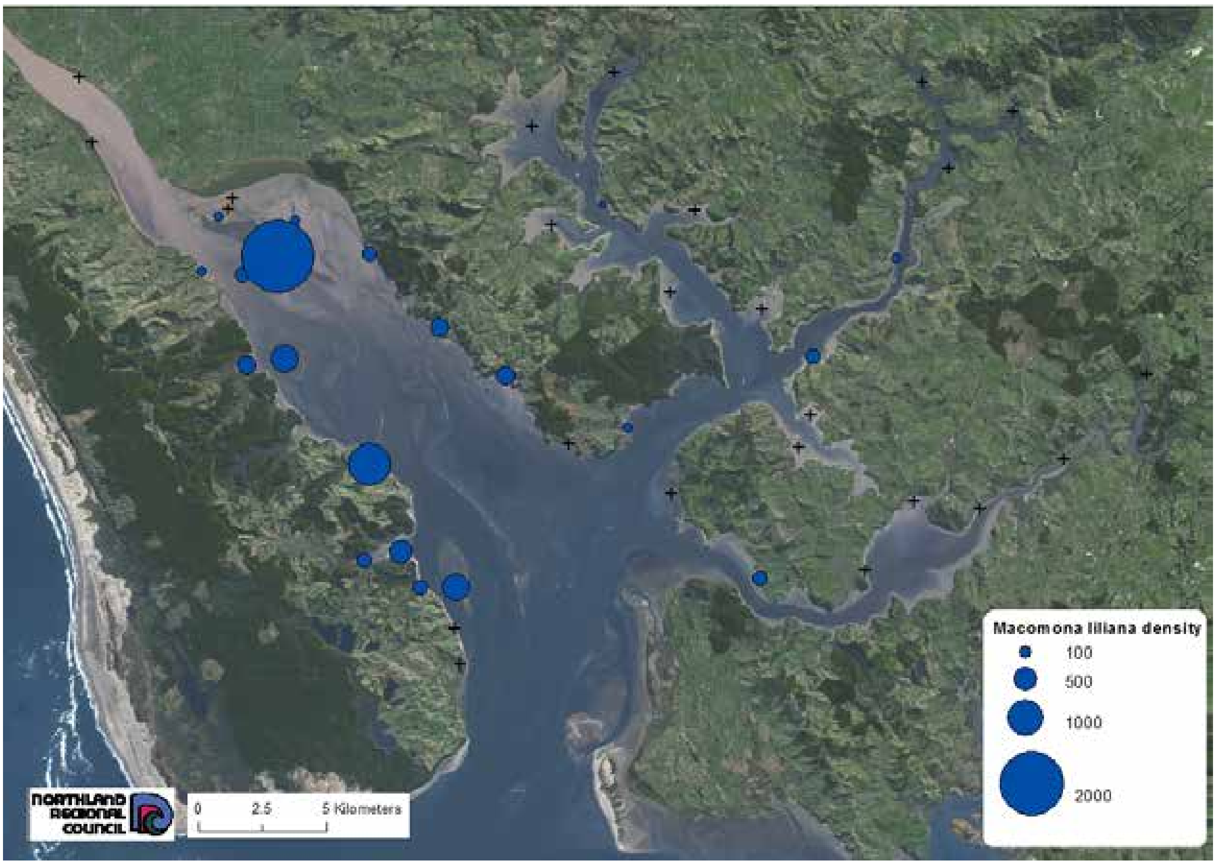


Figure 27. Density of wedge shells in cores collected in the Kaipara Harbour in 2014.

3.4.4 Non-indigenous species

Three non-indigenous species were identified in this survey: *Theora lubrica*, the Asian date mussel (*Musculista senhousia*) and the pacific oyster (*Crassostrea gigas*).

Theora lubrica

The small invasive bivalve *Theora lubrica* was the most widespread non-indigenous species found and was identified at 18 of the 44 sites (Figure 28). The highest densities were found in the Arapaoa River at K3 Whakapirau Creek and K2 Te Kopua Point Bay and it was found at all seven sites in this arm of the harbour. High abundances were also found at both sites in the Whakaki River, which is opposite the Arapaoa River.

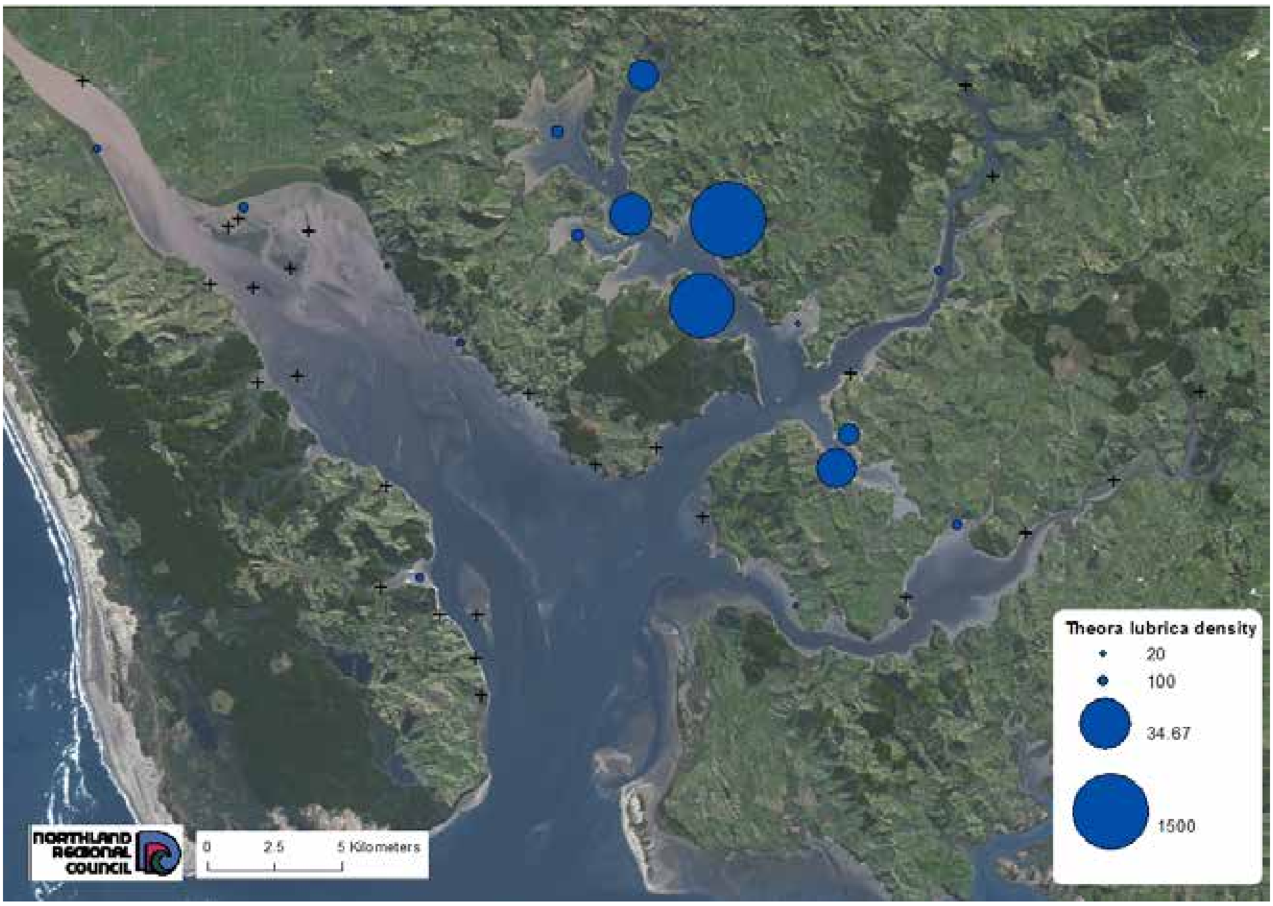


Figure 28. Density of *Theora lubrica* in cores collected in the Kaipara Harbour in 2014.

