Whāngārei Harbour
Estuary Monitoring Programme
2012

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NORTHLAND REGIONAL COUNCIL

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Executive summary

In 2012, Northland Regional Council (Council) sampled 25 intertidal and 13 subtidal sites throughout the Whāngārei 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, and the ecological communities. The survey will provide baseline data to track changes in the health of the harbour over time.

Sediment grain size

The sediment grain size characteristics of intertidal sites displayed a general pattern of higher proportions of mud and fine sand in the tidal creek environments of the upper harbour, giving way to more medium sand and coarse sand at the higher energy environments found near the harbour entrance. A similar pattern was observed for subtidal sites, with the proportion of mud decreasing from the upper harbour to the harbour entrance, although there were some noticeable exceptions to this pattern. For example, the sediment at the Upper Hātea, the Waiharohia Canal and the Mangapai River sites, in the upper harbour, had high proportions of medium sand and coarse sand. These two sites are located in the centre of relatively narrow tidal creek channels where there is likely to be high flow so they are unlikely to be depositional areas.

Sediment nutrients

A similar pattern was observed for levels of total organic carbon, nitrogen and phosphorus, with the highest levels recorded at sites in the Hātea River and to a lesser extent the Mangapai River, with lower levels generally recorded towards the entrance of the harbour. This pattern is consistent with the sites in the Hātea River being located close to potential sources of nutrients in depositional tidal creek environments with higher proportions of mud, as sediment carbon and nutrients absorb onto mineral surfaces and tend to increase with decreasing sediment grain size. The highest concentrations of both nitrogen and phosphorus were found in sediment in Limeburner's Creek, which is the receiving environment for discharges from the Whāngārei waste water treatment plant. The sediment at this site was classified as 'very enriched' for both nitrogen and phosphorus, using criteria developed by Robertson and Stevens. Using Robertson and Stevens' criteria a further nine sites, all located in the Hātea River were classified as 'enriched' based on the concentrations of phosphorus found in the sediment. While nutrients are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertilizer, storm water and treated wastewater may exceed the needs of an ecosystem and have adverse effects on the health of the harbour. Potential sources of nutrients in the Whāngārei Harbour include the Whāngārei waste water treatment plant, seepage from the waste water network, runoff from agricultural land and discharges from farm dairy effluent systems.

Sediment metals

Heavy metals can have lethal and sub lethal effects on benthic invertebrates and in a contaminated environment the species diversity and species richness may decrease as the community becomes dominated by a smaller number of more tolerant species, which are able to survive and reproduce in these conditions.

The most contaminated sediment was found in the Hātea River and the Waiharohia Canal, which is consistent with the findings of previous surveys in the harbour. At the Waiharohia Canal the concentrations of copper, lead and nickel all exceeded the ANZECC ISQG-Low trigger values. The elevated levels of metals in the Hātea River and the Waiharohia Canal are likely to come from urban and industrial activities in the catchment.

The survey also found elevated concentrations of nickel and chromium along the northern shoreline of the harbour. The concentration of nickel at Waikaraka was almost double the concentration at the next highest site and exceeded the ANZECC ISQG-Low trigger value, while the concentration of chromium exceeded the threshold effects levels. There are no known point source discharges of nickel or chromium along the northern shoreline of the harbour but there is some evidence that the soils in this area of the catchment may be naturally high in these metals.

Ecological communities

The intertidal habitats surveyed were reasonably varied, including sheltered muddy tidal creek environments, exposed sand flats, exposed sandy beaches, exposed stone and pebble beaches and seagrass beds. Cluster analysis and non-metric multi-dimensional scaling (MDS) ordination of the ecological data, was used to examine the ecological data. Cluster analysis and MDS ordination are visual displays of a species similarity matrix which can help to identify groups of samples. Samples close to each on an MDS plot are more similar to each other. The analysis showed that the intertidal sites could be separated into three main groups. One group consisted of sites located in sheltered tidal creek environments in the upper Harbour, a second group comprised sites generally located on semi-exposed sand flats and mud flats, and a third group comprised sites on exposed sand and pebble beaches.

The subtidal locations sampled were less varied than the intertidal sites, comprising mainly soft sediment habitats with no biogenic structures, shellfish beds or sea grass beds encountered, although these are known to exist in the harbour. MDS and cluster analysis of the subtidal ecological data also separated the subtidal sites into three groups. One group again corresponded to sites located in sheltered locations in the upper Harbour, a second group comprised sites located in the mid harbour and a third group comprised just two sites, Manganese Point and Snake Bank.

Relating ecological communities to sediment data

A distance-based linear model (DISTLM) was used to model the relationship between the ecological data and the sediment data. This found that most of the sediment properties measured in this study had significant relationships to the variation observed in the ecological communities. These results indicate that the physical properties of the sediment and the concentration of metals and nutrients have influenced the ecological communities found in the harbour.

The proportion of mud was the strongest predictor of intertidal ecological community structure and the concentration of copper was the strongest predictor of subtidal community structure. The combination of mud, coarse sand, zinc and chromium was able to explain 40% of the variation in the intertidal community structure, while the combination of copper and coarse sand explained 39% of the variation in the subtidal communities.

1 Introduction

1.1 Background

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

Council subsequently undertook a survey of 25 intertidal and 13 subtidal sites throughout the Whāngārei Harbour in order to provide more spatial information about the sediment quality and ecological status of the harbour to complement the existing data from the four sentinel sites (Griffiths 2011). This survey will provide baseline data to track changes in the health of the estuary over time.

The monitoring methods has been adapted from the Estuary Monitoring Protocol (Robertson *et al* 2002), which was developed by Cawthron for use by Regional Councils, and involves sampling the physical and chemical properties of the sediment, and the ecological communities of representative intertidal habitats. The methods are similar to those used to monitor the ecological communities and sediment quality at Council's existing sentinel sites (Griffiths 2011).

1.2 Study area

1.2.1 The harbour

Whāngārei Harbour is a drowned river valley system located on the east coast of the Northland peninsula. The harbour covers an area of approximately 10,000 ha and includes 5,400 ha of intertidal flats, 1,400 ha of mangroves and 200 ha of saltmarsh (Morrison 2003). The harbour is connected to Bream Bay, a large coastal embayment, via an inlet approximately 2.4 km wide, between Marsden Point and Home Point. The main channel extends inland approximately 24 km in a westerly direction and then divides into two arms, the Hātea River in the north and the Mangapai River in the south.

1.2.2 The catchment

The harbour drains a catchment of 29,507 ha and the land use in the catchment has been heavily modified, with a considerable proportion of the catchment cleared for urban use in the north-west and agricultural land use in the east and south. Catchment analysis using the land use classification from the New Zealand Land Cover Database (LCDB2) indicated that in 2001, 49% (14541 ha) of the catchment was covered by high producing exotic grassland, for cattle and dairy farming, 10% (3006 ha) with plantation forestry, 10% (2933 ha) with urban land uses, and 20% (5903 ha) with indigenous forest (Figure 1 & Appendix 1). The city of Whāngārei, located on the banks of the Hātea River, is the regional capital of Northland and had an estimated population of 51,900 in June 2010 (Statistics New Zealand, 2010).

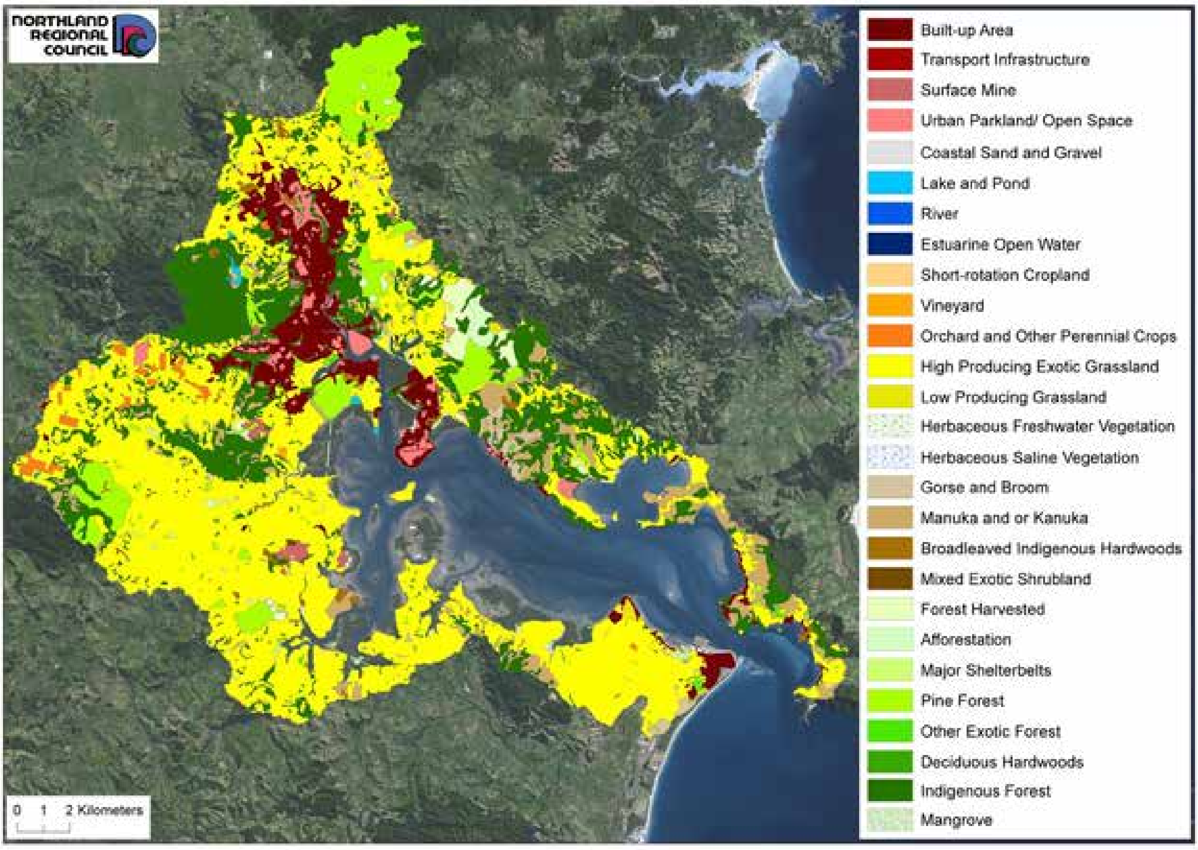


Figure 1. Land use in the Whāngārei Harbour catchment, from the New Zealand Land Cover Database (2001).

1.2.3 Sediment characteristics

Several surveys of surficial sediment have been conducted in the Whāngārei Harbour. Bioresearches (1976) produced a soft sediment map of the lower half of the harbour, which showed shell gravel in the deeper parts of the tidal channels, sand on Snake Bank and McDonalds Bank and out from Takahiwai, with the rest of the area being a mixture of sand, muddy sand and muds. Venus (1984a) provided a general harbour map, modified from Millar (1980), which showed the mid to lower harbour to be mainly fine to medium sands, with some coarser sands in the lower channels, while Parua Bay was composed of muds and sand muds. The upper harbour was a mixture of muddy sand and sandy mud, and a broad arc of sediments next to the cements work.

A more recent survey by Acosta *et al.* (2003) showed higher proportions of mud in the upper Harbour and Parua Bay, with lower proportions of mud in the main channel and towards the harbour entrance. A survey by Council in 2010 also showed higher proportions of mud in the upper harbour with increasing proportions of medium sand and coarse sand towards the harbour entrance (Northland Regional Council unpublished data).

Results from Council's four sentinel sites (2008-2010) showed that the highest proportions of mud were at the site in the Hātea River, followed by the Mangapai River with very low percentages of mud measured at the sites in Portland Channel and Otaika Channel (Griffiths 2011).

1.2.4 Sediment nutrients

There is limited information available about sediment nutrient concentrations in Whāngārei Harbour aside from data collected by Council from the four sentinel sites (Griffiths 2011). This data showed a similar pattern for levels of nitrogen, phosphorus and ash free dry weight, (AFDW) with the highest concentrations recorded at the Hātea River site (Hātea Two in the current study), followed by the

Mangapai River site (Mangapai) and low concentrations recorded at the sites in the Otaika Channel (Otaika Two) and Portland Channel (Portland Two). The ANZECC guidelines do not currently include trigger values for nutrients in marine sediments and there are no nationally accepted guideline values. However, the levels of AFDW, nitrogen and phosphorus in the sediment at the Hātea River and Mangapai River sites were high in comparison to concentrations recorded in similar monitoring programmes elsewhere in New Zealand and were at levels which suggest that these sites were 'enriched', using criteria developed by Robertson and Stevens (2007).

1.2.5 Sediment metals

Sediment metal concentrations in Whāngārei Harbour have been surveyed in 1983 (Venus 1984b), 1985, 1988 (Northland Regional Council 1990), 1990 (Northland Regional Council 2003), 1994, 1997, 1999 (Webster *el al.* 2000), 2002 (Northland Regional Council 2003) and 2010 (Northland Regional Council 2011). These surveys all showed a clear difference between the concentrations of metals in the Hātea River and the lower harbour. Concentrations in the Hātea River were typically 1-2 orders of magnitude higher than those in the lower harbour. Within the Hātea River the most contaminated sediment was generally recorded in the Waiharohia Canal and in the area around the Town Basin Marina in the Upper Hātea River.

In the 1985 and 1988 surveys the concentrations of copper, lead, zinc and chromium in the upper harbour were sufficiently high to cause the sediment to be designated as 'moderately to highly polluted' according to the USEPA sediment classification criteria (Northland Regional Council 1990). In the most recent survey by Council in 2012 the concentration of zinc in the Waiharohia Canal exceeded the ANZECC ISQG-Low trigger value and the concentrations of copper and lead exceeded the threshold effect levels developed by MacDonald *et al*. (1996). The concentrations of copper and zinc also exceeded the threshold effect levels at the Town Basin and Otaika Creek (Northland Regional Council 2011).

Results from Council's four sentinel sites (2008-2010) showed that concentrations of metal contaminants at all four sites were below ANZECC guideline values but concentrations of copper, zinc and lead at the Hātea River site (Hātea Two in the current study) exceeded the threshold effect levels (Griffiths 2011).

1.2.6 Ecology

A number of ecological surveys of Whāngārei Harbour have been conducted since the 1980s although many of these have been limited to either intertidal habitats (Dickie 1984), subtidal habitats (Venus 1984c, Acosta 2003) or specific areas of interest within the Harbour, such as the Hātea River (Bioresearches 1976). A number of other studies have investigated the distribution and abundance of selected species, with much of this work focused on edible shellfish (Venus 1984d, Cryer *et al*. 2003, Williams *et al.* 2009). Two sites in Parua Bay and Takahiwai were also sampled by NIWA as part of a cockle reseeding project (Cummings *et al.* 2008).

Mason and Ritchie (1979) did carry out a comprehensive survey of both intertidal and subtidal habitats. Unfortunately this survey used a larger mesh sieve (2mm) than the present survey (0.5mm) which makes direct comparison with the present survey problematic. More recently Lundquist (2008 unpublished data) surveyed the benthic invertebrates at 42 sites throughout the harbour in 2008. Lundquist identified over 20,000 individuals belonging to 121 taxa. The amphipod Paramoera was the most abundant taxa although most individuals were found at one site on Mair bank. The nut shell *Nucula hartvigiana* the polychaete worms *Aonides trifida*, *Heteromastus filiformis*, *Prionospio aucklandica*, *Syllidae*, the invasive Asian date mussel *Musculista senhousia,* the anemone *Anthropleura aueoradiata* and oligochaete worms were all abundant.

Data from Council's sentinel sites showed that the ecological communities at the four sites were quite distinct (Griffiths 2011). The community at the Hātea River site (Hātea Two in the current survey) included a high number of polychaete worms and small bivalves such as *Arthritica* sp. and the invasive Asian date mussel *Musculista senhousia*, while the community at Mangapai River (Mangapai) was dominated by polychaete worms. At Otaika (Otaika Two) the small bivalve *Nucula hartvigiana*, the polychaete worms *Boccardia (Paraboccardia) syrtis* and *Sphaerosyllis hirsute*, and the wedge shell *Macomona liliana* were numerically important taxa in all three years. At Portland Channel (Portland Two), the wedge shell *Macomona liliana*, the cockle *Austrovenus stutchburyi*, the small bivalve *Nucula hartvigiana* and the polychaete worm Paraonidae sp.#2 were all abundant. The four sentinel sites were re-sampled in this current survey.

Council has mapped the extent of mangrove and saltmarsh habitats in the Whāngārei Harbour. Saltmarsh and mangrove habitat were hand digitalised at a scale of 1:2000 using aerial images from 2004. In 2004 saltmarsh habitat covered 56.1 ha and mangrove forest covered 1587.3 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 Programmes in Whāngārei Harbour, Kerikeri Inlet, Ruakaka Estuary, Whangaroa Harbour and Kaipara Harbour (Griffiths 2011).

2.1.1 Sampling sites

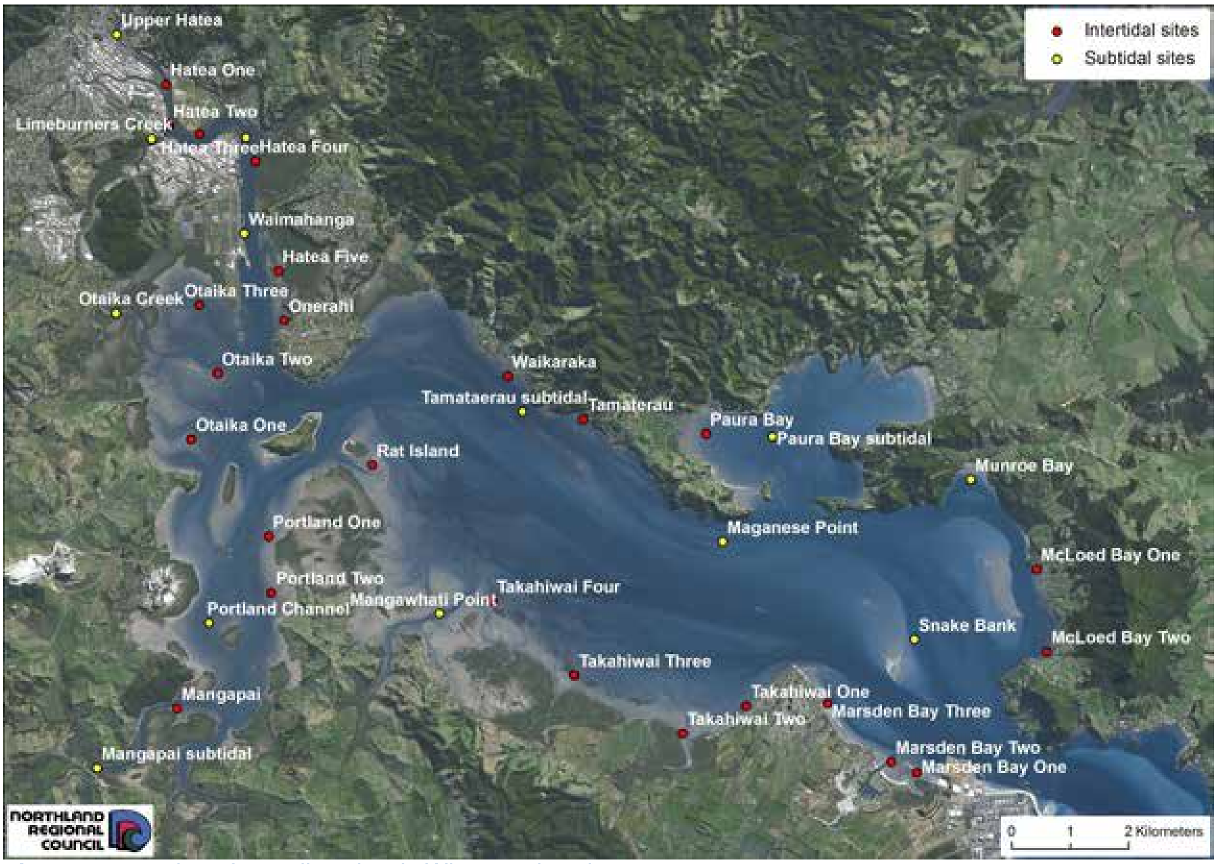


Figure 2. Location of sampling sites in Whāngārei Harbour.

A total of 25 intertidal sites and 16 subtidal sites were sampled in the current survey (ecological samples were only collected from 13 subtidal sites). These included the four sentinel sites that have been monitored in Council's Estuary Monitoring Programme (Griffiths 2011) and 14 sites previously monitored by Council for sediment metal concentrations (Northland Regional Council 2011). The four sentinel sites are Hātea Two, Otaika Two, Portland Two and Mangapai in the current study. 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).

2.1.2 Timing of sampling

Sampling was conducted over eight days during April 2012.

2.1.3 Ecological sampling

At intertidal sites epifauna (animals living on the surface of the sediment) were sampled with a 0.25 m^2 quadrat. Three replicates were made at 15 m intervals along a 30 m transect positioned parallel to the shoreline. All animals observed on the sediment surface were identified and counted. In addition macro-algae or seagrass cover was recorded.

The infauna (animals living buried within the sediment) were sampled using a perspex core (with a diameter of 150 mm and 150 mm deep). Three core samples were collected at each site at 15m intervals along the 30m transect positioned parallel to the shoreline. The core samples were collected adjacent to the quadrat samples.

At subtidal sites the perpex core was used to sample the infauna by free diving. Samples were also collected approximately 15m apart, and where possible parallel to the channel. The epifauna was not surveyed at subtidal sites but observations of any epifauna and the sediment composition were recorded. Unfortunately it was not possible to collected benthic invertebrates samples from Waiharohia Canal, Home Point and Marsden Point. At the Waiharohia Canal the sediment comprised stones and gravel and was so compact it was impossible to penetrate the sediment with the perspex core. The sites at Home Point and Marsden Point were both located in water greater than 10m and it was not possible to collect core samples by free diving.

All core samples were sieved through a 500 µm 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 an external taxonomic expert (Gary Stephenson of Coastal Marine Ecology Consultants).

Individuals identified as belonging to the taxon category Nereidae (unidentified juveniles) were omitted from analysis on the advice of the external taxonomic expert (G. Stephenson 2011 pers. comm.). Fish (Osteicthyes) and insects (Insecta) identified from the samples were also excluded as these animals are not marine benthic invertebrates.

2.1.4 Sediment properties

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

2.2 Statistical analysis

The sediment metal results were assessed against appropriate water quality guidelines ANZECC ISQG-Low Trigger values (Australian New Zealand Environment Conservation Council 2000) and threshold effect levels developed by MacDonald *et al*. (1996). ANZECC guidelines do not include trigger values for TOC, nitrogen or phosphorus 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).

The ecological data were analysed using PRIMER v6.1.12 & PERMANOVA V1.0.2 (Plymouth Marine Laboratory, Plymouth, UK). Four measures of biological diversity were calculated: species richness (s); the total number of individuals (n); the Shannon-Wiener diversity index and Pielou's evenness index (J') for each core sample. Mean values were then calculated for each site. An expression of within-site variability was also calculated by determining the Bray-Curtis similarity between individual site replicates. The biodiversity scores are presented in Appendix 4.

The infauna species abundance data was also examined with cluster analysis and multi-dimensional 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 are more similar to each other. Prior to this analysis the species abundances from the three core samples were combined. A square root transformation was also performed on the benthic infauna abundance data in order to downplay the influence of numerically dominant taxa (Clark and Warwick 2001). 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 at these groupings. The site groupings are overlain on maps of the Harbour. 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 at each 'group'.

A distance-based linear model (DISTLM) was then used to model the relationship between the ecological data and the 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 because most of the concentrations were below or very close to the detection limits.