Asian date mussel

The Asian date mussel (*Musculista senhousia*) was identified from cores at just two of the sites (K27 Moturoa Island and K32 Kumuakiiti Point) (Figure 29) but 'mats' or 'humps' of Asian date mussels were observed at a number of locations throughout the northern harbour during the survey. At Moturoa Island very high densities were recorded although interestingly almost all of the individuals were collected from just one core (only two cores were analysed from this site).

During the survey we also observed evidence that the 'mats' or 'humps' of Asian date mussels had modified the sediment characteristics of intertidal habitat. On Fifty Acre Bank, which is a large intertidal bank in the Wairoa arm of the harbour, we encountered a large mat of Asian date mussels, which appeared to have trapped fine sediment at the southern end of the bank (Figure 30). As we walked towards the centre of the bank, where we had planned to collect our sample, the sediment transitioned from very soft mud to firm sand (Figure 31).

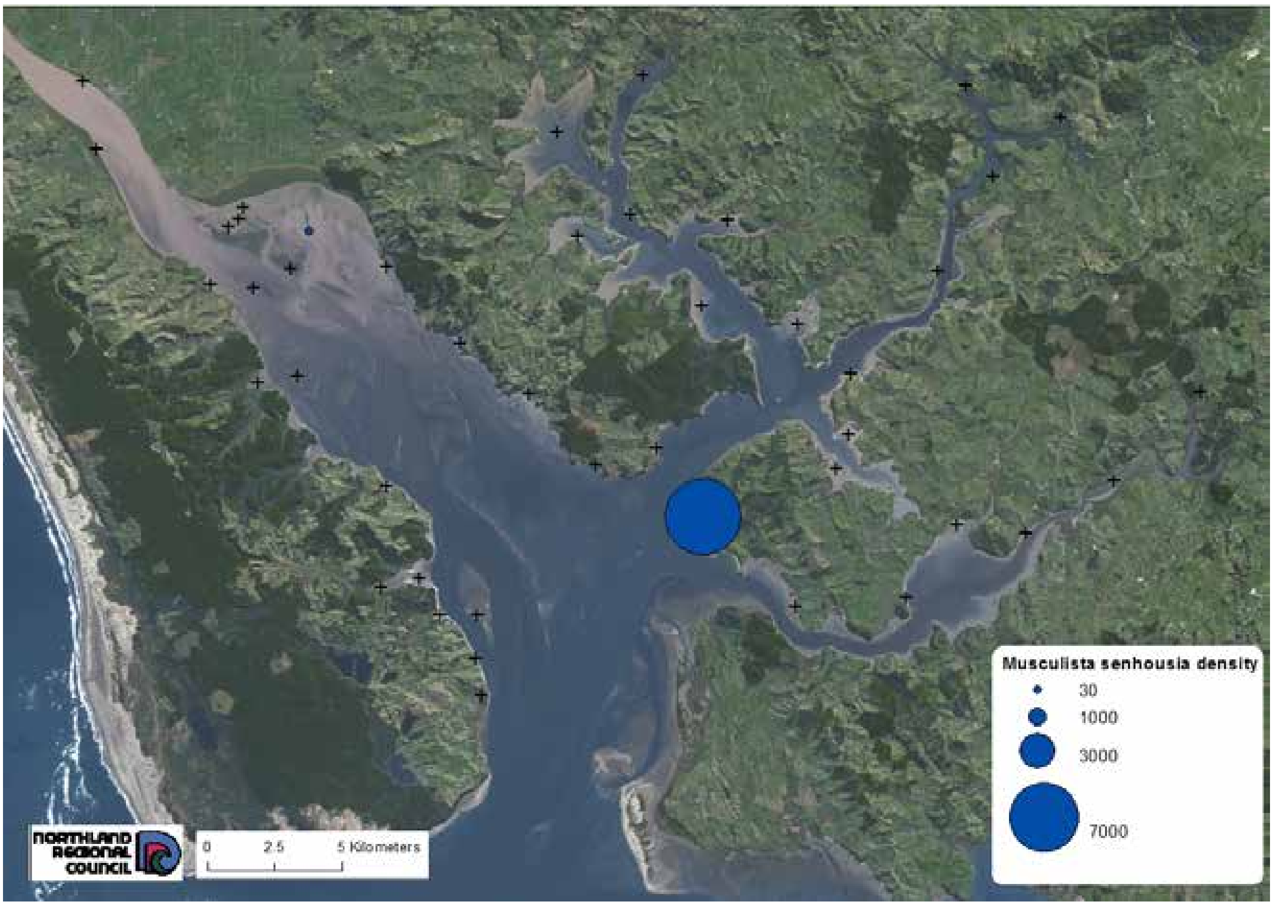


Figure 29. Density of Asian date mussel in cores collected in the Kaipara Harbour in 2014.

Figure 30. Asian date mussels on Fifty Acre Bank.

Figure 31. Firm sand in the centre of Fifty Acre Bank.

Pacific oyster

The other invasive taxa identified in the core samples was the pacific oyster (*Crassostrea gigas*) with three individuals recorded at Frenchman's Bay (K26). In addition reefs of pacific oysters were observed throughout the harbour. On the Avril Flats at the northern end of the main Wairoa arm an extensive area of oyster reef was observed, which appears to have modified the surrounding intertidal flats. The oyster reefs appear to have created a barrier with the intertidal area behind the reefs comprising soft mud (Figure 31).

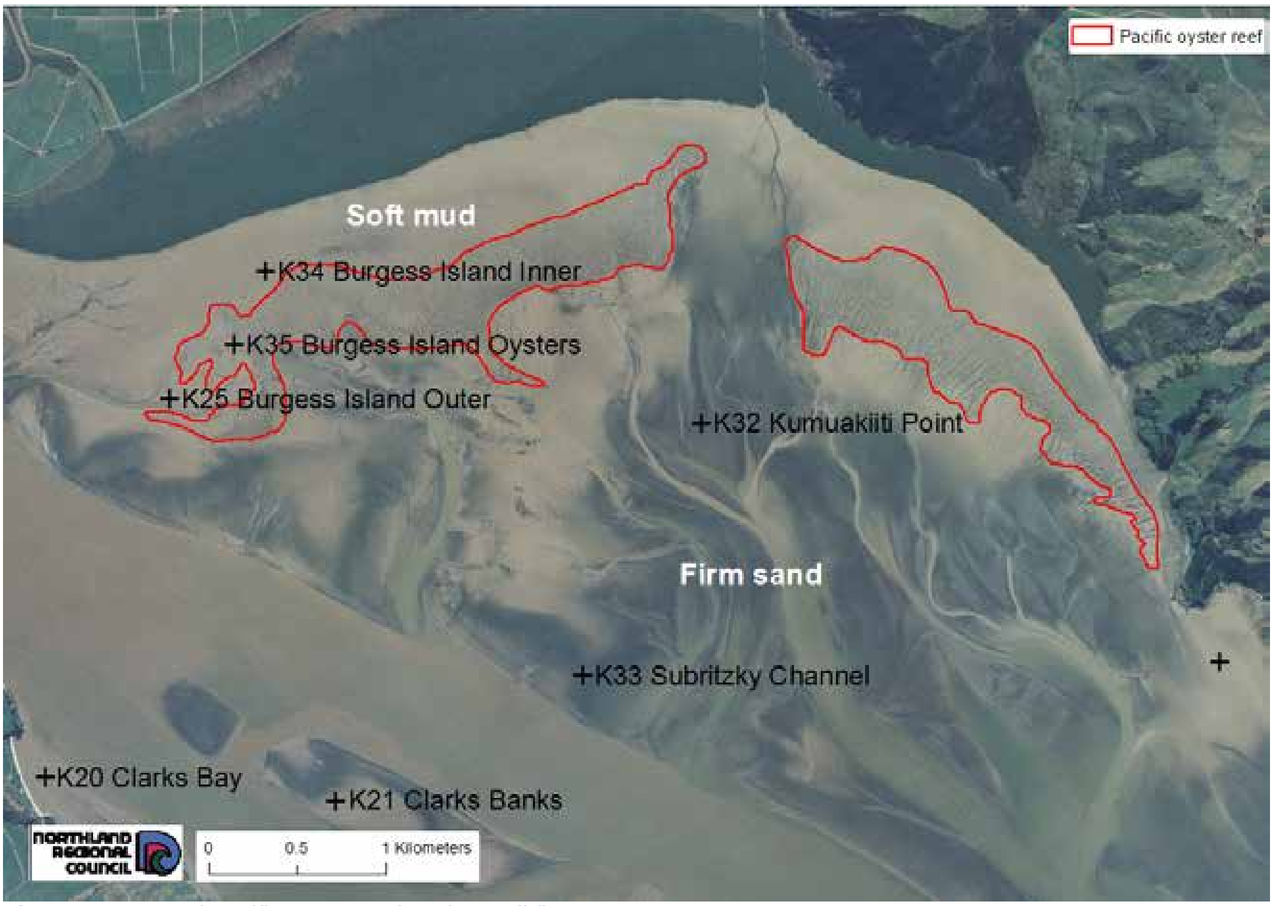


Figure 32. Map of Pacific oyster reef on the Avril flats.

3.5 Relating inter-tidal 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 all of the sediment properties, except coarse sand had a significant relationship to the intertidal ecological community structure (Table 9). The proportion of mud (17%) and TOC (16%) explained the highest amount of the variation in the ecological data.

DISTLM conducted using a forward selection procedure showed that the combination of mud, medium sand, TOC, lead, chromium, zinc and phosphorus explained 39% of the variation in the community structure (Pseudo-F = 1.7728, P-value = 0.049). The p-values associated with the conditional test to add further sediment properties to the model were not significant and the variation explained by subsequent variables were relatively small.

Table 9. DISTLM marginal tests for log_{10} sediment properties and abundance data from the Kaipara Harbour in 2014.

Sediment properties	Pseudo-F	P-value	Proportion of variation explained
Mud	7.84	0.001	17
TOC	7.00	0.001	16
Lead	5.76	0.001	13
Medium sand	5.50	0.001	13
Nitrogen	5.17	0.001	12
Fine sand	4.95	0.001	12
Zinc	4.86	0.001	11
Phosphorus	4.36	0.001	10
Copper	3.44	0.001	8
Chromium	3.06	0.002	7
Nickel	2.96	0.002	7
Coarse sand	1.80	0.056	5

4 Discussion

Council has implemented Estuary Monitoring Programmes in the Whāngārei Harbour, Kerikeri Inlet, Ruakaka Estuary, Whangaroa Harbour, and the Arapaoa River, in the Kaipara Harbour. In total 13 'sentinel' sites are surveyed in these five estuaries. 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.

In order to provide more spatial information about the sediment quality and ecological status of the northern Kaipara Harbour, Council surveyed 44 intertidal sites throughout the northern Kaipara Harbour in 2014. This survey will provide baseline data to track changes in the health of the harbour over time and complement the existing data from the two sentinel sites in the Arapaoa River.

The monitoring methods were adapted from the Estuary Monitoring Protocol (Robertson *et al.* 2002), and involved sampling the physical and chemical properties of the sediment, and the ecological communities of representative intertidal habitats.

4.1 Sediment grain size

The sediment grain size characteristics displayed a general pattern of higher proportions of mud in tidal creek environments such as the Otamatea River and the Oruawharo River, giving way to more fine and medium sand in the main Wairoa arm and towards the harbour entrance. 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. The proportions of mud at four sites previously surveyed by Council and Robertson *et al.* (2002) were similar to what has previously been found at these sites and the sediment characteristics observed in this survey are similar to patterns reported in the Otamatea River by Poynter (2014).

4.2 Sediment TOC and nutrient concentrations

Using criteria developed by Robertson and Stevens (2007), 13 sites were classified as 'enriched' for TOC, ten sites were 'enriched' for phosphorus and four sites were 'enriched' for nitrogen. 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 and have adverse effects on the health of the harbour. 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.

The mean nitrogen concentration in the northern Kaipara Harbour was higher than most values previously recorded in sediment surveys of estuaries in Northland, with higher mean nitrogen values only found in the Bay of Islands and Hokianga Harbour. The nitrogen concentration recorded at K36 Matanginui, in the upper Wairoa arm, was also particularly high in comparison to other sites surveyed recently by Council. Higher concentrations of nitrogen have only been recorded at Limeburners Creek in Whāngārei Harbour (Griffiths 2013), Orira River in the Hokianga Harbour (Northland Regional Council 2013) and at WAT 8 in the Waitangi Estuary (Griffiths 2013). The mean phosphorus and TOC levels recorded in the northern Kaipara Harbour were towards the middle of the range of values recorded at other estuaries surveyed recently by Council.

A similar spatial pattern was observed for levels of TOC, nitrogen and phosphorus, with the highest levels recorded at mud dominated sites in the upper reaches of the different arms of the harbour, with levels generally decreasing down each arm towards the entrance of the harbour. This pattern is consistent with these sites being located close to potential freshwater inputs of nutrients, in depositional tidal creek environments with higher proportions of mud. Sediment carbon and nutrients absorb onto mineral surfaces and tend to increase with decreasing sediment grain size. Potential sources of nutrients to the Kaipara Harbour include discharges from municipal wastewater treatment plants and milk processing plants, seepage from the wastewater networks and septic tanks, stormwater, runoff from agricultural land and discharges from farm dairy effluent systems.

The concentrations of nutrients recorded at Council's two sentinel sites (K38 Whakapirau and K2 Te Kopua Point Bay) and the two sites previously surveyed by Robertson *et al.* (2002) were generally lower than the concentrations previously recorded at these sites. The exceptions to this were increases in total nitrogen and TOC at K38 Whakapirau. There was also a small increase in nitrogen at K2 Te Kopua Point.