3. Results

3.1 Sediment physical properties

3.1.1 Intertidal sites

The sediment grain size characteristics of intertidal sites displayed a general pattern of higher mud and fine sand content in the tidal creek environments of the upper harbour, giving way to more medium and coarse sand at higher energy environments towards the harbour entrance (Figure 3).

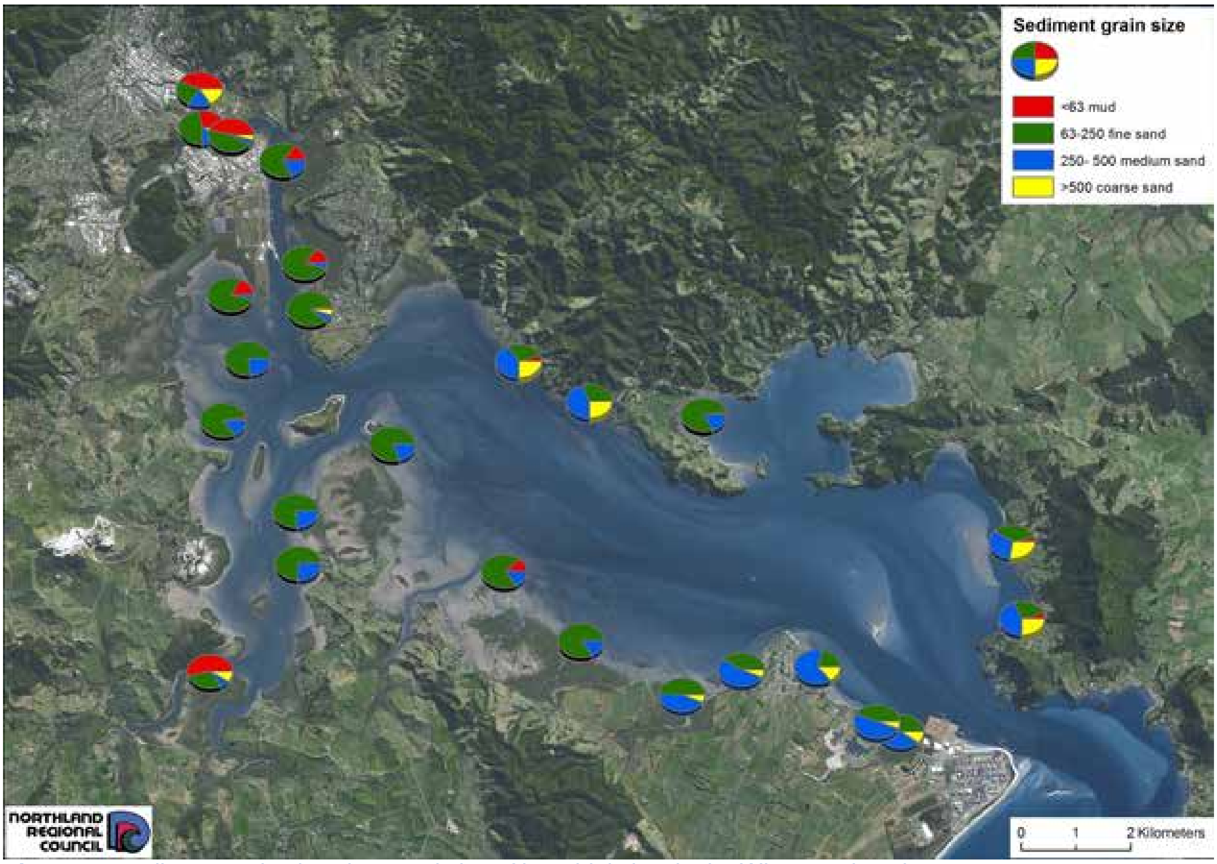


Figure 3. Sediment grain size characteristics of intertidal sites in the Whāngārei Harbour 2012.

3.1.2 Subtidal sites

Sites in in the tidal creek environments of the upper harbour tended to have high proportions of mud and fine sand (Figure 4). However the sediment composition at the Upper Hātea, Waiharohia Canal and Mangapai was quite different. The Upper Hātea and Waiharohia sites comprised mainly coarse sand and at Mangapai the sediment comprised approximately equal proportions of mud, fine sand, medium sand and coarse sand. These sites are located in the centre of narrow tidal creek channels where there is likely to be high tidal and fresh water flow. Sites in the outer harbour tended to comprise mainly medium sand and fine sand. The exception to this was Munro Bay on the northern shore of the harbour which had high proportions of mud and fine sand.

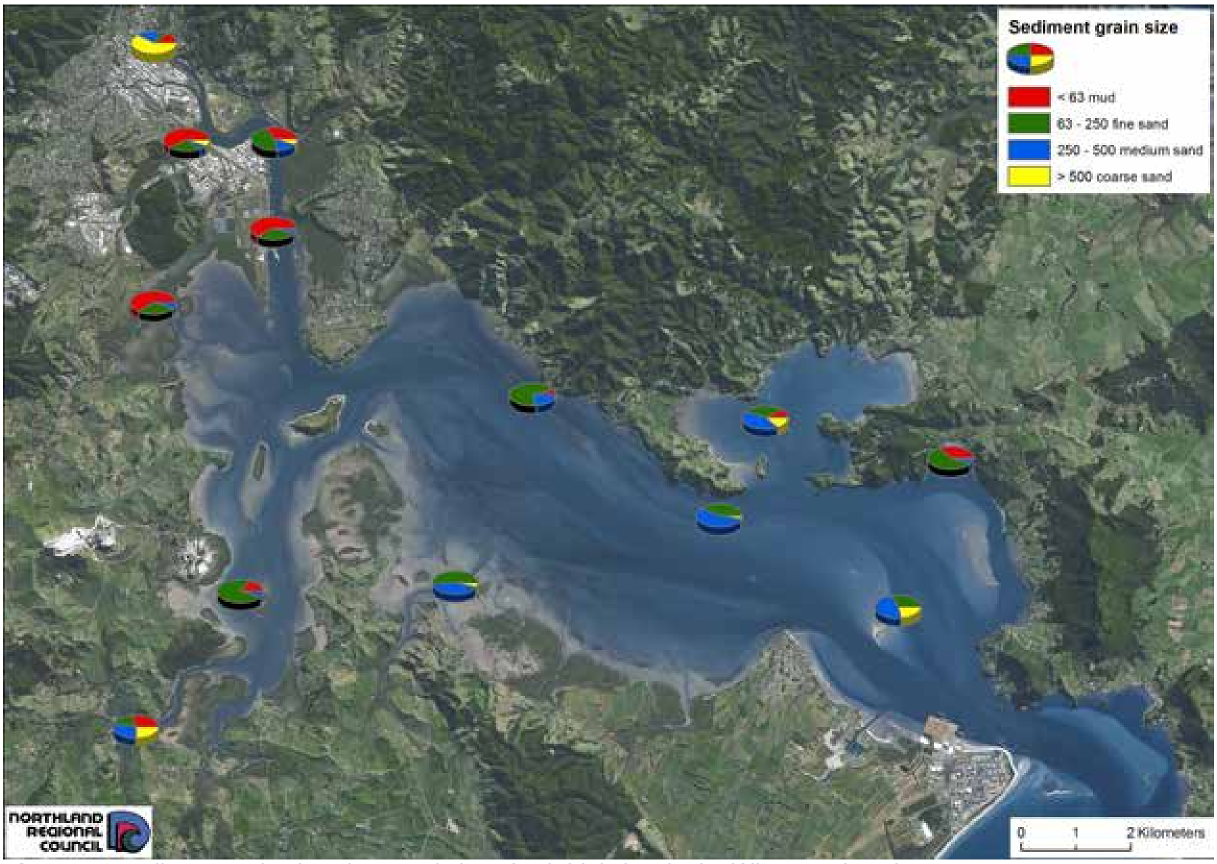


Figure 4. Sediment grain size characteristics of subtidal sites in the Whāngārei Harbour 2012.

3.2 Sediment TOC and nutrient concentrations

3.2.1 TOC

The highest level of TOC was found at Hātea One (6.04 %w/w) (Figure 5). Other sites in the Hātea River, Mangapai River and also at Tamaterau and Takahiwai had high levels of TOC (>2%). The lowest values were recorded at Munro Bay, Manganese Point and Rat Island. ANZECC guidelines do not include trigger values for TOC in marine sediments and there are currently no nationally accepted guideline values. Robertson and Stevens (2007) have developed their own classifications for TOC. In their classification levels below 1% are classified as 'very good', levels between 1-2% are classified as 'low to moderately enriched', levels between 2-5% are classified as 'enriched' and levels above 5% as 'very enriched'. Using these criteria Hātea One was classified as 'very enriched', and eight sites as 'enriched'. 18 sites were 'low to moderately enriched' and 14 were 'very good' (Figure 5).

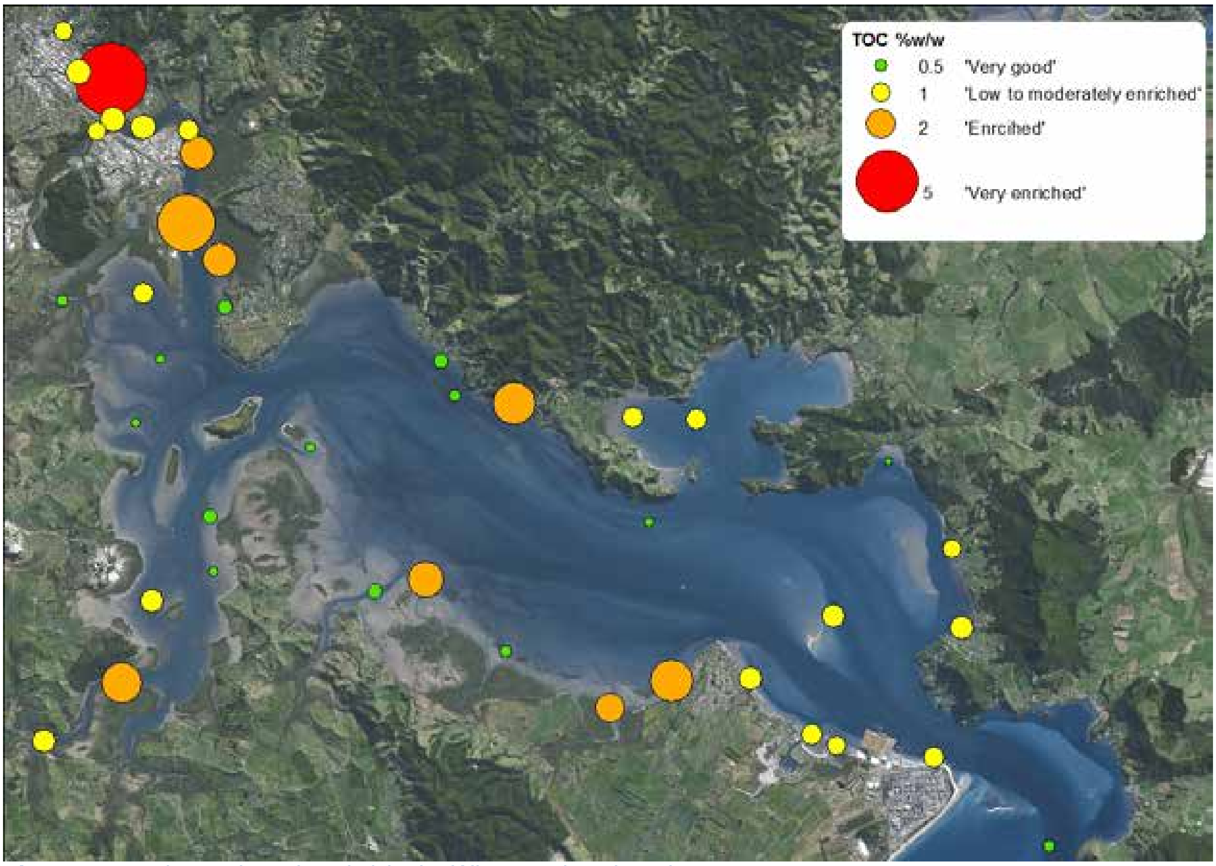


Figure 5. Total organic carbon (%) in the Whāngārei Harbour in 2012.

3.2.2 Total nitrogen

The highest concentration of nitrogen was recorded at Limeburners Creek (Figure 6). The concentration at Limeburners Creek (4900 mg/kg) was more than double the concentration at the next highest site. High concentrations were also found at Hātea two, Hātea Three, Hātea Four, Takahiwai Four and Mangapai (Figure 6). ANZECC guidelines do not include trigger values for nitrogen in marine sediments and there are currently no nationally accepted guideline values. Robertson and Stevens (2007) have developed their own classifications for sediment nitrogen concentrations. In their classification concentrations below 500 mg/kg are classified as 'very good', concentrations between 500-2000 mg/kg are classified as 'low to moderately enriched', concentrations between 2000-4000 mg/kg are classified as 'enriched' and concentrations above 4000 as 'very enriched'. Using the criteria developed by Robertson and Stevens the concentrations of nitrogen at Limeburner's creek was at a level that indicates the sediment is 'very enriched'. Sixteen sites, mostly located in the Hātea River and Mangapai River in the upper harbour were classified as 'low to moderately enriched' with the remaining 24 sites classified as 'very good'.

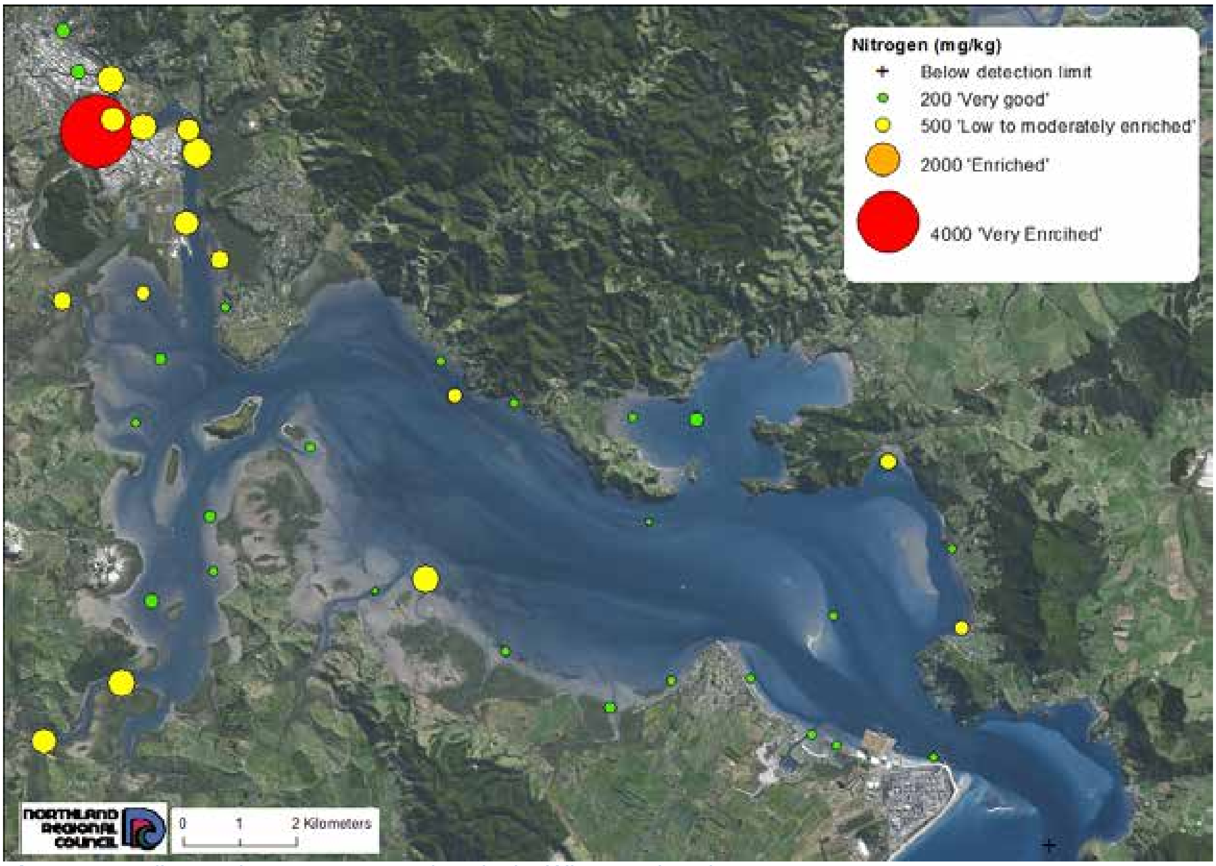


Figure 6. Sediment nitrogen concentrations in the Whāngārei Harbour 2012.

3.2.3 Total phosphorus

The highest concentration of phosphorus was also recorded at Limeburners Creek (Figure 7). High concentrations were also found at the Upper Hātea, Waimahanga, Hātea One, Otaika Three and Waiharohia Canal. The lowest concentrations were found at Mangawhati Point, Marsden Bay and Home Point. ANZECC guidelines do not include trigger values for phosphorus in sediments and there are currently no nationally accepted guideline values for phosphorus in marine sediment but Robertson and Stevens (2007) have also developed a classification for sediment phosphorus concentrations. In their classification concentrations below 200 mg/kg are classified as 'very good', concentrations between 200-500 mg/kg are classified as 'low to moderately enriched', concentrations between 500-1000 mg/kg are classified as 'enriched' and concentrations above 1000 as 'very enriched'. Under this classification the concentration of phosphorus at Limeburner's Creek was at a level which indicates that the sediment was 'very enriched'. Nine sites, all located in the Hātea River were classified as 'enriched', 14 sites as 'low to moderately enriched' and 17 sites, all located in the outer harbour, as 'very good' (Figure 7).

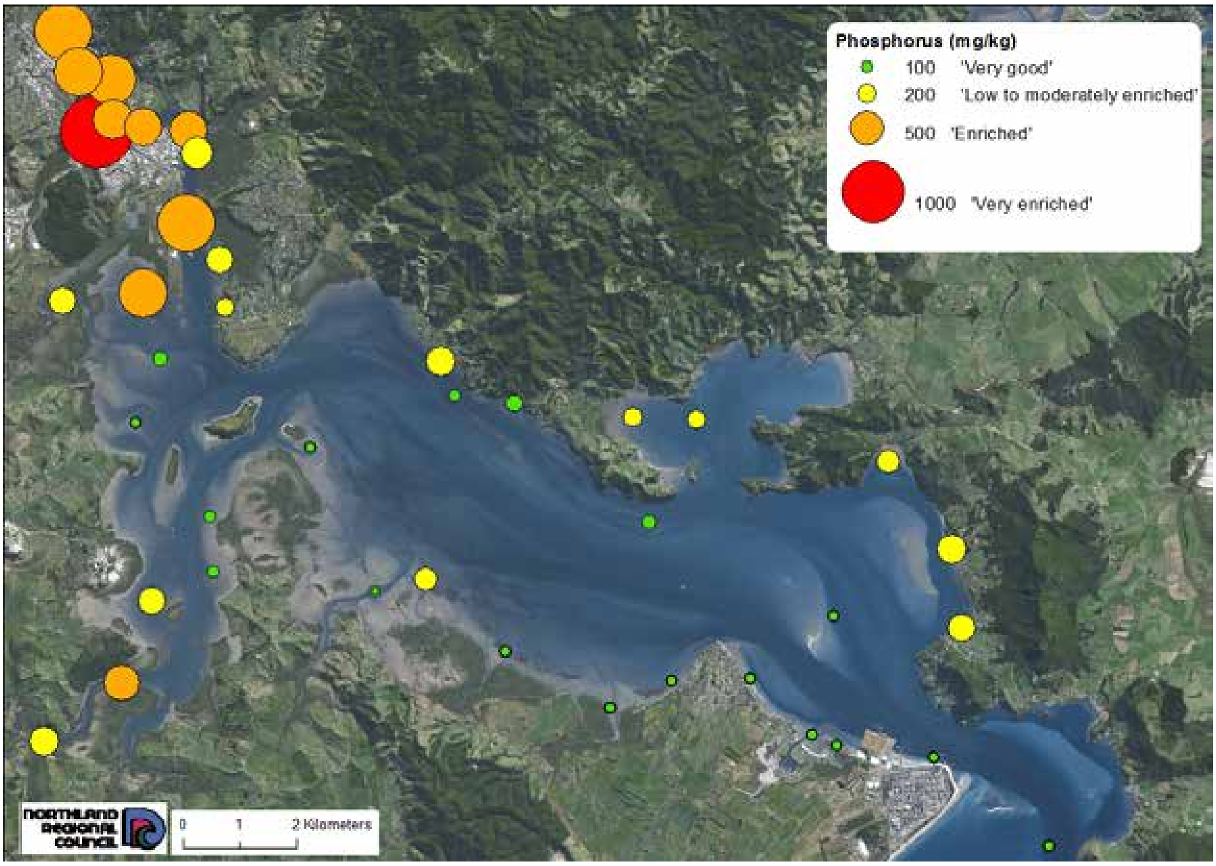


Figure 7. Sediment phosphorus concentrations in the Whāngārei Harbour in 2012.

3.3 Sediment metal concentrations

3.3.1 Cadmium

The highest concentrations of cadmium were recorded in the Hātea River with the lowest concentrations generally recorded towards the entrance of the Harbour and along the southern shore of the Harbour (Figure 8). All of the cadmium concentrations were below the ANZECC ISQG-Low effect trigger value of 1.5 mg/kg and the threshold effect level of 0.68 mg/kg developed by MacDonald *et al*. (1996). The cadmium concentrations at 35 of the 41 sites were below the laboratory detection limit (<0.1 mg/kg).

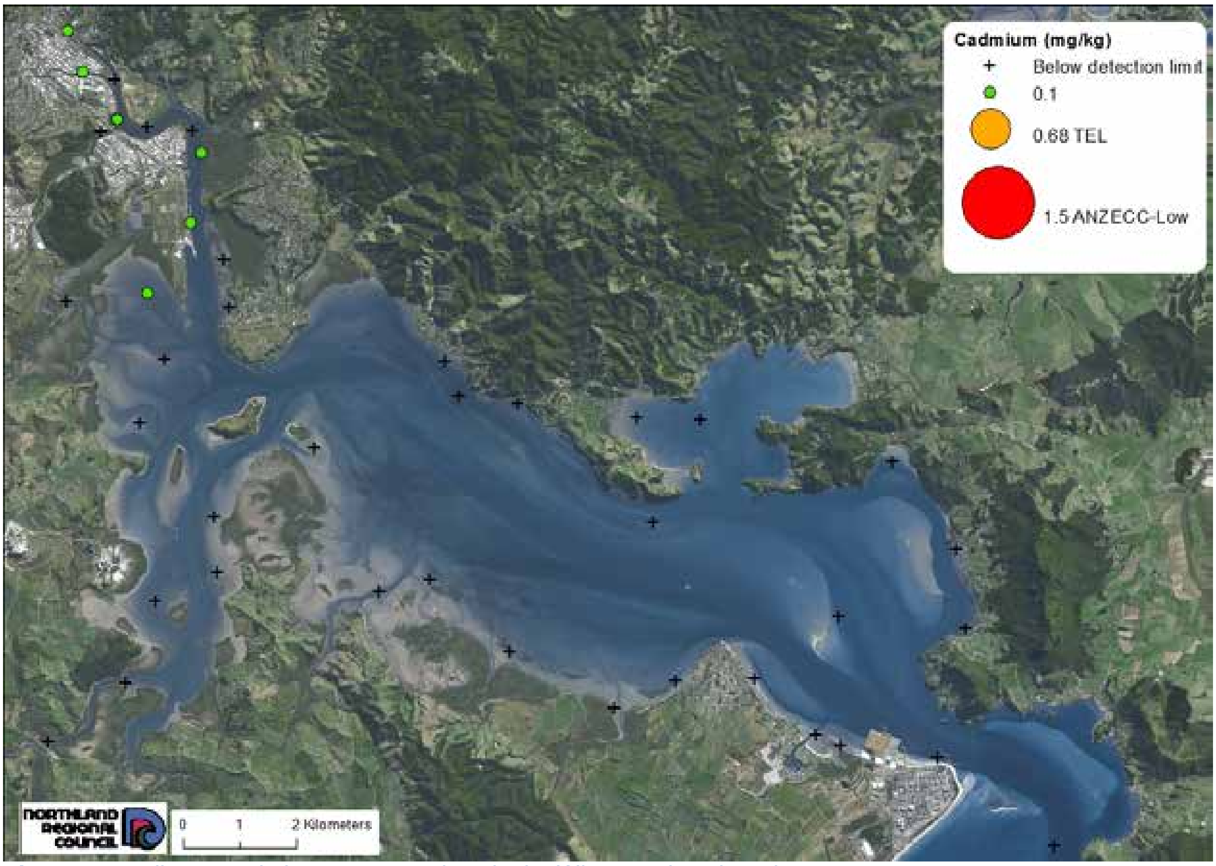


Figure 8. Sediment cadmium concentrations in the Whāngārei Harbour in 2012.