4.3 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.

The concentration of nickel at K34 Burgess Island Inner exceeded 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 concentration of copper at this site exceeded the threshold effect level developed by MacDonald *et al*. (1996). The relatively high concentrations of nickel and copper at this one site are surprising as there are no obvious sources of metal contaminants in the vicinity and two other sites located relatively close to this site did not have elevated metal concentrations. The concentration of copper at K41 Kaiwaka River also exceeded the threshold effect level. K41 Kaiwaka River is located in a sheltered tidal creek location. Potential sources of metal contaminants at this site include discharges from municipal waste water treatment plants, stormwater discharges and road runoff.

At the other 42 sites all of the other metal concentrations were below (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 harbour are unlikely to be having an adverse effect on the ecology although work by Hewitt *et al.* (2009) has found community responses below these guideline values.

Within the harbour the highest concentrations of metals were generally recorded towards the top of the Wairoa arm and in the upper reaches of the other arms of the harbour. These sites are generally depositional 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). The lowest concentrations were generally recorded along the shoreline of the Pouto peninsula in the main Wairoa arm of the harbour.

The concentrations of metals recorded at Council's two sentinel sites (K38 Whakapirau and K2 Te Kopua Point Bay) and the two sites previously surveyed by Robertson *et al.* (2002) were lower than the concentrations previously recorded at these sites. The mean metal concentrations recorded in the Northern Kaipara Harbour were also generally lower than those reported in recent sediment surveys conducted by Council in the Waitangi Estuary (2013), Bay of Islands and Whāngārei Harbour (both 2012).

4.4 Ecology

The intertidal habitats surveyed were reasonably varied, including sheltered muddy tidal creek environments, sand flats, sand banks, and exposed sandy beaches. One sample was also collected from an area of oyster reef. Sites were located on the mid inter-tidal so no mangrove forests were sampled. No seagrass beds were encountered and we are not aware of any intertidal or subtidal seagrass beds in the northern Kaipara Harbour.

Using cluster analysis and non-metric MDS ordination of the ecological data four main ecological community groups were identified. The first group (Group A) included sites found on sheltered mud flats in the different arms of the harbour and was characterised by polychaete worms, and the invasive bivalve *Theora lubrica*. A second group (Group B) comprised sites found in the upper reaches of the estuarine arms of the harbour with a high proportion of mud and was characterised by oligochaete and polychaete worms. A third group (Group C) included sites found on more sandy sites in the main Wairoa arm of the harbour. This group was characterised by the cockle *Austrovenus stutchburyi*, the polychaete worm *Aonides trifida*, and the wedge shell *Macomona liliana*. The fourth group (Group D) comprised four sites located on exposed sand flats and sand banks in the main Wairoa arm of the harbour. This group was characterised by the bivalves Soletellina sp., the wedge shell *Macomona liliana* and the cockle *Austrovenus stutchburyi*.

Sites in Group A and Group B tended to have lower species richness, lower total numbers of individuals and lower Shannon-Wiener diversity scores than sites in Group C and Group D. In addition, although biomass was not measured in this survey it is likely that sites in Group C and D had much higher biomass than sites in Group A and Group B. This is likely because sites in Group A and B were characterised by small animals (marine worms) and generally had low abundances of large bodied animals (e.g. cockles, pipi and wedge shells), while sites in Groups C and D were characterised by high abundances of large bodied shellfish.

The cluster analysis and MDS ordination also identified a fifth group (Group E) comprising just two sites, which were both located in the upper reaches of the Oruawharo River. A further four sites were in groups by themselves: K18 Tauhara, K19 Tauhara Creek K28 Sandy Beach, and K27 Moturoa Island. K18 Tauhara, K19 Tauhara Creek and K28 Sandy Beach all had low species richness and low abundances of animals. Only two cores were analysed from K27 Moturoa Island and the taxa found in these cores were quite different resulting in a very low within site similarity (Bray Curtis similarity).

A system of ecological classification rules developed by Hewitt and Funnell (2005) in their survey of the southern Kaipara was also used to allow for comparisons with their work. Using this classification system 12 community types were identified, although most sites belonged to just two groups: a Polychaete – Deposit feeder community and an *Austrovenus* community. Sites belonging to the Polychaete-Deposit feeder community type were generally located on sheltered mud flats in the different arms of the harbour, while sites belonging to the *Austrovenus* community type tended to be located on more exposed sand flats. The average similarity of these community types was lower than the groups identified from the cluster and MDS analysis and the dissimilarity between the community types tended to be lower than the dissimilarity between groups identified by cluster and MDS analysis. The groups identified with MDS and cluster analysis therefore appear to have been better at identifying the ecological communities at the sites sampled in the northern Kaipara.

The ecological communities found at Council's two sentinel sites were similar to what has been found in previous surveys of these sites between 2009 and 2011 (Griffiths 2013). Both of Council's sentinel sites were within Group A, characterised by the invasive bivalve *Theora lubrica* and polychaete worms. At K30 Otairi Creek an almost identical set of taxa was found compared to Robertson *et al.* (2002) and high abundances of cockles *Austrovenus stutchburyi* were found in both surveys. However at K40 Wahiwaka Creek the community appeared to have changed somewhat since the survey by Robertson *et al.* (2002). Robertson *et al.* (2002) found that oligochaete worms, the polychaete worm *Heteromastus filiformis* and the cockle *Austrovenus stutchburyi* were the most abundant taxa but in this survey the polychaete worm Paraonidae was the most abundant taxa and no cockles at all were found.

4.5 Shellfish

A number of dense shellfish beds were encountered in the current survey and the communities at a number of sites were characterised by large bodied shellfish species. Cockles (*Austrovenus stutchburyi*) were found at 22 sites with densities of over 1000 per m^2 recorded at eleven sites. These densities 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. Cockles were mainly found at firm sandy sites in the Wairoa arm of the harbour with very few cockles found at muddy tidal creek locations in the other arms of the harbour. Particularly high densities were found at K17 Waikeri Creek, K15 Okaro Creek, K16 Pareotaunga Point, K23 Kotiroreka Bay, K24 Tangitiki Bay, K26 Frenchmans Bay and K33 Subritzky Channel. Pipi were found at 14 sites, mostly located at firm sandy sites along the shoreline of the Tinopai and Pouto peninsulas in the Wairoa arm of the harbour with particularly high densities found at K29 Komiti Beach, at Tinopai, and K17 Waikeri Creek on the Pouto peninsula. Wedge shells were found at 20 sites mostly on firm sandy substrate in the Wairoa arm of the harbour with the highest density found at K33 Subritzky Channel.

4.6 Non-indigenous species

Three non-indigenous bivalve species were identified in the current survey, including the pacific oyster (*Crassostrea gigas*), the Asian date mussel (*Musculista senhousia*) and a small bivalve *Theora Lubrica*.