3.3.2 Chromium

The highest concentrations of chromium were recorded along the northern shoreline of the harbour at Waikaraka and McLeod Bay with the lowest concentrations generally recorded along the southern shore of the Harbour (Figure 9). All of the chromium concentrations were below the ANZECC ISQG - Low effect trigger value of 80 mg/kg but the concentration at Waikaraka (57 mg/kg) exceeded the threshold effect level of 52.3 mg/kg developed by MacDonald *et al*. (1996).

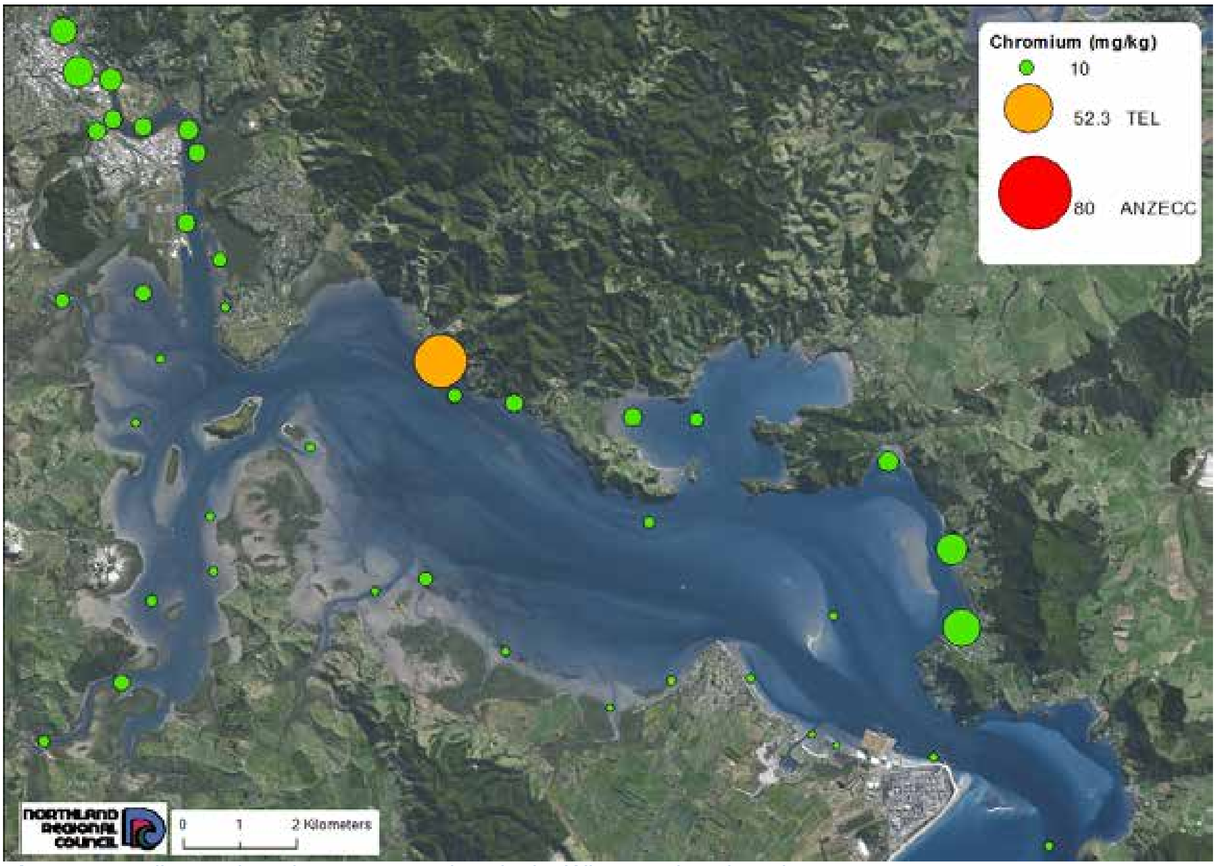


Figure 9. Sediment chromium concentrations in the Whāngārei Harbour in 2012.

3.3.3 Copper

The highest concentrations of copper were generally found at sites in the Hātea River with the lowest concentrations towards the entrance of the Harbour and along the southern shore of the Harbour (Figure 10). The highest concentration was recorded at the Waiharohia Canal (79 mg/kg), which was more than double the concentration at the next highest site and exceeded the ANZECC ISQG-Low trigger value of 65 mg/kg. No other sites exceeded the ANZECC ISQG-Low trigger value but seven sites (Upper Hātea, Hātea One, Hātea Three, Limeburner's Creek, Hātea Two, Awaroa Creek and Hātea Four) exceeded the threshold effect level of 18.7 mg/kg developed by MacDonald *et al*. (1996). The lowest concentrations were recorded towards the Harbour entrance and 11 sites had concentrations below the laboratory detection limit (<0.5 mg/kg).

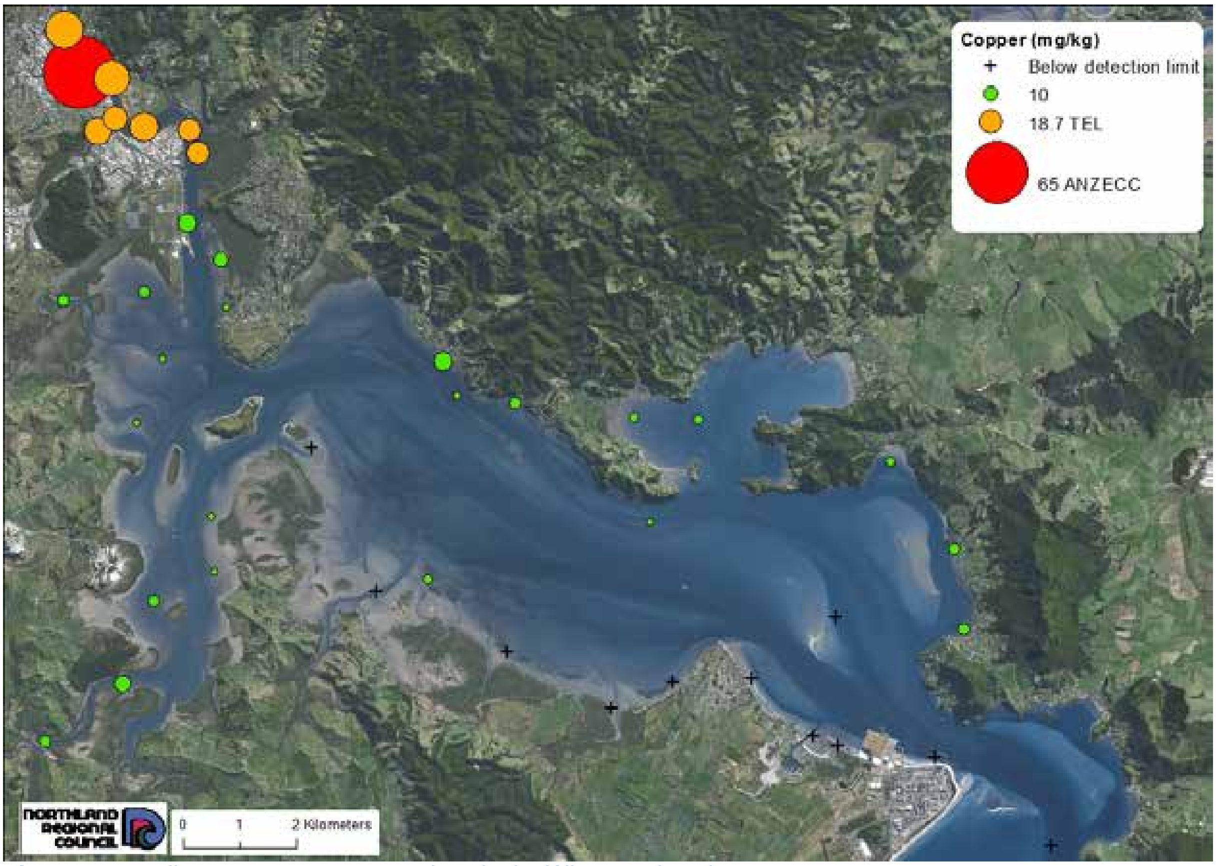


Figure 10. Sediment copper concentrations in the Whāngārei Harbour 2012.

3.3.4 Nickel

The highest concentrations of nickel were recorded along the northern shore of the Harbour at Waikaraka and McLeod Bay with elevated concentrations also found at sites in the Hātea River and Mangapai River. The lowest concentrations were generally recorded towards the entrance of the Harbour and along the southern shore of the Harbour (Figure 11). The highest nickel concentrations were recorded at Waikaraka (30 mg/kg), which was almost double the concentration at the next highest site and exceeded the ANZECC ISQG low effect trigger value of 21 mg/kg. No other sites exceeded the ANZECC ISQG-Low effect trigger but the concentration of nickel at the Waiharohia Canal exceeded the threshold effect level of 15.9 mg/kg developed by MacDonald *et al*. (1996).

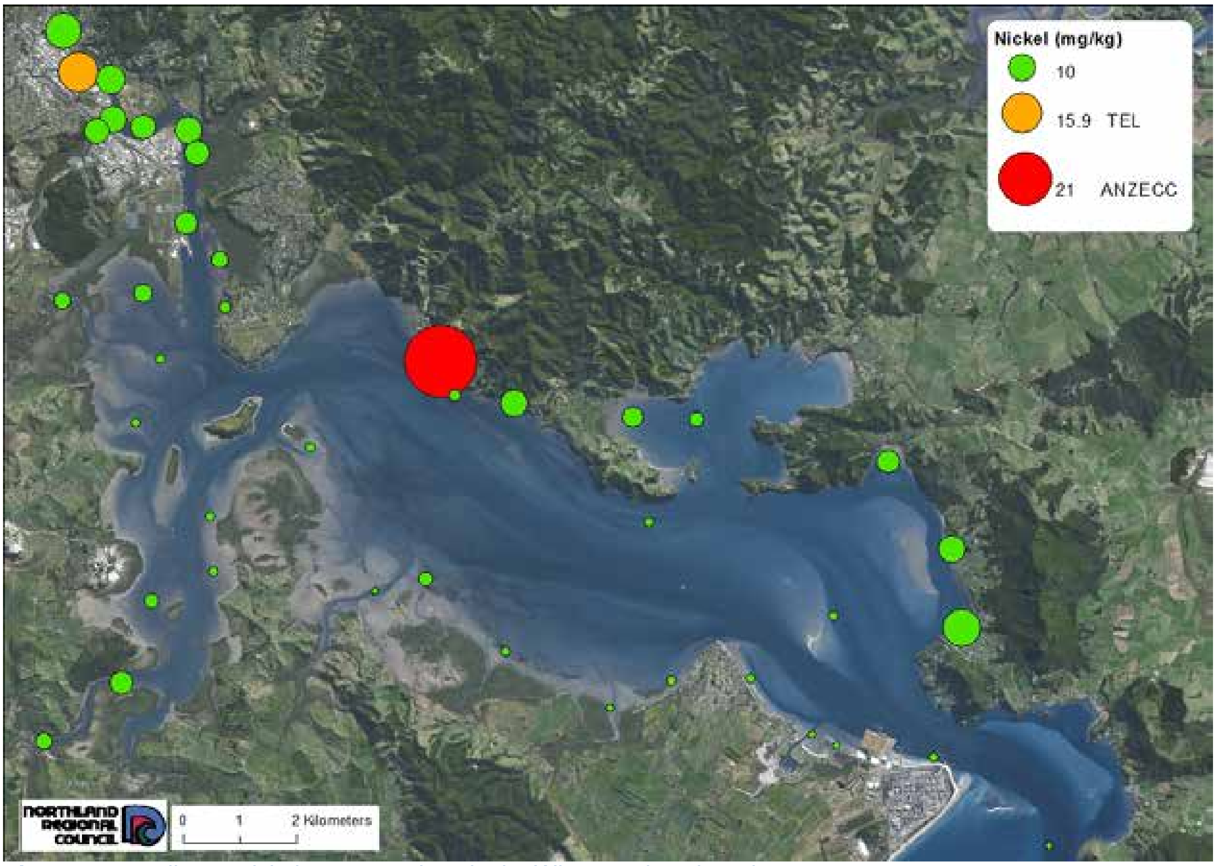


Figure 11. Sediment nickel concentrations in the Whāngārei Harbour in 2012.

3.3.5 Lead

The highest concentrations of lead were recorded at sites in the Hātea River and Mangapai River while the lowest concentrations were generally recorded towards the entrance of the Harbour and along the southern shore of the Harbour (Figure 12). The highest concentration of lead was recorded at the Waiharohia Canal (51 mg/kg) and this exceeded the ANZECC ISQG-Low trigger value of 50 mg/kg. No other sites exceeded the ANZECC ISQG low effect trigger but the concentration of lead at the Upper Hātea exceeded the threshold effect level of 30.2 mg/kg developed by MacDonald *et al*. (1996).

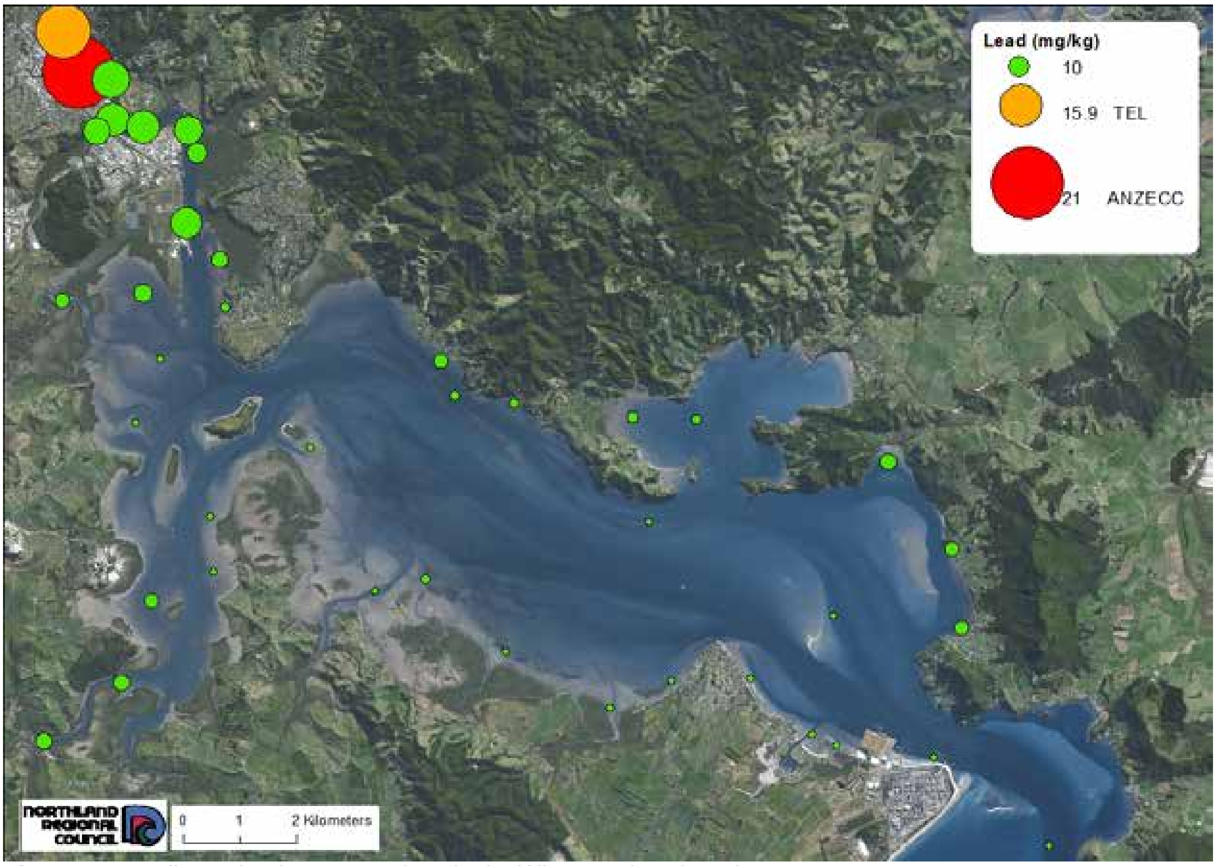


Figure 12. Sediment lead concentrations in the Whāngārei Harbour in 2012.

3.3.6 Zinc

The highest concentrations of zinc were recorded at sites in the Hātea River, with the lowest concentrations generally recorded towards the entrance of the Harbour and along the southern shore of the Harbour. All the zinc concentrations were below the ANZECC ISQG-Low effect trigger value of 200 mg/kg but five sites in the Hātea River (Upper Hātea, Waiharohia Canal, Hātea One, Hātea Two and Hātea Three) exceeded the threshold effect level of 124 mg/kg developed by MacDonald *et al*. (1996). Eleven sites had concentrations below the laboratory detection limit (<7.5 mg/kg).

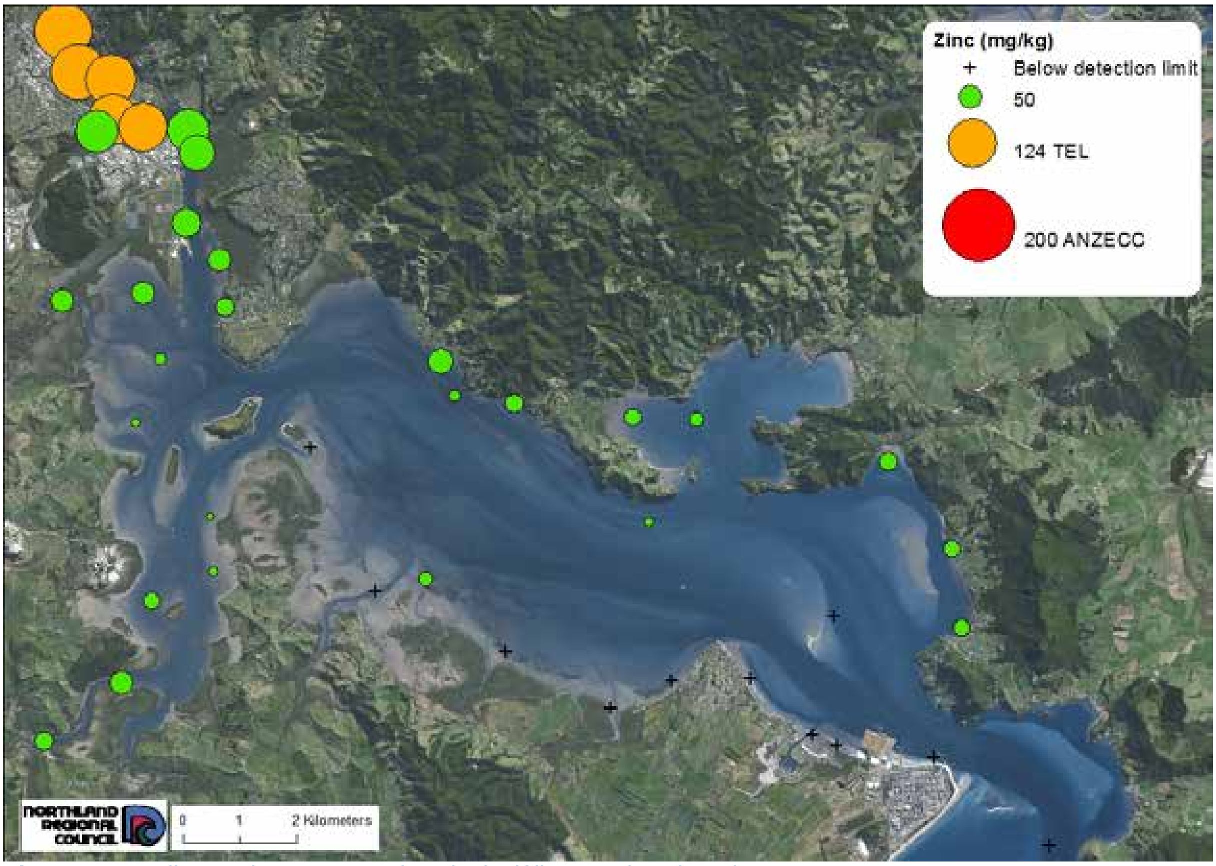


Figure 13. Sediment zinc concentrations in the Whāngārei Harbour in 2012.

3.4 Ecology

3.4.1 Intertidal ecology

The Hātea River

The Hātea River is flanked by sheltered mud flats and fringing mangrove stands (Figure 14a). The five intertidal sites in the Hātea River (Hātea One – Hātea Five), were located on mud flats, with very soft muddy sediment. The sediment surface at these sites tended to be uneven and mottled with numerous burrows visible on the surface (Figure 14b). Sediment analysis indicated that these sites comprised mainly fine sand and mud (Figure 3).

a) b)

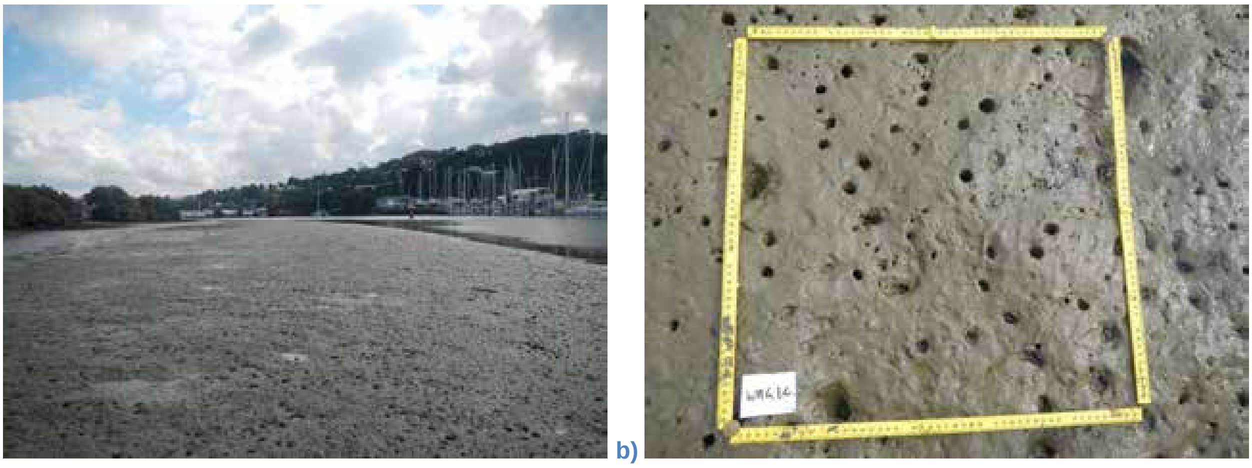


Figure 14: a) Intertidal mud flat in the Hātea River (Hātea One), and b) Sediment consisting of soft mud with numerous burrows visible on the surface.