The small bivalve *Theora lubrica* was the most widespread invasive species found in this survey, being present at 18 sites. It was mainly found in muddy tidal creek locations with very few individuals found in the Wairoa arm of the harbour. The highest densities were found in the Arapaoa River and it was found at all seven sites in this arm of the harbour. *Theora Lubrica*, typically lives in muddy sediments from the low tide mark to 50m and thrives in highly disturbed and polluted environments (Hayward 1997) and in many localities is an indicator species for eutrophic and anoxic areas (Inglis *et al*. 2005). *Theora Lubrica* has previously been recorded in high densities at Council's two sentinel sites in the Arapaoa River, between 2009 and 2011 (Griffiths 2013) and was found at all four sites in the Otamatea River surveyed by Poynter in 2014, with particularly high densities at the uppermost site (near to K42 Wairau River in this survey). *Theora lubrica* was not found at the three sites sampled in the Otamatea River by Robertson *et al.* (2002) and was not found at the two of these sites resampled in the current survey.

The Asian date mussel *Musculista senhousia* was found at just two sites (K27 Moturoa Island and K32 Kumuakiiti Point) with very high densities recorded at K27 Moturoa Island although interestingly the majority of individuals were collected from just one core. The Asian date mussel has previously been found at Council's two sentinel sites in the Arapaoa River although only one individual has been found at each site between 2009 and 2011. Inglis *et al*. (2010) also found the

Asian date mussel at nine sites in the northern Kaipara Harbour including sites in the Wairoa arm, Oruawharo River and Arapaoa River. In a recent subtidal beam trawl survey of the Kaipara Harbour large densities of Asian date mussels were found as bycatch, south of Pahi, in the Arapaoa River, at the entrance to the Wairoa River, in the funnel in the Otamatea River, and east of Hargreaves Basin (Morrison *et al*. 2014).

In addition to the individuals identified from the core samples, large 'mats' of Asian date mussel were observed at a number of locations during the current survey and we have received anecdotal reports from local fishermen and oyster farmers that it is widespread throughout the northern harbour. We also observed evidence that the Asian date mussel had modified the sediment characteristics of intertidal habitat, with the mats appearing to trap fine sediment.

The pacific oyster *Crassostrea gigas* was only found at one site but reefs of pacific oysters were observed throughout the harbour. We also observed modification of the intertidal habitat by oyster reefs, in particular on the Avril flats at the northern end of the main Wairoa arm of the harbour. An extensive area of oyster reef appears to have created a barrier, which appears to have acted as a sediment trap and/or a barrier from wave and wind action, resulting in a large area of soft mud behind the oyster reef.

4.7 Relating ecological and sediment data

A distance-based linear model (DISTLM) showed that all the sediment properties, except coarse sand had significant relationships to the ecological community structure. When examined individually the proportion of mud and TOC explained the highest amount of the variation in the ecological data with these properties able to explain 17% and 16% of the variation in the ecological data respectively. DISTLM also showed that the combination of mud, medium sand, TOC, lead, chromium, zinc and phosphorus explained 39% of the variation in the community structure. Previous analysis of data collected from Council's two sentinel sites in the Arapaoa River arm of the Kaipara Harbour also showed that the sediment properties were significantly related to the ecological data (Griffiths 2013). 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 northern Kaipara.

5 Acknowledgements

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7 Appendices

Appendix 1 Land Use in the northern Kaipara Harbour catchment

Land Classes in northern Kaipara Harbour catchment from Zealand Land Cover Database (2001).

1st Order Class	2nd Order Class	Area (Ha)	Percentages
Artificial surfaces (<1%)	Built-up Area	723	<1
	Urban Parkland/ Open Space	203	<1
	Surface Mine	133	<1
	Transport Infrastructure	40	<1
Bare or lightly vegetated surfaces (<1%)	Coastal Sand and Gravel	1239	<1
	River and Lakeshore Gravel and Rock	1	<1
	Landslide	2	<1
Water bodies (1%)	Lake and Pond	1070	<1
	River	1470	<1
Cropland (1%)	Short-rotation Cropland	2147	<1
	Vineyard	1	<1
	Orchard and Other Perennial Crops	1053	<1
Grassland (63%)	High Producing Exotic Grassland	278670	62
	Low Producing Grassland	5129	1
	Herbaceous Freshwater Vegetation	1271	<1
	Herbaceous Saline Vegetation	202	<1
	Flaxland	40	<1
Scrub (4%)	Fernland	8	<1
	Gorse and Broom	1123	<1
	Manuka and or Kanuka	12799	3
	Broadleaved Indigenous Hardwoods	5605	1
	Mixed Exotic Shrubland	318	<1
			<1
Forest (30%)	Major Shelterbelts	130	<1
	Afforestation	4701	1
	Forest Harvested	3878	1
	Pine Forest	57142	13
	Other Exotic Forest	1649	<1
	Deciduous Hardwoods	762	<1
	Indigenous Forest	68411	15
	Mangrove	363	<1
Total		**450285**	**100**

Appendix 2 Site co-ordinates (NZGD 2000 New Zealand Transverse Mercator)

Site Name	x	y
K1 Hokorako Creek	1717545	5991892
K2 Te Kopua Point Bay	1713964	5992570
K3 Whakapirau Creek	1714948	5995801
K4 Kirikiri Inlet	1709301	5995221
K5 Paparoa Creek	1708581	5999093
K6 Pahi River	1711791	6001183
K7 Hargreaves Basin	1721596	5981671
K8 Oruawharo River	1726098	5984074
K9 Gittos Point	1723510	5984378
K10 Koareare Creek	1729394	5986023
K11 Topuni River	1732656	5989383
K12 Waitieke Creek	1704918	5991198
K13 Te Kiakia Bay	1707500	5989293
K14 Waikeri Bank	1705557	5981027
K15 Okaro Creek	1701979	5982067
K16 Pareotaunga Point	1703387	5982395
K17 Waikeri Creek	1704170	5980990
K18 Tauhara	1705500	5979399
K19 Tauhara Creek	1705744	5978003
K20 Clarks Bay	1695578	5993397
K21 Clarks Banks	1697215	5993266
K22 Fifty Acre Bank	1698850	5989941
K23 Kotiroreka Bay	1702193	5985837
K24 Tangitiki Bay	1697354	5989724
K25 Burgess Island Outer	1696276	5995524
K26 Frenchmans Bay	1717470	5981332
K27 Moturoa Island	1713998	5984683
K28 Sandy Beach	1710012	5986615
K29 Komiti Bay	1712267	5987267
K30 Otairi Creek	1719554	5990040
K31 Te Ruruku Bay	1702190	5994045
K32 Kumuakiiti Point	1699271	5995387
K33 Subritzky Channel	1698603	5993965
K34 Burgess Island Inner	1696819	5996241
K35 Burgess Island Oysters	1696644	5995830
K36 Matanginui	1691324	5998469
K37 Ruawai	1690824	6000992
K38 Whakapirau	1711309	5995997
K39 Hanerau Stream	1722797	5993878
K40 Wahiwaka Creek	1724884	5997422
K41 Kaiwaka River	1727399	5999618
K42 Wairau River	1723836	6000819
K43 Otara	1719444	5987766
K44 Stony Creek	1718979	5986505