Epifauna

No animals were observed in any of the quadrats at these five sites.

Infauna

Polychaete and oligochaete worms dominated the communities at all five sites in the Hātea River accounting for 78% of all the individuals identified at these sites. Four taxa - the polychaete worms *Boccardia (Paraboccardia) syrtis*, *Prionospio yuriel*, Capitella sp.#1 and oligochaete worms were particularly abundant and accounted for more than half of all individuals at these five sites.

At Hātea One, 274 individuals belonging to 21 taxa were found. The most abundant taxa were oligochaete worms (51 individuals), the small bivalve Arthritica sp., the crustacean copepod sp.1 (40) and the polychaete worms *Scolecolepides benhami*, Capitella sp.#1 and *Boccardia (Paraboccardia).*

At Hātea Two, 271 individuals belonging to 25 taxa were identified. The polychaete worms Paraonidae sp.#2 and sp.#1, Capitella sp.#1, the invasive bivalve *Musculista senhousia* and oligochaete worms and were abundant and ubiquitous.

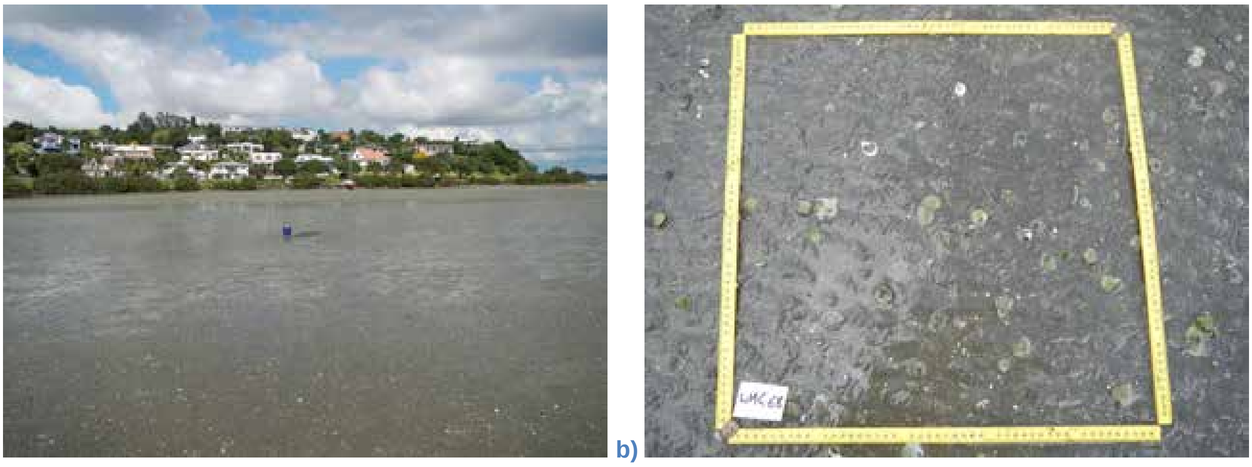
At Hātea Three, 792 individuals from 22 taxa were identified. The polychaete worm *Boccardia (Paraboccardia) syrtis* was numerically dominant with 450 individuals found. The polychaete worms *Capitella* sp.#1, *Prionospio yuriel, Polydora* sp.#1, the invasive Asian date mussel *Musculista senhousia* and oligochaete worms were also abundant.

At Hātea Four, 381 individuals belonging to 21 taxa were found, with polychaete and oligochaete worms accounting for over 90% of all individuals. The polychaete worms *Prionospio yuriel*, *Heteromastus filiformis* and the oligochaete worms were the most abundant taxa.

At Hātea Five, 148 individuals belonging to 22 different taxa were found. The community at Hātea Five appeared to differ most to the other sites in the Hātea River with polychaete and oligochaete worms accounting for only 51% of the individuals at this site. The mud snail *Amphibola crenata was the most abundant taxa with* the polychaete worms *Polydora* sp.#1and *Heteromastus filiformis* also abundant.

Onerahi

The site at Onerahi was located on a gentle sloping sand flat, which is exposed to the prevailing south westerly winds (Figure 15). The surface was firm with very small sand ripples visible and the sediment comprised mainly fine sand (~90%) with some shell fragments (Figure 3).



a) b)

Figure 15: a) Intertidal sand flat at Onerahi, and b) Firm sand and shells visible on the surface.

a) b)

Figure 16: a) The top shell *Diloma subrostrata*, and b) The horn snail *Zeacumantus lutulentus*.

Epifauna

In the three quadrats surveyed at Onerahi 78 individuals belonging to eight taxa were found. The most abundant taxa were the marine snails *Diloma subrostrata* (Figure 16a), *Zeacumantus lutulentus* (Figure 16b) and the limpet *Notoacmea helmsi*.

Infauna

At Onerahi 136 individuals belonging to 21 taxa were identified. The ecological community at Onerahi was very different to the intertidal sites in the Hātea River. In contrast to the sites in the Hātea River no oligochaete worms were found, polychaete worms accounted for just 39% of individuals and bivalves were more abundant accounting for 34% of individuals. The polychaete worm *Scoloplos cylindrifer,* the wedge shell *Macomona liliana* and the cockle *Austrovenus stutchburyi,* were the most abundant taxa.

Waikaraka - Tameterau

The intertidal shore of the northern Harbour from the Onerahi peninsula to Manganese Point is also exposed to the prevailing south westerly winds and is characterised by firm sand and stony substrata (Figure 17 & 18). The Intertidal shoreline at Waikaraka was characterised by firm sand and stones, while the site at Tamaterau was firm sand with relatively few stones (Figure 18). The sediment at both sites comprised roughly equal proportions of fine sand, medium sand and coarse sand, with shell and rock fragments recorded in both samples.

a)  b) 

Figure 17: a) Intertidal shoreline at Waikaraka characterised by firm sand pebbles and stones and b) Firm sand flat at Tamaterau.

Epifauna

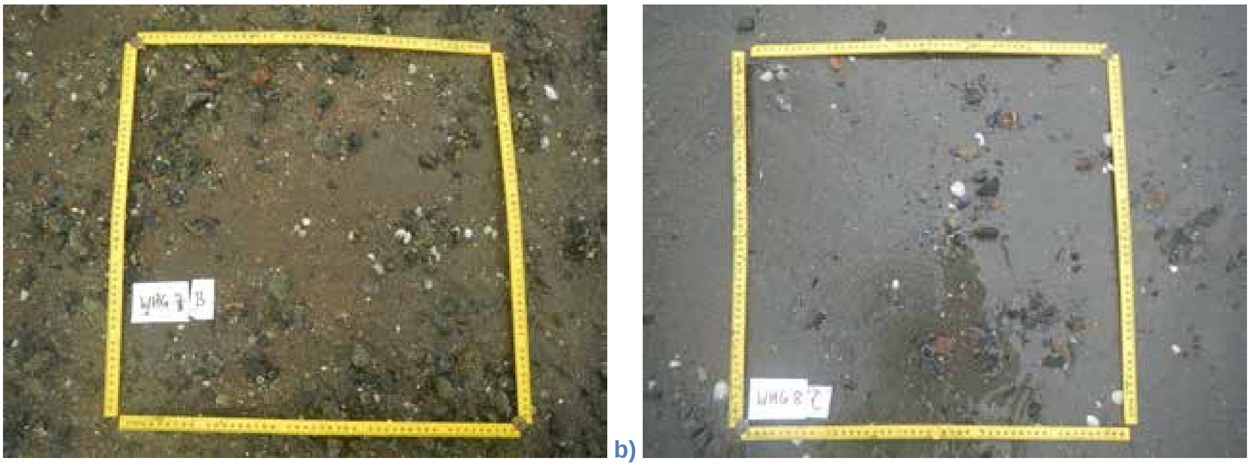
244 individuals belonging to 10 taxa were found at Waikaraka. The most abundant taxon was the barnacle *Austrominius modestus*, followed by the marine snails *Diloma subrostrata, Nassarius (Plicarcularia) burchardi* and *turbo smaragdus*.

44 individuals belonging to three taxa were found at Tamaterau but the barnacle *Austrominius modestus* (37 individuals) accounted for most of the animals found. The limpet *Notoacmea helmsi* was the next most abundant animal.

Infauna

At Waikaraka, 501 individuals belonging to 26 taxa were identified. Crustaceans and bivalves were the most abundant groups with very few polychaete and oligochaete worms found. The barnacle *Austrominius modestus* the nut shell *Nucula hartvigiana* and the cockle *Austrovenus stutchburyi* were the most abundant taxa.

At Tamaterau, 324 individuals belonging to 23 taxa were found. Polychaete worms were more abundant than at Waikaraka reflecting a shift from hard shore species to more soft sediment taxa. Large bodied bivalves were again abundant but fewer crustaceans were found at Tamaterau compared to Waikaraka. The polychaete worms *Aonides* sp.#1 and *Heteromastus filiformis*, the cockle *Austrovenus stutchburyi,* the pipi *Paphies australis* and the isopod Paravireia *sp.#1* were all abundant and ubiquitous.



a) b)

Figure 18: a) Sediment at Waikaraka consisted of a mixture of firm sand and stones, and b) Firm sand at Tamaterau.

Parua Bay

Parua Bay is a sheltered embayment on the northern shore of the Harbour. It is characterised by a series of bays with gentle sloping sand and mud flats dissected by rocky outcrops and headlands. The site in Parua Bay was sampled by snorkel and field observations indicated that the surface was even and characterised by fine sand. Grain size analysis showed that the surface sediment comprised mainly fine sand (~80%) and medium sand (~20%) (Figure 3).

Epifauna

Parua Bay was sampled by snorkel so no quadrats were surveyed.

Infauna

138 individuals belonging to 22 taxa were identified from the three cores at Parua Bay. The most abundant taxa were the nut shell *Nucula hartvigiana* and the Nemertean worm Nemertea sp.#3 with the remaining taxa found in small numbers.

McLeod’s Bay

McLeod’s Bay has a gently sloping intertidal shoreline exposed to the prevailing south westerly winds (Figure 19). The northern site (McLeod Bay One) comprised firm sand, while the southern site (McLeod Bay Two) comprised firm sand, stones and shell hash (Figure 20). Sediment analysis indicated that both sites comprised roughly equal proportions of firm sand, medium sand and coarse sand, with shell and rock fragments recorded in both samples (Figure 3).

a)  b) 

Figure 19: a) McLeod Bay and b) Firm sand, stones and shell hash at McLeod Bay Two.

Epifauna

32 individuals belonging to eight taxa were found at McLeod Bay One (Figure 20a). The most abundant taxon was the barnacle *Austrominius modestus*, followed by the marine snails *Diloma subrostrata* and the invasive whelk *Nassarius (Plicarcularia) burchardi*.

At McLeod Bay Two, 56 individuals belonging to eight taxa were identified. The cockle *Austrovenus stutchburyi* was the most abundant taxa followed by the barnacle *Austrominius modestus and* the marine snail *Zeacumantus lutulentus*.

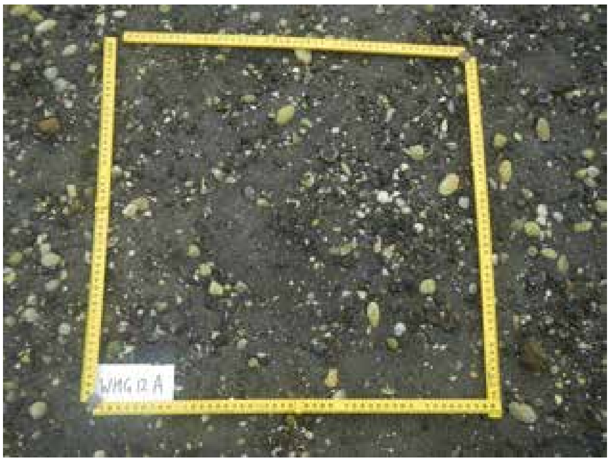
a)  b) 

Figure 20: a) Small sand ripples at McLeod Bay One and b) Firm sand, stones and shells hash at McLeod Bay Two.

Infauna

At McLeod Bay One, 835 individuals belonging to 32 different taxa were found. Polychaete worms (40% of all individuals), crustaceans (31%) and bivalves (18%) were the most abundant taxonomic groups. The seed shrimp Ostracoda sp.#8 and the polychaete worm Syllidae sp.#2 were the two most abundant taxa, with the nut shell *Nucula hartvigiana*, the polychaete worms *Prionospio aucklandica* , the cockle *Austrovenus stutchburyi,* the anemone *Anthopleura aureoradiata* the nemertean worm Nemertea sp.#3 and the wedge shell *Macomona liliana* all abundant and ubiquitous.

At McLeod Bay Two, 513 individuals belonging to 31 taxa were found. Polychaete worms (39% of all individuals), bivalves (13%) and crustacean (38%) were again the main groups found. The isopod Paravireia sp.#1 and the polychaete worm *Prionospio aucklandica* were the most abundant taxa, with the cockle *Austrovenus stutchburyi*, the polychaete worms Aonides sp.#1 and *Heteromastus filiformis*, and the hooded shrimp *Colurostylis lemurum* also abundant and ubiquitous.

Marsden Bay

A gentle sloping sandy shoreline extends from Northport to One Tree Point (Figure 21). Three sites were located along the Bay. Sediment analysis indicated that the sediment from the three sites comprised >50% coarse sand, 30-40% fine sand and 10% coarse sand (Figure 3).

a)  b) 

Figure 21: a) Gentle sloping sand at Marsden Bay Three and b) Sand ripples at Marsden Bay One.

Epifauna

Only one horn shell *Zeacumantus lutulentus* and one mud whelk *Cominella glandiformis* were found at Marsden Bay One. Marsden Bay Two was sampled by snorkelling so no quadrats were sampled. Only one top shell, *Diloma subrostrata* was found at Marsden Bay Three.

Infauna

At Marsden Bay One, 356 individuals belonging to 15 taxa were found. The ecological community was dominated by crustaceans, which accounted for 70% of individuals. The crustaceans Amphipoda sp.#5, Exosphaeroma sp.#1 and *Colurostylis lemurum* were the most abundant taxa with the pipi *Paphies australis* and the nut shell *Nucula hartvigiana* also abundant and ubiquitous.

Marsden Bay Two and Marsden Bay Three appeared to have very similar communities, with polychaete worms and bivalves the most abundant taxonomic groups. Just three taxa (the polychaete worm *Prionospio aucklandica*, the cockle *Austrovenus stutchburyi* and the anemone *Anthopleura aureoradiata*) accounted for 66% of all individuals at both these sites.

At Marsden Bay Two, 481 individuals belonging to 16 taxa were found. The most abundant taxa were the cockle *Austrovenus stutchburyi* and the polychaete worm *Prionospio aucklandica*, with the anemone *Anthopleura aureoradiata*, the nut shell *Nucula hartvigiana* and the crustacean Amphipoda sp.#2 also abundant and ubiquitous.

Marsden Bay Three, 182 individuals belonging to 17 taxa were found. The most abundant taxa were the polychaete worms *Prionospio aucklandica,* the pipi *Paphies australis,* the nut shell *Nucula hartvigiana* and the anemone *Anthopleura aureoradiata.*

Takahiwai

Extensive tidal flats extend along the foreshore at Takahiwai on the southern shore of the harbour (Figure 22a). Four sites were located along this tidal flats with three sites located among seagrass beds (Figure 22 b). The other site (Takahiwai Two) was located on bare sand near to the mouth of the Takahiwai Creek. Sediment at the two eastern sites (Takahiwai One and Takahiwai Two) comprised approximately equal proportions of fine sand and medium sand (~45%) with a small portion of coarse sand (~5%). Coarse sand was absent from the two western sites (Takahiwai Three & Four) with the sediment at these site mainly comprising fine sand (~80%).

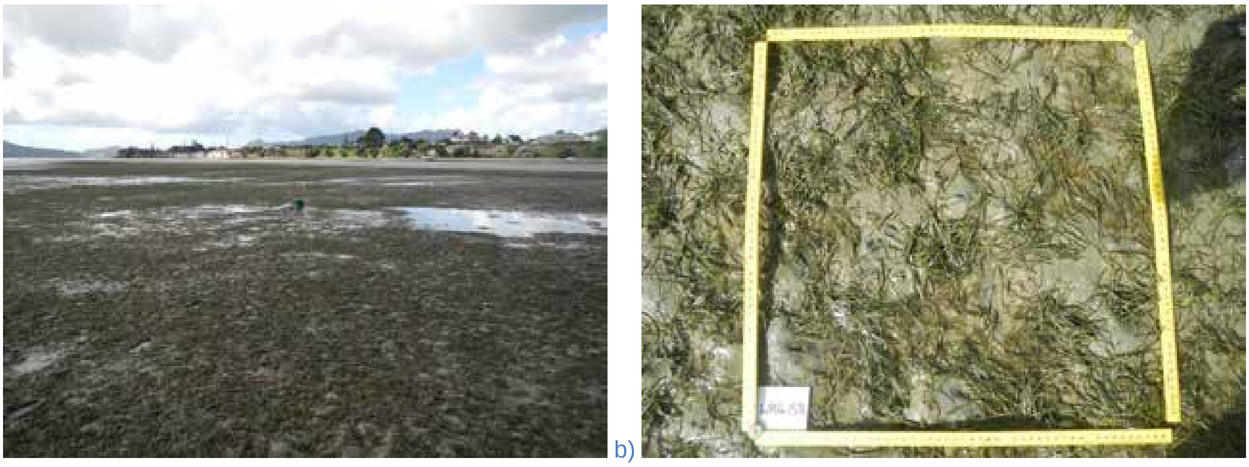
a) b)


Figure 22: a) Extensive tidal flats and sea grass beds at Takahiwai and b) Sea grass at Takahiwai.

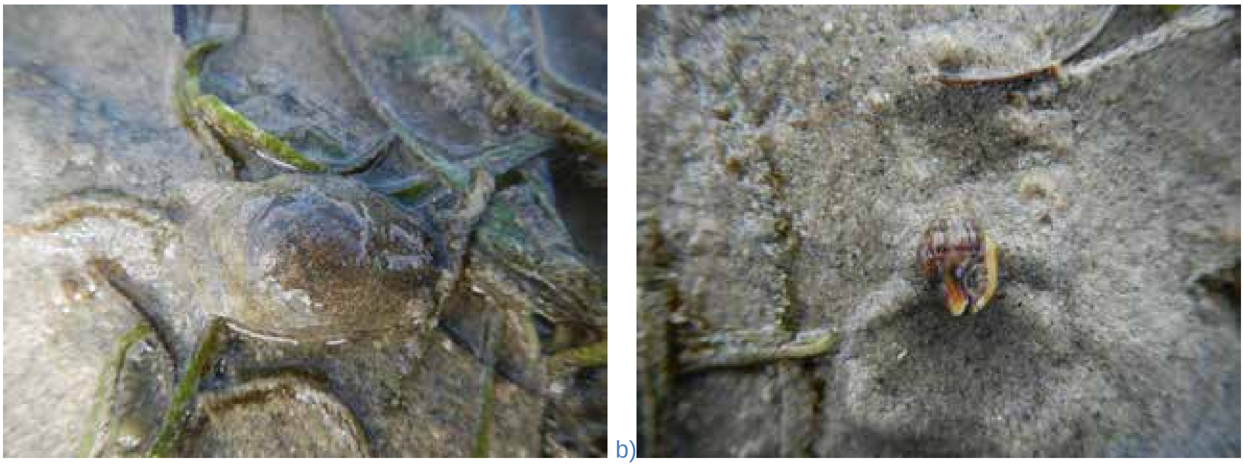
a) b)


Figure 23: a) The bubble snail *Haminoea zelandiae* and b) The invasive whelk *Nassarius (Plicarcularia) burchardi*.

Infauna

The bubble snail *Haminoea zelandiae* was found at both Takahiwai One and Takahiwai Three (Figure 23 a). The invasive snail *Nassarius (Plicarcularia) burchardi* was also found at Takahiwai One (Figure 23b). Takahiwai Two and Takahiwai Four were sampled by snorkelling so no quadrats were sampled.

Infauna

The species composition of the three sites located within seagrass beds (Takahiwai One, Takahiwai Three and Takahiwai Four) were very similar, with bivalves, polychaete worms and crustaceans all well represented.

At Takahiwai One, 710 individuals were identified from 42 taxa. The most abundant taxon was the nut shell *Nucula hartvigiana*, followed by the polychaete worms *Boccardia (Paraboccardia) syrtis* , Syllidae sp.#2 and *Prionospio aucklandica* and the crustaceans Ostracoda sp.#8 and Amphipoda sp.#1 and Ostracoda sp.#1.

At Takahiwai Three, 692 individuals belonging to 41 taxa were identified. The most abundant taxon was the seed shrimp Ostracoda sp.#8 followed by the nut shell *Nucula hartvigiana*. The crustaceans

Phoxocephalidae sp.#2, Tanaidacea sp.#1 and Ostracoda sp.#1, the bivalve *Arthritica* sp.#1 and the polychaete *Boccardia (Paraboccardia) syrtis* and Syllidae sp.#2.

At Takahiwai four 476 individuals from 39 taxa were found. The most abundant taxon was the seed shrimp Ostracoda sp.#8 followed by the polychaete *Heteromastus filiformis*, the nut shell *Nucula hartvigiana,* the polychaete worms Syllidae sp.#2, Terebellidae sp.#1, *Prionospio aucklandica and Boccardia (Paraboccardia) syrtis*, and the crustacean Phoxocephalidae sp.#2.

At Takahiwai Two 565 individuals were found from 19 taxa. The two most abundant taxa were the polychaete worm *Prionospio aucklandica* and the nut shell *Nucula hartvigiana*, which were also abundant at the other three Takahiwai sites. But the next most abundant taxa, the crustacean Amphipoda sp.#2, the anemone *Anthopleura aureoradiata*, the cockle *Austrovenus stutchburyi* and the wedge shell *Macomona liliana* were either absent or rare at the other sites in Takahiwai.

Rat Island

The site at Rat Island was located beyond Skull Creek near a tidal channel. The surface was firm with very small sand ripples visible and the sediment comprised mainly fine sand (80%) with some medium sand (20%) (Figure 3).

Epifuana

96 *Anthopleura aureoradiata,* two cockles *Austrovenus stutchburyi* and one limpet *Notoacmea helmsi* were found in the three quadrats at Rat Island.

Infauna

Species richness and the number of individuals found at Rat Island were low compared to the other sites surveyed, with just 82 individuals belonging to 12 taxa identified. The community was dominated by the nut shell *Nucula hartvigiana*, the wedge shell *Macomona liliana* and the hooded shrimp *Colurostylis lemurum*.

Portland

The Portland Channel is bordered by fringing mangrove forest and gently sloping extensive sand and mud flats (Figure 24a). Two sites were located on the eastern side of the Channel. The sediment at both sites comprised approximately 75% fine sand and 25% medium sand (Figure 3).

a)

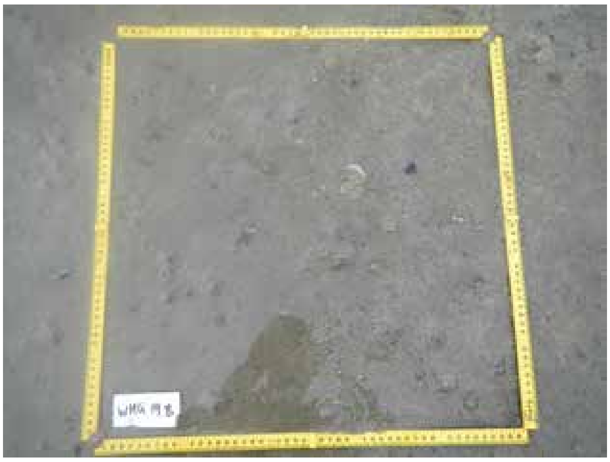
b)


Figure 24: a) Extensive tidal flats at Portland and b) Quadrat at Portland One.

Epifauna

40 individuals belonging to six taxa were found at Portland One. The most abundant species was the marine snail *Zeacumantus lutulentus* followed by the mud flat anemone *Anthopleura aureoradiata*.

At Portland Two, 105 individuals belonging to eight taxa were identified. The most abundant species was the marine snail *Zeacumantus lutulentus* followed by the mud flat anemone *Anthopleura aureoradiata* and the invasive snail *Nassarius (Plicarcularia) burchardi*.

Infauna

The ecological communities at Portland One and Portland Two were similar to each other and were also similar to Otaika One and Otaika Two. Just three taxa, the nut shell *Nucula hartvigiana* the polychaete worm Syllidae sp.#2 and the wedge shell *Macomona liliana* accounted for 62% of the individuals found at these four sites (Portland One, Portland Two, Otaika One and Otaika Two).

At Portland One, 294 individuals belonging to 24 taxa were found. The most abundant taxon was the nut shell *Nucula hartvigiana*, followed by the wedge shell *Macomona liliana* and the polychaete worm Syllidae sp.#2.

At Portland Two, 325 individuals belonging to 25 taxa were found. The most abundant taxon was the nut shell *Nucula hartvigiana*, followed by the polychaete worms Syllidae sp.#2 and *Boccardia (Paraboccardia) syrtis*, the wedge shell *Macomona liliana* and the anemone *Anthopleura aureoradiata*.

Mangapai

The Mangapai River is a sheltered tidal creek with fringing mangrove forest and mud flats. One site was located on soft intertidal mud flat in Mangapai River. The surface at the site was uneven with numerous burrows (Figure 25). The sediment comprised 50% mud, 30% fine sand,>10% medium sand and >10% coarse sand (Figure 3).

a) b)

Figure 25: a) Sheltered tidal creek at Mangapai and b) Soft uneven mud with burrows at Mangapai.

Epifauna

No animals were found in the three quadrats surveyed at Mangapai.

Infauna

The ecological community at Mangapai was similar to the communities at sites in the Hātea River sites and at Otaika Three with polychaete and oligochaete worms making up 90% of all individuals. 1159 individuals were found belonging to 24 taxa. The polychaete worms *Boccardia (Paraboccardia) syrtis, Polydora* sp.#1 and *Cossura consimilis* and the gastropod Nudibranchia sp.#1 were the most abundant taxa.

Otakia

Extensive sand and mud flats pan out from the mangrove forests that fringe the Otaika Creek. Two sites (Otaika One and Otaika Two) were located on exposed firm sand flats (Figure 26a). The sediment at these two sites comprised approximately 80% fine sand and 20% medium sand (Figure 3) with shell fragments. A third northern site (Otaika Three) was located in a more sheltered environment on soft mud. The surface at this site appeared to be more similar to the site in the Mangapai River. The sediment comprised 15% mud and 80% fine sand.

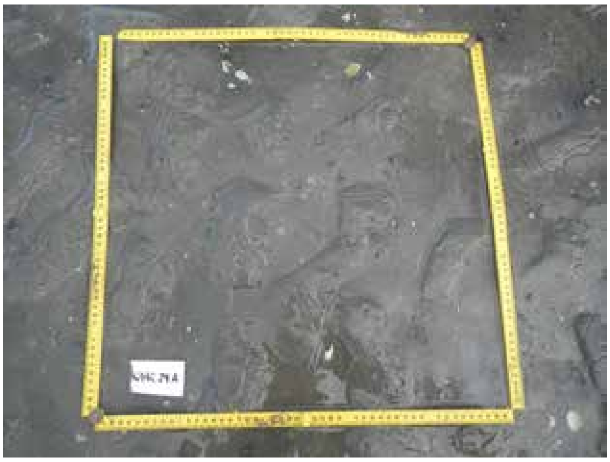
a)  b) 

Figure 26: a) Exposed sand flats at Otaika and b) Firm sand with ripples at Otaika 2.

Otaika One and Otaika Three were sampled by snorkelling at high tide so no quadrats were surveyed at these sites. At Otaika Two, 90 individuals belonging to six taxa were identified. The most abundant species was the marine snail *Zeacumantus lutulentus* followed by the mud flat anemone *Anthopleura aureoradiata* and the invasive snail *Nassarius (Plicarcularia) burchardi*.

Infauna

The communities at Otaika One and Otaika Two were very similar with the nut shell *Nucula hartvigiana* and the wedge shell *Macomona liliana* abundant at both sites. The communities were also very similar to Portland One and Portland Two.

At Otaika One, 178 individuals belonging to 18 taxa were identified, with bivalves accounting for more than two thirds or all animals found. The nut shell *Nucula hartvigiana*, the nemertean worm Nemertea sp.#3) and the wedge shell *Macomona liliana* were all abundant and ubiquitous and accounted for 81% of all individuals.

At Otaika Two, 186 individuals belonging to 19 taxa were identified with bivalves again abundant. Four taxa: the nut shell *Nucula hartvigiana*; the anemone *Anthopleura aureoradiata*; the polychaete worm Syllidae sp.#2; and the wedge shell *Macomona liliana* accounted for 77% of all individuals.

The community at Otaika Three was quite different to Otaika One and Otaika Two. Instead it was more similar to the communities in the Hātea River and Mangapai River, with polychaete worms the most abundant taxonomic group. 419 individuals were identified belonging to 27 taxa, with the polychaete worms *Cossura consimilis* and Paraonidae sp.#1 were the most abundant taxa.

3.4.2 Multivariate analysis of intertidal ecological data

Analysis of the average linkage clustering and MDS ordination (Figure 27 and 28) of the species abundance data indicated that most of the samples could be separated into three main groups. PERMANOVA showed that there were significant differences between these three 'groups' (Pseudo $F_{4, 27}$ 4.73, P-value < 0.01) and pairwise tests indicated the three groups were all significantly different from each other. One group (Group A) corresponded to sites located in sheltered tidal creek environments in the upper Harbour, a second group (Group B), comprised sites generally located on semi exposed sand flats and mud flats from Takahiwai, Portland and Otaika and a third group (Group C) comprised sites on exposed sand and pebble beaches including Tamaterau, Waikaraka, Marsden Bay and Onerahi (Figure 29). Group C also included one site from Takahiwai located outside of the seagrass beds in the mouth of the Takahiwai Creek, which is also likely to be a high energy environment. Rat Island and Marsden Bay One were not part of these three main groups but appeared to be most similar to sites from Group C (Figure 28).

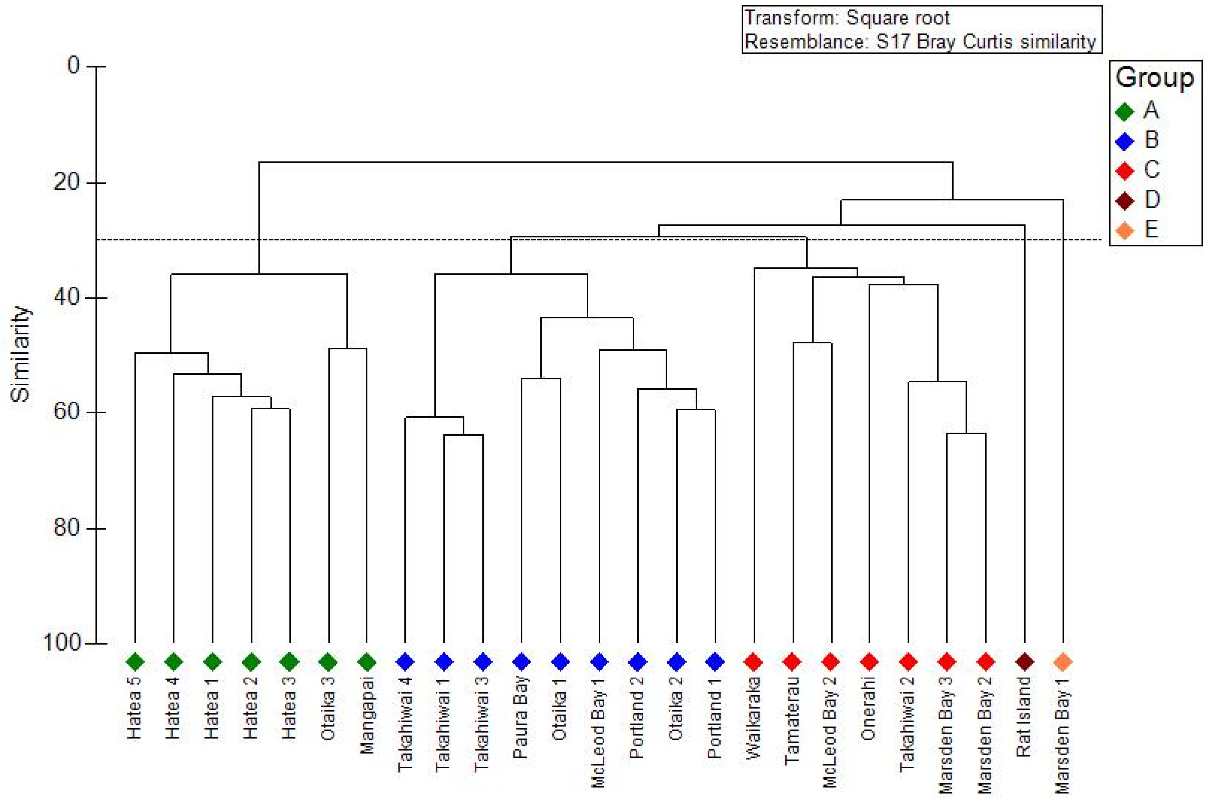


Figure 27. Group average linkage cluster of Bray-Curtis similarities from square root transformed infauna abundance data collected from 25 intertidal sites in Whāngārei Harbour in 2012.

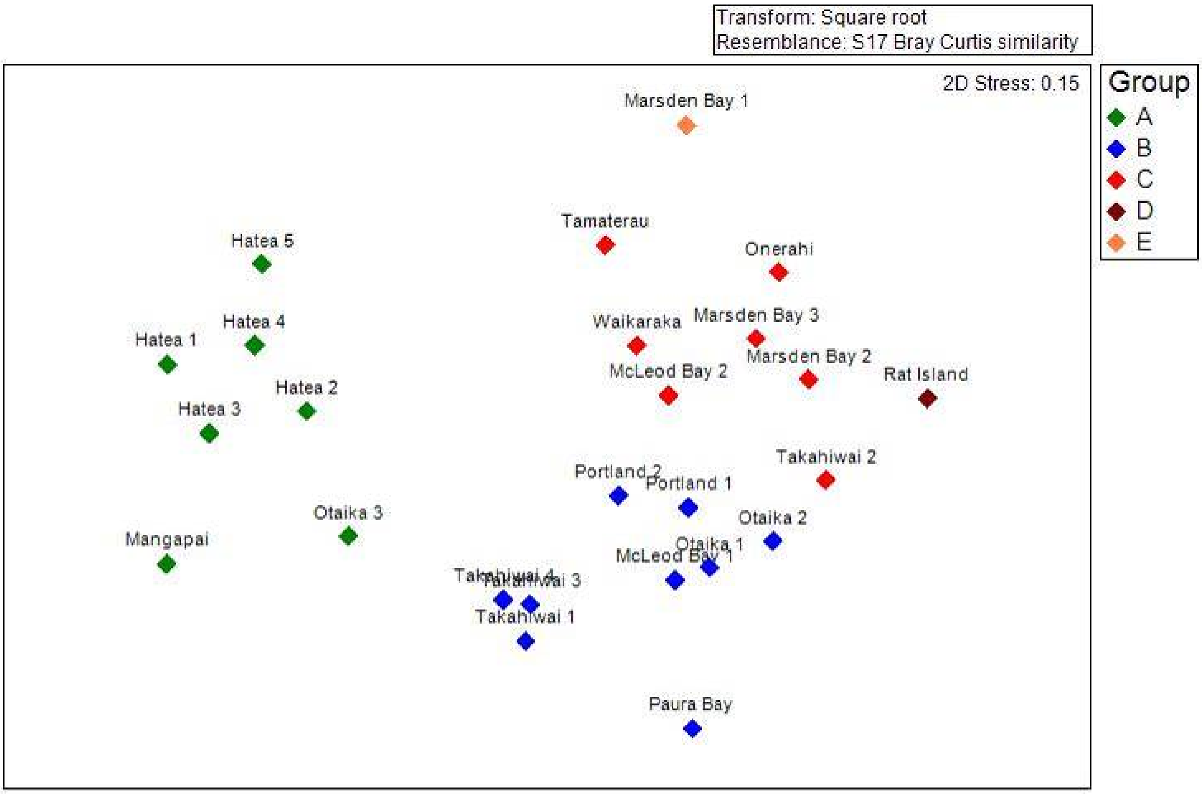


Figure 28. Non-metric MDS ordination of Bray-Curtis similarities from square root transformed infauna abundance data collected from intertidal sites in Whāngārei Harbour in 2012. Sites closest together are more similar.

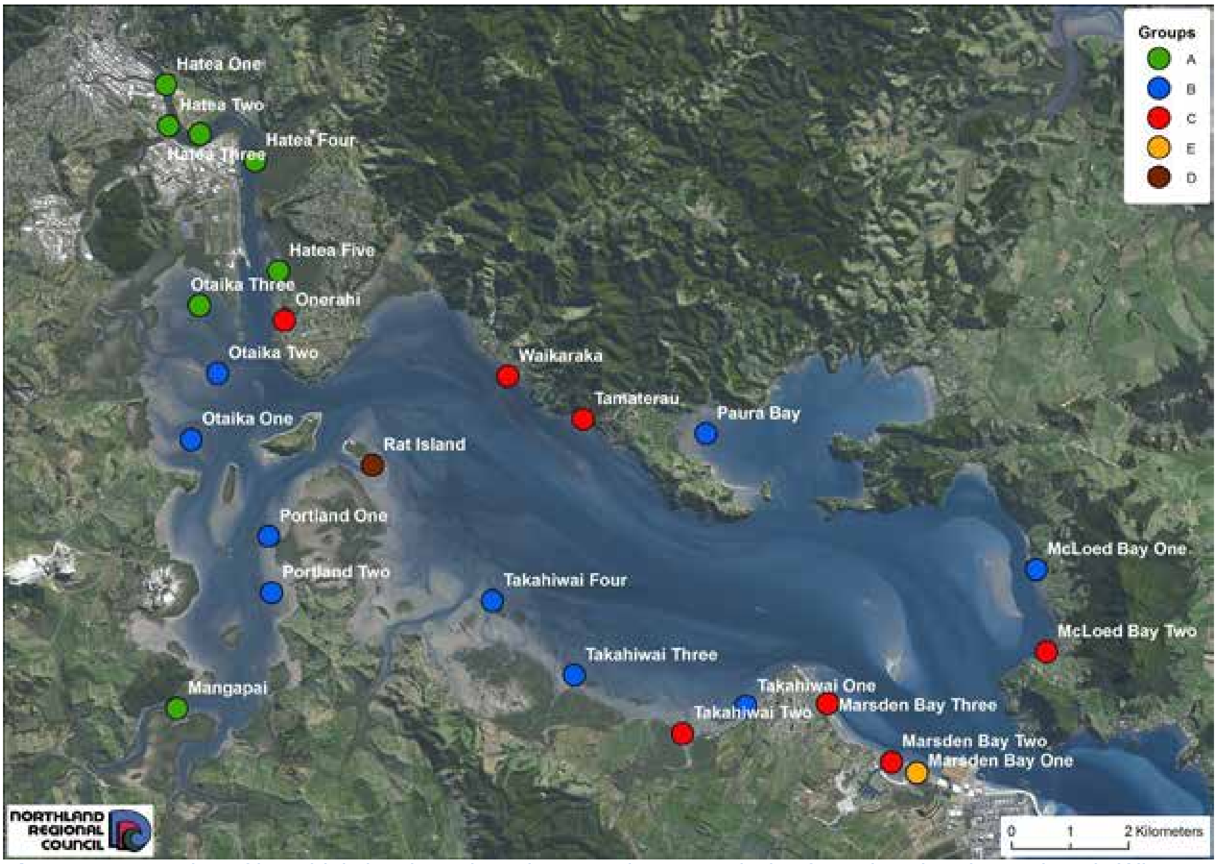


Figure 29. Grouping of intertidal sites based on cluster and MDS analysis of species abundance data, in Whāngārei Harbour in 2012.

Group A

Sites in Group A tended to be dominated by polychaete worms and oligochaete worms, with relatively few gastropods, crustaceans and bivalves found at any of these sites. Simper analysis identified the polychaete worms *Boccardia (Paraboccardia) syrtis,* Capitella sp.#1, and oligochaete worms as the most important taxa accounting for the similarity of samples from this group, with these three taxa accounting for more than 30% of the similarity between samples (Table 1).

Table 1. Mean abundance of benthic infauna taxa at sites in Group A and their contribution to 'group' similarity. Average similarity = 45%.

Taxon	Description	Mean abundance	% contribution towards similarity	% cumulative contribution towards similarity
Boccardia (Paraboccardia) syrtis	Polychaete worm	41	12	12
Oligochaeta	Oligochaete worm	9	11	23
Capitella sp.#1	Polychaete worm	9	10	33
Heteromastus filiformis	Polychaete worm	6	8	41
Paraonidae sp.#2	Polychaete worm	7	7	49
Copepoda sp.#1	Crustacean	5	7	56
Polydora sp.#1	Polychaete worm	21	6	62
Paraonidae sp.#1	Polychaete worm	10	6	68
Arthritica sp.#1	Bivalve (nut clam)	4	6	73
Prionospio yuriel	Polychaete worm	11	5	79
Cossura consimilis	Polychaete worm	16	4	82

Group B

Sites in Group B three tended to have high abundances of the nut clam *Nucula hartvigiana* and the polychaete worm Syllidae sp.#2. Simper analysis identified the nut clam *Nucula hartvigiana* as the most important taxa accounting for the similarity of samples within this group, accounting for more than 50% of the similarity between samples (Table 2). Within this Group B, clustering and MDS ordination indicated that three sites located within seagrass beds at Takahiwai formed a subgroup (Figure 27 & 28).

Table 2. Mean abundance of benthic infauna taxa at sites in Group B and their contribution to 'group' similarity. Average similarity = 43%.

Taxon	Description	Mean abundance	% contribution towards similarity	% cumulative contribution
Nucula hartvigiana	Bivalve (nut clam)	32	51	51
Syllidae sp.#2	Polychaete worm	16	12	63
Boccardia (Paraboccardia) syrtis	Polychaete worm	11	6	69
Nemertea sp.#3	Ribbon worm	5	5	74
Ostracoda sp.#8	Polychaete worm	18	5	79
Macomona liliana	Bivalve (Wedge shell)	4	5	83
Prionospio aucklandica	Polychaete worm	6	2	86
Anthopleura aureoradiata	Anemone	4	2	88
Macroclymenella stewartensis	Polychaete worm	1	1	89
Ostracoda sp.#1	Crustacean (shrimp)	4	1	90

Group C

Sites in Group C, tended to have high abundances of polychaete worms, bivalves and anemones. Simper analysis identified the polychaete worm *Prionospio aucklandica,* the cockle *Austrovenus stutchburyi* and the nut shell *Nucula hartvigiana* as being the most important taxa accounting for the similarity of samples from this group, with these three taxa accounting for more than 60% of the similarity between samples (Table 3).

Table 3. Mean abundance of benthic infauna taxa at sites in Group C and their contribution to 'group' similarity. Average similarity = 40%.

Taxon	Description	Mean abundance	% contribution towards similarity	% cumulative contribution towards similarity
Prionospio aucklandica	Polychaete worm	25	24	24
Austrovenus stutchburyi	Bivalve (cockle)	17	22	46
Nucula hartvigiana	Bivalve (nut clam)	16	18	64
Anthopleura aureoradiata	Anemone	7	7	71
Aonides sp.#1	Polychaete worm	12	4	76
Macomona liliana	Bivalve (Wedge shell)	3	3	79
Scoloplos cylindrifer	Polychaete worm	3	3	82
Colurostylis lemurum	Crustacean (shrimp)	2	3	85
Paphies australis	Bivalve (pipi)	3	2	87
Heteromastus filiformis	Polychaete worm	3	2	89
Capitella sp.#1	Polychaete worm	1	2	91

3.4.3 Intertidal biodiversity

The average number of taxa varied from eight at Rat Island to 29 at Takahiwai One and Takahiwai Three. Group B appeared to have slightly higher species richness than Group A and C (Table 4). The total number of individuals varied widely from just 27 individuals at Rat Island to 391 at Mangapai with high numbers of individuals also recorded at the sites located in the seagrass beds at Takahiwai. Group A had the highest mean number of individuals, followed by Group B and then Group C (Table 4). The highest Shannon-Wiener diversity score was found at the three sites located in the seagrass beds at Takahiwai and appeared to be higher at Group B than Group A and C. The lowest Shannon-Wiener diversity score was found at Otaika One. The highest Evenness was at Rat Island and the lowest at Mangapai. Evenness did not appear to vary according to Group (Table 4). Bray-Curtis similarity appeared to be slightly higher at Group B and Group C, compared to Group A.

Table 4. Mean diversity indices at different intertidal 'Groups' in Whāngārei Harbour.

	Species richness	Number of individuals	Shannon diversity	Evenness	Bray- Curtis
Group A	17	174	2.0	0.7	63
Group B	19	143	2.1	0.7	66
Group C	16	151	1.9	0.7	68
Marsden Bay One	12	128	2.0	0.8	64
Rat Island	8	27	1.8	0.9	67

3.4.4 Subtidal ecology

Hātea

Four sub tidal sites were surveyed in the Hātea River (The Upper Hātea, Limeburners Creek Waimahanga and Awaroa Creek). Unfortunately the Waiharohia Canal was not sampled as the sediment was so compact it was impossible to penetrate the sediment with the perspex core. At the Upper Hātea sediment comprised mainly coarse sand (60%) and medium sand (20%) with smaller portions of fine sand and mud. The sediment composition at Limeburners Creek and Waimahanga were very similar with approximately 60% mud and 30% fine sand (Figure 18). Awaroa Creek comprised mainly mud (35%) and fine sand (45%) with smaller proportions of medium sand and coarse sand (5%).

The communities at the Upper Hātea and Limeburners Creek were similar with oligochaete and polychaete worms dominating both communities. At the Upper Hātea, 268 individuals belonging to 17 taxa were identified. Oligochaete worms and the polychaete worms *Prionospio yuriel* and Polydora sp.#1 were the most abundant taxa. At Limeburners Creek 235 individuals belong to 26 taxa were found with oligochaete worms and the polychaete worm *Prionospio yuriel* again the most abundant taxa.

The communities at Awaroa Creek and Waimahanga were very similar to each other and also similar to the communities at Otaika Creek and Portland Channel. Polychaete worms accounted for >90% of individuals at all four of these sites and the polychaete worms *Cossura consimilis* and Paraonidae sp.#1 were the most abundant taxa at all four sites. These two taxa accounted for 75% of all animals found at these four sites.