Appendix 3 Field notes

Site	Date	Field notes
K1 Hokorako Creek	18/03/2015	Flat mud (sandy mud) – quite sticky. First push on the core only went in 2 inches. Needed to hammer the core in several times.
K2 Te Kopua Point Bay	18/03/2015	Very soft mud. Surface flat with crab holes and the odd shell. Very easy to push core in. When sieving the sediment was noticeably more sticky (clay like sediment). The sediment stuck to the bucket and was very clumpy.
K3 Whakapirau Creek	18/03/2015	Surface flat, soft mud, crab holes. Very easy to push sediment core in.
K4 Kirikiri Inlet	18/03/2015	Surface flat, soft mud, crab holes. Shell has at the bottom of core. Site 10m away from a reasonable size oyster reef.
K5 Paparoa Creek	18/03/2015	Surface flat. Muddy sand, small crab holes no large ones. Semi hard to push core in.
K6 Pahi River	18/03/2015	Surface flat, crab holes – easy to push core in.
K7 Hargreaves Basin	19/03/2015	Surface firm to walk on. Hard to push core in. It needed stomping and multiple attempts. Surface is hard sediment with some mud. Shell hash and bivalves. Stones up to 40mm. Cockles, pipi, nut shell all on surface. Core comes out intact. In the core we found sand down to 10cm before hitting clay (sticky). The upper shore is shell hash and stones before a distinct shift to coarse sand and less shell hash waste deep.
K8 Oruawharo River	19/03/2015	Surface semi firm to walk on (sink 1.5cm). Core easy to push in. Surface gravel, coarse sand with a film of mud on the surface. A 'cap' of coarse material at 10cm -15cm in the core.
K9 Gittos Point	19/03/2015	Soft mud, surface flat. Easy to push core in. Lighter brown mud on surface. From 1-11cm darker mud, very liquidy.
K10 Koareare Creek	19/03/2015	Site 6m from mangroves. Very soft mud, surface flat, very small holes.
K11 Topuni River	19/03/2015	Soft mud not as easy to push core in as at K10. Surface flat. Mangrove seedlings on site. Site 4m to mangroves.
K12 Waitieke Creek	20/03/2015	Firm sand. All of the bay appeared similar. Easy to walk on, no crab holes. *Zeacumantus lutulentus* observed on the surface. No shell hash. Some sand ripples.
K13 Te Kiakia Bay	20/03/2015	Firm sand but softer than K12. Foot sank about 2 cm. Appearance similar to K12 but patches of silt on the surface in places. Small sand ripples. Some large shells on surface. *Zeacumantus lutulentus* and *Diloma subrostrata* on the surface.
K14 Waikeri Bank	20/03/2015	Firm golden sand. Steep sand ripples. A few crab holes widely dispersed. No shells on surface.
K15 Okaro Creek	20/03/2015	Firm sandy mud with large cockle shells. No crab holes. Upper Okaro Creek all firm sandy mud up from Point. Lots of stingrays.
K16 Pareotaunga Point	20/03/2015	Firm sand with lots of shells on the surface. All appeared to be firm sand in surrounding area. Lots of stingrays.
K17 Waikeri Creek	20/03/2015	Firm golden sand with ripples. Big sting ray holes. Ron Matich commented that there were strong swells along this coast.
K18 Tauhara	20/03/2015	Golden sand, nothing on surface. Sand ripples, short steep beach.
K19 Tauhara Creek	20/03/2015	Soft pudgy sand, no crab holes, no shells, no ripples.
K20 Clarks Bay	21/3/2014	Soft mud, surface flat with crab holes. No shell hash on surface but in the cores we hit shell hash. Clarks Bay is very heterogeneous. At northern end of Bay we found firm sand and a cockle bed and two smallish raised Asian date mussel beds. As we walked south the sediment turned to soft mud although it was firmer again up the beach towards the shore. At the far southern end of the bay there was a large expanse of raised oyster beds with lots of mud on them. We also observed horse mussel shells at the northern end of

		beach.
K21 Clarks Banks	21/3/2014	At the northern end of the Bank where the samples were collected the sediment comprised firm sand with ripples, with some shells on surface but no crab holes. We observed some small patches of silt on top of the surface in the troughs of the sand ripples. At the southern end of the bank the sediment comprised soft mud and there was a transition zone, approximately 50m wide, where it went from soft mud to the firm sand with ripples. Ron Matich said that 30 years ago the bank used to be all firm sand. He explained that now the southern end of the bank is protected from the incoming tide by a big bank of Asian date mussels, which has caused it to become muddier.
K22 Fifty Acre Bank	21/3/2014	Firm hard sand. At the southern end of the Bank, Ron Matich says it is very firm packed sand and that the bank is one big cockle bed although the eastern side of the bank has Asian date mussels on it around the low water mark. On the western side we observed lots of dead cockle shells and a smell of dead cockles. At the sampling site there were not many shells on the surface.
K23 Kotiroreka Bay	21/3/2014	Firm sand with lots of big cockles, pipi and wedge shells. At the sample site live cockles observed on the surface. The Bay was quite heterogeneous. At northern end a slightly raised triangular shaped area of golden sand was observed with ripples and not much shell hash. Lots of pipi and some cockles at low water mark.
Kelly's Bay		At the shoreline/low water mark we observed a raised firm sandy plateau with some shells with sand ripples. As we walked towards the shore we dropped into an area of more muddy sand with lots of shell hash and gastropods. No sample collected at this Bay. Ron Matich said that it is a large cockle bed like K23.
K24 Tangitiki Bay	21/3/2014	Medium soft mud. Ron Matich told us that the Bay is all very homogenous with some patches of softer mud. Mature mangroves surround the Creek.
K25 Burgess Island Outer	21/3/2014	Soft mud, very uneven terrain, lots of gullies and ruts.
K26 Frenchmans Bay	25/03/2015	Firm mud. Lots of cockle shells on the surface. Hard to push core in. At about 8-10cm down the core there we encountered very hard clay like sediment. This was not like anything was had seen before and it was very hard to retrieve the core.
K27 Moturoa Island	25/03/2015	Firm mud, easy to push core in.
K28 Sandy Beach	25/03/2015	Firm sandy beach.
K29 Komiti Bay	25/03/2015	Firm sand with lots of cockle and pipi shell hash on the surface. We needed to hammer the core in and had to dig it out.
K30 Otairi Creek	25/03/2015	Firm mud with lots of shell (cockle) hash on the surface. Smell of rotting shellfish.
K31 Te Ruruku Bay	3/4/2015	Layer of mud 15mm deep over firm muddy sand. No crab holes. *Zeacumantus lutulentus* and *Diloma subrostrata* observed on the surface.
K32 Kumuakiiti Point	3/4/2015	Firm sand with ripples *Zeacumantus lutulentus* and cockles visible on the surface.
K33 Subritzky Channel	3/4/2015	Firm flat sand (sink approximately 5mm). Expansive sand flat. Barnacles observed on crabs.
K34 Burgess Island Inner	3/4/2015	Soft sloppy mud but not too bad to walk across. Lots of crab holes. A layer of shell was encountered approximately 10-15cm down the core.
K35 Burgess Island Oysters	3/4/2015	Oyster reef. Soft clay mud (very sticky cohesive mud). Lots of crab holes and surface uneven. When we sieved the core samples the sediment that washed away was bright orange and very terrestrial looking.
K36 Matanginui	3/4/2015	No comments made.