Otaika Creek

The sediment at Otaika Creek comprised approximately 60% mud and 30% fine sand with smaller proportions of medium sand (6%) and coarse sand (>1%) (Figure 18). At Otaika Creek, 272 individuals belonging to 19 taxa were found. The polychaete worm *Cossura consimilis* was numerically dominant with 143 individuals found. The polychaete worms *Paraonidae* sp.#1, *Heteromastus filiformis* and *Prionospio yuriel* were also relatively abundant and ubiquitous.

Tamaterau and Manganese Point

The sediment composition at Tamaterau and Manganese Point was quite different. At Tamaterau the sediment comprised 75% fine sand and 21% medium sand, while at Manganese Point the sediment comprised 55% medium sand and 42% fine sand. The community at Manganese Point was also quite different to Tamaterau and contained a number of different taxa.

At Tamaterau 174 animals were found belonging to 28 taxa. The most abundant taxon was the polychaete worm Syllidae sp.#2 and the nut shell *Nucula hartvigiana*. The polychaete worms *Heteromastus filiformis* and Paraonidae sp.#1 and the nemertean worm Nemertea sp.#3 were also relatively abundant.

At Manganese Point 665 individuals to 57 taxa were found, with 13 of the taxa identified at Manganese Point not found at any other site. The most abundant taxa were the polychaete worms Syllidae sp.#2, Euchone sp.#1 and *Boccardia (Paraboccardia) syrtis* and the Asian date mussel *Musculista senhousia*.

Parua Bay

The sediment at Parua Bay comprised approximately 40% medium sand, 35% fine sand, 10% mud, and 15% coarse sand. 569 individuals belonging to 40 taxa were identified at Parua Bay. The most abundant taxa were the polychaete worms Paraonidae sp.#1 and *Heteromastus filiformis* followed by the seed shrimp Ostracoda sp.#5 and the polychaete worm Syllidae sp.#2.

Munroe Bay

The sediment at Munro Bay comprised 35% mud and 60% fine sand with smaller proportions of medium sand (5%) and coarse sand (1%). 803 individuals belonging to 36 taxa were found at Munro Bay. The most abundant taxa were the polychaete worms Syllidae sp.#2, *Boccardia (Paraboccardia) syrtis* and Paraonidae sp.#1 followed by the crustacean Phoxocephalidae sp.#1.

Snake Bank

The sediment at Snake Bank comprised 31% fine sand, 46% medium sand and 22% coarse sand. 1534 individuals belonging to 56 taxa were found at Snake Bank. 17 of these taxa were not found at any other site. The polychaete worm Euchone sp.#1 was the most abundant taxon with 942 individuals found. The crustaceans Tanaidacea sp.#1 Ostracoda sp.#11, Amphipoda sp.#12 and the polychaete *Boccardia (Paraboccardia) syrtis* were also relatively abundant.

Mangawhati Point

The sediment at Mangawhati Point comprised approximately 50% fine sand, 45% medium sand and 5% coarse sand. 160 individuals were found belonging to 25 taxa were found. The most abundant taxa were the polychaete worm Syllidae sp.#2 and the nut shell *Nucula hartvigiana*.

Portland

The sediment at Portland comprised mostly fine sand (80%), with smaller proportions of mud (15%) and medium sand (5%). 453 individuals from 16 taxa were found. The polychaete worm *Cossura consimilis* was numerically dominant with 283 individuals found. The polychaete worms Paraonidae sp.#1 and *Heteromastus filiformis* were the next most abundant taxa.

Mangapai Creek

The sediment at Mangapai Creek comprised approximately equal proportions of mud, fine sand, medium sand and coarse sand (Figure 4). 1405 individuals belonging to 25 taxa were found. The Asian date mussel *Musculista senhousia* was the most abundant taxa followed by the polychaete worms Cirratulidae sp.#1 and Paraonidae sp.#1.

Marsden Point and Home Point

The sites at Home Point and Marsden Point were both located in water greater than 10m and it was not possible to collect core samples by free diving.

3.4.2 Multivariate analysis of subtidal ecological data

Analysis of the average linkage clustering and MDS ordination (Figure 30 and Figure 31) of the subtidal abundance data separated the samples into three main groups. One group (Group A) corresponded to sites located in in the upper Harbour, a second group (Group B), comprised sites located in the mid harbour and a third group (Group C) comprised just two sites, Snake Bank and Manganese Point (Figure 32). PERMANOVA showed that there were significant differences between these three ‘groups’ (Pseudo $F_{2, 12}$ 4.3088, P-value < 0.01) and pairwise tests showed that ‘Group A’ was significantly different to Group B and Group C but there was no significant difference between ‘Group B’ and ‘Group C’ at the 5% level (t =1.7118, P-value =0.072).

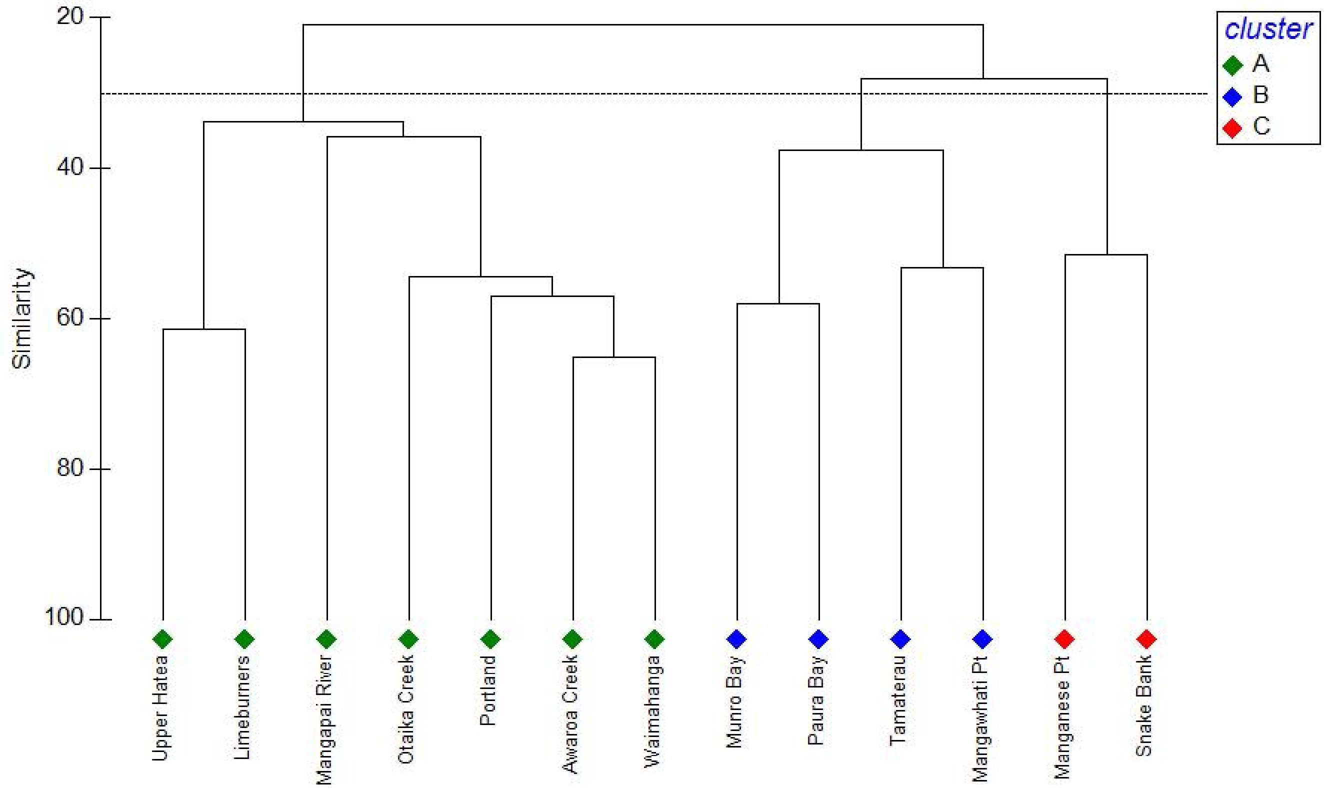


Figure 30. Group average linkage cluster of Bray-Curtis similarities from square root transformed infauna abundance data collected from 13 subtidal sites in Whāngārei Harbour in 2012.

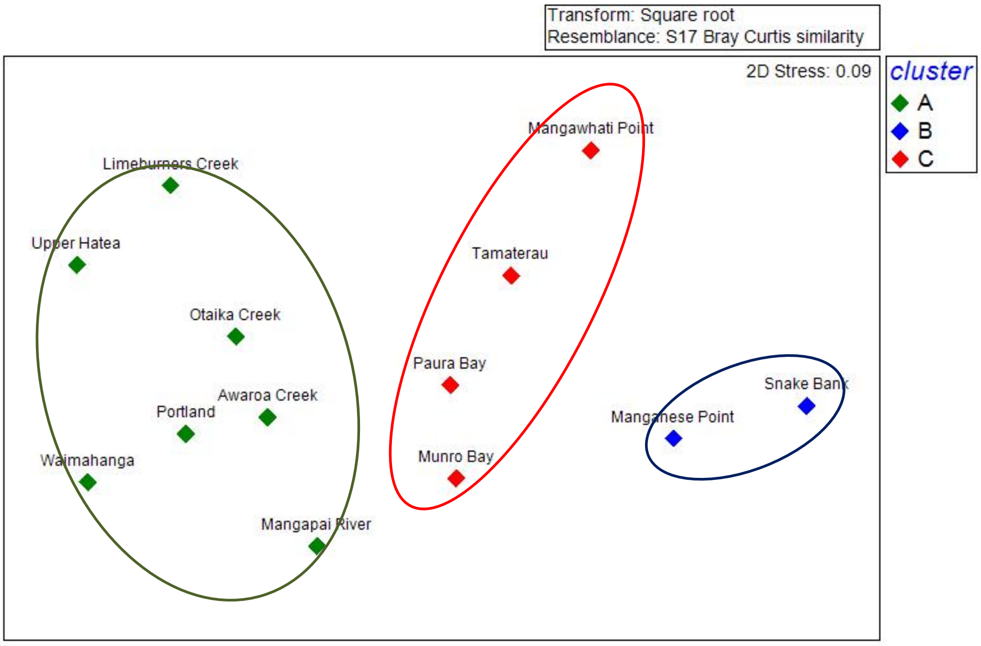


Figure 31. Non-metric multidimensional scaling (MDS) ordination of Bray-Curtis similarities from square root transformed infauna abundance data collected from 13 subtidal sites in Whāngārei Harbour in 2012.

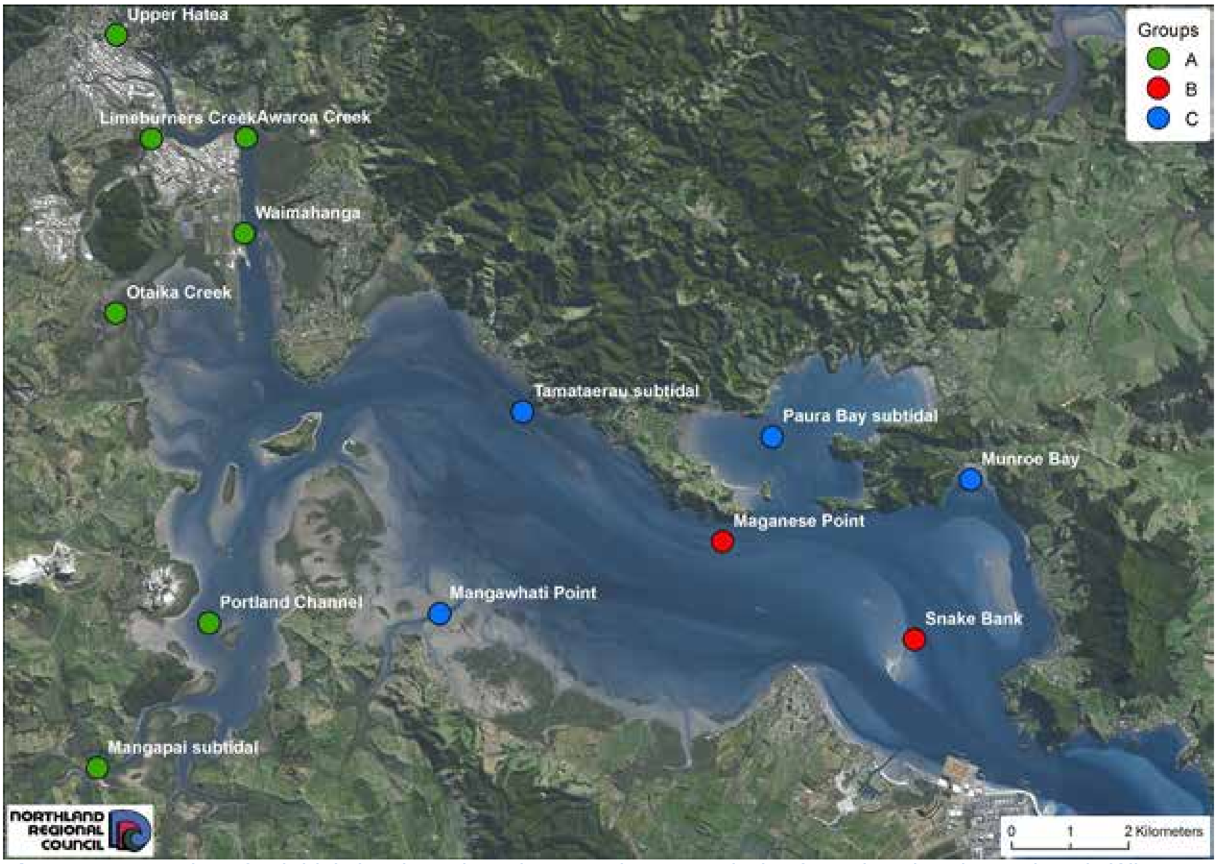


Figure 32. Grouping of subtidal sites based on cluster and MDS analysis of species abundance data, in Whāngārei Harbour in 2012.

Group A

Simper analysis identified the polychaete worms *Cossura consimilis* and Paraonidae sp.#1, and oligochaete worms as the most important taxa accounting for the similarity of samples from the Group A. These three taxa accounting for 74% of the similarity between samples (Table 5).

Table 5. Mean abundance of benthic infauna taxa at sites in Group A and their contribution to 'group' similarity. Average similarity = 28 %.

Taxon	Description	Mean abundance	% contribution towards similarity	% cumulative contribution towards similarity
Cossura consimilis	Polychaete worm	30	40	40
Paraonidae sp.#1	Polychaete worm	24	24	64
Oligochaeta	Oligochaete worm	10	10	74
Heteromastus filiformis	Polychaete worm	6	7	81
Prionospio yuriel	Polychaete worm	9	7	88
Boccardia (Paraboccardia) syrtis	Polychaete worm	2	2	90
Polydora sp.#1	Polychaete worm	2	2	92

Group B

Simper analysis identified the polychaete worm Syllidae sp.#2 and the nut clam *Nucula hartvigiana* and the polychaete worm Paraonidae sp.#1 as the most important taxa accounting for the similarity of samples, with these taxa accounting for 62% of the similarity between samples (Table 6).

Table 6. Mean abundance of benthic infauna taxa at sites in Group B and their contribution to 'group' similarity. Average similarity = 35%.

Taxon	Description	Mean abundance	% contribution towards similarity	% cumulative contribution
Syllidae sp.#2	Polychaete worm	28	35	35
Nucula hartvigiana	Bivalve (nut clam)	7	14	49
Paraonidae sp.#1	Polychaete worm	22	13	62
Heteromastus filiformis	Polychaete worm	12	11	73
Nemertea sp.#3	Ribbon worm	3	6	79
Oligochaeta	Oligochaete worm	4	3	82
Phoxocephalidae sp.#1	Crustacean (amphipod)	7	2	84
Dorvilleidae sp.#1	Polychaete worm	5	2	86
Boccardia (Paraboccardia) syrtis	Polychaete worm	12	1	88
Macroclymenella stewartensis	Polychaete worm	1	1	89
Ostracoda sp.#5	Crustacean (shrimp)	4	1	91

Group C

The ecological communities at the two sites in Group C (Manganese Point and Snake Bank) appeared to be quite different to the other sites, and contained a number of taxa not found at any other sites. 41 taxa found at Snake Bank and Manganese Point were not found at any other sites in Whāngārei Harbour. The polychaete worm Euchone sp.#1, was identified as the most important taxon accounting for 50% of the similarity between samples (Table 7).

Table 7. Mean abundance of benthic infauna taxa at sites in Group C and their contribution to 'group' similarity. Average similarity = 38%.

Taxon	Description	Mean abundance	% contribution towards similarity	% cumulative contribution towards similarity
Euchone sp.#1	Polychaete worm	191	50	50
Boccardia (Paraboccardia) syrtis	Polychaete worm	17	11	61
Syllidae sp.#2	Polychaete worm	8	5	66
Nucula hartvigiana	Bivalve (nut clam)	6	3	69
Nemertea sp.#3	Ribbon worm	4	3	72
Syllidae sp.#4	Polychaete worm	4	3	75
Amphipoda sp.#12	Crustacean (amphipod)	8	2	77
Nereis cricognatha	Polychaete worm (shrimp)	4	2	79
Oligochaeta	Oligochaete worm	3	2	82
Cirratulidae sp.#2	Polychaete worm	3	2	84
Amphipoda sp.#8	Crustacean (amphipod)	3	2	85
Tanaidacea sp.#1	Crustacean	31	2	87
Macroclymenella stewartensis	Polychaete worm	3	1	89
Spionidae sp.#4	Polychaete worm	5	1	90

3.4.4 Subtidal biodiversity

The average number of taxa varied from eight at Waimahanga to 34 at Snake Bank. The total number of individuals varied widely from 53 individuals at Mangawhati Point to 511 at Snake Bank. Higher species richness and higher numbers of individuals were associated with Group C (Table 8). The highest Shannon diversity was at Manganese Point and the lowest at Hātea subtidal Two. High diversity appeared to be associated with Group B and Group C (Table 8). Evenness was highest at Manganese Point and lowest at Snake Bank. Both these sites are in Group C.

The Bray-Curtis similarity at Group C appeared to be much lower than Group A and B (Table 8), driven mainly by the low Bray-Curtis similarity at Manganese Point. Analysis of the abundance data indicated that the species abundance at one of the replicates from at Manganese Point was very different to the other two replicates.

Table 8. Mean diversity indices at different subtidal 'Groups' in Whāngārei Harbour.

	Species richness	Number of individuals	Shannon diversity	Evenness	Bray- Curtis
Group A	12	150	1.5	0.62	59
Group B	20	136	2.2	0.75	59
Group C	32	367	2.2	0.67	45

3.5 Shellfish

Cockles

Cockles (*Austrovenus stutchburyi*) were found at most intertidal sites but the highest densities of cockles were found towards the entrance of the harbour at McLeod Bay and Marsden Bay (Figure 33). These sites all had high proportions of coarse sand and medium sand. Lower densities of large cockles were found at Onerahi, Waikaraka, Tamaterau, Takahiwai Two and Portland.

Figure 33. Length frequency distribution of cockles (*Austrovenus stutchburyi*) in Whāngārei Harbour in 2012.

Pipi

Pipi (*Paphies australis*) were found at just six intertidal sites, mainly located towards the harbour entrance. High numbers of large pipi were only found at one site, Marsden Bay Three, while the largest number of juvenile pipi were found at Marsden One. Smaller densities of large pipi were also found at Tamaterau and McLeod Bay Two on the northern shore of the harbour.

Figure 34. Length frequency distribution of pipi (*Paphies australis*) in the Whāngārei Harbour in 2012.

Wedge Shells

Wedge shells (*Macomona liliana*) were found throughout the harbour but the highest densities of wedge shells tended to be found on semi-sheltered sand and mud tidal flats in the upper harbour and towards the entrance of the harbour. Wedge shells were rare or absent from the mud dominated tidal creek environments in the Hātea River and Mangapai River. High densities were also found at a couple of sites towards the entrance of the harbour, at McLeod Bay One and Takahiwai Two.

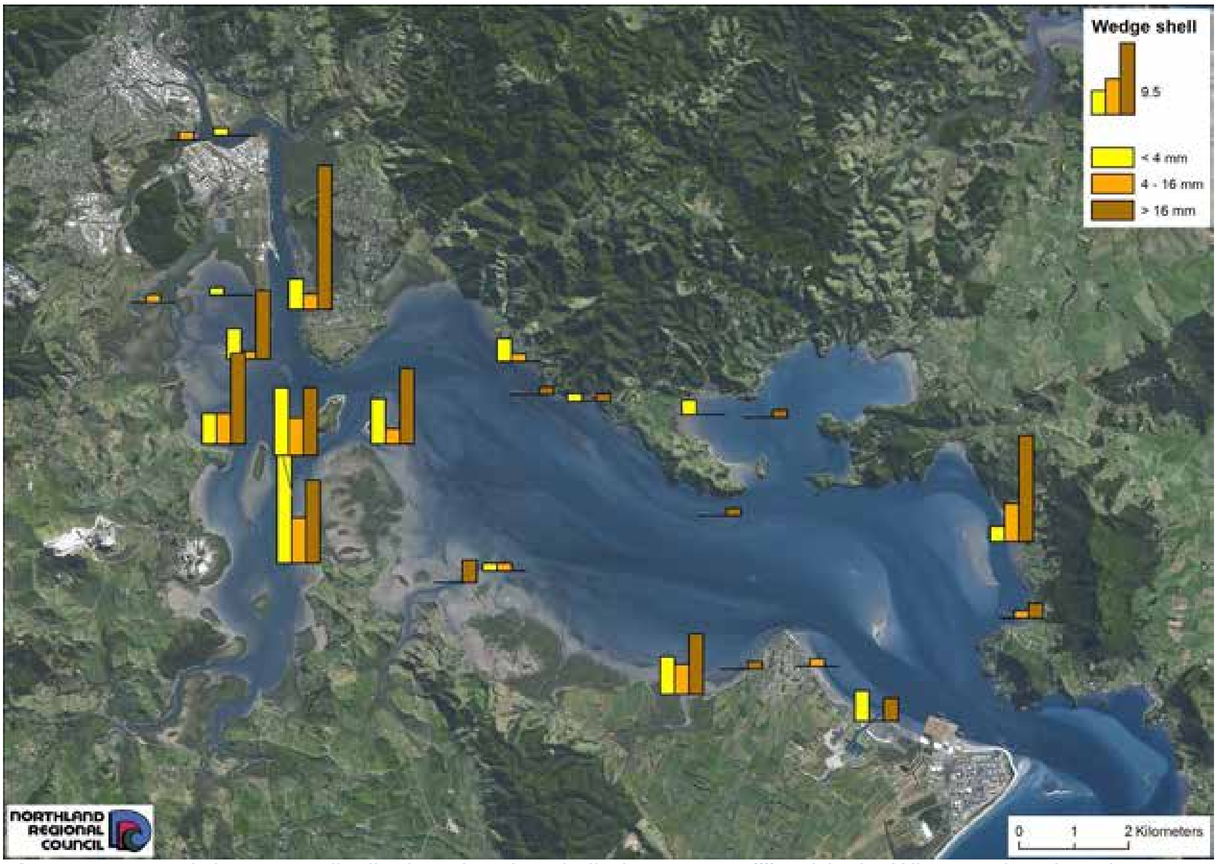


Figure 35. Length frequency distribution of wedge shells (*Macomona liliana*) in the Whāngārei Harbour in 2012.

3.6 Non-indigenous species

Three non-indigenous species were identified from the infauna cores samples: *Theora lubrica;* the Asian date mussel (*Musculista senhousia*); and the Australian dog whelk (*Nassarius (Plicarcularia) burchardi*). *Theora lubrica* was found in cores at 13 sites (Figure 36). It was mainly found at sites in the Hātea River, Mangapai River and along the northern shoreline of the harbour. The highest densities were found at the subtidal sites: Munroe Bay and Parua Bay subtidal, which are both located on the northern shore of the harbour.