K37 Ruawai	3/4/2015	No comments made.
K38 Whakapirau	4/4/2015	Soft mud, sink to shins, crab holes.
K39 Hanerau Stream	4/4/2015	Soft mud, sink to shins, crab holes.
K40 Wahiwaka Creek	4/4/2015	Most of the Bay was soft mud with crab holes but the sample site was on a raised plateau which was soft mud on top of shell hash. Shell hash was found very close to the surface with only about 2cm of mud at the surface.
K41 Kaiwaka River	4/4/2015	No comments made.
K42 Wairau River	4/4/2015	No comments made.
K43 Otara	4/4/2015	Soft mud with crab holes. Shell hash encountered at 10-15cm harder to push core in.
K44 Stony Creek	4/4/2015	Soft mud with crab holes. Shell hash encountered at 15cm deep. Easy to push core in.

Appendix 4 Sediment results

Site Name	<63 (Mud)	63-250 (Fine sand)	250- 500 (medium sand)	>500 (coarse sand)
K1 Hokorako Creek	6	84	10	0
K2 Te Kopua Point Bay	36	61	3	0
K3 Whakapirau Creek	54	44	2	0
K4 Kirikiri Inlet	90	9	0	0
K5 Paparoa Creek	9	48	38	5
K6 Pahi River	48	27	17	8
K7 Hargreaves Basin	10	11	55	24
K8 Oruawharo River	34	8	12	46
K9 Gittos Point	89	10	1	0
K10 Koareare Creek	99	1	0	0
K11 Topuni River	100	0	0	0
K12 Waitieke Creek	9	63	22	6
K13 Te Kiakia Bay	6	54	24	16
K14 Waikeri Bank	0	70	30	0
K15 Okaro Creek	10	72	17	0
K16 Pareotaunga Point	0	48	33	19
K17 Waikeri Creek	2	53	44	2
K18 Tauhara	0	46	48	6
K19 Tauhara Creek	3	71	26	0
K20 Clarks Bay	14	62	24	0
K21 Clarks Banks	0	91	9	0
K22 Fifty Acre Bank	1	86	13	0
K23 Kotiroreka Bay	1	21	37	41
K24 Tangitiki Bay	6	60	28	6
K25 Burgess Island Outer	6	87	7	0
K26 Frenchmans Bay	23	58	20	0
K27 Moturoa Island	6	87	7	0
K28 Sandy Beach	0	2	37	61
K29 Komiti Bay	4	12	53	31
K30 Otairi Creek	23	50	13	14
K31 Te Ruruku Bay	13	68	18	0
K32 Kumuakiiti Point	0	86	14	0
K33 Subritzky Channel	6	88	6	0
K34 Burgess Island Inner	67	30	3	0
K35 Burgess Island Oysters	85	14	0	0
K36 Matanginui	98	2	0	0
K37 Ruawai	100	0	0	0
K38 Whakapirau	30	62	8	0
K39 Hanerau Stream	77	19	3	1
K40 Wahiwaka Creek	64	18	7	11
K41 Kaiwaka River	98	2	0	0
K42 Wairau River	47	38	11	5
K43 Otara	53	40	3	5
K44 Stony Creek	86	9	0	4

Site Name	AFDW	TOC	Nitrogen (mg/kg)	Phosphorus (mg/kg)
K1 Hokorako Creek	1.5	0.6	240	240
K2 Te Kopua Point Bay	2.9	1.2	620	370
K3 Whakapirau Creek	3.8	1.6	630	360
K4 Kirikiri Inlet	7.6	3.2	1400	240
K5 Paparoa Creek	1.6	0.6	250	160
K6 Pahi River	3.8	1.6	1200	360
K7 Hargreaves Basin	3.8	1.6	660	450
K8 Oruawharo River	3.3	1.3	350	500
K9 Gittos Point	6.4	2.7	1400	320
K10 Koareare Creek	9.0	3.8	1100	580
K11 Topuni River	8.8	3.7	2700	700
K12 Waitieke Creek	3.6	1.5	320	400
K13 Te Kiakia Bay	3.4	1.4	360	640
K14 Waikeri Bank	0.9	0.4	55	90
K15 Okaro Creek	3.6	1.5	930	140
K16 Pareotaunga Point	1.8	0.7	310	73
K17 Waikeri Creek	1.1	0.4	160	41
K18 Tauhara	0.9	0.4	33	27
K19 Tauhara Creek	0.6	0.2	690	86
K20 Clarks Bay	4.9	2.0	660	180
K21 Clarks Banks	1.4	0.6	190	220
K22 Fifty Acre Bank	1.2	0.5	160	170
K23 Kotiroreka Bay	1.3	0.5	180	45
K24 Tangitiki Bay	1.9	0.8	530	160
K25 Burgess Island Outer	3.2	1.3	640	200
K26 Frenchmans Bay	2.8	1.1	590	190
K27 Moturoa Island	1.6	0.6	290	290
K28 Sandy Beach	0.5	0.2	71	50
K29 Komiti Bay	1.1	0.4	200	160
K30 Otairi Creek	3.4	1.4	1000	530
K31 Te Ruruku Bay	2.5	1.0	430	220
K32 Kumuakiiti Point	0.9	0.4	210	160
K33 Subritzky Channel	1.3	0.5	350	240
K34 Burgess Island Inner	5.4	2.2	1200	430
K35 Burgess Island Oysters	6.6	2.7	1400	560
K36 Matanginui	9.3	3.9	3900	550
K37 Ruawai	8.5	3.6	2200	540
K38 Whakapirau	4.2	1.7	1200	270
K39 Hanerau Stream	3.9	1.6	170	410
K40 Wahiwaka Creek	5.5	2.3	930	400
K41 Kaiwaka River	7.6	3.2	2300	610
K42 Wairau River	6.3	2.6	1400	590
K43 Otara	4.2	1.7	770	490
K44 Stony Creek	5.2	2.1	1000	340