The Asian date mussel (*Musculista senhousia*) was the most widespread non-indigenous species found and was identified at 18 sites (Figure 37). The Asian date mussel was found throughout the harbour but the highest densities were found at sites in the Mangapai River and Hātea River.

The Australian dog whelk was found in cores at nine sites (Figure 38). The Australian dog whelk was found also found in quadrat samples at seven sites, including at three sites where they were not found in the infauna cores.

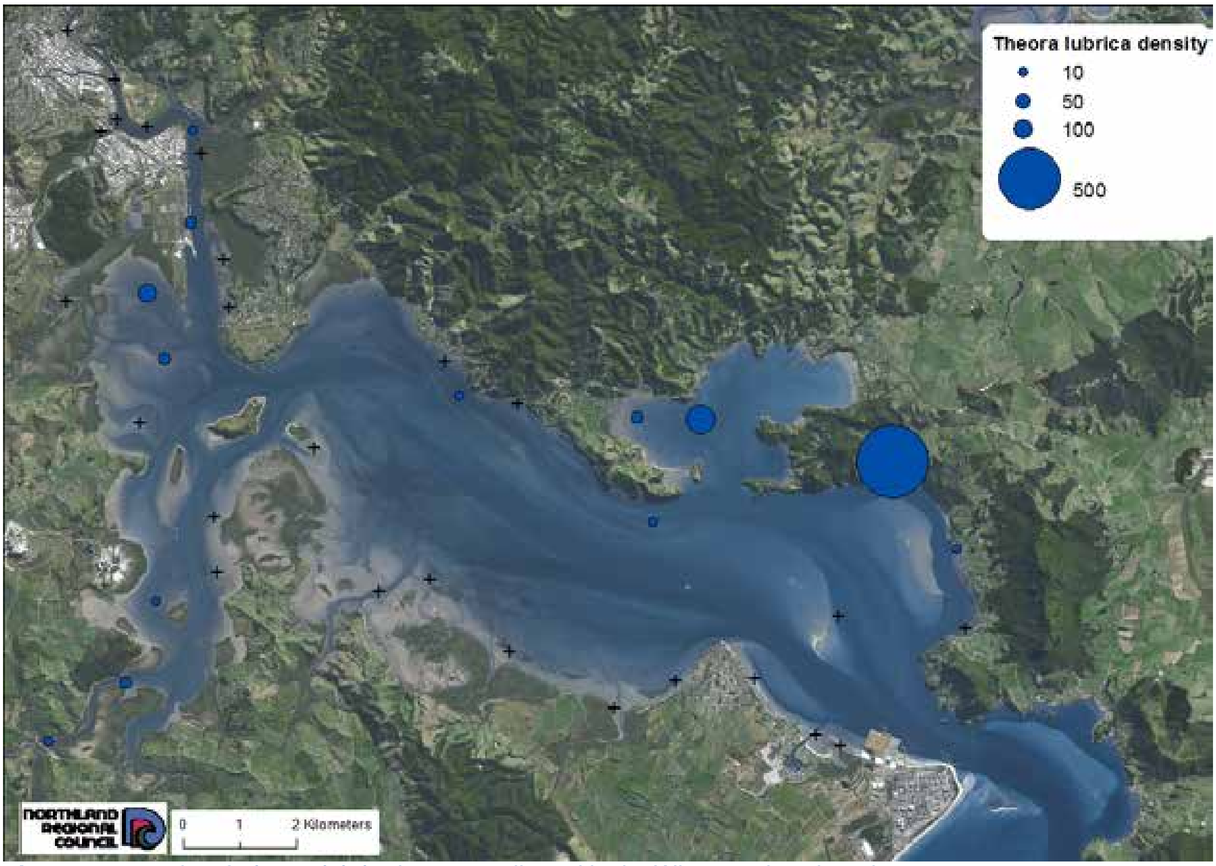


Figure 36. Density of *Theora lubrica* in cores collected in the Whāngārei Harbour in 2012.

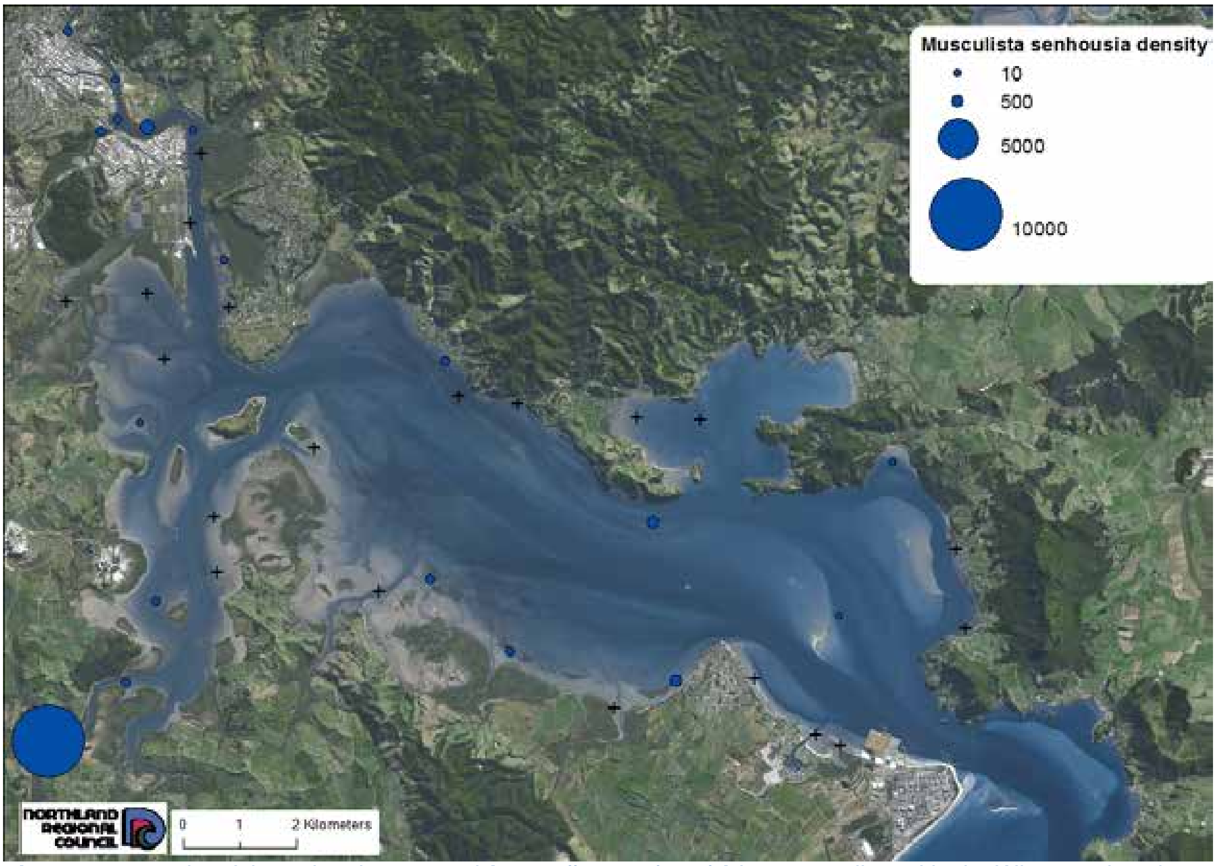


Figure 37. Density of the Asian date mussel (*Musculista senhousia*) in cores collected in the Whāngārei Harbour.

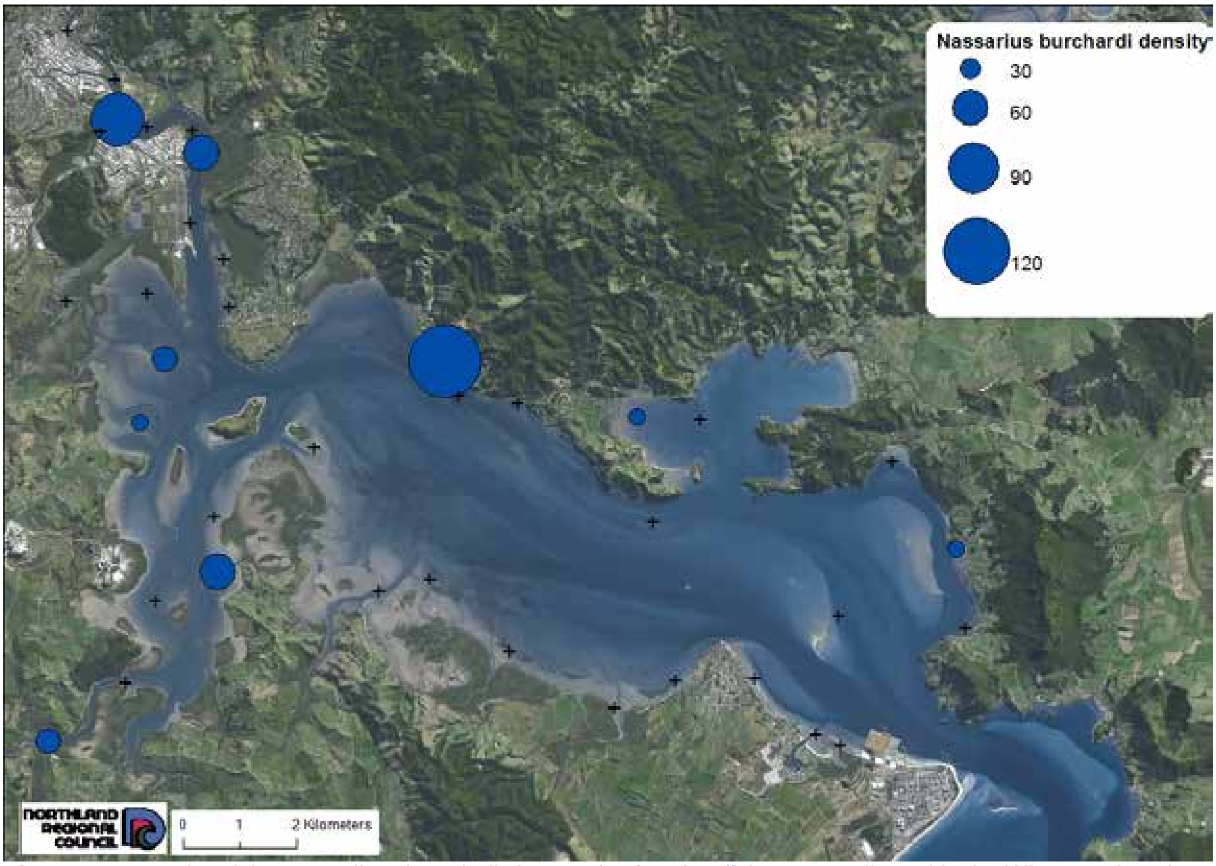


Figure 38. Density of the Australian dog whelk (*Nassarius burchardi*) in cores collected in the Whāngārei Harbour.

3.7 Relating intertidal community structure and sediment properties

A distance-based linear model (DISTLM) using the Bray-Curtis similarity matrix, and the log_{10} transformed sediment data, showed that all of the sediment properties, except fine sand and coarse sand had a significant relationship to the intertidal ecological community structure (Table 9). The proportion of mud, lead, nitrogen, copper and zinc each individually explained at least 20% of the variation in the ecological data.

DISTLM conducted data using a forward selection procedure showed that the combination of mud, coarse sand, zinc and chromium explained 40% of the variation in the community structure (Pseudo-F = 1.78, P-value = 0.043). 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 25 intertidal samples collected from Whāngārei Harbour in 2012.

Sediment properties	Pseudo-F	P-value	Proportion of variation explained
Mud	6.84	0.001	23
Lead	6.23	0.001	23
Nitrogen	5.93	0.001	21
Copper	5.61	0.001	20
Zinc	5.14	0.001	20
Phosphorus	4.73	0.001	18
Total organic carbon	3.59	0.002	17
Medium sand	3.56	0.001	14
Nickel	2.62	0.008	13
Chromium	1.92	0.041	9
Coarse sand	1.54	0.141	8
Fine sand	1.45	0.117	6

3.8 Relating subtidal community structure and sediment properties

DISTLM performed using the Bray-Curtis similarity matrix, and the $\log_{10}$ transformed sediment data, showed that all of the sediment properties, except total organic carbon, fine sand, cadmium and coarse sand had significant relationships to the subtidal ecological communities (Table 10). The concentrations of copper, phosphorus, zinc, lead and the proportion of mud each individually explained more than 25% of the variation in the ecological data.

DISTLM conducted using a forward selection procedure indicated that copper and coarse sand, explained 39% of the variation in the community structure but this was only significant at the 10% level (Pseudo-F = 1.69, P-value = 0.071).

Table 10. DISTLM marginal tests for $\log_{10}$ sediment properties and abundance data from 13 subtidal samples collected from Whāngārei Harbour in 2012.

Sediment properties	Pseudo-F	P-value	Proportion of variation explained
Copper	4.43	0.001	29%
Phosphorus	4.33	0.001	28%
Zinc	3.96	0.001	26%
Lead	3.95	0.001	26%
Mud	3.93	0.001	26%
Nickel	3.44	0.004	24%
Medium sand	2.84	0.008	21%
Nitrogen	2.78	0.009	20%
Chromium	2.23	0.019	17%
Total organic carbon	1.59	0.110	13%
Fine sand	1.59	0.120	13%
Cadmium	1.37	0.155	11%
Coarse sand	1.19	0.272	10%

4 Discussion

4.1 Sediment physical properties

The sediment grain size characteristics of intertidal sites displayed a general pattern of higher mud and fine sand content in the Hātea River and Mangapai River, giving way to more medium and coarse sand towards the harbour entrance. The sites in Hātea River and Mangapai River are located in more sheltered tidal creek environments, close to inputs of terrigenous sediment where high rates of sediment deposition are likely. In contrast sites in the outer harbour are generally higher energy environments where there is likely to be more inputs of coarser grain marine sediment.

The sediment composition of subtidal sites followed a similar pattern although there were some noticeable exceptions. The sites in the tidal creek environments of the upper harbour tended to have high proportions of mud and fine sand but the sediment composition at the Waiharohia Canal, Upper Hātea and Mangapai was quite different. The sediment at the Upper Hātea and Waiharohia Canal comprised mainly coarse sand and at Mangapai the sediment comprised approximately equal proportions of mud, fine sand, medium sand and coarse sand. These sites are located in the centre of relatively narrow channels where there is likely to be high flow. Similar sediment characteristics were found at these sites in 2010 (Northland Regional Council 2011).

Subtidal sites in the outer harbour tended to comprise mainly medium sand and fine sand. The exception to this was Munro Bay on the northern shore of the harbour, which had a sediment composition similar to the upper harbour sites with relatively high proportions of mud. The relatively high proportion of mud at Munro Bay was previously reported in an investigation of sedimentation rates in the Harbour by Swales *et al.* 2013. Swales noted that with the progressive infilling of the upper estuary fine-sediment is now being exported to the lower estuary. Sediment transport modelling undertaken as part of that project indicated that some of the mud discharged by the Hātea and Otaika Rivers is exported to the lower harbour and deposited in Parua Bay and Munroe Bay, and a sediment core collected at Munroe Bay indicated that mud exported from rivers discharging to the upper harbour began impacting this area in the mid-1950s. Radio carbon dating of sediment from this core showed that mud has accumulated at a rate averaging 3.1 mm per year since the 1950s time so that today a 15 cm thick layer of mud has buried the previous shell-rich sand.

In general, the sediment characteristics observed in this study are similar to patterns previously reported by Acosta *et al.* (2003), Lundquist (2008 unpublished data) and Northland Regional Council (2011) who all found muddier sediments in the upper harbour and more coarse sediments near the entrance of the harbour.

4.2 Sediment TOC and nutrient concentrations

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

A similar pattern was observed for levels of TOC, nitrogen and phosphorus, with the highest levels generally recorded in the upper Harbour at sites in the Hātea River and to a lesser extent the

Mangapai River. Lower levels were generally recorded towards the entrance of the harbour, although there were some noticeable exceptions to this. For example at Takahiwai Three high levels of TOC, nitrogen and phosphorus were recorded. The higher levels measured in the Hātea River and Mangapai River compared to the lower values towards the entrance of the Harbour is consistent with these sites being located close to potential sources of nutrients in depositional tidal creek environments with higher proportions of mud as sediment carbon and nutrients absorb onto mineral surfaces and tend to increase with decreasing sediment grain size.

The highest concentrations of both nitrogen and phosphorus were recorded at the Limeburners Creek, which is the receiving environment for discharges from the Whāngārei waste water treatment plant. The sediment at this site was classified as 'very enriched' for both nitrogen and phosphorus using criteria developed by Robertson and Stevens (2007). The concentrations of both phosphorus and nitrogen at Limeburners Creek was much higher than concentrations previously recorded in Council's Estuary Monitoring Programmes and in a recent survey of harbours in the Far North (Northland Regional Council 2013). Using Robertson and Stevens' criteria a further nine sites, all located in the Hātea River were classified as 'enriched' based on the concentrations of phosphorus.

The potential sources of nutrients to the Whāngārei Harbour include the Whāngārei waste water treatment plant in Limeburners Creek, seepage from the waste water network, stormwater, runoff from agricultural land and discharges from farm dairy effluent systems.

4.3 Sediment metal concentrations

Heavy metals can have lethal and sub lethal effects on benthic invertebrates and in a contaminated environment the species diversity and species richness may decrease as the community becomes dominated by a smaller number of more tolerant species, which are able to survive and reproduce in these conditions (Clarke & Warwick 2001).

The highest concentrations of cadmium, copper, lead and zinc were recorded in sites in the Hātea River, with the highest concentrations in the Waiharohia Canal and sites in the upper Hātea River. Concentrations of these metals decreased towards the entrance of the Harbour. Previous studies have also reported elevated concentrations of metals in the sediment at the upper Hātea River and the Waiharohia Canal (Venus 1984b, Northland Regional Council 1990, Webster *et al*. 2000, Northland Regional Council 2003, Northland Regional Council 2011, Griffiths 2011). Interestingly metal concentration in the sediment at Limeburner's Creek, which is the receiving environment for discharges from the Whāngārei waste water plant, were generally much lower than other sites in the Hātea River.

The Hātea River, flows through the city of Whāngārei, where the majority of the urban and industrial development in the catchment is centred. Road runoff, storm water discharges, industrial discharges and leachates from landfills are all possible sources of metal contamination. The higher concentrations of metals in the Hātea River are also consistent with these sites being located in depositional tidal creek environments, where there is a high proportion of mud. Sediment grain size is an important factor which influences the concentrations of heavy metals in estuarine sediments (Abrahim *et al.* 2007). Heavy metal absorption tend to increase as sediment grain size decreases, which reflects the tendency for heavy metals to be preferentially absorbed on the large surface area of fine grained sediments rich in clay minerals (Abrahim *et al.* 2007).

Interestingly, the highest concentrations of nickel and chromium were recorded at Waikaraka and Tamaterau respectively. The concentration of nickel at Waikaraka was almost double the concentration at the next highest site and exceeded the ANZECC ISQG-Low trigger value, while the concentration of chromium exceeded the threshold effects levels, developed by MacDonald *et al* (1996).

High concentrations of nickel and chromium have previously been reported along the northern shoreline of the Harbour. Surveys in 1985 and 1988 showed elevated concentrations of chromium and nickel at Parua Bay and a more recent survey carried out by Council in 2010 found elevated concentrations of chromium at Tamaterau and Parua Bay (Northland Regional Council 2011). There are no known point source discharges of nickel or chromium along the northern shoreline of the Harbour and the authors of the surveys in the 1980s speculated that the catchment soils surrounding Parua Bay may be high in chromium (Northland Regional Council 1990). A recent magnetic and radiometric survey of Northland has also indicated that there may be elevated levels of nickel and chromium along the northern shore of the Harbour.

4.4 Intertidal ecology

Epifauna

Quadrat surveys of the epifauna were carried out at 20 of the intertidal sites. Only 14 taxa were identified and species richness and the number of individuals were generally low. No animals were recorded at any sites in the Hātea River or at the site in the Mangapai River. The highest species richness was generally found along the northern shore of the Harbour at Waikaraka and McLeod Bay.

Infauna

The intertidal habitats surveyed were reasonably varied, including sheltered muddy tidal creek environments, exposed sand flats, exposed sandy beaches, exposed rock and pebble beaches and seagrass beds. Cluster analysis and MDS ordination of the ecological data showed that the intertidal sites could be separated into three main groups. One group 'Group A' comprised sites located in tidal creek environments of the upper Harbour, which were characterised by polychaete and oligochaete worms. The second group 'Group B' comprised sites generally located on semi exposed sand flats and mud flats from Takahiwai, Portland and Otaika and these sites were characterised by the nut clam *Nucula hartvigiana* and the polychaete worm Syllidae sp.#2. A third group 'Group C' comprised sites on exposed sand and pebble beaches including Tamaterau, Waikaraka, Marsden Bay and Onerahi and was characterised by the polychaete worm *Prionospio aucklandica,* the cockle *Austrovenus stutchburyi* and the nut clam *Nucula hartvigiana*. Two sites, Rat Island, and Marsden Bay One, fell outside of these three main groups, indicating that these sites had different ecological communities to the other sites. Both these sites were firm to walk on and sand ripples were visible on the surface. Species richness and the number of individuals found at Rat Island were low compared to the other sites surveyed and the community was dominated by the nut shell *Nucula hartvigiana*, the wedge shell *Macomona liliana* and the hooded shrimp *Colurostylis lemurum*. The community at Marsden Bay One was dominated by crustaceans, which accounted for 70% of all individuals. Another feature of the cluster analysis and MDS ordination was a tight sub-group within 'Group B' comprising the three sites located within the seagrass beds at Takahiwai. These three sites all had high species richness, high numbers of individuals and high biodiversity scores.

The ecological communities found at Council's four sentinel sites were similar to what has been found in previous surveys of these sites. Two of Council's sentinel sites Hātea River Two and Mangapai were within Group A, while the other two sites Otaika Two and Portland Two were within Group B.

4.5 Subtidal ecology

Infauna

The subtidal locations sampled were less varied than the intertidal sites, comprising mainly soft sediment habitats with no biogenic structures, shellfish beds or sea grass beds encountered, although these are known to exist in the harbour. Cluster analysis and MDS ordination of the species abundance data separated the sites into three main groups. One group 'Group A' corresponded to sites located in in the upper Harbour and Simper analysis showed that this group was characterised by the polychaete worms *Cossura consimilis,* and Paraonidae sp.#1, and oligochaete worms. A second group 'Group B' comprised sites located in the mid harbour and was characterised by the nut clam *Nucula hartvigiana* and the polychaete worm Paraonidae sp.#1. A third group 'Group C' contained two sites, Manganese Point and Snake Bank, which were quite different to the other sites and contained a number of taxa that were not found elsewhere in this survey. Simper analysis showed that the polychaete worm Euchone sp.#1 contributed most to the similarity of this Group.

4.6 Shellfish

Cockles were found at most intertidal sites but the highest densities were found towards the entrance of the harbour at sites in McLeod Bay and Marsden Bay. These sites all had high proportions of coarse sand and medium sand. High densities of cockles were also found at Onerahi, Waikaraka, Tamaterau, Takahiwai Two and Portland. The cockle densities found at Marsden Bay Two (3304 per m^2), McLeod's Bay One (963 per m^2), McLeod's Bay Two (850 per m^2), Waikaraka (434 per m^2) and Takahiwai Creek (378 per m^2) 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. In general the distribution and abundance patterns found in this study are similar to previous surveys by Mason and Ritchie (1979) and Lundquist (2008 unpublished data). Mason and Ritchie (1979) reported that the highest densities and the largest cockles were found near low tide mark in Parua Bay, Snake Bank, McLeod Bay, Taurikura and Calliope Bank. The intertidal Snake Bank and McGregor Bank were not sampled in this survey but high densities of large adults and juveniles have recently been recorded on these banks by Lundquist (2008 unpublished data).