Site Name	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
K1 Hokorako Creek	<0.09	5.7	2.2	3.2	2.3	21
K2 Te Kopua Point Bay	<0.09	9.7	6.6	5.8	4.9	34
K3 Whakapirau Creek	<0.09	8.9	8.9	6.1	5.2	33
K4 Kirikiri Inlet	<0.09	8.0	7.2	5.1	4.6	26
K5 Paparoa Creek	<0.09	3.3	2.6	2.5	2.3	15
K6 Pahi River	<0.09	9.3	11.0	6.9	6.0	36
K7 Hargreaves Basin	<0.09	5.6	6.2	5.3	3.7	24
K8 Oruawharo River	<0.09	4.5	8.2	6.1	5.2	25
K9 Gittos Point	<0.09	18.0	8.9	6.8	5.5	32
K10 Koareare Creek	<0.09	16.0	14.0	9.7	7.8	48
K11 Topuni River	<0.09	14.0	14.0	8.5	8.0	44
K12 Waitieke Creek	<0.09	18.0	18.0	12.0	5.8	50
K13 Te Kiakia Bay	<0.09	17.0	13.0	13.0	8.2	57
K14 Waikeri Bank	<0.09	4.2	0.8	2.1	0.9	9.2
K15 Okaro Creek	<0.09	4.0	1.0	1.6	1.3	13
K16 Pareotaunga Point	<0.09	1.7	<0.45	0.8	0.5	<6.8
K17 Waikeri Creek	<0.09	1.0	<0.45	<0.45	0.4	<6.8
K18 Tauhara	<0.09	2.6	0.5	1.0	0.7	6.9
K19 Tauhara Creek	<0.09	7.4	1.3	2.8	1.8	21
K20 Clarks Bay	<0.09	6.4	3.5	3.6	2.2	19
K21 Clarks Banks	<0.09	9.4	2.4	5.2	2.1	25
K22 Fifty Acre Bank	<0.09	6.8	1.5	3.5	1.5	16
K23 Kotiroreka Bay	<0.09	1.0	<0.44	0.5	0.6	<6.6
K24 Tangitiki Bay	<0.09	4.3	1.3	2.2	1.3	13
K25 Burgess Island Outer	<0.09	7.5	3.0	4.3	2.0	22
K26 Frenchmans Bay	<0.09	6.8	3.4	3.3	2.7	16
K27 Moturoa Island	<0.09	11.0	2.6	5.8	2.5	27
K28 Sandy Beach	<0.09	0.7	1.2	0.7	1.7	9.4
K29 Komiti Bay	<0.09	6.2	2.6	3.6	6.9	18
K30 Otairi Creek	<0.09	4.5	6.3	6.3	3.2	22
K31 Te Ruruku Bay	<0.09	11.0	3.8	7.0	2.7	28
K32 Kumuakiiti Point	<0.09	6.0	1.3	3.3	1.3	16
K33 Subritzky Channel	<0.09	9.9	2.1	5.5	2.0	25
K34 Burgess Island Inner	<0.09	17.0	45.0	26.0	5.2	54
K35 Burgess Island Oysters	<0.09	21.0	12.0	11.0	6.8	56
K36 Matanginui	<0.09	24.0	15.0	13.0	7.5	62
K37 Ruawai	<0.09	22.0	14.0	12.0	7.1	58
K38 Whakapirau	<0.09	6.7	5.6	4.7	4.0	25
K39 Hanerau Stream	<0.09	8.3	14.0	8.9	7.8	43
K40 Wahiwaka Creek	<0.09	6.4	9.2	5.8	5.7	35
K41 Kaiwaka River	<0.09	12.0	21.0	11.0	10.0	53
K42 Wairau River	<0.09	8.0	16.0	8.6	8.1	48
K43 Otara	<0.09	8.6	7.1	5.6	5.0	33
K44 Stony Creek	<0.09	9.0	7.4	5.5	5.1	29

Appendix 5 Diversity indices

Site Name	Species richness	Number of individuals	Shannon diversity	Bray-Curtis
K1 Hokorako Creek	15	72	1.98	40
K2 Te Kopua Point Bay	10	244	1.77	42
K3 Whakapirau Creek	9	218	1.37	70
K4 Kirikiri Inlet	16	138	1.96	39
K5 Paparoa Creek	19	195	1.93	68
K6 Pahi River	10	159	1.11	76
K7 Hargreaves Basin	23	809	1.08	70
K8 Oruawharo River	15	53	2.31	29
K9 Gittos Point	11	148	1.60	67
K10 Koareare Creek	7	522	1.02	70
K11 Topuni River	5	884	1.15	55
K12 Waitieke Creek	26	249	2.58	63
K13 Te Kiakia Bay	30	514	2.15	73
K14 Waikeri Bank	13	126	1.85	57
K15 Okaro Creek	32	384	2.21	69
K16 Pareotaunga Point	35	759	2.34	57
K17 Waikeri Creek	28	487	1.87	67
K18 Tauhara	3	13	0.90	45
K19 Tauhara Creek	2	7	0.41	0
K20 Clarks Bay	11	42	1.99	33
K21 Clarks Banks	17	147	2.05	61
K22 Fifty Acre Bank	30	343	2.36	66
K23 Kotiroreka Bay	27	845	2.35	68
K24 Tangitiki Bay	26	808	1.80	66
K25 Burgess Island Outer	13	295	1.56	46
K26 Frenchmans Bay	39	764	2.44	67
*K27 Moturoa Island	17	298	0.49	1.12
K28 Sandy Beach	8	123	0.92	29
K29 Komiti Bay	28	1278	1.71	69
K30 Otairi Creek	28	390	2.69	59
K31 Te Ruruku Bay	23	122	2.71	52
K32 Kumuakiiti Point	20	162	2.12	44
K33 Subritzky Channel	27	524	2.00	71
K34 Burgess Island Inner	16	54	2.37	40
*K35 Burgess Island Oysters	8	78	1.69	8.45
K36 Matanginui	9	53	1.51	30
K37 Ruawai	8	78	1.31	44
K38 Whakapirau	16	317	1.41	67
K39 Hanerau Stream	14	279	1.32	66
K40 Wahiwaka Creek	15	153	1.67	65
K41 Kaiwaka River	12	84	1.55	13
K42 Wairau River	8	106	1.43	18
K43 Otara	13	105	1.91	42
K44 Stony Creek	9	223	1.46	72

*only two cores were analysed from these sites

Appendix 6 Simper analysis

Mean abundance of taxa at sites in Group A and their contribution to 'group' similarity. Mean similarity = 43%.

Taxon	% contribution towards similarity	% cumulative contribution towards similarity
Heteromastus filiformis	29	29
Aricidea sp.	17	46
Theora lubrica	16	62
Paraonidae	12	74
Nicon aestuariensis	7	81
Macrophthalmus hirtipes	6	87
Cossura consimilis	4	91

Mean abundance of taxa at sites in Group B and their contribution to 'group' similarity. Mean similarity = 38%.

Taxon	% contribution towards similarity	% cumulative contribution towards similarity
Oligochaeta	30	30
Paraonidae	16	46
Heteromastus filiformis	13	59
Polydorid	9	68
Macrophthalmus hirtipes	5	73
Helice crassa	4	77
Amphipoda	3	80
Arthritica bifurca	3	83
Nicon aestuariensis	3	86
Aricidea sp.	2	89
Phoxocephalidae	2	91

Mean abundance of taxa at sites in Group C and their contribution to 'group' similarity. Mean similarity = 45%.

Taxon	% contribution towards similarity	% cumulative contribution towards similarity
Austrovenus stutchburyi	20	20
Aonides trifida	12	32
Macomona liliana	8	40
Nucula hartvigiana	6	46
Prionospio aucklandica	6	53
Heteromastus filiformis	6	58
Aricidea sp.	3	62
Anthopleura aureoradiata	3	65
Zeacumantus subcarinatus	3	68
Paphies australis	3	71
Austrominius modestus	2	73
Prionospio sp.	2	75
Zeacumantus lutulentus	2	78
Diloma subrostrata	2	80
Notoacmea helmsi	2	82
Nemertea sp. 4	2	83
Amphipoda	2	85
Paraonidae	1	86
Arthritica bifurca	1	87
Macrophthalmus hirtipes	1	88
Nemertea sp. 1	1	89
Scolecolepides benhami	1	90

Mean abundance, of taxa at sites in Group D and their contribution to 'group' similarity. Average similarity = 35%.

Taxon	% contribution towards similarity	% cumulative contribution towards similarity
Soletellina sp.	22	22
Macomona liliana	16	39
Austrovenus stutchburyi	16	55
Magelona dakini	8	63
Polydorid	6	69
Aglaophamus sp.	3	73
Nemertea sp. 4	3	76
Austrominius modestus	3	79
Heteromastus filiformis	3	82
Waitangi brevirostris	3	85
Cumacea	3	87
Flabellifera (juvenile)	2	89
Amphipoda	2	91

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