Pipi were found at just six intertidal sites, mainly towards the harbour entrance. High numbers of large pipi were only found at one site, Marsden Bay Three, while the most juveniles were found at Marsden Bay One. Mair Bank, which supports an important recreational, cultural and commercial fishery was not sampled in this survey. Smaller densities of large pipi were also found at Tamaterau and McLeod Bay Two on the northern shore of the harbour. Lundquist (2008 unpublished data) also found the highest abundances of pipi near the harbour entrance and Mason and Ritchie (1979) described a pipi zone, which occupied much of Mair Bank at the entrance of the harbour, with smaller pipi beds in Urquhart's Bay, McLeod Bay, Parua Bay, Marsden Bay and at Tamaterau. Lundquist also recorded that pipi were common in the upper Harbour, but the current survey only found low densities of pipi at one site in the upper Harbour.

Wedge shells *Macomona liliana* were found throughout the Harbour but the highest densities tended to be found on semi-sheltered sand and mud flats in the upper Harbour and were rare or absent from the mud dominated tidal creek environments in the Hātea River and Mangapai River. High densities were also found at a couple of sites towards the entrance of the harbour, at McLeod Bay One and Takahiwai Two. Lundquist (2008 unpublished data) also found that wedge shell were abundant in the middle and Upper Harbour but found the highest densities of adults at Takahiwai.

4.7 Non-indigenous species

Three non-indigenous species were identified from the infauna cores samples: *Theora lubrica*, the Asian date mussel *Musculista senhousia* and the Australian dog whelk *Nassarius (Plicarcularia) burchardi*.

The Asian date mussel (*Musculista senhousia*) was the most widespread non-indigenous species found and was identified at 18 sites. It was found throughout the harbour but the highest densities were recorded at sites in the Mangapai River and Hātea River. The Asian date mussel has previously been identified at all four of Council's sentinel sites, with particularly high abundances recorded at the Hātea River site (Hātea Two in this study) in 2008 (Griffiths 2011). Lundquist (2008 unpublished data) also identified the Asian date mussel at two of the 35 sites sampled in Whāngārei Harbour (at one site on the boundary of the marine reserve at Waikaraka and another site in the Hātea River near to Hātea River Five in the current study). The Asian date mussel is an opportunist species which can modify native habitats. The Asian date mussel can form dense mats inhibiting native species and the mussels produce byssal threads which can trap fine sediment altering the physical environment (Hayward *et al*. 2008).

Theora lubrica was found in cores at 13 sites. It was mainly found at sites in the Hātea River, Mangapai River and along the northern shoreline of the harbour. The highest densities were found at the subtidal sites: Munroe Bay and Parua Bay subtidal, which are both located on the northern shore of the harbour. *Theora lubrica* has previously been identified at two of Council's four sentinel sites (Hātea River Two and Mangapai in this study) with the highest abundances recorded at the Hātea River site (Hātea River Two) in 2008 (Griffiths 2011). Lundquist (2008 unpublished data) identified one individual at one of the 35 sites sampled in Whāngārei Harbour (the site was located on the boundary of the marine reserve at Waikaraka). *Theora lubrica* 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).

The Australian dog whelk *Nassarius (Plicarcularia) burchardi* was found in cores at nine sites and was also found in quadrat samples at seven sites. We are not aware of any previous observations of the Australian dog whelk in Whāngārei Harbour, although the species has recently been found at a number of sampling sites in the Waitemata Harbour (Townsend *et al.* 2010).

4.8 Relating ecology and sediment data

Intertidal

A distance-based linear model (DISTLM) showed that all of the sediment properties, except fine sand and coarse sand had significant relationships to the intertidal community structure. The concentrations of lead, nitrogen, copper, zinc and the proportion of mud, explained the highest proportions of the variation. All of these properties were individually able to explain at least 20% of the variation in the ecological data. DISTLM also showed that the combination of mud, coarse sand, zinc and chromium were able to explain 40% of the variation in the community structure. Previous analysis of data collected from Council's sentinel sites in Whāngārei also showed that the sediment properties were significantly related to the ecological data (Griffiths 2011).

Subtidal

DISTLM showed that all of the sediment properties, except TOC, fine sand and coarse sand had significant relationships to the subtidal ecological communities. The concentrations of copper, phosphorus, zinc, lead and the proportion of mud were all individually able to explain more than 25% of the variation in the ecological data. DISTLM also showed that the combination of copper and coarse sand, explained 39% of the variation in the community structure although this was only significant at the 10% level.

The significant relationships between the sediment properties and ecological data therefore indicate that the physical characteristics of the sediment and the concentrations of nutrients and metals have influenced the ecological communities found in the Whāngārei Harbour.

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6 References

Acosta, H., Taylor, R.B., & Tricklebank, K.A. (2003). *A baseline survey for monitoring future effects of the Marsden Point deepwater development on the subtidal ecology of the Whāngārei Harbour*. Report to Northland Regional Council, Whāngārei. University of Auckland. 40p.

Abrahim, G.M.S., Parker R.J. and Nichol S.L. (2007). Distribution and assessment of sediment toxicity in Tamaki estuary, Auckland, New Zealand. *Environmental Geology* 52: 1315-1323.

Australian and New Zealand Environment and Conservation Council (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. ANZECC, Canberra.

Bioresearches (1976). *Aspects of the ecology of the area surrounding the oil refinery at Marsden Point*. Report for New Zealand Refining Company Limited. 190p.

Clark, K.R. & Warwick, R.M. (1994). Similarity-based testing for community pattern: the 2-way layout with no replication. *Marine Biology* 118:167-176.

Clark, K.R. & Warwick, R.M. (2001). *Change in Marine communities: An Approach to statistical Analysis and Interpretation*. PRIMER-E: Plymouth.

Cryer, M. Smith, M., Parkinson, D., MacKay, G. & Tasker, R. (2003). *Biomass surveys of cockles in Whāngārei Harbour, 2002*. Final Research Report of Ministry of Fisheries Research Project COC2002/01 Objectives 3.

Cummings, V., Hewitt, J.E., Hailes, S., Mackay, G., Harding, B. (2008). *Towards the long term enhancement of shellfish beds in the Whāngārei Harbour. Part 5A: Completion of parallel trials*. NIWA Consultancy Report No. NRC09301, 35p.

Dickie, B.N. (1984). *Soft shore investigations. Whāngārei Harbour study*. Northland Harbour board. Technical Report No.4. 132p.

Griffiths, R. (2011). *Whāngārei Harbour Estuary Monitoring Programme: Results from 2008 – 2010*. Northland Regional Council technical report.

Hayward B. (1997). Introduced marine organisms in New Zealand and their impact in the Waitemata Harbour, Auckland. *Tane 36: 197-223*.

Inglis G, Gust, N., Fitridge, I., Floerl, O., Woods, C., Hayden, B. & Fenwick, G. (2005). *Whāngārei Marina Baseline survey for non-indigenous marine species*. Biosecurity New Zealand Technical Paper No: 2005/15.

Lundquist, C. (2008). Unpublished benthic macro infauna data from 42 sites in the Whāngārei Harbour December 2008.

Lundquist, C. & Broekhuizen, N. (2012). *Predicting suitable shellfish restoration sites in Whāngārei Harbour – Larval dispersal modelling and verification*. Client report prepared by NIWA for the Ministry of Science and Innovation Envirolink Fund to Northland Regional Council. Project #ELF12202, Report #HAM2012-024.

Mason, R.S & Ritchie, L.D. (1979). *Aspects of the ecology of Whāngārei Harbour*. Fisheries Management Division. Ministry of Agriculture & Fisheries. Whāngārei.

MacDonald, D.D., Carr, R.S., Calder, F.D., Long, E.R. & Ingersoll, C.G. (1996). Development and evaluation of sediment quality guidelines for Florida coastal waters. *Ecotoxicology* 5:253-278.

McArdle, B.H. & Anderson M.J. (2001). Fitting multivariate models to community data: a comment on distance based redundancy analysis. *Ecology* 82:290-297.

Millar, A.S. (1980). *Hydrology and surficial sediments of Whāngārei Harbour*. Masters of Science thesis, Department of Earth Sciences, University of Waikato, New Zealand 212p.

New Zealand Land Cover Database (2001). New Zealand Climate Change Office (Ministry of the Environment).

Northland Regional Council (1990). *Whāngārei Harbour Water Quality Management Plan. Working Reports No. 7, 12 and 14*. Whāngārei, New Zealand, Northland Regional Council.

Northland Regional Council (2003). *Whāngārei Harbour Sediment-Metal Survey NRC 2003*. Report prepared by Northland Regional Council -Coastal Monitoring Team.

Northland Regional Council (2011). *Annual Monitoring Report 2010-2011*.

Northland Regional Council (2013). *Far North Harbours Water and Sediment Quality Investigation.* Northland Regional Council technical report.

Pawley, M.D.M. (2011). *The distribution and abundance of pipis and cockles in the Northland, Auckland, and Bay of Plenty regions, 2010*. New Zealand Fisheries Assessment Report 2011/24. Published by the Ministry of Fisheries, Wellington 2011.

Robertson, B.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., Thompson & S.J., Tuckey, B.J. (2002). *Estuarine environmental; Assessment and Monitoring: A National Protocol*. Part A. Development, Part b Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry of Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40 p plus field sheets.

Robertson, B. & Stevens, L. (2007). *Waikawa Estuary 2007. Fine scale Monitoring and Historical sediment coring*. Prepared for Environment Southland.

Statistics New Zealand (2010). Subnational Population Estimates: At 30 June 2010 – Tables. Retrieved January 30th 2011 from http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/SubnationalPopulationEstimates_HOTP30Jun10.aspx

Townsend, M., Marshall, B & Greenfield B. (2010). First records of the Australian dog whelk, *Nassarius (Plicarcularia) burchardi* (Dunker in Philippi, 1849) (Mollusca: Gastropoda) from New Zealand. New Zealand Journal of Marine and Fresh Water Research 44: 343-348.

Venus, G.C. (1984a). *Physical oceanography. Whāngārei Harbour study*. Northland Harbour board. Technical Report No.1. 25p.

Venus, G.C. (1984b). *Water quality. Whāngārei Harbour study. Northland Harbour board*. Technical Report No.2. 115p.

Venus, G.C. (1984c). *Harbour entrance subtidal investigations. Whāngārei Harbour study*. Northland Harbour board. Technical Report No.8. 22p.

Venus, G.C. (1984d). *Paphies australis (pipis) in Whāngārei Harbour. Whāngārei Harbour study. Northland Harbour board.* Technical Report No.6. 60p.

Webster, J.G., Brown, K.L. & Webster, K.S. (2000). Source and transport of trace metals in the Hātea River catchment and estuary, Whāngārei. *New Zealand Journal of Marine and Freshwater Research* 34: 187-201.

Williams, J.R., Smith, M.D., Mackay, G. (2009). *Biomass survey and stock assessment of cockles (Austrovenus stutchburyi) on Snake Bank, Whāngārei, 2009*. New Zealand Fisheries Assessment Report 2009/29. 22pp.

7 Appendices

Appendix 1 Land use in the Whāngārei Harbour catchment

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

1st Order Class	2nd Order Class	Area (Ha)	Percentage
Artificial Surfaces (10%)	Built-up Area	2357	8
	Urban Parkland/ Open Space	576	2
	Surface Mine	148	1
	Transport Infrastructure	6	<1
Bare/lightly vegetated surfaces (<1%)	Coastal Sand and Gravel	12	<1
	River and Lakeshore Gravel and Rock	2	<1
Water Bodies (<1%)	Lake and Pond	57	<1
	River	8	<1
	Estuarine Open Water	0	<1
Cropland (<1%)	Short-rotation Cropland	69	<1
	Vineyard	12	<1
	Orchard and Other Perennial Crops	270	1
Grassland (50%)	High Producing Exotic Grassland	14541	49
	Low Producing Grassland	134	<1
	Herbaceous Freshwater Vegetation	9	<1
Sedgeland Saltmarsh (<1%)	Herbaceous Saline Vegetation	43	<1
Scrub and Shrubland (7%)	Gorse and Broom	267	1
	Manuka and or Kanuka	1592	5
	Broadleaved Indigenous Hardwoods	265	1
	Mixed Exotic Shrubland	15	<1
Forest (31%)	Major Shelterbelts	13	<1
	Afforestation	199	1
	Forest Harvested	413	1
	Pine Forest - Closed Canopy	1130	4
	Pine Forest - Open Canopy	1170	4
	Other Exotic Forest	94	<1
	Deciduous Hardwoods	47	<1
	Indigenous Forest	5903	20
	Mangrove	157	1
Total		**29507**	**100**

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

Site Name	x	y
Hātea One	1720630	6045190
Hātea Two	1720676	6044485
Hātea Three	1721205	6044344
Hātea Four	1722154	6043884
Hātea Five	1722550	6042003
Onerahi	1722652	6041158
Waikaraka	1726467	6040204
Tamaterau	1727755	6039468
Parua Bay	1729849	6039220
Munroe Bay	1734371	6038434
McLeod Bay One	1735494	6036900
McLeod Bay Two	1735667	6035492
Marsden Bay One	1733453	6033425
Marsden Bay Three	1731928	6034609
Takahiwai One	1730535	6034560
Takahiwai Three	1727603	6035088
Takahiwai Four	1726203	6036360
Rat Island	1724155	6038684
Portland One	1722385	6037462
Portland Two	1722436	6036500
Mangapai	1720820	6034521
Portland Channel	1721365	6035985
Otaika One	1721063	6039122
Otaika Two	1721516	6040249
Otaika Three	1721200	6041417
Upper Hātea	1719787	6046046
Waiharohia Canal	1720056	6045310
Limeburners Creek	1720384	6044265
Hātea subtidal One	1721996	6044280
Hātea Subtidal Two	1721970	6042641
Otaika Creek	1719774	6041282
Mangapai subtidal	1719456	6033503
Mangawhati Point	1725301	6036143
Tamaterau subtidal	1726715	6039595
Manganese Point	1730135	6037374
Takahiwai Creek	1729451	6034096
Parua Bay subtidal	1730981	6039170
Snake Bank	1733409	6035702
Marsden Bay Two	1733016	6033608
Home Point	1737221	6031647
Marsden Point	1735163	6033209

Appendix 3 Sediment results

Site Name	AFDW	TOC	Nitrogen (mg/kg)	Phosphorus (mg/kg)
Hātea One	13.9	6.0	1600	810
Hātea Two	4.6	1.9	1400	610
Hātea Three	4.6	1.9	1500	560
Hātea Four	6.6	2.7	1700	470
Hātea Five	6.2	2.6	840	390
Onerahi	2.3	0.9	220	250
Waikaraka	2.3	0.9	250	450
Tamaterau	7.8	3.3	160	200
Parua Bay	3.3	1.3	260	210
Munroe Bay	0.6	0.2	740	300
McLeod Bay One	2.5	1.0	280	420
McLeod Bay Two	4.0	1.6	590	380
Marsden Bay One	2.5	1.0	190	70
Marsden Bay Three	4.2	1.7	170	64
Takahiwai One	7.8	3.3	210	60
Takahiwai Three	1.4	0.6	180	79
Takahiwai Four	6.7	2.8	1600	300
Rat Island	0.8	0.3	190	75
Portland One	1.9	0.8	400	110
Portland Two	0.9	0.4	200	120
Mangapai	7.5	3.1	1500	540
Portland Channel	3.9	1.6	480	370
Otaika One	1.0	0.4	150	86
Otaika Two	1.2	0.5	380	150
Otaika Three	3.4	1.4	570	790
Upper Hātea	3.0	1.2	500	950
Waiharohia Canal	4.4	1.8	450	780
Limeburners Creek	3.0	1.2	4900	1200
Hātea subtidal One	3.3	1.3	1200	580
Hātea Subtidal Two	11.2	4.8	1400	920
Otaika Creek	1.8	0.7	860	380
Mangapai subtidal	3.9	1.6	1300	430
Mangawhati Point	2.4	1.0	100	50
Tamaterau subtidal	1.3	0.5	540	120
Manganese Point	0.8	0.3	87	140
Takahiwai Creek	4.9	2.0	320	83
Parua Bay subtidal	3.2	1.3	460	230
Snake Bank	4.1	1.7	190	83
Marsden Bay Two	3.6	1.5	140	54
Home Point	1.3	0.5	14	59
Marsden Point	3.2	1.3	110	75

Site Name	<63 (Mud)	63-250 (Fine sand)	250- 500 (medium sand)	>500 (coarse sand)
Hātea One	43	22	18	16
Hātea Two	28	47	17	7
Hātea Three	46	46	4	4
Hātea Four	15	67	17	1
Hātea Five	14	82	4	0
Onerahi	2	87	6	5
Waikaraka	4	31	40	25
Tamaterau	0	31	44	25
Parua Bay	2	81	17	0
Munroe Bay	35	58	5	1
McLeod Bay One	3	37	32	27
McLeod Bay Two	4	27	43	25
Marsden Bay One	0	32	58	10
Marsden Bay Three	0	21	66	13
Takahiwai One	0	42	52	7
Takahiwai Three	0	85	15	0
Takahiwai Four	11	75	14	0
Rat Island	0	81	19	0
Portland One	0	76	24	0
Portland Two	0	75	25	0
Mangapai	54	31	7	8
Portland Channel	16	79	5	0
Otaika One	2	83	15	0
Otaika Two	0	78	22	0
Otaika Three	16	80	3	0
Upper Hātea	12	7	22	59
Waiharohia Canal	7	9	15	69
Limeburners Creek	59	29	5	7
Hātea subtidal One	34	44	17	6
Hātea Subtidal Two	60	34	5	1
Otaika Creek	61	32	6	1
Mangapai subtidal	29	18	28	25
Mangawhati Point	0	51	44	5
Tamaterau subtidal	5	74	21	0
Manganese Point	0	42	55	3
Takahiwai Creek	0	49	44	6
Parua Bay subtidal	10	34	43	14
Snake Bank	0	31	46	22
Marsden Bay Two	0	44	50	6
Home Point	0	43	55	2
Marsden Point	0	45	40	15

Site Name	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Hātea One	<0.1	20	36	11	25	140
Hātea Two	0.14	14	24	9.1	22	140
Hātea Three	0.05	15	27	8.4	21	130
Hātea Four	0.13	15	19	8.6	12	89
Hātea Five	<0.1	9.6	8.4	4.6	8.7	51
Onerahi	<0.1	6	1.3	2.3	4	36
Waikaraka	<0.1	57	15	30	7	56
Tamaterau	<0.1	16	5.7	10	4	38
Parua Bay	<0.1	14	4.7	7	4.8	31
Munroe Bay	<0.1	17	4.9	7.2	7.4	38
McLeod Bay One	<0.1	30	5.2	9.6	5.4	32
McLeod Bay Two	<0.1	39	8	15	6.7	35
Marsden Bay One	<0.1	2.8	<0.05	0.78	0.46	<7.5
Marsden Bay Three	<0.1	3.9	<0.05	1.4	0.84	<7.5
Takahiwai One	<0.1	5.1	<0.05	1.2	0.95	<7.5
Takahiwai Three	<0.1	5.5	<0.05	1.4	1.3	<7.5
Takahiwai Four	<0.1	9.5	3.7	3.3	3.6	21
Rat Island	<0.1	4.4	<0.05	1.1	0.79	<7.5
Portland One	<0.1	3.7	1	1.2	1.3	8.2
Portland Two	<0.1	5.1	1.2	1.7	1.6	11
Mangapai	<0.1	12	13	7.3	8.3	49
Portland Channel	<0.1	7.5	7.2	4	5.8	34
Otaika One	<0.1	5.5	1.3	1.6	1.7	12
Otaika Two	<0.1	5.7	1	2	1.6	16
Otaika Three	0.15	13	6.5	5.1	9.8	54
Upper Hātea	0.16	27	38	14	39	160
Waiharohia Canal	0.16	31	79	16	51	150
Limeburners Creek	<0.1	15	26	8.6	17	110
Hātea subtidal One	<0.1	17	19	9.5	18	110
Hātea Subtidal Two	0.11	16	16	7.3	20	73
Otaika Creek	<0.1	9.4	6.8	4.7	6.4	52
Mangapai subtidal	<0.1	7.6	8.5	5	8.4	38
Mangawhati Point	<0.1	3.8	<0.05	0.93	0.66	<7.5
Tamaterau subtidal	<0.1	8.6	2.3	2.7	2.5	18
Manganese Point	<0.1	7.3	0.71	2	1.9	14
Takahiwai Creek	<0.1	2.4	<0.05	0.88	0.62	<7.5
Parua Bay subtidal	<0.1	11	3.2	3.9	3.9	22
Snake Bank	<0.1	4.4	<0.05	1.1	1.1	<7.5
Marsden Bay Two	<0.1	2.7	<0.05	0.83	0.53	<7.5
Home Point	<0.1	4.5	<0.05	1	0.67	<7.5
Marsden Point	<0.1	5.8	<0.05	1.2	1	<7.5

Appendix 4 Diversity indices

Site Name	Species richness	Number of individuals	Shannon diversity	Evenvess	Bray-Curtis
Hātea One	17	108	2.31	0.82	69
Hātea Two	19	102	2.57	0.87	68
Hātea Three	16	273	1.92	0.7	53
Hātea Four	16	129	1.89	0.69	64
Hātea Five	15	72	2.13	0.79	67
Onerahi	15	53	2.39	0.88	66
Waikaraka	18	195	1.68	0.59	61
Tamaterau	15	140	1.73	0.64	65
Parua Bay	11	46	1.76	0.73	56
Munroe Bay	25	268	2.4	0.75	71
McLeod Bay One	23	278	2.28	0.73	76
McLeod Bay Two	21	193	2.01	0.67	52
Marsden Bay One	12	128	1.99	0.79	64
Marsden Bay Three	13	99	1.97	0.77	71
Takahiwai One	29	237	2.57	0.77	65
Takahiwai Three	29	237	2.5	0.74	64
Takahiwai Four	26	164	2.66	0.82	62
Rat Island	8	27	1.81	0.85	66
Portland One	17	99	1.8	0.64	69
Portland Two	17	109	2.28	0.81	74
Mangapai	17	391	1.61	0.57	56
Portland Channel	10	155	1.26	0.55	69
Otaika One	10	59	1.55	0.68	65
Otaika Two	13	62	1.75	0.7	62
Otaika Three	16	144	1.71	0.62	60
Upper Hātea	11	94	1.72	0.71	52
Waiharohia Canal			Not sampled		
Limeburners Creek	12	84	1.96	0.81	39
Hātea subtidal One	13	90	1.56	0.61	60
Hātea Subtidal Two	8	61	1.18	0.58	60
Otaika Creek	13	93	1.55	0.61	66
Mangapai subtidal	19	470	1.45	0.49	66
Mangawhati Point	13	53	1.9	0.76	45
Tamaterau subtidal	15	58	2.13	0.79	55
Manganese Point	29	222	2.68	0.83	28
Takahiwai Creek	15	192	1.84	0.68	82
Parua Bay subtidal	26	163	2.37	0.73	64
Snake Bank	34	511	1.71	0.49	62
Marsden Bay Two	13	185	1.9	0.74	78
Home Point			Not sampled		
Marsden Point			Not sampled		

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